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Performance analysis for low-complexity detection of MIMO V2V communication systems

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ABSTRACT

In Vehicle-to-Vehicle (V2V) communication, the rapid movement of vehicles brings fast attenuation of signal propagation and serious shift effect of Doppler frequency, leading to serious transmission performance deterioration. Multiple-Input Multiple-Output (MIMO) technique can be well applied in V2V communication by exploiting diversity and multiplexing gain to improve the system reliability and increase the data rate. In an MIMO system, the achieved diversity and multiplexing gain is closely related to its detection method. Integer-Forcing (IF) detection is one of the linear detections proposed in recent years. Compared to the traditional linear and Maximum Likelihood (ML) detection, IF has a good tradeoff between the complexity and system performance. In this paper, considering its good detection performance, IF is applied to the detection of a MIMO V2V communication system and the performance is further analyzed theoretically by employing Alamouti code at the transmitters. The diversity gain proves to be full and is confirmed by the simulation results.

1. Introduction

The rapid development of traffic network transport brings great pressure to traffic safety, transport efficiency and sustainable development of a city. At the same time of causing huge economic loss, it also induces traffic accidents, increased environmental pollution and other traffic problems. The relevant traffic management division have taken various measures, such as odd-and-even license plate rule, license auction, raise parking fees, but the cost is high. As a fairly complex system, it is difficult to solve the problem by considering vehicles or road separately [1–3].

Intelligent Transportation System (ITS) is a comprehensive technology that integrates a variety of computer, sensing technology and communication technology into the management and control of a traffic system. It can effectively utilize the existing transportation facilities to make the traffic system more secure, efficient and reliable [4–6]. In essence, the vehicle networking is a huge wireless sensor network, in which each car can be considered as a super sensor node [7]. Wireless sensor networks are composed of a large number of randomly-configured sensor nodes and network coverage is one of the most basic problems [8]. The wireless communication of ITS mainly relies on two technologies: short-range wireless communication and long-distance mobile communication, which is mainly mobile communication technologies such as GPRS(General Packet Radio Service), 3G(3rd Generation communication system), 4G(4th Generation communication system), LTE(Long Term Evolution) [9]. With the rapid development of big data, cloud computing and wireless communication technologies, network support is provided for the specific service applications of ITS [10]. A lot of storage resources of cloud computing are utilized to protect important data [11]. As one crucial component of ITS, vehicle communication is the focus of research [12,13].

Generally speaking, the communication between vehicles in ITS can be divided into V2V and Vehicle-to-Infrastructure (V2I). As shown in Fig. 1, V2V communication system utilizes vehicles equipped with transmit unit to transmit signals through high-speed wireless network, including vehicle's speed, direction, geographical location, routes and so on. Other vehicles will receive the transmitted wireless signal in real time and feedback similar information, forming an information exchange process. By sharing real-time information among vehicles, the system can respond more timely to avoid danger and further enhance the traffic safety. The V2V system can prejudge dangers in case the driver is unaware of

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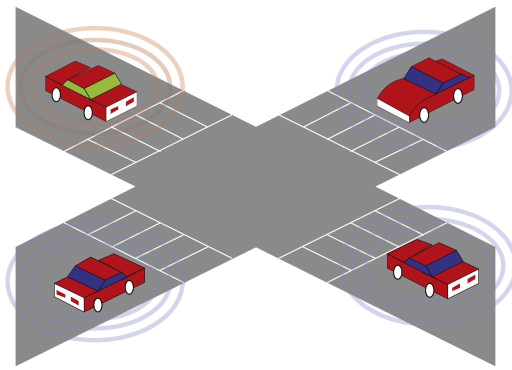

Fig. 1. V2V communication diagram.

in various road conditions by communicating with the surrounding vehicles. For example, a vehicle in emergency braking will broadcast a corresponding signal to the surrounding vehicles so that they can take actions automatically to avoid accidents, which is more accurate and quicker than the driver's judgment [14–16]. In theory, the accident rate can be reduced by more than 70%.

When the vehicle moves quickly, it will cause serious Doppler shift phenomenon. Especially in the actual urban traffic environment, high buildings, bridges, tunnels and green belts make the channel attenuate more serious together with the high-speed movement of vehicles. When two vehicles are moving rapidly towards each other, the polarity of the Doppler frequency shift will be reversed in a short time, resulting in channel deterioration. While one vehicle moves with high buildings and other reflective objects around it, different paths of the same transmitted signal will superpose at the receiver and form multi-path fading, which may seriously affect the signal strength and communication quality. In most vehicle scenarios, especially in the urban scenes, the channel of V2V system has a highly dynamic characteristic due to the multi-path fading.

Traditional wireless communication technology cannot solve the above problems easily. MIMO technology with more than one antenna at both the transmitter and receiver, can satisfy higher rate requirements and shorten the transmission delay of emergency messages, realizing real-time communication among vehicles. Furthermore, it can also exploit diversity gain to provide more reliable communication for ITS applications by using Space-Time Block Code (STBC) and other signal processing techniques such as V-BLAST (Vertical-Bell Labs layered Space-Time) coding and space-time coding [17–19]. Beamforming technology can spatially converge the transmitted signals and expand the communication range significantly, which is more useful in scenarios where the vehicle density is low. Therefore, MIMO technology can be well applied in V2V communication to improve the anti-fading and anti-jamming capability, enhancing the channel capacity and transmission reliability. As shown in Fig. 2, assume that the transmitter and receiver are equipped with more than one antennas respectively. The input signal is transmitted through transmit antennas after modulation, and then the receiver receives multi-channel signal superposition and resolves the original signal through effective detection and demodulation. Although MIMO technology has many advantages, the adopted detection method directly determines the system performance and also the computational complexity. Therefore, many researchers have carried out research on signal detection and put forward relevant algorithms. IF detection is proposed in recent years as one linear detection for MIMO systems. Compared with the traditional linear and maximum likelihood detection, IF can obtain a tradeoff between complexity and performance. In this paper, we apply IF detection to a MIMO V2V communication system with Alamouti STBC. The specific detection steps are clarified and the system performance is analyzed theoretically and proves to be full in diversity gain.

Notations. Row vectors are presented by boldface letters and matrices are denoted by capital boldface letters. $(.)^*$, $(.)^H$, $(.)^T$ denotes conjugation, transpose and Hermitian of a vector or matrix respectively. $\mathbf{I}_n$ and $\mathbf{0}_n$ represents $n \times n$ identity and zero matrix respectively. $\mathbb{C}$, $\mathbb{Z}$, $\mathbb{R}$ denotes the set of complex numbers, integers numbers and real numbers respectively. The operator $\otimes$ denotes Kronecker product. $\|\cdot\|$ and $\|\cdot\|_F$ denotes Euclidean norm of a vector and Frobenious norm respectively. Let $\lfloor x \rceil$ represents the closest integer to x and $\lfloor \mathbf{x} \rceil$ denotes component-wise equivalent operation.

2. Related work

The decoding complexity of MIMO is much higher than single antenna communication system due to that it utilizes multiple antennas for signal transmission and the received information includes multiple signals and interference. To recover the original transmitted information, the detection algorithm is very important since it directly affect the system performance. The common detection methods include ML and conventional linear detection with different performance and computational complexity.

ML detection: ML is the optimal detection, which detects the transmit symbols by traversing all possible transmit signals and finds the closest symbols to the received signal, but the computational complexity increases exponentially with the number of antennas and modulation order, which restricts its application.

Conventional linear detection: It can be described that the interference between the signals is forced to zero by multiplying the received vector with a linear filter matrix, traditional linear detection algorithms are Zero-Forcing (ZF) and Minimum Mean Square Error (MMSE) [20–23].

ZF detection is usually simple and easy to implement. The computational complexity is greatly reduced compared to ML. In many research literature, ZF filter matrix is calculated based on Least Square (LS) criteria [24]. ZF can restrain interference, but the noise is amplified simultaneously, i.e., the corresponding noise matrix element will be amplified by ZF filter matrix and the final decision performance will be affected. MMSE detection also considers the interference of channel and noise. The linear filter matrix is selected under the mean square error minimization criterion. Therefore, this algorithm can eliminate the interference between the channel without seriously exacerbating the noise. Compared to ZF algorithm, the performance is better with a little higher complexity.

IF detection: It was first proposed as one linear receiver in the V-BLAST coding scheme where codeword is transmitted through different layers at the same time [25–28]. Instead of detecting the transmitted symbols directly, IF generates an integer channel matrix at first and then decodes the integer linear combination of codewords, at last recovering the transmitted codewords by solving a linear equation. It can be regarded as traditional linear detection when integer channel matrix is an identity matrix. In contrast, IF converts the channel matrix into a full rank integer matrix under the premise of minimizing noise power. In the V-BLAST scheme, IF detection achieves a higher transmission rate and obtains full diversity with relatively lower computational complexity, which can be regarded as a tradeoff between the ML and traditional linear detections.