

## Research Article

# A Power Control Algorithm Based on Outage Probability Awareness in Vehicular Ad Hoc Networks

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This paper addresses the problem of adaptive power control based on outage probability minimization in Vehicular Ad Hoc Networks (VANETs), called a Power Control Algorithm Based on Outage Probability Awareness (PC-OPA). Unlike most of the existing works, our power control method aims at minimizing the outage probability and then is subject to the density of nodes in certain area. To fulfill power control, cumulative interference is assumed to be available at the transmitter of each terminal. The transmitters sent data by maximum power and then get the cumulative interference-aware outage probability. Furthermore, we build the interference model by stochastic geometric theory and then derive the expression between outage probability and cumulative interference. According to the expression, we adjust the transmitter power and optimize the outage probability. Simulation results are provided to demonstrate the effectiveness of the proposed power control strategies. It is shown that the PC-OPA can achieve a significant performance gain in terms of the outage probability and throughputs. Comparing MPC (Maximum Power Control algorithm) and WFPC (Water-Filled Power Control algorithm), the proposed PC-OPA decreased by 23% in terms of the outage probability and increased by 25% in terms of throughputs.

## 1. Introduction

Vehicular Ad Hoc Networks (VANETs) are a promising intelligent transportation system technology that offers many applications such as traffic and congestion control, safety assistance, and autodriving, all of which will drastically change and provide tremendous benefits to our lives [1–5]. The key technologies for VANETs, called Vehicle-to-Vehicle (V2V) communication, involve the networking of vehicles and other communication devices, e.g., roadside units (RSUs). Power control is the key to maintain the better connectivity of networks among devices, which is used for VANETs. However, unlike the current mobile ad hoc networks, VANETs have a lot of characteristics, such as broadcasting, random node mobility, time-space uncertainty transmission, and interference [6–8]; this makes VANETs more challenging. For example, when the transmitter with the maximum power control sends the data, in certain area big density of nodes brings more interference to the receiver, which results in high outage probability. Addressing

this issue, a Power Control Algorithm Based on Outage Probability Awareness, simply named PC-OPA, is proposed.

In VANETs, traffic congestion is easy to happen [9–11]. When congestion happens, more density of nodes results in more interference, which leads to high outage probably. Furthermore, the retransmission results in more consumption, which leads to the poor connectivity in VANETs. If the high channel capacity is pursued, the probability of collision is greater. Therefore, compared to traditional power control algorithm, the PC-OPA aims at the optimal outage probability regardless of the optimal channel capacity. In [12], Power Control based on Broadcasting Messages (PCBM) algorithm is proposed, in which the transmission power is adjusted according to the distance of the nodes. Further, the broadcasting area of nodes is restricted, which reduces the interference among nodes. However, the constant position in nodes is hard to get due to the random mobility in nodes. Therefore, PCBM algorithm has rarely considered the random mobility in reality environment. In [13], in highway scene, Power Control based on Roadside Unit (PSRSU)

algorithm is proposed, in which the aim is to be sure of connectivity in nodes of one side. However, Roadside Unit (RSU) costs more. When the congestion happens, PCRSU algorithm is not good to solve the question of more interference because of the more density. In [14], Power Control based on Beacon (PCB) algorithm is proposed, in which action time of driver and access collision in nodes are considered. In long distance communication, the peak power control algorithm based on L beacon is used to obtain the SINR, whereas in short distance communication the minimum power control algorithm based on S beacon is used to satisfy the SINR. According to the communication distance, in PCB algorithm, difference beacon is selected to be adaptive to VANET. Therefore, PCB algorithm is widely used. However, when the speed of a vehicle is very fast, the power in transmitter is used more, which leads to more communication areas. Further, multiuser interference is serious due to more high density in nodes, which leads to high outage probability. At present for more interference of multiusers few powers control algorithm is considered.

In this paper, the performance of improvement of the proposed power control algorithm is achieved in terms of reducing cumulative interference of multiusers. Based on the stochastic-geometry theory in receiver the spatial user interference model is built. Further, the expression of outage probability is deduced. After the outage probability awareness, the transmitter adjusts the power. At last, PC-OPA is subject to obtaining the optimal outage probability and good throughput.

The rest of this paper is organized as follows. Section 2 discussed the related work on the system model, as well as its usage in the analysis of VANETs characteristics. Section 3 describes the mechanism of PC-OPA. Simulation results and the validation of the proposed matching mechanism are presented in Section 4. Finally, concluding remarks are given in Section 5.

## 2. System Model

VANETs have the obvious characteristics such as randomness and dynamics which makes interference of multiuser difficult to find. Therefore, multiuser's interference in power control of VANETs is rarely considered. Addressing this issue, the expression about interference is needed to describe the relationship between interference and outage probability, which is the theoretical support for power control algorithm. Therefore, according to the randomness, stochastic-geometry theory is applied to build the system model and then deduce the expression [15, 16]. In Figure 1, we present the model of urban road system.

Due to the fact that characteristics of VANETs are randomness and dynamic, multiple user interference model is established that node random arrived at some region, which can be regarded as stochastic point process. Using identical probability  $p$  ( $0 \leq p \leq 1$ ), any nodes are joined by edges among  $N$  ( $N \geq 1$ ) nodes. The total of edges is random variable and average value of edges is  $pN(N-1)/2$ . When  $N \rightarrow \infty$ , we consider a set of transmitting nodes with locations specified by a homogeneous Poisson Point Process

(PPP) [17],  $\pi(\lambda) = \{x_i \in R^2, i \in Z\}$ , of transmitting nodes  $i$  on the infinite two-dimensional plane. The nodes of random walk obey independent and uniform distribution and have the mobility and substitutable. Let  $h_i$  and  $h_j$  denote the random walk between two adjacent vehicles. Let  $V_i$  and  $V_j$  denote the speed of  $h_i$  and  $h_j$ . Therefore, the probability density of TX within communication coverage area is

$$f_{T_f}(\lambda) = \int_{-\infty}^{\infty} f_{T_f}(t) e^{-\lambda t} dt \quad (1)$$

Within communication coverage area of  $h_i$ , multiple user interference increased with density and mobility of nodes and then the information may not be decoded properly in target node, while outage probability increased significantly. We assume that network tends to be infinity, of Palm distribution [18] and Slivnyak theorem [19]; according to the requirement, the interference of receiver is analyzed by conditional distribution of TX and follows a homogeneous Poisson Point Process, where Poisson Point Process is moved. The signal-to-interference-and-noise ratio seen at the  $RX_0$  is

$$SINR = \frac{P_0 h_0 d_0^{-\alpha}}{\sum_{i=1}^n P_i h_i d_i^{-\alpha} + N_0} \quad (2)$$

where  $I = \sum_{i=1}^n P_i h_i d_i^{-\alpha}$ , denoted by multiple user interference; therefore,

$$SINR = \frac{P_0 h_0 d_0^{-\alpha}}{I + N_0} \quad (3)$$

where  $N_0$  is background noise,  $P_0$  is transmission power,  $P_i$  is transmission power of other users,  $h_0$  is channel gain, and  $d$  is propagation distance. Therefore, the reference node has effects on background noise and on interference of other users. In Figure 2, we present the relationship between receiver and interference.

According to stochastic geometry, we consider a Vehicular Ad Hoc network that has the following key properties.

(1) Transmitter node locations are modeled by a homogeneous spatial Poisson Point Process. The number of random nodes in two-dimensional arbitrary finite area  $A \in R^2$  is limited, which is called local finiteness of Poisson Point Process, and then any nodes' locations are nonoverlapping.

(2) Suppose that bounded  $A$  and  $B$  are disjoint areas, where  $A, B \in R^2$ , and  $\Pi(A)$  and  $\Pi(B)$  are independent random variables, where  $\Pi(\cdot)$  denotes the set of Poisson Point Process in plane.

(3) The density of bounded disjoint area is superposition; in other words, aiming at characteristics of random mobility in VANETs,  $\lambda_1$  and  $\lambda_2$  random process is assumed to be a  $\lambda_1 + \lambda_2$  homogeneous Poisson Point Process.

(4) According to theorem of Slivnyak, when moving and removing of nodes, the distribution of homogeneous Poisson Point Process will not be affected.

In short, we introduce theories and properties of random geometric, by space accumulated interference model building in VANETs; it is seen that accumulated interference and outage probability increased with density of nodes, which lead to the network throughput decreasing significantly.

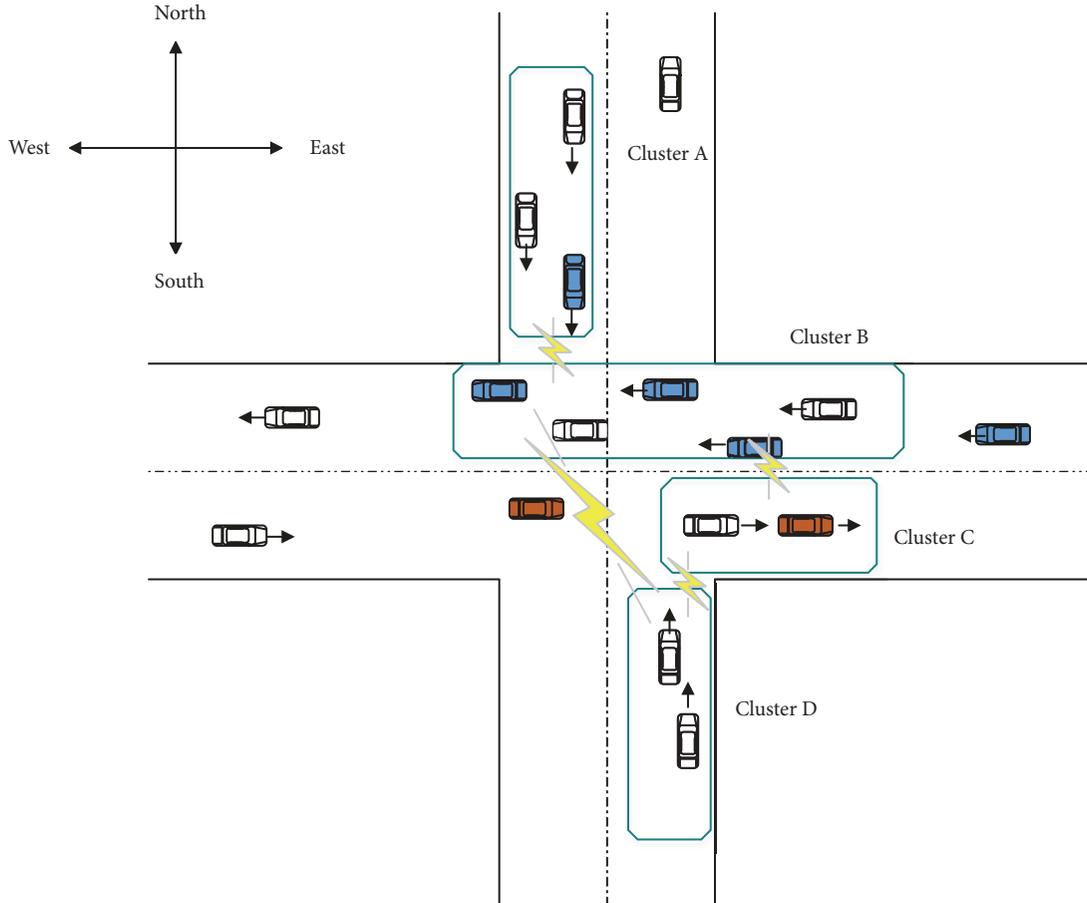


FIGURE 1: Urban road system model [3].

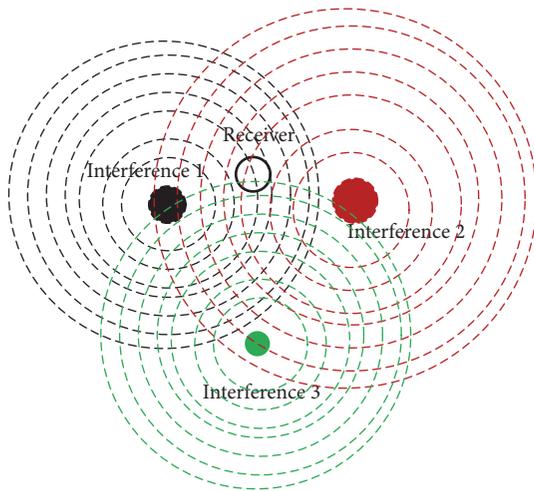


FIGURE 2: The multiple user interference [20].

### 3. The Mechanism of Power Control Algorithm Based on Outage Probability Awareness

In this section, we consider a power control algorithm that sends data with a maximum power to make a deduction of

the formula of outage probability and then adjusts transmission power on the basis of outage probability information of awareness [21]. Finally, optimal outage probability and network throughput were obtained by PC-OPA.

3.1. Sending Data with a Maximum Power. SINR is shown as follows:

$$SINR = \frac{P_0 h_0 d_0^{-\alpha}}{\sum_{i=1}^n P_i h_i d_i^{-\alpha} + N_0} = \frac{S}{I + N_0} \quad (4)$$

where  $S = P_0 h_0 d_0^{-\alpha}$ , if  $SINR < \beta$ , the thesis holds that network transmission is interrupted. In accordance with statistical law, stochastic node sets distributed in space are called Poisson Point Processes. Suppose  $\Pi(x_n)$  satisfies  $\Pi_x = (x_n + x)$ ,  $\Pi$  and  $\Pi_x$  have the same distribution, and then  $\Pi$  is homogeneous Poisson Point Processes. Therefore,  $\Pi(B)$  obeys the Poisson distribution in a bounded domain of B, and the bounded function  $\Lambda(B) = \lambda v_d(B)$  is a measurement.

$$\Pr(\Pi(B) = k) = \exp(-\lambda v_d(B)) \frac{\lambda v_d(B)^k}{k!} \quad (5)$$

$k = 0, 1 \dots$

where  $v_d(B)$  is Lebesgue measure, namely, area of B.  $\lambda$  is intensity or average density of unit space. It is based on

such an assumption that location of interference sources obeys the Poisson Point distribution and interference power is function of power law decay of transmission distance. The accumulated interference signal in receiver constitutes the shot noise in two-dimensional space  $I(x)$ ; we obtain that

$$I(x) = \sum_{x_i \in \Pi(\lambda)} h_i I(|x_i - x|) \quad (6)$$

where  $h_i$  is small scale power fading factor.

According to the above properties, when data is sent with a maximum power, outage probability is as follows:

$$\Pr_{\text{outage}}(SINR < \beta) = \Pr_{\text{outage}}\left(\frac{S}{(I + N_0)} < \beta\right) \quad (7)$$

where  $I = \sum_{d_i \in \Pi(\lambda) \cap b(0,a)} h_i |d_i|^{-\alpha}$  denotes accumulated interference with area  $b(0, a)$  of radius  $a$ ; from the definition of (7), we obtain

$$\Pr(SINR < \beta) = 1 - \Pr(SINR > \beta) \quad (8)$$

$\Pr(SINR > \beta)$  is success probability:

$$\begin{aligned} \Pr(SINR > \beta) &= \exp\left(-\frac{\beta d^\alpha N}{P}\right) E\left(e^{-\beta d^\alpha I}\right) \\ &= \Pr_{s,n} \Pr_{s,I} \end{aligned} \quad (9)$$

and  $\Pr_{s,n}$ ,  $\Pr_{s,I}$  denote the success probabilities taking into account only noise and interference, respectively. Since  $s = \beta d^\alpha$ , the Laplace transform of the accumulated interference of  $\Pr_{s,I}$  is

$$\Pr_{s,I} = \exp\left(-\lambda c_d d^\alpha \beta^\delta E[h^\delta] E[h^{-\delta}]\right) \quad (10)$$

Applying here with  $c_d = 4\lambda\pi r^2$ ,  $E[h^\delta] = \Gamma(1 + \delta)$ :

$$\Pr_{s,I} = \exp\left(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta)\right) \quad (11)$$

Outage probability in a closed-form expression is as follows:

$$\begin{aligned} \Pr_{\text{outage}} &= 1 - \Pr_{s,n} \Pr_{s,I} \\ &= 1 - \Pr_{s,n} \exp\left(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta)\right) \end{aligned} \quad (12)$$

with

$$L = -\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta) \quad (13)$$

$$\Pr_{\text{outage}} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta L) \quad (14)$$

We define  $\varepsilon$  as outage probability. Now consider network throughput of success delivery with constrained outage probability.

$$C = \varepsilon^\varepsilon (1 - \varepsilon) B \log\left(1 + \frac{S}{N}\right) \quad (15)$$

where  $B$  is bandwidth.

**3.2. Adjusting Transmission Power.** Adjust transmission power  $P = ph^{-\omega}$  based on channel state information, where  $\omega$  is chosen in  $[0, 1]$ . Clearly, if  $\omega = 0$ ,  $P = p$  implies maximum transmission power; whereas  $\omega = 1$ ,  $P = p$  is channel inversion.

From function (10), we have that

$$\begin{aligned} SINR &= \frac{P_0 h^{-\omega} h_0 d_0^{-\alpha}}{\sum_{i=1}^n P_i h^{-\omega} h_i d_i^{-\alpha} + N_0} \\ &= \frac{P_0 h^{1-\omega} d_0^{-\alpha}}{\sum_{i=1}^n P_i h^{1-\omega} d_i^{-\alpha} + N_0} \end{aligned} \quad (16)$$

Adjusting transmission power, we obtain

$$\begin{aligned} \Pr'_{\text{outage}} &= 1 - \Pr_{s,n} \Pr'_{s,I} = 1 \\ &- \Pr_{s,n} \exp\left(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \omega\delta) \right. \\ &\left. \cdot \Gamma(-(1 - \omega)\delta)\right) \end{aligned} \quad (17)$$

$$L' = \Gamma(1 + \delta) \Gamma(1 - \omega\delta) \Gamma(-(1 - \omega)\delta) \quad (18)$$

Then, the outage probability in a closed-form expression is as follows:

$$\Pr'_{\text{outage}} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta L') \quad (19)$$

From (19),  $L'$  is the accumulated interference of channel fading. It can be verified that outage probability  $\Pr'_{\text{outage}}$  decreased with power control exponent  $\omega$  since transmission power is adjusted. In order to improve the network throughput, after derivation calculus to (19), we can get optimal solution of power control exponent  $\omega$ .

**3.3. Adjusting behind Transmission Power of Outage Probability.** Adjust behind transmission power of outage probability  $\Pr'_{\text{outage}}$  to judge whether there is maximum value. If  $\Pr'_{\text{outage}}$  is not maximum value, outage probability information is obtained with feedback CSI in sender. If  $\Pr'_{\text{outage}}$  is maximum value, outage probability minimum is obtained with adjusting behind transmission power. Since  $L(h) = E(h^{-\omega})E(h^{-(1-\omega)})$ ,  $L(h)$  is convex function:

$$E(h^{-\omega}) E(h^{-(1-\omega)}) = \Gamma(1 - \omega\delta) \Gamma(-(1 - \omega)\delta) \quad (20)$$

Taking logarithm on (20),

$$\log L(h) = \log\left(E[X^{-\omega}] E[X^{\omega-1}]\right) \quad (21)$$

By Holder's inequality,

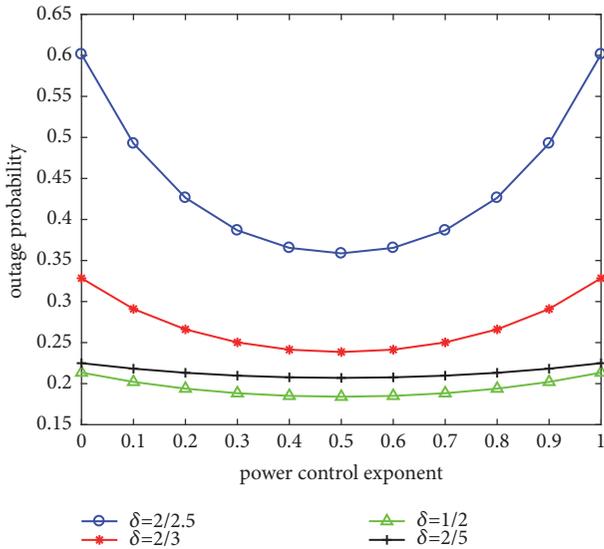
$$E[XY] \leq (E[X^p])^{1/p} (E[Y^q])^{1/q} \quad (22)$$

Applying here with  $1/p + 1/q = 1$  and  $p = 1/T$ ,  $q = 1/(1-T)$ ,

$$\begin{aligned} &L(Th_1 + (1-T)h_2) \\ &= \log\left(E\left[h^{-(Tx_1 + (1-T)x_2)}\right] E\left[h^{(Tx_1 + (1-T)x_2) - 1}\right]\right) \\ &\leq \log\left(E\left[h^{x_1}\right]^T E\left[h^{x_2}\right]^{1-T} E\left[h^{x_1 - 1}\right]^T E\left[h^{x_2 - 1}\right]^{1-T}\right) \\ &= Th(x_1) + (1-T)h(x_2) \end{aligned} \quad (23)$$

TABLE 1: Simulation parameter setting.

Simulation Area	2000m*2000m
Number of Vehicle	0-160
Transmission Distance	100m-300m
Channel Bandwidth	5-20MHz
Signal-to-Noise Ratio	15-30dB
Doppler Frequency Shift	100-300Hz

FIGURE 3: Power control exponents  $w$  versus outage probability.

Calculating the derivatives of (22),

$$\begin{aligned} & (L(Th_1 + (1-T)h_2))' \\ &= E[h^{-T}]E[h^{T-1}\log h] - E[h^{T-1}]E[h^{-T}\log h] \end{aligned} \quad (24)$$

Function (20) is lowest when  $T = 0.5$ . The results show that transmission power is adjusted at  $P = ph^{-w} = ph^{-0.5}$ ; the outage probability has minimum value.

#### 4. Simulation and Results

Here, we present some numerical results to evaluate the performance our proposed PC-OPA strategies. We compared the outage performance of the proposed strategies with that of WFPC (Water-Filled Power Control Algorithm) and NPC (Non-Power Control algorithm). Assume that simulation area is 2000 m\*2000m; the numbers of nodes vary from 0 to 160. The simulation parameters are shown in Table 1.

In Figure 3 we present relationship between outage probability and power control exponent. Path loss exponents for different environments are shown in Table 2. Figure 3 is for the case of  $2 < \alpha < 6$ , where four different values of  $\alpha$ , i.e.,  $\alpha = 2.5$ ,  $\alpha = 3$ ,  $\alpha = 4$ , and  $\alpha = 5$  are assumed. Different parameters represent the different environments for wireless channel. As is shown, the PC-OPA is more effective and achieves the minimization of the

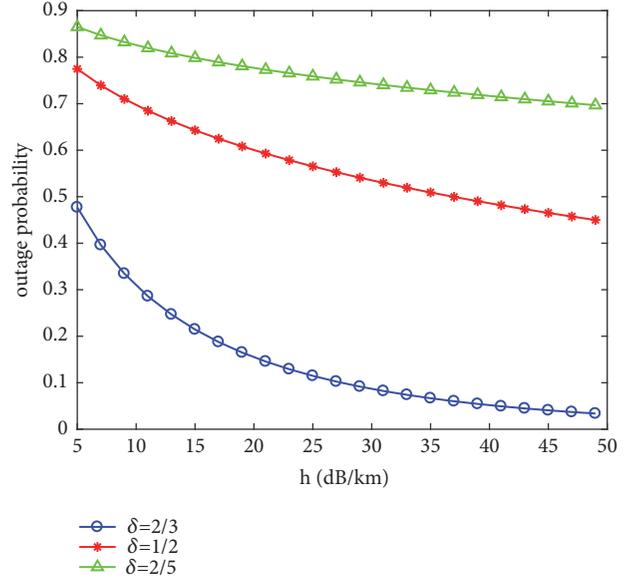
FIGURE 4: Outage probability versus  $h$  (dB/km) for absorption factor.

TABLE 2: Path loss exponents for different environments.

Environment	Path Loss Exponent, $\alpha$
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

outage probability.  $w = 0$  represents maximum transmission power, whereas  $w = 1$  is channel inversion. Clearly,  $w = 0.5$  achieves a significant performance gain in terms of the outage probability regardless of the radio environment, whereas  $w = 0$  and  $w = 1$  are seen to be essentially equivalent, which is high cumulative interference and outage probability in receiver. This simulation is provided to demonstrate the effectiveness of the proposed power control strategies.

Figure 4 is for the case of  $2 < \alpha < 6$ , where three different values of  $\alpha$ , i.e.,  $\alpha = 3$ ,  $\alpha = 4$ , and  $\alpha = 5$ , are assumed. We plot the outage probability as absorption factor for the proposed PC-OPA strategy. Clearly, when the absorption factor varies from 5 to 50 dB/km, the outage probabilities reduce. The reason is that the accumulated interference declines as absorption factor  $h$  grows. Few accumulated interferences make it easy to be adaptive to the SINR of the receiver. Therefore, in different radio environment, the proposed PC-OPA is subjected to the minimization of outage probability according to the distribution of absorption factor.

Figure 5 shows that the optimized outage probability is a function of density of nodes for the proposed PC-OPA strategy. Clearly, as the density of nodes grows, the outage

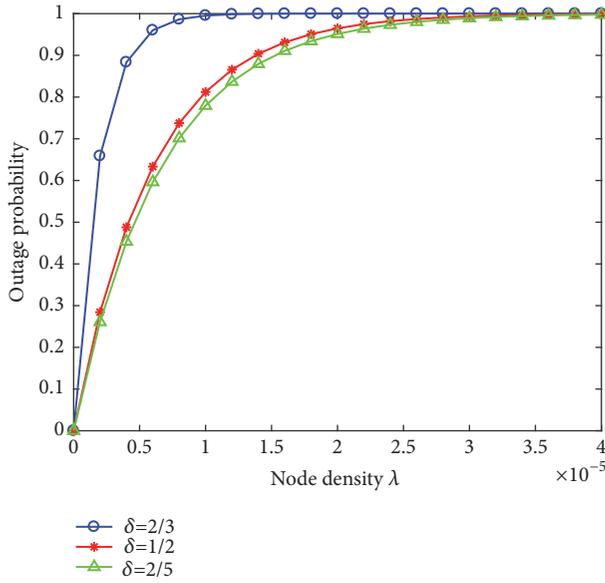


FIGURE 5: Outage probability versus  $\lambda$  density of nodes.

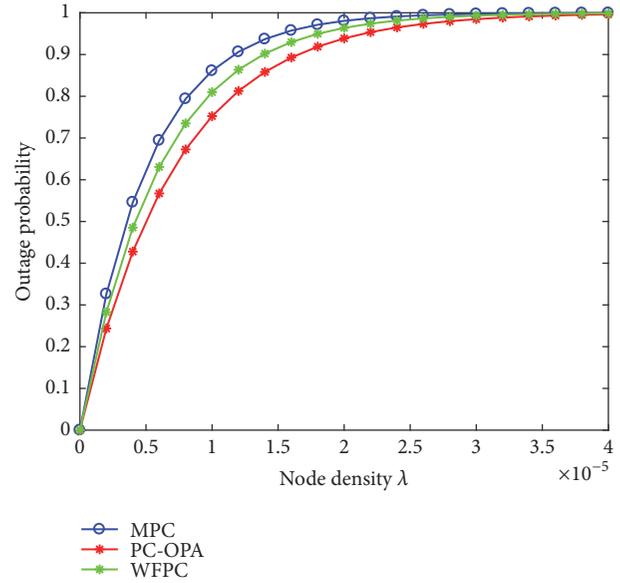


FIGURE 6: Outage probability for different algorithm versus  $\lambda$  density of nodes.

probability grows. The reason is that the more the number of the nodes is, the more accumulated the interference is. Then a lot of accumulated interference leads to more outages. Therefore, to reduce accumulated interference between multiusers, the density of nodes is limited in a certain area. According to the feedback of channel fading distribution, the transmitter adjusted the power to reduce the accumulated interference. The simulation results show that the proposed PC-OPA strategy achieves the optimum outage probability in different environment, in which the aim is to achieve the optimal outage probability by reducing accumulated interference.

In Figures 6, 7, and 8, we plot the outage probability as some parameters for the proposed the power control strategies, such as PPC (Peak Power Control), PC-OPA, and WFPC (Water-Filled Power Control). Considering above the parameters, we can see that outage probability increased with the density of nodes. As is shown, the PC-OPA strategy achieves the minimization of the outage probability. In the case of the same density, outage probabilities of PC-OPA, WFPC, and MPC are, respectively, 0.63, 0.75, and 0.86. The outage probability is significantly decreased by the PC-OPA compared with that by MPC, which is decreased by 23%. The MPC algorithm uses the maximum power to send the data. When the channel deteriorates beyond some point, transmissions are made in vain. The WFPC algorithm is greedy. However, the WFPC algorithm aims at achieving the optimal capacity regardless of the outage probability. More outage probability leads to deterioration of the network connectivity and brings more retransmission probability. Therefore, in this paper, the optimal outage probability algorithm is proposed. The PC-OPA achieves the optimal outage probability under multiusers.

In Figure 7, we plot the outage probability as a function of the distance from 0 to 250 m. The outage probability varies with the distances. It should be noted that the expression in

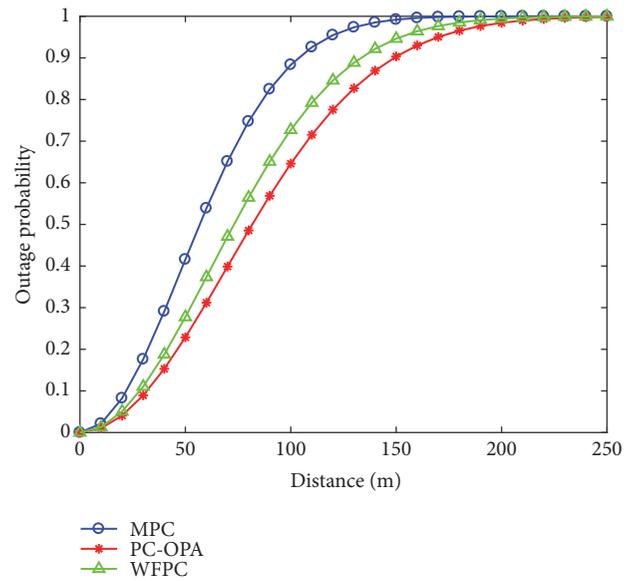


FIGURE 7: Outage probabilities versus distance.

(14) is for the case of channel fading. The method of PC-OPA provides channel fading variations for different distance and adaptively adjusts the transmission power according to the time varying characteristic of wireless channel; thus the outage probability of PC-OPA is lower compared to WFPC and MPC.

In Figure 8, we plot the outage probability as a function of the density of nodes for the three power control algorithms. As is shown in reality environment, there is serious Doppler frequency. When the density and the Doppler frequency increase, the accumulated interference in the receiver grows more. In certain area the density of nodes trends very fast to the saturation, which leads to the outage probability attaining

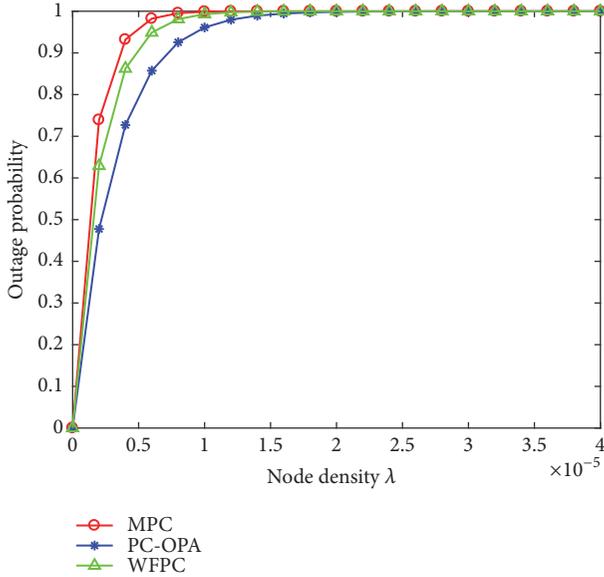


FIGURE 8: The outage probability for different algorithm versus  $\lambda$  density of nodes (Doppler frequency shift).

to the maximum very fast. Therefore, the density of nodes is closer to the outage probability. The simulation results in Jack channel model show that when vehicle speed is equal to  $50\text{km/h}$ , the Doppler frequency is given for  $f_d = 135\text{Hz}$ . Compared with Figure 4, outage probability increased with the number of nodes for the same density. In the case of Doppler frequency, the outage probabilities of PC-OPA, WFPC, and MPC are, respectively, 0.83, 0.92, and 0.98. The outage probability is significantly decreased by the PC-OPA compared with that by MPC, which is decreased by 9%. The simulation results demonstrate that the reality of PC-OPA is better. The reason is that, considering the multiuser interference and joint with the feedback of CSI, the PC-OPA achieves the optimal outage probability.

The outage probability awareness algorithm is shown in Algorithm 1. Figure 9 shows that the throughput is varying as the node densities. With the increasing of the density nodes, the throughput grows more. Clearly, MPC is very fast trending to the saturation, and then WFPC is second. The PC-OPA achieves the most throughputs among the three algorithms. In the case of the same density of nodes, the network throughput of PC-OPA was significantly higher than that of WFPC and MPC, and then success delivery rate of PC-OPA is 600. The high delivery rate makes more throughputs, but results in more cumulative interference. As is shown, the PC-OPA can adjust the transmitter power according to CSI, in which the aim is to optimize the outage probability. Therefore, among three power control algorithms, the PC-OPA achieves the optimal outage probability and then achieves the most throughput.

## 5. Conclusion

In this paper, to address these issues, such as random mobility of nodes, interference in multiusers, and high outage

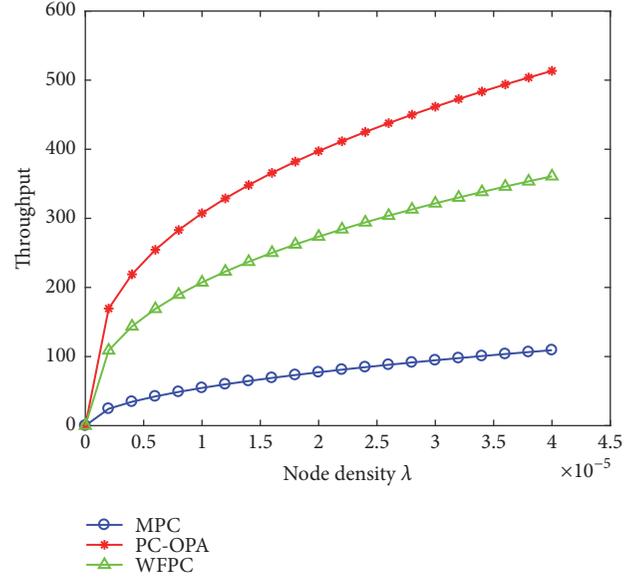


FIGURE 9: Throughput for different algorithm versus  $\lambda$  density of nodes.

probability, we proposed a power control algorithm, called simply PC-OPA. The PC-OPA analyzes the situation of multiple user interference through stochastic geometry and then establishes relationship between outage probability and channel accumulated interference. At last, the aim of the PC-OPA is to minimize the outage probability. Further, the throughputs increase, while the outage probability declines. Our simulation results validated the derived expression and confirmed the feasibility of the proposed PC-OPA. It is shown that, in general, not all the terminals need to use their maximum power consumption to achieve the best outage probability. If all the terminals use their maximum power consumption, it is easy to increase cumulative interference. Therefore, based on CSI, the PC-OPA in this paper is proposed. The simulation results show that the outage probability of the PC-OPA decreased by 23% and the throughput is increased by 25%, compared to MPC and WFPC.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

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1: set  $P_0 = P_{\max}$ 
2:  $\Pr_{\text{outage}} = 1 - \Pr_{s,n} \Pr_{s,I} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta))$ 
3:  $\Pr_{\text{outage1}} = 1 - \Pr_{s,n} \Pr_{s,I} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta))$  (CSI)
4: if  $\Pr_{\text{outage1}} = \Pr_{\text{outage}}$  then
5:    $P = P_0 h^{-w}$ 
6:    $\Pr'_{\text{outage}} = 1 - \Pr_{s,n} \Pr'_{s,I} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \omega \delta) \Gamma(-(1 - \omega) \delta))$ 
7: else
8:    $\Pr_{\text{outage1}} = 1 - \Pr_{s,n} \Pr_{s,I} = 1 - \Pr_{s,n} \exp(-\lambda c_d d^\alpha \beta^\delta \Gamma(1 + \delta) \Gamma(1 - \delta))$  (CSI)
9: end if

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ALGORITHM 1: The flow diagram of power control algorithm based on outage probability awareness.

and Guangxi University Science Research Project (ZD 2014146).

## References

- [1] Y. Zhang, W.-Q. Xu, J.-M. Chen, and Y.-X. Sun, "Steepest descent method based transmission power control in vehicular networks," *Journal of Electronics and Information Technology*, vol. 32, no. 10, pp. 2536–2540, 2010.
- [2] F. Cunha, L. Villas, A. Boukerche et al., "Data communication in VANETs: Protocols, applications and challenges," *Ad Hoc Networks*, vol. 44, pp. 90–103, 2016.
- [3] G. Samara, T. Alhmiedat, and Salem. A. O. A., "Dynamic Safety Message Power Control in VANET Using PSO," *Computer Science*, vol. 3, 2014.
- [4] Y. Wu, L. Shen, Z. Shao, Q. Su, and X. Lin, "Power control algorithm based on probe message in vehicular ad hoc network," *Journal of Southeast University (Natural Science Edition)*, vol. 41, no. 4, pp. 659–664, 2011.
- [5] T. Hengliang, *Research on the Key Technology of Vehicular Ad Hoc Network in Urban Transportation Environment*, Beijing Jiaotong University, 2013.
- [6] G. Jia, "Design and Implementation of Vehicular Ad Hoc Network Communication System," *University of Electronic Science and Technology of China*, 2012.
- [7] A. Nabeel, S. C. Ergen, and O. Ozkasap, "Vehicle mobility and communication channel models for realistic and efficient highway vanet simulation," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 1, pp. 248–262, 2014.
- [8] W.-B. Yu, D.-W. Niu, Z.-C. Mi, and C. Dong, "Research on fairness in vehicle networks based on power adjusting," *Journal of the University of Electronic Science and Technology of China*, vol. 40, no. 5, pp. 706–710, 2011.
- [9] X. Guan, R. Sengupta, H. Krishnan, and F. Bai, "A feedback-based power control algorithm design for VANET," in *Proceedings of the 2007 Mobile Networking for Vehicular Environments (MOVE '07)*, pp. 67–72, May 2007.
- [10] L. Cheng and R. Shakya, "VANET Adaptive power control from realistic propagation and traffic modeling," in *Proceedings of the 2010 IEEE Radio and Wireless Symposium (RWS '10)*, pp. 665–668, January 2010.
- [11] C. Shuqun and L. Xiaohua, "Power control method based on network condition information for VANET," *Transducer and Microsystem Technologies*, vol. 36, no. 11, pp. 44–46, 2017.
- [12] X. Zhixin, L. Shijie, L. Xiao, and Y. Wu, "Power control mechanism for vehicle status message in VANET," *Journal of Computer Applications*, vol. 36, no. 8, pp. 2175–2180, 2016.
- [13] S. Sou, "A Power-Saving Model for Roadside Unit Deployment in Vehicular Networks," *IEEE Communications Letters*, vol. 140, no. 7, pp. 623–625, 2010.
- [14] Y.-F. Mo, D.-X. Yu, S.-N. Bao, and S.-T. Gao, "Beacon Transmission Power Control Algorithm Based on the Preset Threshold in VANETs," *Dongbei Daxue Xuebao*, vol. 38, no. 3, pp. 331–334, 2017.
- [15] X. Ruifeng, F. Ming, and T. Yulong, "Routing Optimization Scheme Based on L in k Reliability in Vehicular Ad Hoc Network," *Computer Engineering*, vol. 42, no. 3, pp. 13–17, 2016.
- [16] F. Qu, Z. Wu, F.-Y. Wang, and W. Cho, "A security and privacy review of VANETs," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 6, pp. 2985–2996, 2015.
- [17] B. L. Arkin and L. M. Leemis, "Nonparametric estimation of the cumulative intensity function for a nonhomogeneous Poisson process from overlapping realizations," *Management Science*, vol. 46, no. 7, pp. 989–998, 2000.
- [18] J.-F. Coeurjolly, J. Møller, and R. Waagepetersen, "A Tutorial on Palm Distributions for Spatial Point Processes," *International Statistical Review*, vol. 85, no. 3, pp. 404–420, 2017.
- [19] M. Schlather, "On a class of models of stochastic geometry constructed by random measures," *Mathematische Nachrichten*, vol. 213, pp. 141–154, 2000.
- [20] C. Campolo, C. Sommer, F. Dressler, and A. Molinaro, "On the impact of adjacent channel interference in multi-channel VANETs," in *Proceedings of the 2016 IEEE International Conference on Communications, ICC 2016*, pp. 1–7, Malaysia, May 2016.
- [21] C. Jiang, H. Zhang, Z. Han, Y. Ren, V. C. M. Leung, and L. Hanzo, "Information-Sharing Outage-Probability Analysis of Vehicular Networks," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 12, pp. 9479–9492, 2016.

