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Decode-and-Forward cooperative vehicular relaying for LTE-A MIMO-downlink

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ABSTRACT

Cooperative multiple-input multiple-output technology allows a wireless network to coordinate among distributed single or multiple antenna deployments and achieves considerable performance gains compared to those provided by conventional transmission techniques. It promises significant improvements in spectral efficiency and network coverage and is a major candidate technology in various standard proposals for the fourth-generation wireless communication systems. We propose to use cooperative multiple antenna deployment links in Long Term Evolution-Advanced networks where vehicles act as relaying terminals using Decode-and-Forward relaying. To maintain orthogonality of signals, we deploy a modified Alamouti-based Space–Time Block Coding technique. Our approach allows exploitation of the multiplexing capability and spatial diversity of typical multiple antenna schemes in distributed way. We further contribute by deriving error rate, diversity gain and outage probability closed form expressions as a benchmark to assess our analysis and future research studies. Our findings indicate that significant diversity gains and reduced error rates are achievable. As well, a noticeable reduction in the required transmitting power, and an increase in coverage distance are observed compared to traditional single antenna deployments.

1. Introduction

The evolution of fourth generation (4G) mobile communication has enabled new services and usage models with higher efficiency networks. 4G systems support a wide range of applications that require high data rates and reliable transmission. To meet this demand, wireless communication system designers need to advance and optimize network performance in terms of better link reliability, fewer dropped connections and longer battery life. Long Term Evolution-Advanced (LTE-A), which was ratified by the International Telecommunication Union (ITU) as an IMT-Advanced 4G technology in November 2010, has adopted relaying for cost-effective throughput enhancement and coverage extension. The utilization of multi-hop relaying techniques aims at increasing network performance without the need to undergo costly network infrastructure expansion [1,2].

Concurrently, the continuous increase of mobile data traffic has created a substantial demand for high data rate transmission over 4G mobile networks. The uplink power and efficiency constrains are studied in [3,4]. In [3], two power-efficient schedulers for mixed streaming services are presented to minimize transmission power for all users in LTE uplink systems. Simulation results show that the proposed schedulers offer a significant transmission power reduction for the LTE link. In [4], a framework for energy efficient resource allocation in multiuser synchronous constraints is presented. Using this framework, the authors formulate the optimal margin adaptive allocation problem, and proposed two suboptimal approaches to minimize average power allocation required for resource allocation for LTE links while attempting to reduce complexity. For the multiple-input multiple-output (MIMO) downlinks, the authors in [5] focus on minimizing the long-term average power consumption of a transmitter providing Quality of Service (QoS) enabled traffic to a receiver. While both the transmitting and receiving stations are equipped with multiple antennas. The designed policy exploits queue state information to schedule traffic while meeting throughput and loss constraints.

Recently, vehicular networks cooperative relaying has been proposed to extend coverage, enable ad-hoc connectivity and enhance link reliability. Cooperative communication has been proposed for vehicular networks through distributed spatial diversity by making use of vehicles equipped with low elevation antennas, and short and medium range wireless communication technologies. The ad-

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vantages of vehicular relaying networks include the abundant energy and computing power, the predictable movement that is in the most common cases limited to roadways, the availability of positioning systems and map-based technologies, and the frequent availability of travelling vehicles. Hence, vehicular relaying is envisaged to be a key technology enabling significant network growth in the coming years. Most vehicular wireless communication measurement campaigns have focused on single-antenna applications, leading to the development of single-input single-output (SISO) systems, e.g., [6–9] and the references within. However, only a few measurement campaigns [10–12] have so far been conducted for MIMO Vehicular channels. For simplicity assumptions, multiple uncorrelated Rayleigh fading processes often implemented MIMO channel models.

It is well recognized that MIMO wireless systems can improve link performance and spectral efficiency by utilizing diversity and multiplexing gains [10,13]. For MIMO channels it is very likely that correlated channel fading coefficients appear if the transmit antennas of the same transmitter/receiver are within a range of a few wavelengths. This leads to a degradation of the error rate performance as diversity is lost. To overcome this phenomenon, Space–Time Block Coding (STBC) [14] is used to enforce orthogonality of the transmitted signals. This in turn provides the ability to extract full signal diversity. STBC can achieve an optimal tradeoff between multiplexing gain and diversity gain, which means such codes can achieve the optimal diversity gain [15]. Provisioning practical STBC for cooperative relay channels is fundamentally different from STBC for MIMO link channels and is still an open and challenging area of research. Apart from practical STBC for the cooperative relay channel, the formation of virtual antenna arrays using individual terminals distributed in space requires a significant amount of coordination. Specifically, involves distributed transmissions while synchronizing at the packet level amongst the different communicating nodes. In this paper, we make use of a modified STBC-MIMO deployment for dual-hop cooperative systems.

Although the expectations for this emerging technology are set very high, many practical challenges still remain unsolved. In most practical scenarios in such high mobility communication, intersymbol interference (ISI) due to the broadband nature of the system introduces frequency-selectivity, and Doppler spreads resulting in time-selectivity. Within the research of cooperative diversity, one commonly used technique for the transmission between a source and a destination through relays is Decode-and-Forward (DF). In DF, relays first decode the received signal, re-encode it, and then transmit the re-encoded signal to the destination. Beside DF, the most common relaying strategy is amplify-and-forward (AF). AF simply amplifies and retransmits the signal without decoding. It was shown in [16] that the DF protocol achieve higher ergodic (mean) capacity than the AF. A similar conclusion was found in [17] for the ergodic capacity of MIMO multi-hop relay systems. From [16] and [17] we conclude that while the AF protocol is better for uncoded systems (where the error propagation effect outweighs the noise amplification), the opposite is true for systems using powerful capacity-approaching codes, where DF outperforms AF. DF also avoids error propagation in practice, where a relay node can decide that an incorrect decision has been made through cyclic redundancy check (CRC) deployment.

In this paper, we study cooperative vehicular relaying for a downlink LTE-A communication session, using a multiple antenna deployment installed at a transmitting cellular base-station (eNodeB/BS) and a designated receiving end vehicle through a highway traffic. The source and destination nodes are equipped each with two antennas while the relay node has a single transmit/receive antenna. Note that a single antenna at the relaying vehicle allows maintaining the basic minimum required power and processing capabilities without the need for extra hardware deployment. As mentioned above, Alamouti-type STBC [14] is modified and used across the two transmit antennas of the source node and the two receive antennas at the designated vehicle.[1] Since time-selectivity destroys the orthogonality of STBC, we employ digital phase sweeping (DPS) to overcome the degrading effects of time-selectivity. DPS converts space–time time-selective channels into a single faster time-selective channel [18]. We further contribute by

1) deploying an effective pre-coding transmission scheme and a MIMO encoding technique for the model under consideration (illustrated in Table 1) that significantly increase diversity gains and reduce error rates;

2) the derivation of closed-form formulae for the error performance rate, diversity gains and outage probability as a benchmark to assess our analysis and future research studies of such an approach; and

3) demonstrating the performance gains of the proposed approach, analytically and through simulation, compared to the traditional approaches.

In addition to higher diversity and improved levels of error rates, our transmission scheme shows tight performance compliance to similar ideal stationary flat-fading scenarios even under high mobility and selective fading.

The paper is organized as follows: In Section 2, we present the pre-coded cooperative system model along with the vehicular fading channel. In Section 3, we provide diversity gain analysis through derivation of the Pairwise Error Probability (PEP); further we derive the outage probability. In Section 4, we present numerical and simulation results for the error rate performance, the diversity gains and the coverage distance advantages of our proposed scheme. We conclude our findings in Section 5.

Notations. $(.)^{\mathrm{T}}$, $(.)^{*}$ and $(.)^{\mathrm{H}}$ denote transpose, conjugate and Hermitian operations, respectively. $\mathbb{E}[.]$, $|.|$ and $\otimes$ denote expectation, absolute value and Kronecker product, respectively. $[\mathbf{H}]_{k,m}$ represents the (k,m)-th entry of $\mathbf{H}$. $\mathbf{I}_N$ indicates an $N \times N$-size identity matrix. $\mathbf{0}$ represents all-zeros matrix with proper dimensions. $\lceil . \rceil$ and $\lfloor . \rfloor$ denotes integer ceil and integer floor operations, respectively. $*$ is the convolution operator. x, i, j, k are dummy variables. $F(.)$ and $f(.)$ are the cumulative distribution function (CDF) and probability density function (pdf) for a given random variable, respectively. **Bold** letters/symbols denote matrices and vectors.

2. System model

As illustrated in Fig. 1, we consider a highway traffic scenario, where the relay and destination vehicles are assumed to be travelling in the same direction with similar speeds and communicating with a fixed BS through an LTE-A downlink session.[2] In this scenario, source-to-destination and source-to-relay links are modelled by a doubly-selective channel due to the relative velocity between the communicating nodes. On the other hand, since the relative Doppler frequency of the relaying and destination vehicles travelling in the same direction with similar speeds becomes nearly zero, the relay-to-destination link can be modelled by a time- and frequency-flat channel. In this section, we first describe the vehicular channel model and then present the pre-coded cooperative MIMO scheme under consideration. There are mainly two approaches to handle cooperative communications. The first approach involves adaptive transmission in which one or more transmission parameters (coding, modulation, power, etc.) are varied

[1] Extension to more than two antennas is straightforward with a more cumbersome notation.

[2] A scheme similar to the one in [19] can be used to ensure such relay selection.