Antenna Selection Diversity for IEEE 802.11p

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Abstract—**Dependable vehicular communications systems are a key requirement for the implementation of intelligent transportation systems (ITS). Multiple antenna receivers enable the utilization of spatial diversity to increase the reliability as well as improve the availability. The cost of a multiple antenna receiver is the increased hardware complexity due to multiple receive chains. In this paper we demonstrate that antenna selection for IEEE 802.11p allows to connect the antenna with the best instantaneous signal to noise ratio (SNR) to a single receive chain while maintaining the diversity gain. We extend the IEEE 802.11p frame structure by two short preambles to estimate the SNR for each receive branch. The numerical simulation results from our standard compliant link level simulation show a bit error ratio reduction from $8.159 \cdot 10^{-3}$ to $6.681 \cdot 10^{-3}$ at an SNR of 8 dB and from $4.688 \cdot 10^{-5}$ to $1.063 \cdot 10^{-5}$ at an SNR of 12 dB with antenna selection.**

I. INTRODUCTION

Multiple-input multiple-output (MIMO) systems have become popular due to their high efficiency. MIMO systems can provide a diversity gain by transmitting several copies of the signal. On the other hand, multiplexing gain is also feasible by sending independent data streams and therefore, higher capacity is achievable. Regardless of the mentioned advantages of MIMO system, high complexity and consequently increased cost can be considered as the drawback of MIMO systems. Since, in such a system, there are multiple antenna elements at the transmitter and receiver side, a radio frequency (RF) unit and also a powerful digital signal processing (DSP) unit are required for each antenna and this will lead to an increase in complexity and cost.

Antenna selection is introduced as a solution to reduce the complexity of MIMO systems. In such an approach, only a subset of antenna elements are selected to be connected to RF chains while the achievable MIMO diversity gain is retained. MIMO systems with antenna selection are described in [1]. In [2], a suboptimal method for antenna selection is presented for MIMO orthogonal frequency division modulation (OFDM) systems. In this method, complexity reduction is possible via inter-subcarrier correlation or by employing disjoint selection of transmit and receive antennas. For slowly varying channel, it is possible to choose the optimal antenna subset by linear and coherent receivers [3]. For this purpose, the optimum antenna subset is chosen based on the SNR values of multiplexed sub-streams and the maximum of minimum SNR can determine the selected antenna. Although, antenna selection is a promising solution for hardware cost reduction, there are always concerns regarding RF imbalance and the training protocol design for the such selection schemes. In [4], these two major concerns have been taken into account and novel solutions for slowly time-variant environments have been presented.

Most of the works related to antenna selection issues are based on frequency–flat channels, such as the one described in [3]. Moreover, a selection algorithm for the transmit antenna is introduced in [5] which maximizes the ergodic capacity and minimizes the error probability for a zero forcing spatial multiplexing system. The authors of [6] present a receive antenna selection method using discrete prolate spheroidal (DPS) sequences for channel prediction in highly time-variant scenarios.

Antenna selection algorithms for frequency selective fading channels are proposed in [7], [8]. A joint antenna selection technique is introduced for the transmit and receive antennas in a MIMO-OFDM system by exploiting the minimum sub-stream SNR in all subcarriers [7]. In [8], an adaptive antenna selection approach for transmit diversity is presented with subcarrier to antenna allocation and the channel knowledge is considered available at the transmitter which is not feasible for vehicular scenarios.

Contribution of this work:

- We propose a receive antenna selection scheme suitable for the IEEE 802.11p standard. The frame structure is extended by additional short training sequences (like in IEEE 802.11n) to perform antenna selection in vehicular environments which are characterized by a time-varying frequency selective channel.
- Numerical simulation results validate that the proposed frame structure allows to achieve an increased diversity gain for vehicular velocities.

The rest of the paper is as follows: the system model is explained in Sec. II. The OFDM frame structure of IEEE 802.11p is then illustrated in Sec. III. Sec. IV describes the proposed antenna selection algorithm in detail and Sec. V is assigned for the simulation results. Conclusion and References are given in Sec. VI and VII, respectively.

II. SYSTEM MODEL

A MIMO system has M_t transmit antennas and M_r receive antennas from which a subset of optimum receive antennas N_r are selected for reception. For each link between transmitter and receiver, we define the time-variant frequency response $H_{n,m}(t, f)$, where n and m denote the receiver and transmitter index, t denotes time and f frequency.

The proposed scheme for antenna selection diversity is tailored to a MIMO-OFDM system. The OFDM system has N subcarriers and a cyclic prefix of length G. The transmission unit is a frame with a frame length of L OFDM symbols. The system utilizes a bandwidth of B and a sampling rate at the receiver side $B = 1/T_C$ [9]. We assume the cyclic prefix is longer than the maximum path delay, such that the sampled time-variant frequency response can be rewritten as below, cf. [7]:

$$H_{n,m}[p, q] = H_{n,m}(pT_S, q\Delta f) \tag{1}$$

where $p \in \{0, \ldots, L-1\}$ denotes the OFDM symbol index, $q \in \{0, \ldots, N-1\}$ the subcarrier index, $T_S = 1/B(N+G)$ the OFDM symbol length and $\Delta f = B/N$ the subcarrier spacing.

After the OFDM demodulation the received signal can be expressed as in (2), cf. [7]

$$Y_n[p, q] = \sum_{m=1}^{M_t} H_{n,m}[p, q] X_m[p, q] + \eta_n[p, q] \tag{2}$$

where $X_m[p, q]$ denotes the symbols sent from the m-th transmit antenna and η_n denotes additive white Gaussian noise at the n-th receive antenna.

III. PROPOSED ANTENNA SELECTION SCHEME

Antenna selection is carried out at the receiver side only. We propose to add two preambles for the estimation of the SNR on each receive antenna to enable the implementation of SNR-based receive antenna switching. In the following subsection, the IEEE 802.11p OFDM frame structure is described and then the receive antenna selection criterion is explained.

A. IEEE 802.11p OFDM Frame Structure

The OFDM frame and pilot structures is illustrated in Fig. 1. As it is shown, a frame consists of 12 preamble symbols in which 10 short training symbols and 2 long training symbols exist. The next symbol in the frame is the SIGNAL symbol which is equal to one OFDM symbol and after that there are a variable number of OFDM symbols that are assigned to DATA.

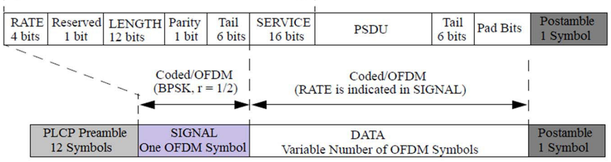

Fig. 1. IEEE 802.11p PHY Packet Structure

Fig. 2 shows the pilot structure in an IEEE 802.11p OFDM frame. As it is represented in this figure, the first two columns are the long preamble symbols which are used for channel estimation and afterwards the SIGNAL and DATA OFDM symbols are placed. It should be noted that the short preamble is not shown in this figure. At the end of the frame, one postamble symbol is considered in the reserved bit of the header structure [9]. Four pilot subcarriers are used throughout the whole OFDM frame.

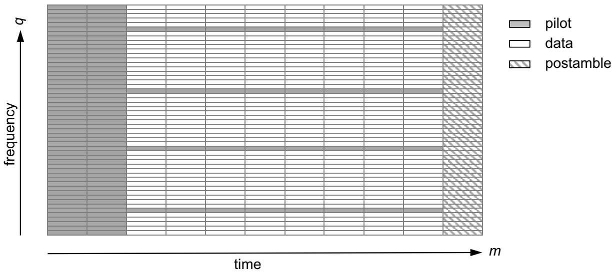

Fig. 2. IEEE 802.11p OFDM Pilot Structure [9]

B. Antenna Selection Phase

In this work, receive antenna selection is proposed due to having a time-varying channel in vehicular environments. The selection scheme is carried out based on the training symbols and for this purpose, the frame structure is modified and two more preamble symbols are added to the current IEEE 802.11p frame. The modified frame structure is shown in Fig. 3 in which one transmit antenna and two receive antennas are considered. At the receiver side, the receive antennas are equipped with radio frequency switched implemented by a micro electromechanical system (MEMS) which can provide switching between the receive antennas during the selection phase. As it is illustrated, the first added preamble is transmitted and received by the first antenna (Rx1) and with a 15 μs delay the second preamble is sent and received at the second receive antenna (Rx2).Then, after a delay of 15 μs, the data frame is received by the selected receive antenna. The 15 μs is the time which is required to switch between the receive antennas.

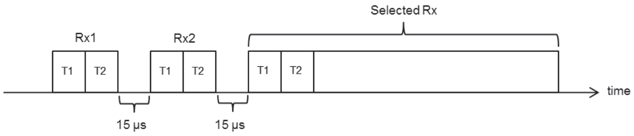

Fig. 3. Proposed Frame Structure

At each receive antenna, the SNR is calculated for each subcarrier as written in (3) and based on these SNR values for all subcarriers, a matrix is formed containing the calculated value for all possible combinations of the transmit antenna and receive antennas, which for this work is two, since, we consider one transmit antenna and two receive antennas. The matrix is shown in Fig 4.

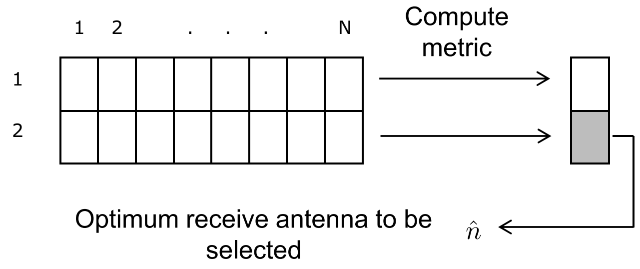

Fig. 4. Matrix of estimated SNR and selected index $\hat{n}$ according to (5)

The (n, q)-element of the matrix stores the estimated SNR for receive antenna n and subcarrier q,

$$\widehat{\mathrm{SNR}}_n[q] = \frac{\hat{S}_n[q]}{\sigma_N^2}, \qquad (n = 1, 2;\ q = 1, \ldots, N), \tag{3}$$

where σ_N^2 is the noise variance and the estimated signal power $\hat{S}_n[q]$ is evaluated as:

$$\hat{S}_n[q] = \sum_{p=1}^{2} |Y_n[p, q]|^2 \tag{4}$$

We note that $\widehat{\mathrm{SNR}}_n[q]$ is evaluated from the nth transmitted preamble. The number of rows in this matrix is $\binom{2}{1} = 2$ which equals the number of all combinations of antenna pairs. It has N columns corresponding to the number of subcarriers. We choose the following maxmin criterion for antenna selection

$$\hat{n} = \arg\max_{n=1,2} \left(\min_{1 \leq q \leq N} \widehat{SNR}_n[q] \right). \tag{5}$$

The minimization is over subcarriers and the maximization is over all combinations of antenna pairs. Therefore, first in each row of this matrix, the minimum value of the SNR is chosen and then a vector is formed which contains these minimum values and consequently the maximum SNR value is selected in this vector which leads to the optimum receive antenna since the rows of the vector correspond to the receive antennas.

IV. SIMULATION RESULTS

In order to evaluate the proposed antenna selection scheme, an 802.11p link-level simulator implemented in MATLAB is used. A carrier frequency of $f_c = 5.9\,\mathrm{GHz}$ is assumed and the system bandwidth is $B = 10\,\mathrm{MHz}$ as used in 802.11p standard. The total number of subcarriers is $N = 64$ where 52 subcarriers out of total numbers are allocated for data transmission. In this scheme, quadrature phase shift keying (QPSK) and a convolutional code with code rate $R_C = \frac{1}{2}$ are used. In the numerical simulations, we use a time-variant channel model with an exponentially decaying power delay profile and a Clarke Doppler profile for each channel tap [10]. The small-scale fading processes associated with the two receive antennas are assumed to be uncorrelated.

Each OFDM frame contains 38 OFDM symbols (including the postamble symbol). For numeric Monte Carlo simulations $F = 1000$ frames are used. The resulting frame length is 200 Bytes in this simulation. The simulation is performed over two number of iterations for channel estimation. There are one transmit antenna ($M_t = 1$) and two receive antenna ($M_r = 2$). The assumed scenario is Vehicle-to-Infrastructure (V2I) where the transmitter is fixed and the receiver is mobile with a velocity of $50\,\mathrm{km/h} \approx 13.9\,\mathrm{m/s}$. In Table I, the simulation parameters which have been considered for the proposed antenna selection scheme are illustrated.

Carrier Frequency (f_c)	5.9 GHz
Bandwidth (B)	10 MHz
Channel Model	Clarke's Doppler Profile
Number of OFDM Symbols	38
Total Number of Subcarriers	64
Number of Frames	1000
Frame Length	200 Bytes
Number of Receive Antenna	2
Number of Transmit Antenna	1
Velocity	50 km/h

TABLE I
SIMULATION PARAMETERS

The simulation results of the proposed antenna selection scheme is compared with the single-input-single-output (SISO) case. In addition, the presented scheme has been simulated with perfect channel state information (CSI) and with discrete prolate spheroidal sequences (DPSS) with a soft decision feedback channel estimator. The bit error ratio (BER) results are illustrated versus E_b/N_0, whereas E_b is the energy per bit and N_0 denotes the noise power spectral density.

Fig. 5 illustrates the comparison between the simulation results of the proposed antenna selection method and the SISO case. The dashed lines are associated with two iterations of the antenna selection scheme and the solid lines are related to SISO case. We can show that the proposed method outperforms the SISO case. The BER is improved remarkably in comparison to the SISO transmission. To be more precise, it can be said that at an SNR of 12 dB, the BER is decreased from $4.688 \cdot 10^{-5}$ to $1.063 \cdot 10^{-5}$. Furthermore, it can be inferred that there is a significant improvement in the transmit signal power. The curves' slopes imply that the diversity gain is not only retained but also improved since, the proposed scheme tries to choose the better link for transmission.

In order to evaluate the antenna selection more accurately, we also compare the results with the case in which the perfect channel knowledge is available at the receiver. All the simulation parameters are similar except that the antenna selection has DPSS estimator but one scenario with perfect CSI is also considered. The results are represented in Fig. 6.

In this figure, the solid line shows the BER vs. E_b/N_0 curve for the antenna selection scheme with perfect CSI and the antenna selection scheme with estimator is displayed with the dashed lines for two iterations. As it has been illustrated after the first iteration, the antenna selection scheme with channel estimation approximately approaches the antenna selection result with perfect CSI. At an $E_b/N_0 = 12\,\mathrm{dB}$, the BER is around $1.063 \cdot 10^{-5}$ for the second iteration of the proposed antenna selection with channel estimation and $0.688 \cdot 10^{-5}$ for

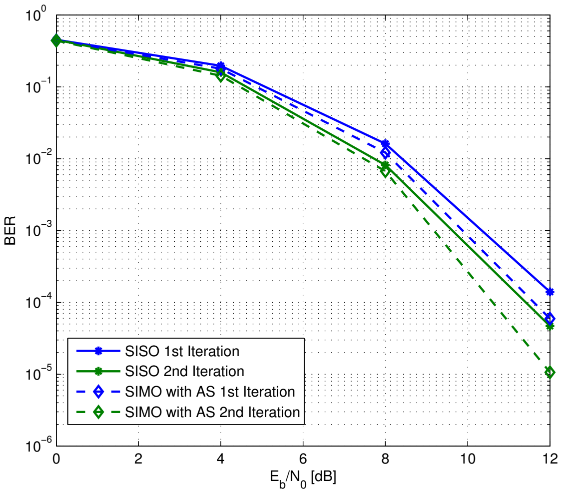

Fig. 5. SIMO Case with Antenna Selection versus SISO Case without Antenna Selection

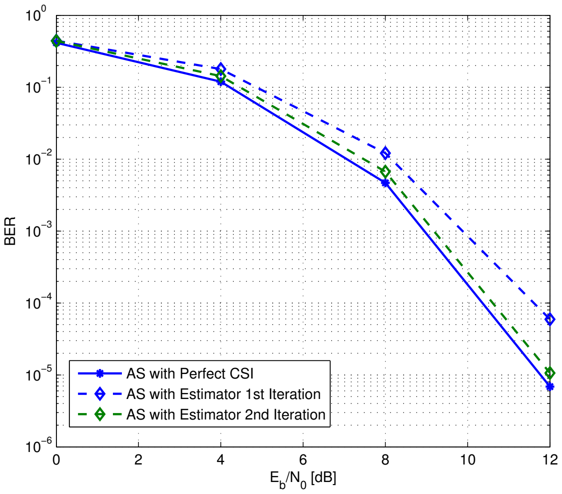

Fig. 6. Antenna Selection with Estimator versus Antenna Selection with Perfect CSI

the one with perfect CSI.

V. CONCLUSION

In this contribution, we describe and numerically evaluate antenna selection diversity for IEEE 802.11p for a SIMO-OFDM setting. In our simulations, one transmit antenna and two receive antennas have been modeled. Due to the difficulties of the time-varying vehicular channel, the proposed diversity scheme performs antenna selection only at the receiver side because this restriction does not require feedback signaling to the transmitter. The main figure of merit is the improvement in diversity gain and our simulation results indicate a significant improvement in the BER. The numerical simulation results from our standard compliant link level simulator show a BER reduction from $4.688 \cdot 10^{-5}$ to $1.063 \cdot 10^{-5}$ at an SNR of 12 dB with antenna selection diversity.

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