Application of the Alamouti Scheme in Resilient Microwave Radio Links

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Abstract: Conventionally, space-time codes are used in fading environments in order to improve system capacity or to achieve a diversity gain. In this letter, it is shown that the Alamouti scheme provides a switchless alternative to current resilient microwave radio links.

Introduction: Recently, the application of multiple antennas in wireless communication systems has gained much interest. In fading environments, multiple antenna systems promise huge capacity gains over conventional (1x1)-systems with only one transmit and one receive antenna (see, e.g., [1]) or – especially in rich scattering environments – large spatial diversity gains (see, e.g., [2]-[5]) or a trade-off of both.

In this letter, the possible application of space-time codes (STC) in microwave radio communication links with a line-of-sight (LOS) component is investigated [6]. Focus is on the wireless interconnection of base stations (BS) or other fixed nodes within a cellular mobile radio network. Other application examples include satellite links to fixed earth stations and fixed broadband wireless access networks connecting residential sites to a high-data-rate backbone network ('last mile'). Often, such microwave radio links are *resilient* in the sense that each of the two nodes is equipped with two complete, independent, parallel transmitter/receiver (Tx/Rx) chains and particularly with two antennas. Only one Tx/Rx chain is active, while the other one is kept in a 'hot-stand-by' mode. In this letter, an alternative resilient system design based on the *Alamouti scheme* [7] is proposed because of the following reasons: The Alamouti scheme (i) is shown to yield significant diversity gains under realistic assumptions when two Tx antennas are simultaneously active; (ii) retains the data rate of a (1x1)-system; (iii) is resilient because one Tx chain may fail without causing a rate loss; (iv) does virtually not affect the complexity of the transmitter or the receiver.

System Model: In the Alamouti scheme, M-ary data symbols are processed as pairs $[x(k), x(k+1)]$ and transmitted over two antennas according to

$$\mathbf{A} = \begin{array}{c} \left[\begin{array}{cc} x(k) & -x^*(k+1) \\ x(k+1) & x^*(k) \end{array} \right] \begin{array}{l} \text{Time index } k \\ \text{Time index } k{+}1 \end{array} \\ \begin{array}{cc} \text{Antenna 1} & \text{Antenna 2} \end{array} \end{array} \tag{1}$$

where $(.)^*$ denotes complex conjugation[1]. The Alamouti matrix $\mathbf{A}$ is *unitary.* In case of a flat fading channel, this property enables maximum-ratio combining by means of a simple matrix multiplication, provided that the channel is perfectly known at the receiver [7].

The transmitter structure of the enhanced system is shown in Fig. 1. First, symbol mapping and Alamouti mapping is performed. Subsequently, pulse shaping is applied (square-root Nyquist filter $g_t(\tau)$). Finally, the baseband signals are converted to passband, and the resulting HF signals are transmitted over the two antennas. At the receiver, one or two Rx antennas may be used. The received HF signals are converted to baseband. Then, matched filtering and sampling is performed and finally Alamouti detection and symbol demapping.

Link Model and Channel Model: The link model considered in the sequel is depicted in Fig. 2. Without loss of generality, only one link is considered here. In case of multiple Tx/Rx antennas, the statistics of all links are assumed to be the same. The following reasonable assumptions have been made: (i) The two BS have equal heights h (within this letter $h = 20$ m is assumed); (ii) the horizontal distance between the two BS is $R \leq 30$ km (thus there is always a LOS path, despite the spherical shape of the earth); (iii) all reflected rays are combined in one scattered component [8, Ch. 5.4] with Rayleigh distributed amplitude; (iv) Tx and Rx antenna are congenerous parabolic reflector antennas with horizontally directed main beams. Moreover, the roughness of the earth's surface is neglected, which means that the angle γ between LOS and reflected path is the same at the transmitter and the receiver.

The equivalent discrete-time channel model is determined by just two characteristic parameters. The first parameter is a delay τ_d of the scattered component w.r.t. the LOS component (due to the path length difference ΔL). The second parameter is the Rice factor $K \doteq P_{\text{LOS}}/P_{\text{refl}}$, where P_{LOS}

[1]Throughout this letter, the transposed of the original matrix [7] is used.

and P_{refl} are the average received powers of the LOS component and the scattered component, respectively. The Rice factor K is determined by (i) an attenuation α_Θ of the scattered component due to the angle γ w.r.t. the main beam of the Tx/Rx antenna pattern; (ii) an attenuation α_{refl} of the scattered component due to reflection from the earth's surface; (iii) an additional *relative* free space loss/ atmospheric attenuation $\alpha_{\Delta L}$ of the scattered component, due to the path length difference ΔL. Note that absolute attenuation, e.g., due to rain, is not relevant for the computation of K, since it equally affects the LOS and the reflected path.

In case of a small horizontal distance R, ΔL is comparably large and thus τ_d. On the other hand, since the angle γ is quite large, the scattered component is strongly attenuated. The converse applies if R is large. For realistic system parameters (symbol duration $T = 0.05$ μs, carrier frequency 20 GHz, a Tx/Rx antenna with 3 dB beam width of $\Theta_{\text{3dB}} = 0.5°$) and dry conditions, one obtains the following values for the delay τ_d and the Rice factor K: (i) 'Short distance scenario' ($R = 500$ m): $\tau_d \approx 0.1\,T$, $K \approx 67$ dB; (ii) 'Long distance scenario' ($R = 30$ km): $\tau_d \approx 0.002\,T$, $K \approx 0$ dB (since $\gamma \leq 0.15 \cdot \Theta_{\text{3dB}}$). In the short distance scenario, the channel is virtually an additive white Gaussian noise (AWGN) channel, due to the large value of K. However, in the long distance scenario, the channel is virtually a flat Rician fading channel (due to the small delay τ_d) with a strong Rayleigh component. It appears that for data rates of practical interest, the channel is approximately flat for all distances R since either τ_d is small or the scattered component is strongly attenuated.

Simulation results: In this section, the performance improvements obtainable by means of the Alamouti scheme shall be illustrated. The simulation results have been obtained by means of Monte-Carlo simulations over 10^6 blocks, where each block contained 100 quaternary phase shift keying (QPSK) symbols ($M = 4$, Gray mapping used). Channel coding has not been performed. An outer channel code may, however, be added to the proposed system to further improve performance. For the scattered component, block fading has been assumed, i.e., the channel is constant over a complete block. The individual links between the Tx and Rx antennas have been considered statistically independent. In all cases, the channel coefficients have been perfectly known at the receiver. A root-raised-cosine filter with roll-off factor $r = 0.15$ has been used both in the transmitter and the receiver. Clock synchronization has been performed w.r.t. the LOS path.

Fig. 3 presents simulation results for the long distance scenario, which is the crucial scenario in practice. Moreover, analytical curves are included [9, Ch. 14.4] for *diversity reception* of uncoded QPSK over ν statistically independent Rayleigh fading channels with identical average signal-to-noise ratios of $(E_s/N_0)/\nu$ (N_0 denotes the single-sided noise power density and E_s the average energy per data symbol). In all cases, E_s/N_0 is normalized w.r.t. the number of Tx and Rx antennas. As shown in Fig. 3, the bit error rate (BER) performance of the (1x1)-system is very close to the case of a Rayleigh fading channel ($\nu=1$). By means of the Alamouti scheme with two transmit and one receive antenna ('(2x1)-Alamouti'), a significant performance gain is accomplished (6 dB at a BER of $5 \cdot 10^{-3}$). Utilization of a second receive antenna ('(2x2)-Alamouti') yields further significant gain. At the same BER, the overall gain w.r.t. the (1x1)-system is 9 dB.
In the short distance scenario, there is no diversity to be gained. The Alamouti scheme therefore has the same performance as the (1x1)-system.

Conclusions: In this letter, it has been shown that the Alamouti scheme is very well suited as a switchless alternative to current resilient microwave radio links and yields significant diversity gains under realistic conditions.

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Figure Captions

Fig. 1. Proposed transmitter structure based on the Alamouti scheme.

Fig. 2. Model of a point-to-point link between two BS.

Fig. 3. Performance improvements for the long distance scenario.

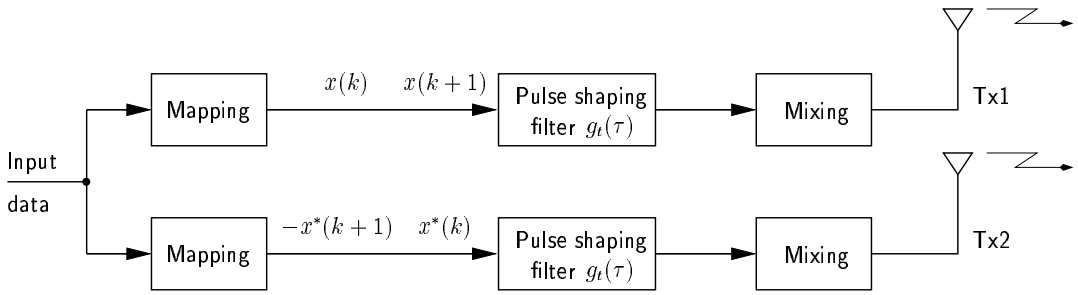
Input
data
Mapping
$x(k)$ $x(k+1)$
Pulse shaping
filter $g_t(\tau)$
Mixing
Tx1
Mapping
$-x^*(k+1)$ $x^*(k)$
Pulse shaping
filter $g_t(\tau)$
Mixing
Tx2

Fig. 1

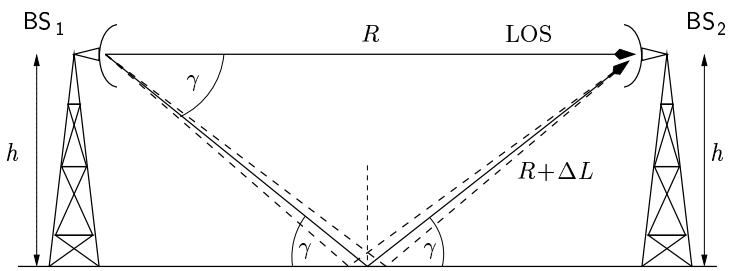

Fig. 2

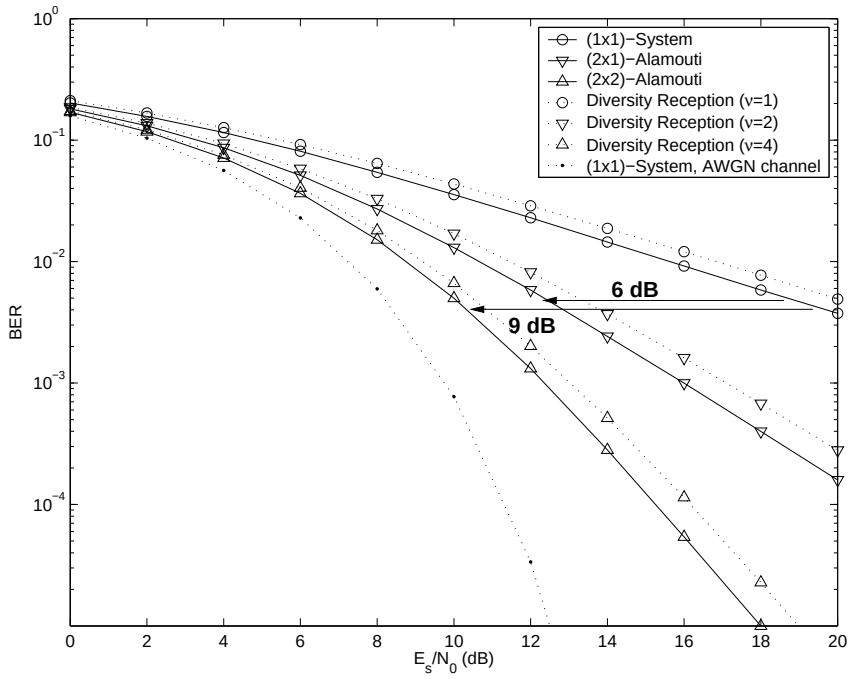
(1x1)−System
(2x1)−Alamouti
(2x2)−Alamouti
Diversity Reception (v=1)
Diversity Reception (v=2)
Diversity Reception (v=4)
(1x1)−System, AWGN channel
6 dB
9 dB
BER
E_s/N_0 (dB)

Fig. 3