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Improving the Channel Utilization of Basic Safety Message in VANETs with Superposition Coded Modulation

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Abstract

In this paper, we propose a broadcast scheme to effectively utilize the scarce and shared wireless medium for vehicular ad-hoc networks (VANETs). By using superposition coded modulation (SCM), information elements that comprise basic safety messages (BSMs) were delivered with different service qualities determined by real-time traffic situations. The optimal power allocation strategy and achievable performance gain of the proposed method were first theoretically analyzed. To apply the proposed method into practice, the hierarchical quadrature amplitude modulation technology was then employed to implement the proposed SCM-based broadcast scheme for VANETs. To evaluate the performance of the proposed method in real-time traffic environments, a joint traffic-communication simulation was further conducted. Results agree that the proposed method extends the coverage of the BSM broadcast while maintaining an acceptable communication reliability to meet the requirement of driving safety.

Keywords: *Vehicular ad hoc networks, Superimposed coded modulation, Hierarchical quadrature amplitude modulation*

1. Introduction

As a promising wireless communication technology for future intelligent transportation systems, vehicular ad-hoc networks (VANETs) [1] have attracted significant attention. By providing high speed and low-latency data links among vehicles, VANETs enable a broad range of applications to enhance driving safety and transportation efficiency [2]. VANETs have been standardized by IEEE 802.11p [3]. However, given the high mobility of vehicles and the time-varying requirements of quality-of-service (QoS), 802.11p-based vehicular communications still suffer from a few open challenges. One of the most important problems is medium access congestion [4]. To enable versatile applications, moving vehicles in VANETs need to periodically broadcast their own status information, i.e., the so-called basic safety message (BSM), which is composed of several data elements (DEs), e.g., position, acceleration, heading, and velocity. The BSM packet has a typical length of 300–400 bytes, is disseminated at a data rate of 6 Mbps, has single-hop coverage of 300–500 m, and has a message rate of 1–10 Hz [5]. The bandwidth of the shared wireless medium is limited, and guaranteeing the required delivery rate and transmission delay of the BSM dissemination of all vehicles is difficult, particularly in dense traffic scenarios. This problem significantly reduces the validity of VANETs in aiding driving. In the current paper, we aim to reduce the bandwidth requirement of BSM broadcast by improving channel utilization.

Several studies have addressed this problem in the context of VANETs and have used media-access-control (MAC) methods and information compression methods in the application layer. On one hand, given that the random access scheme employed by the MAC layer of the IEEE 802.11p standard is the main inducement of packet collisions and medium access congestion [6, 7], numerous studies have focused on improving channel utilization by novel access schemes [4]. In [8], instead of the random media access, a time-slotted-based MAC scheme was proposed to reduce packet collisions. By dividing the entire service period into the collision detection and collision avoidance phases, a content-based MAC scheme was proposed in [9] to improve the reliability of BSM delivery. On the other hand, considering that the BSM is

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composed of several individual DEs and that different applications would broadcast the same DEs, several methods were proposed to compress the data to transmit in the application layer. The message composition and coding scheme in [10] reduced the bandwidth requirement by merging the packets broadcasted in different VANET applications and by eliminating redundant DEs. On the basis of the analysis of real-time traffic environments or channel status, the adaptive broadcast rate control methods proposed in [11, 12] improved channel utilization by reducing the frequency of BSM dissemination. Moreover, adaptive power control contributed a class of useful methods [13] to increase the reusability of bandwidth resource by adaptively adjusting the coverage of single-hop transmission, and network coding was also employed to improve the reliability of BSM dissemination [14-16]. Although significant improvements on channel utilization have been achieved by the aforementioned works, the differences in the QoS requirements of each DE of a BSM have not been considered and can be further enhanced by applying advanced modulation and coding schemes to the physical layer of traditional VANETs. To the best of our knowledge, this issue has not been reported in the context of VANETs by previous works.

In this paper, we propose a novel scheme for BSM broadcast in VANETs to improve channel utilization. By using superposition coded modulation (SCM) [17], the proposed method extends the coverage of BSM while maintaining acceptable communication reliability for driving safety applications. Considering the real-time traffic situation, the proposed method is first theoretically optimized and the achievable performance gain is analyzed. To apply the proposed method into practice, hierarchical quadrature amplitude modulation (HQAM) [18] is employed to implement our SCM-based broadcast scheme. Although HQAM has been used in digital video broadcasting [19], its usage in VANET context is different from the former because of the relatively small single-hop-transmission coverage and time-varying QoS requirements. The results given by a joint traffic-communication simulation in real-time traffic environments agree that the channel utilization of traditional VANETs can be significantly improved by using the proposed method.

The remainder of this paper is organized as follows. Section 2 describes the problem discussed in this paper. Section 3 proposes our SCM-based BSM broadcast scheme and analyzes the achievable performance gain. Section 4 shows the performance evaluation of our method by joint traffic-communication simulation. Section 5 concludes.

2. Description of the Problem

Different from other wireless communication networks, every DE of a BSM packet in VANETs has its own specific QoS requirement, which is significantly determined by real-time traffic scenarios. Figure 1 shows three typical scenarios of vehicular communications. Given that all the neighboring vehicles of vehicle v1 are distant enough, broadcasting DEs that indicate a small adjustment on its status (e.g., its acceleration and the status of its signal lights), is unnecessary. Other DEs, such as its position and velocity, should be transmitted with every effort to enable both early alerting and other applications. The opposite situation occurs to vehicle v2, wherein all DEs should be delivered with a high reliability and low delay to perform collision avoiding. For vehicle v3, several DEs (such as the position and velocity) in its BSM packet should be received as reliably as possible by all neighbors within its coverage; other DEs only need to be delivered to its nearby neighbors. In other words, from the view of aiding driving safety, the QoS requirement of each DE is strongly determined by the distribution of the broadcaster's neighbors. However, all DEs that comprise a BSM are delivered with the same QoS in traditional schemes despite their specific requirements. This situation results in inefficient channel utilization.

Specifying a different QoS for each DE of a BSM is theoretically feasible but is not feasible in practice because of the high implementation complexity. According to their expected coverage, all DEs that comprise a BSM can be divided into two segments: (1) Seg-1: the DE segment that is only essential to neighbors within a relatively small safety-critical coverage (CC) during collision avoidance and includes the acceleration and turn signal; (2) Seg-2: the DE segment that is required by all vehicles within the broadcaster's full coverage (FC) and primarily includes the identification, position, and heading. These DEs are critical not only for the neighbors within the CC to avoid collisions, but also for the neighbors out of the CC to conduct early alerting and other applications. Moreover, from the view of improving driving safety, two requirements for the reliability of BSM dissemination can be defined. On one hand, to avoid the considered collisions, the Level-1 requirement is defined as the reliable delivery of the entire BSM to all neighbors within CC. On the other hand, conveying the Seg-2 to the neighboring vehicles in FC as reliably as possible expresses the Level-2 requirement, which is important to enable other applications. The Level-1 requirement must be guaranteed, whereas the Level-2 requirement should be met as much as possible.

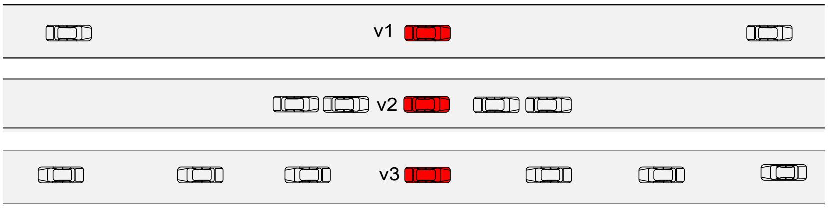


Figure 1. Typical vehicular communication scenarios

To provide different QoS guarantees to the *Seg-1* and *Seg-2* of a BSM, SCM technology is employed in this study. SCM is a spatial multiplexing transmission scheme wherein the BSM symbol to broadcast (denoted by x_s) is a linear superposition in the power domain of the *Seg-1* and *Seg-2* symbol (denoted by x_1 and x_2) with rates R_1 and R_2 (bits/s/Hz). The BSM symbol at the transmitter can be expressed as follows:

$$x_s = \lambda \sqrt{P} x_1 + \sqrt{(1-\lambda^2)P} x_2 , \tag{1}$$

Where λ is a configurable parameter. Without loss of generality, the propagation channel is assumed to be a Rayleigh fading channel characterized by $h(d) \sim CN(0, d^{-n})$, where d is the distance between the broadcaster and receiver and n is the channel fading factor determined by the propagation environments. After propagating through the wireless channel, the BSM symbol at the receiver side reads as follows:

$$x_s = h(d)\lambda \sqrt{P} x_1 + h(d)\sqrt{(1-\lambda^2)P} x_2 + w , \tag{2}$$

Where w denotes the additive noise. By conducting successive interference cancellation (SIC) [20], *Seg-2* (x_2) is decoded first and then subtracted from the received symbol, whose remainder is used to decode *Seg-1* (x_1). For the receivers close to the broadcaster, given the short propagation distance and small channel attenuation, the entire BSM can be decoded. Otherwise, if the receivers are far from the broadcaster, they would be able to decode *Seg-2* even though it would be difficult to decode the whole BSM. Notably, the delivery ratio of both the BSM within CC and *Seg-2* within FC are affected significantly by the value of λ. By optimizing the power allocation according to real-time traffic situation, we expect to meet the *Level-2* requirement as far as the broadcaster could at the condition of guaranteeing the *Level-1* requirement.

Before we proceed, several assumptions should be made. First, the radius of CC (denoted by r_{CC}) is treated to be known. Specifying a proper radius for CC is important for the broadcaster but is not the focus of this study. Second, the broadcaster is assumed to be able to learn the positions of all its neighbors within its CC, from their previous BSM broadcast. Moreover, considering that the optimal power allocation (specified by λ) is affected by the real-time distribution of the neighbors, we assume that the *Level-1* requirement will be met provided that the delivery ratio is guaranteed for the farthest neighboring vehicle within the broadcaster's CC. We also let d_{max} be the distance between the broadcaster and such a neighbor. Finally, considering that the Shannon capacity is zero in Rayleigh fading channel, the outage probability is employed as a performance indicator to evaluate whether the *Level-1* or *Level-2* requirement is satisfied.

3. Proposed SCM-based Broadcast Scheme

In this section, we present our novel BSM broadcast scheme based on the SCM technology. The optimal system parameters are theoretically derived and the achievable performance gain is then analyzed. Moreover, by specifying that both *Seg-1* and *Seg-2* symbols are modulated with a 4-QAM scheme, the proposed method is carried into practice through a 4/16-HQAM constellation.

3.1. Optimal Transmitting Power Allocation

First, to meet the *Level-1* requirement, the total transmitting power of a BSM must be large enough, regardless matter whether the SCM is used or not. For presentation simplicity, we let $\mathrm{E}(R) = 2^R - 1$ be the minimal signal-to-noise ratio (SNR) to achieve the data rate R. According to Shannon's theorems, at a propagation distance of d, the outage probability of a BSM reads

$$P_s^{out'}(d) = Pr\left\{ |h(d)|^2 < \frac{\mathrm{E}(R_1+R_2)}{\alpha_t} \right\} = 1 - e^{-\frac{\mathrm{E}(R_1+R_2)}{\alpha_t}}, \tag{3}$$

Where α_t is the SNR at the transmitter side, and $|h(d)|^2$ is the corresponding channel gain. For the purpose of meeting the *Level-1* requirement, the outage probability of the entire BSM should be below a given threshold P_s^{th}. Within the CC, given that $P_s^{out'}(d) \le P_s^{th}$ holds provided that $P_s^{out'}(d_{max}) \le P_s^{th}$, we obtain:

$$\alpha_t \ge \alpha_{min} = -\frac{\mathrm{E}(R_1+R_2)}{d_{max}^{-n}\, log_2(1-P_s^{th})} \approx \frac{\mathrm{E}(R_1+R_2)}{d_{max}^{-n} P_s^{th}}, \tag{4}$$

Where $P_s^{th} = -log_2(1-P_s^{th})$ is applied, which allows us to consider that P_s^{th} is typically a small enough value, and α_{min} is the minimal SNR that should be satisfied at the transmitter to enable safety-related applications.

Second, for a given transmitting power, an upper bound of λ should be obtained. *Seg-2* expresses the same QoS requirement as *Seg-1* in CC but is expected to be delivered with a larger coverage than the latter. Hence, the outage probability should be smaller than that of the latter at the same channel condition. For an SIC receiver, according to Equation (2), the receiving SNR pair for the *Seg-1* and *Seg-2* symbols at the distance of d reads as follows:

$$\left(\alpha_{r1}(\lambda,d), \alpha_{r2}(\lambda,d)\right) = \left(\lambda^2 |h(d)|^2 \alpha_t,\ \frac{(1-\lambda^2)|h(d)|^2 \alpha_t}{\lambda^2 |h(d)|^2 \alpha_t + 1} \right). \tag{5}$$

With the same channel gain $|h(d)|^2$, we let $Pr\{\alpha_{r2}(\lambda,d) > \varepsilon(R_2)\} \le Pr\{\alpha_{r1}(\lambda,d) > \varepsilon(R_1)\}$. Accordingly, we obtain

$$\lambda \le \lambda_{max} = \sqrt{\frac{\mathrm{E}(R_1)}{\mathrm{E}(R_1+R_2)}}, \tag{6}$$

Where λ_{max} is the maximal allowable value for the parameter λ. If none of the broadcaster's neighbors locates in its CC, then the required data rate R_1 for the *Seg-1* is zero, and thus, we obtain $\lambda_{max} = 0$.

Moreover, λ should be large enough to guarantee the outage probability of the entire BSM within CC. For the SIC receiver, the outage probability of BSM reads.

$$P_s^{out}(\lambda,d) = \underbrace{Pr\left\{\alpha_{r2}(d) < \mathrm{E}(R_2)\right\}}_{Seg-2\quad error} + \underbrace{Pr\left\{\alpha_{r2}(d) > \mathrm{E}(R_2), \alpha_{r1}(d) < \mathrm{E}(R_1)\right\}}_{Seg-1\quad error}. \tag{7}$$

According to Equation (4) and (6), $P_s^{out}(\lambda,d)$ can be rewritten as follows:

$$P_s^{out}(\lambda,d) \le Pr\left\{\alpha_{r1}(\lambda,d) < \mathrm{E}(R_1)\right\}. \tag{8}$$

The *Level-1* requirement is met provided that $P_s^{out}(\lambda,d) \le P_s^{th}$ holds. We can then obtain

$$\lambda \ge \lambda_{min} \approx \sqrt{\frac{\mathrm{E}(R_1)}{d_{max}^{-n} P_s^{th} \alpha_t}}, \tag{9}$$

Which is the lower boundary of λ.

Given that the smaller λ is, the larger power the *Seg-2* can be allocated, we believe that $\lambda^* = \lambda_{min}$ is only the optimal λ to meet the *Level-2* requirement. Notably, the optimal configuration of λ is significantly determined by real-time traffic scenarios. According to Equation (9), the smaller the distance between the broadcaster and its nearest neighbor within its CC, the less transmitting power is allocated to its *Seg-1*.

3.2. Achievable Performance Gain

In this subsection, we analyze the achievable gain on the delivery rate of the *Seg-2* in FC. With the optimal λ^*, according to Equation (5), the maximal delivery probability of the *Seg-2* in logarithmic form reads.

$$P_{2,dB}^{d*}(d) = -\frac{k_0 \mathrm{E}(R_1+R_2)\mathrm{E}(R_2)d^n}{\mathrm{E}(R_1+R_2)\left(\alpha_t - \alpha_{min}\right) + \mathrm{E}(R_2)\alpha_{min}}\ dB, k_0 = log_2 e. \tag{10}$$

With traditional methods (without the use of SCM), such a probability can be easily obtained from Equation (3), that is,

$$\overline{P}_{2,dB}^{d}(d) = -\frac{k_0 \mathrm{E}(R_1+R_2)}{d^{-n}\alpha_t}\ dB. \tag{11}$$

Therefore, at the same channel condition and SNR, the achievable gain on the delivery probability of the *Seg-2* can be expressed in logarithmic form as:

$$G_2^d(d) = \frac{\mathrm{E}(R_1+R_2)\left(\mathrm{E}(R_1+R_2) - \mathrm{E}(R_2)\right)(\alpha_t - \alpha_{min})}{\mathrm{E}(R_2)\alpha_t + \left(\mathrm{E}(R_1+R_2) - \mathrm{E}(R_2)\right)(\alpha_t - \alpha_{min})}\left(\frac{k_0 d^n}{\alpha_t}\right) \ge 0\ dB. \tag{12}$$

We also let $P_{2,dB}^{d*}(d) = \overline{P}_{2,dB}^{d}(\overline{d})$, and thus, the gain on the coverage of the *Seg-2* can be achieved as:

$$G_2^c = \frac{d}{\overline{d}} = \sqrt[n]{\frac{\mathrm{E}(R_1+R_2)\left(\alpha_t - \alpha_{min}\right) + \mathrm{E}(R_2)\alpha_{min}}{\mathrm{E}(R_2)\alpha_t}} \ge 1. \tag{13}$$

According to Equation (12) and (13), both $G_2^d(d)$ and G_2^c are affected by the real-time traffic environment. Under the case of that all neighboring vehicles of the broadcaster are outside of its CC, considering that the *Seg-1* of the BSM to broadcast can be cancelled from the transmitted signal, the maximal gain for both the delivery probability and coverage of the *Seg-2* can be achieved, that is:

$$G^{d}_{2,max}(d)=\left(\frac{k_0 d^n}{\alpha_t}\right)\left(\varepsilon(R_1+R_2)-\varepsilon(R_2)\right)\ dB,\quad G^{c}_{2,max}=\sqrt[n]{\frac{\varepsilon(R_1+R_2)}{\varepsilon(R_2)}}\ . \tag{14}$$

3.3. HQAM-based BSM Broadcast

To apply the proposed method into practice, we present a 4/16-HQAM-based BSM broadcast scheme by specifying both the *Seg-1* and *Seg-2* symbols as square 4-QAM symbols. The optimal power allocation between the *Seg-1* and *Seg-2* symbols and the available performance gain at such a scheme is analyzed in succession. Figure 2 shows the constellation of our method, which is obtained by using the Gray mapping. This constellation can be treated as a linear superposition of two independent square 4-QAM constellations: *L1* and *L2*. The former is dedicated to the delivery of *Seg-1*, whereas the latter is devoted to the delivery of *Seg-2*. In the rest of this paper, we assume that all the symbols are transmitted equally likely. Moreover, we assume that both *Seg-1* and *Seg-2* are protected by error-correcting codes, and that they can be decoded at the receiver provided that their bit error rate (BER) is below the corresponding thresholds, P^{th}_{b1} and P^{th}_{b2}. The proposed scheme is equivalent to the conventional square 16-QAM when $\lambda=\lambda_0=\sqrt{1/5}$, and thus, we only consider the cases when $\lambda\le\lambda_0$. For presentation simplicity, we let $I\ (\beta,x)=1/4\mathrm{erfc}(\beta\sqrt{x/2})$ and $\bar{\lambda}=\sqrt{1-\lambda^2}$, where erfc(□) is the complementary error function.

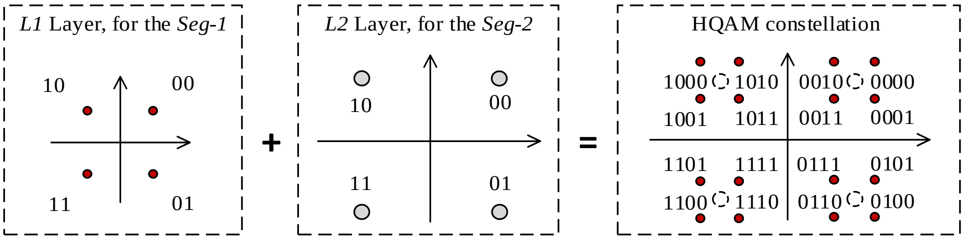


Figure 2. Constellation configuration of the HQAM-based broadcast in VANETs

To obtain a proper λ to maximize the channel utilization, the question regarding how the BERs of *Seg-1* and *Seg-2* are determined by the parameter λ in this situation should be answered first. Following the method proposed in [21], the BER pair of the *Seg-1* and *Seg-2* can be obtained as follows:

$$\begin{cases} P^{be}_1(\lambda,d)=2I\ \left(\lambda,|h(d)|^2\alpha_t\right)+I\ \left(2\bar{\lambda}-\lambda,|h(d)|^2\alpha_t\right)-I\ \left(2\bar{\lambda}+\lambda,|h(d)|^2\alpha_t\right)\\ P^{be}_2(\lambda,d)=I\ \left(\bar{\lambda}-\lambda,|h(d)|^2\alpha_t\right)+I\ \left(\bar{\lambda}+\lambda,|h(d)|^2\alpha_t\right)\end{cases} \tag{15}$$

Where $\alpha_t=E_b/N_0$ is the ratio of the energy per bit to noise power spectral density (also called SNR for presentation simplicity in the remainder of this paper) at the transmitter side. The outage probability in this study is defined as the probability that the BER is above the predefined threshold. Correspondingly, the outage probability pair of *Seg-1* and *Seg-2* reads as follows:

$$P^{out}_1(\lambda,d)=Pr\left\{P^{be}_1(\lambda,d)>P^{th}_{b1}\right\},\quad P^{out}_2(\lambda,d)=Pr\left\{P^{be}_2(\lambda,d)>P^{th}_{b2}\right\}. \tag{16}$$

With the same consideration as in Subsection 3.1, $P_2^{out}(\lambda,d)$ should be far smaller than $P_1^{out}(\lambda,d)$ within the CC, and the latter can thus be treated as an effective approximation of the outage probability of the entire BSM. That is,

$$P_s^{out}(\lambda,d)=1-exp\left(-\frac{2\text{erfc}^{-2}(2P_{b1}^{th})}{\lambda^2 d^{-n}\alpha_t}\right), \tag{17}$$

where only the leading item (the first item) of the $P_1^{be}(\lambda,d)$ is considered because the receiving SNR ($\left|h(d)\right|^2\alpha_t$) is large enough within CC.

To meet the *Level-1* requirement, the outage probability of the BSM must be below a given threshold P_s^{th} within CC, which will be met provided that $P_s^{out}(\lambda,d_{max})>P_s^{th}$. Then, we obtain:

$$\lambda \geq \lambda_{min}=\frac{\sqrt{2}\text{erfc}^{-1}(2P_{b1}^{th})}{\sqrt{d_{max}^{-n}P_s^{th}\alpha_t}}, \tag{18}$$

Where $log_2(1-P_s^{th})\approx -P_s^{th}$ is applied, with the fact that P_s^{th} in consideration should be small enough. Thus, the optimal configuration for λ reads $\lambda^*=min(\lambda_{min},\lambda_0)$. Compared with the conventional square 16-QAM, whose BER can be obtained by applying $\lambda=\lambda_0$ to Equation (17), the achievable gain on P_2^{be} at the SNR regime α_t reads:

$$G_2^{be}(d)=\frac{3I\left(\frac{1}{\sqrt{5}},\left|h(d)\right|^2\alpha_t\right)+2I\left(\frac{3}{\sqrt{5}},\left|h(d)\right|^2\alpha_t\right)-2I\left(\frac{5}{\sqrt{5}},\left|h(d)\right|^2\alpha_t\right)}{2I\left(\bar{\lambda}^*-\lambda^*,\left|h(d)\right|^2\alpha_t\right)+2I\left(\bar{\lambda}^*+\lambda^*,\left|h(d)\right|^2\alpha_t\right)} \tag{19}$$

In this section, we propose an SCM-based BSM broadcast scheme. Both the reliability and coverage of BSM delivery in the proposed scheme are significantly improved compared with those in the traditional VANET scheme. Accordingly, the channel utilization is enhanced. Given that the distance between the broadcaster and its nearest neighbor within the CC is significantly determined by the real-time traffic scenario, obtaining the closed form expression for the average performance gain of the proposed method in real world is difficult. Thus, we analyze the performance of our method in Section 4 through a joint traffic-communication simulation.

4. Simulation Results and Discussion

To evaluate the performance of the proposed BSM broadcast scheme in real traffic scenario, a simulation combining the traffic with communication system is conducted. The trace data of vehicles are generated by using the traffic simulator SUMO [22]. These data are then imported into the communication simulation, which is designed base on the IT++ signal processing library [23]. Different vehicle density values and CC radius are considered in our simulation, and the detailed configuration of this simulation is described in Table 1.

Figure 3 shows the BER of *Seg-1* and *Seg-2* at different SNRs and λ regimes. A small λ decreases *Seg-1* delivery ratio within CC, but helps to improve the *Seg-2* coverage. The receiving SNR in CC is typically large enough, and thus, the *Level-1* requirement still could be met by using a small λ. For example, although the BER of the entire BSM deteriorates significantly with $\lambda=0.3$, the BER could still be below the given P_s^{th} provided that the SNR in the CC is above 18 dB. Such a performance is typically acceptable when an error-correcting code is used. Comparing this proposed method with the conventional square 16-QAM showed that the required SNR threshold is reduced from 14 dB to 10 dB, and a significant coverage enhancement on the *Seg-2* is achieved. Moreover, at the same SNR regime, the delivery rate of *Seg-2* is also improved by the proposed method.

Table 1. Simulation configuration

Traffic Simulation	Road network: grid-like network The number of crossroads in both directions: 5 The length of horizontal and vertical streets: 500 meters Average density of vehicles: 1.5 or 3.5 vehicles per 100-meter road Length of simulation time: 1800 seconds Updating interval of vehicles location: 0.1 second
Communication simulation	SNR at transmitter: $\alpha_t = 115dB$ Fading factor of the channel: $n = 3.76$ Length of *Seg-1* and *Seg-2* bit-stream: 256 bits BER threshold: $P_{b1}^{th} = P_{b2}^{th} = 0.02$ Outage probability threshold: $P_s^{th} = 0.01$ Radius of the CC: $r_{CC} = 100m$ or $150m$

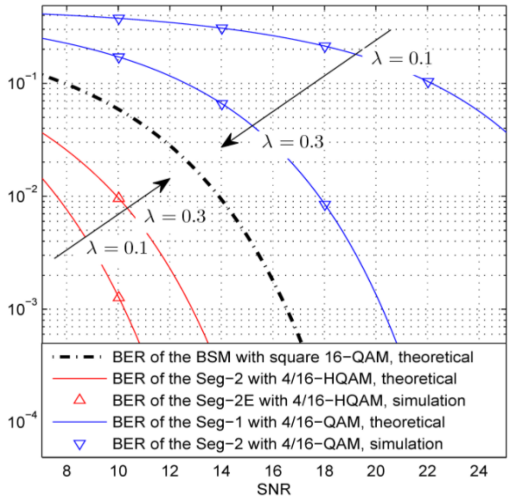
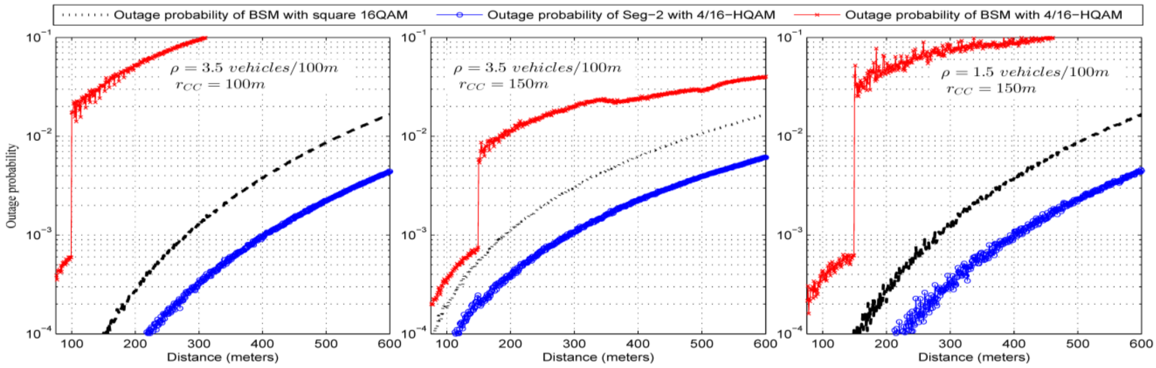


Figure 3. BER of the proposed method at different λ and SNR regimes



(a) $\rho = 3.5$, $r_{CC} = 100m$ (b) $\rho = 3.5$, $r_{CC} = 150m$ (c) $\rho = 1.5$, $r_{CC} = 150m$

Figure 4. Outage probability of our method with different traffic density and CC radius

The achievable performance gain is also evaluated in our simulation. Figure 4 shows the outage probability of the BSM and its *Seg-2* with different traffic density values and CC radius, where the optimal λ is adopted. For a large CC radius, more transmitting power should be assigned to *Seg-1* to meet the *Level-1* requirement. Hence, the performance gain on *Seg-2* is degraded. Comparing Figure 4(a) and Figure 4(b) illustrates the following conclusion. For sparse-traffic scenarios, given that the probability that a broadcaster has no neighbor within its CC is large and that the *Seg-1* can be cancelled from the transmitted BSM in such a case, a large performance gain can be achieved. Comparing Figure 4(b) and Figure 4(c) validates this conclusion. Moreover, a sharp increase in BSM outage occurs at the bound of the CC. This finding is also due to that the *Seg-1* in BSMs are cancelled when no neighbor is present within the broadcaster's CC.

5. Conclusion

In this paper, we propose a novel broadcast scheme to improve the channel utilization of BSM dissemination in VANETs. Specifically, from the view of transportation safety, all information elements included in a BSM are divided into two separated segments. These segments are then concurrently transmitted by using the SCM technology with different QoS guarantees determined by the real-time traffic scenario. The optimal power allocation strategy that maximizes the coverage and delivery rate of BSM is theoretically derived at the condition of meeting the requirement of driving safety. Moreover, to evaluate our method in real traffic environments, we conduct a joint traffic-communication simulation. The results of this simulation indicate that the proposed method can considerably improve the coverage and reliability of BSM delivery compared with traditional VANET scheme. The proposed method is not contradictory to traditional schemes that improve channel utilization in MAC or application layer, but rather the proposed method can be used together with the existing methods.

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