Transmit and Receive Diversity Schemes Simulations for Time-Varying Multipath Fading

Jongoh (Andy) Jeong
jeong2@cooper.edu
The Cooper Union, New York, NY
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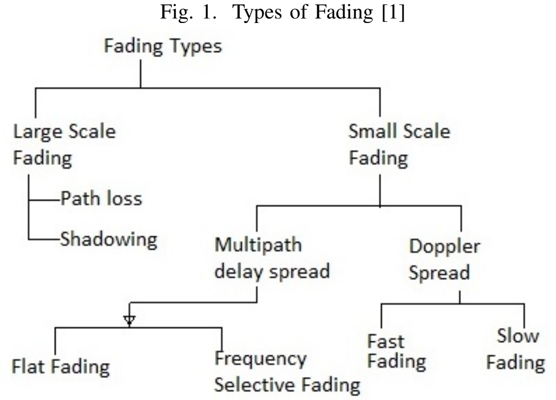
***Abstract*—This report investigates transmit and receive side diversity schemes to mitigate time-varying multipath fading in a flat-fading Rayleigh channel. The two primal diversity schemes, maximal-ratio receiver combining (MRRC) transmit diversity and the transmit diversity scheme proposed by S. M. Alamouti using space-time block coding (STBC), are compared for coherent BPSK signals and two-branch diversity in Rayleigh fading by their bit error rate performances.**

***Index Terms*—diversity schemes, multipath fading, maximal-ratio receiver combining, space-time block coding.**

I. Introduction

A common problem that most wireless systems encounter is the effect of fading at remote units (receiver) and the trade=off at the base stations (transmitter) for power and bandwidth efficiency. While fading is defined as the time variation of received signal power due to changes in transmission medium or paths, it heavily depends on the atmospheric conditions that are adjacent to the main travel path, such as rainfall, buildings, hills, and ground. For mobile units, it is also subject to reflections from obstacles along the time-varying path over which signals are transmitted. Such obstacles in the line of path create complex transmission effects to the transmitted signal [1].

Fig. 1. Types of Fading [1]



Fading can be branched out into large- and small-scale in general, which are then further broken down into path loss and shadowing effects for large-scale and multipath propagation and Doppler spread for small-scale (see Figure 1). In the simulations performed in this paper, only the Rayleigh flat-fading channel is within the scope.

Small-scale fading, which primarily depends on propagation environment, is concerned with rapid fluctuations of received signal strength over very short distance and short time period. Further down the tree is flat fading, which is termed for the wireless channel with constant gain and linear phase response over a bandwidth greater than that of the transmitted signal. In this type of fading, all the frequency components of the received signal fluctuate in same proportions *simultaneously*, and thus is often called non-selective fading. In addition to the channel bandwidth being greater the signal bandwidth, the symbol period is longer than the delay spread of the channel. Under flat fading, the signal will just change in amplitude, rising and falling over a period of time or with movement from one position to another. It is also observed that it leads to a decrease in SNR [2]. For this reason, a common choice for flat fading channel model by designers is the Rayleigh model, in which only Non Line of Sight(NLOS) components are simulated between transmitter and receiver. The randomness, or fading, is often exploited to enhance performance through diversity, a method of conveying information through multiple independent instantiations of these random fades [3]. In the paper, we focus on the spatial diversity through multiple independent transmit/receive antennas.

Alamouti, in his paper back in 1998, denotes what NEXT-generation wireless system ought to achieve for desirable performance – to have better quality and coverage, to be more power and bandwidth efficient, to be deployable in diverse environments, to remain affordable for widespread market acceptance and to keep it relatively simple. In order to overcome issues of multipath fading, which requires 5 to 10 times higher SNR for the same bit error rate level, one can increase the transmit power (dynamic range). However, it is typically impractical due to radiation power limitations and the size and cost of the amplifiers. In addition, in a realistic situation the receiver channel information is hidden to the transmitter, in which case the channel characteristics need to be fed back from the receiver to the transmitter, resulting in throughput degradation and increased complexity to both Tx and Rx. Another effective technique involves time and frequency diversity schemes through time interleaving/spread spectrum and error correction coding, although this also presents large delays when the channel is slowly varying. The spatial antenna diversity is, thus, a more practical and effective way to reduce the effect of multipath fading.

Spatial diversity can be approached from transmit and receive sides. The classical approach of receive diversity scheme uses maximal-ratio receiver combining (MRRC), where multiple antennas are positioned at the receiver, combining and switching are performed to improve the signal quality, although it bears limitations in the cost, size and power of the remote units. The use of this scheme for base stations for these overheads allowed to introduce transmit diversity scheme,as the one proposed by Alamouti with space-time block coding (STBC).

A transmit diversity approch is delay diversity for base station simulcasting, where the base transceiver station (BTS) broadcasts signals through more than one medium or more than one signal through the same medium simultaneously, and then use a maximum-likelihood sequence estimator (MLSE) or a minimum mean squared error (MMSE) equalizer to resolve multipath distortion and obtain diversity gain. Another includes space-time trellis coding, whereby symbols are encoded according to the respective antenna through which they are simultaneously transmitted, and then decoded with a maximum likelihood decoder. This is very effective because it combines FEC coding and diversity transmission to yield considerable performance gains, yet it is costly as bandwidth efficiency and diversity order increase. Alamouti's proposed scheme, on the other hand, is simpler and more cost-effective, as it reduces the complexity in computations, does not expand transmission bandwidth, and does not use Rx to Tx feedback for channel estimation. This method using STBC, which introduces temporal and spatial correlation into the signals transmitted from different antennas without increasing the total transmitted power or the transmission bandwidth, reduces sensitivity to fading, thus allowing higher modulation levels for higher data rates and increased coverage area [4].

II. Approach

In order for simulations for Alamouti's transmit diversity scheme to be compared to MRRC on different diversity orders, several assumptions are made. Throughout this paper, it is assumed that (1) the total power from the antennas for MRRC and Alamouti's scheme is the same, given PSK modulated signals contain equal energy, (2) constant fading across two consecutive symbols, (3) amplitudes of fading from each transmit antenna to each receive antenna are mutually uncorrelated Rayleigh distributed, and the same average signal power at each receiver, (4) receiver is fully aware of the channel characteristics used for the transmitter, and (5) the total radiated power at the transmit is the same, (thus half is radiated for each of the two transmit antennas).

A. Specifications

In order to conduct a fading channel transmission, a Rayleigh channel is constructed from the Doppler Spectrum, with the maximum Doppler shift frequency (f_d) set to 10 Hz, centered around the carrier frequency (f_c) of 0 Hz. The Doppler spectrum for an un-modulated CW carrier in Figure 2 is given by Equation 1.

$$S_{E_Z}(f) = \frac{1.5}{\pi f_m \sqrt{1 - (\frac{(f-f_c)}{f_m})^2}} \tag{1}$$

Fig. 2. Doppler Spectrum for the Rayleigh Channel

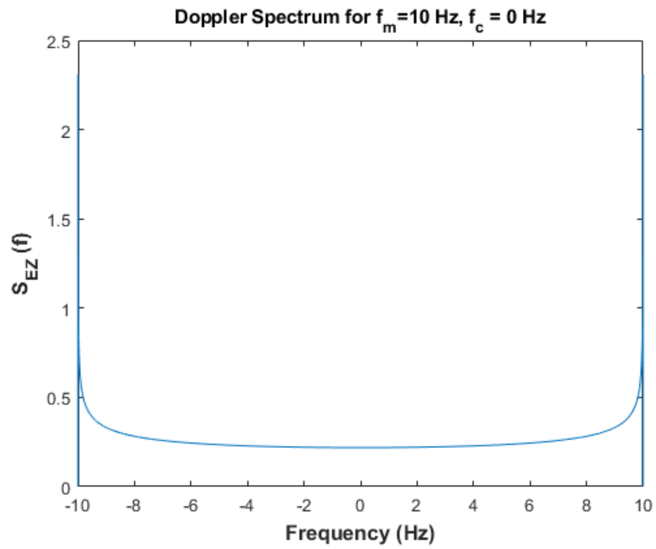
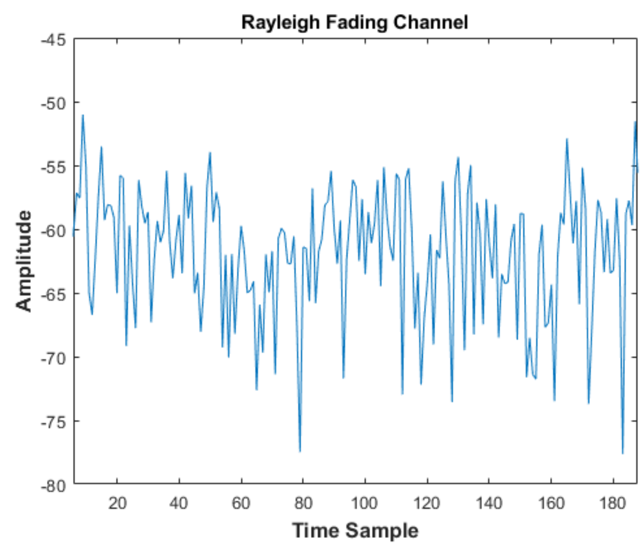


Fig. 3. Rayleigh Flat Fading Channel



B. MRRC Rx Diversity Scheme

The baseband representation of the classical two-branch MRRC is shown in Figure 4. The signal s_0 is sent through channels h_0 and h_1 with path gains α_0 and α_1. At the receive antenna, the received baseband signals are represented by r_0 = $h_0 s_0 + n_0$ and r_1 = $h_1 s_0 + n_1$ where n_0 is Gaussian distributed complex noise and interference through the respective channel. The combining scheme using the maximum likelihood decision rule is applied, as described in Equation 2.

Choose signal s_i if and only if

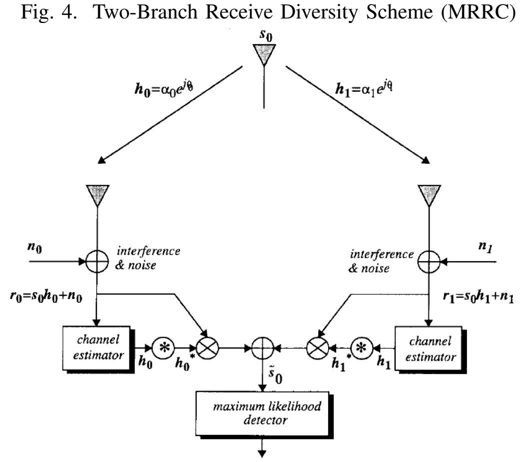
$$d^2(r_0, h_0 s_i) + d^2(r_1, h_1 s_i) \geq d^2(r_0, h_0 s_k) + d^2(r_1, h_1 s_k), \quad \forall i \neq k$$

where $d^2(x,y) = (x-y)(x^* - y^*)$ (sq. Euclidean distance)

$$\hat{s_0} = h_0^* r_0 + h_1^* r_1 = (\alpha_0^2 + \alpha_1^2) s_0 + h_0^* n_0 + h_1^* n_1$$

For PSK, equal energy constellations: $s_i^2 = s_k^2 = E_s$ (2)

Fig. 4. Two-Branch Receive Diversity Scheme (MRRC)



C. Alamouti Tx Diversity Scheme

Alamouti transmit diversity scheme is represented at base-band in Figure 5 and 6. It can be described as (1) the encoding and the transmission sequence of information symbols at each transmitter (see Table I), (2) the combining scheme at the receiver, and (3) the maximum likelihood decision rule. The received symbols (r) and combined signals ($\hat{s}$) are represented differently than those for MRRC (see Eq. 3). The channels h remain the same as those for MRRC – $h_0(t) = h_0(t+T) = \alpha_0 e^{j\theta_0}$ and $h_1(t) = h_1(t+T) = \alpha_1 e^{j\theta_1}$ – assuming constant fading across two consecutive symbols.

$$\begin{aligned} r_0 = r(t) &= h_0 s_0 + h_1 s_1 + n_0 \\ r_1 = r(t+T) &= -h_0 s_1^* + h_1 s_0^* + n_1 \\ &\text{where } T = \textit{symbol duration} \end{aligned} \tag{3}$$

$$\begin{aligned} \hat{s_0} &= h_0^* s_0 + h_0^* n_0 + h_1 n_1^* \\ \hat{s_1} &= h_0^* s_1 - h_0 n_1^* + h_1^* n_0 \end{aligned}$$

TABLE I
TRANSMISSION SEQUENCE FOR TWO-BRANCH (ALAMOUTI)

	Antenna 0	Antenna 1
time t	s_0	s_1
time t+T	$-s_1^*$	s_0^*

Fig. 5. Two-Branch Transmit Diversity Scheme by Alamouti

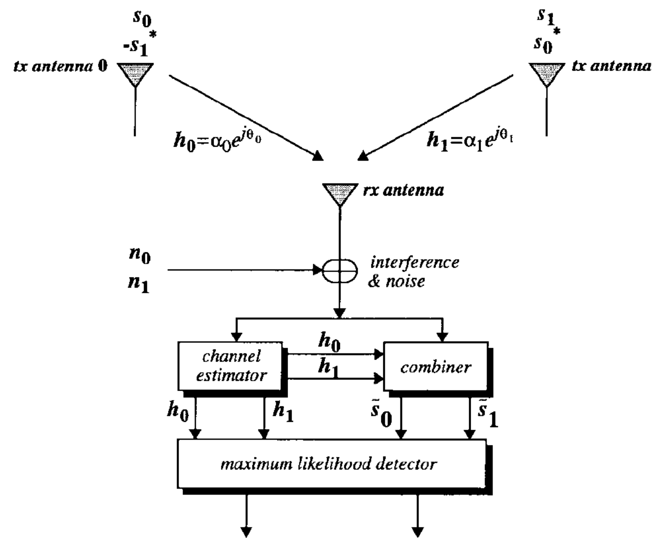
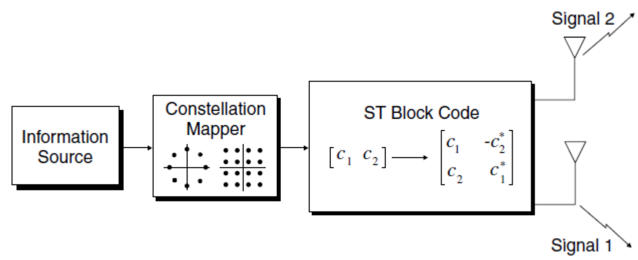


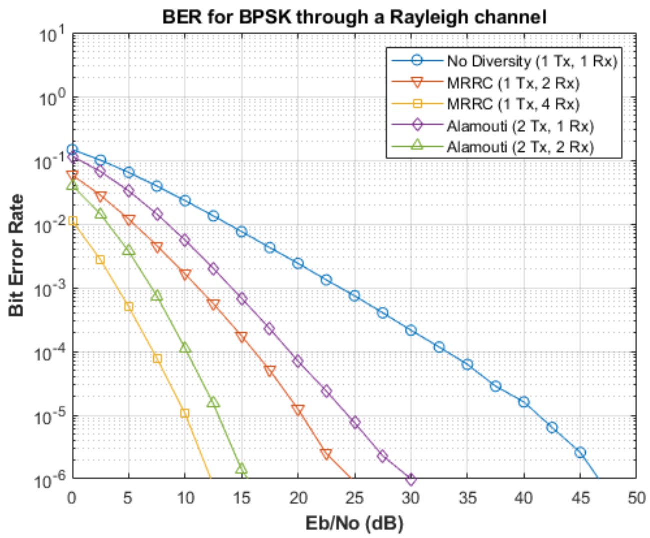
Fig. 6. Spatial Tx Diversity with Alamouti's Space-Time Block Code [2]



III. RESULTS

The transmit and receive diversity schemes are simulated and the bit error rates for diversity orders of 2 and 4, as well as uncoded scheme, are plotted in Figure 7. It is observed that for the same diversity order, MRRC seems to outperform Alamouti codes by 3 dB gain. For instance, for diversity order of 2 – MRRC 1 Tx, 2Rx / Alamouti 2 Tx, 1 Rx – the coding gain for MRRC is approximately 3 dB, which is due to the power reduction by half for Alamouti codes. While the total radiated power remains the same, this disadvantage of 3-dB stems from simultaneous transmission of two distinct symbols from two transmit antennas. Alamouti's code scheme requires twice the number of pilot symbols for channel estimation when pilot insertion and extraction is used. One way to compensate for this power reduction is to use two half-power amplifiers compared to one full-power amplifier for MRRC for equal level comparison. This is practically advantageous as they may be cheaper, smaller, and less linear power amplifiers.

Fig. 7. Bit Error Rate Curve for All Conducted Simulations



IV. Conclusion

In this paper, transmit and receive diversity schemes, namely Alamouti and MRRC, are evaluated for coherent BPSK signals on the bit error rate metric. It is observed that MRRC seems to have 3-dB gain relative to Alamouti codes, but we note that this is due to power reduction from simultaneous transmission at the transmit antennas. The Figure 4 of Alamouti's paper (1998) is replicated and performances for diversity orders of 2 and 4 are evaluated against the uncoded (no diversity) scheme.

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