A Cooperated Approach Between V2I and V2V for High Definition Map Dissemination in Automated Driving

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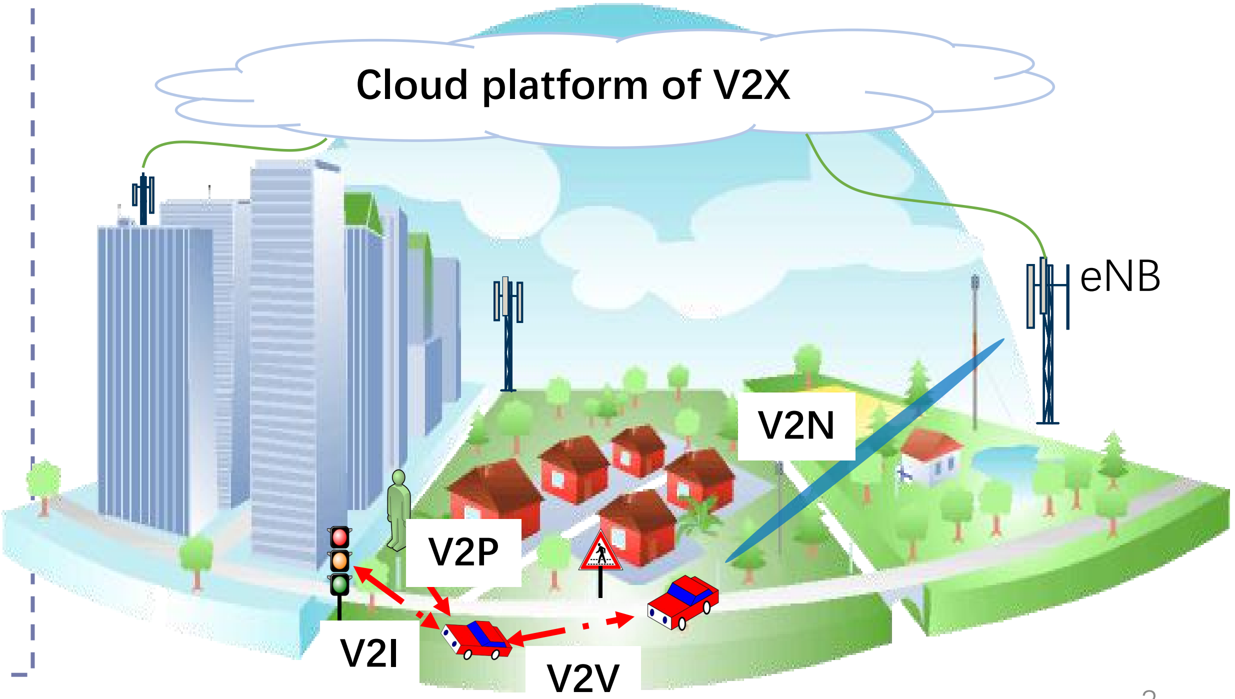
A. V2X / HD map

- Automated driving emerges as a potential technology for safe, convenient, and efficient transportation systems.
- V2X communications can assist autonomous vehicles to understand their ambient environments in real time, which will provide a safer automated driving experience.

- HD map shows high possibility of supporting very high accuracy vehicle localization and navigation ability for automated driving.
- It is still an open problem to support automated driving with higher completeness by HD map transmission.



B. Key Issue

Challenge	The target vehicle needs to receive complete up-to-date map within given delay before roaming into the next region.

V2I communication

- V2I communication provides vehicles with the ability to access to Internet for large area information dissemination.
- However, any vehicle requiring HD map has to go through the RSU, which may result in communication capacity bottleneck in dense vehicular network.

V2V communication

- it is more flexible to set up V2V connections with nearby vehicles who have the similar map information.
- V2V links have shorter communication distance than V2I, which may experience less path loss and transmission delay

The performance of HD map dissemination can further be improved by jointly considering both V2V and V2I communications .

C. Related Works

Support for V2V and V2I services has been introduced in cellular networks during 3GPP Releases 14 and 15

- LTE V2V can be deployed on a shared channel or a dedicated channel.
- For the shared channel case, V2V resources can be located within the downlink resources, which will greatly improve spectrum resource utilization.

diverse 5G deployment scenarios ➔ shared channel is an essential solution

V2V/V2I share the same radio resources ➔ interference control

C. Related Works

channel access mechanisms	interference management	resource management
enhance the transmission performance for spectrum sharing in vehicular network	• Network coding • Successive Interference Cancellation • self-interference cancellation	• reduce interference • improve network capacity

- However, HD map dissemination tasks are quite different from the above scenarios, as they have rigorous requirements of the transmission, including high throughput and real-time update, etc..
- The distinct features of HD map disseminations in V2X networks are not studied efficiently in current researches.

spectrum multiplexing/interference control ——HD map dissemination scheme—— based on cooperative V2X —— to realize large-capacity data transmission in autonomous driving

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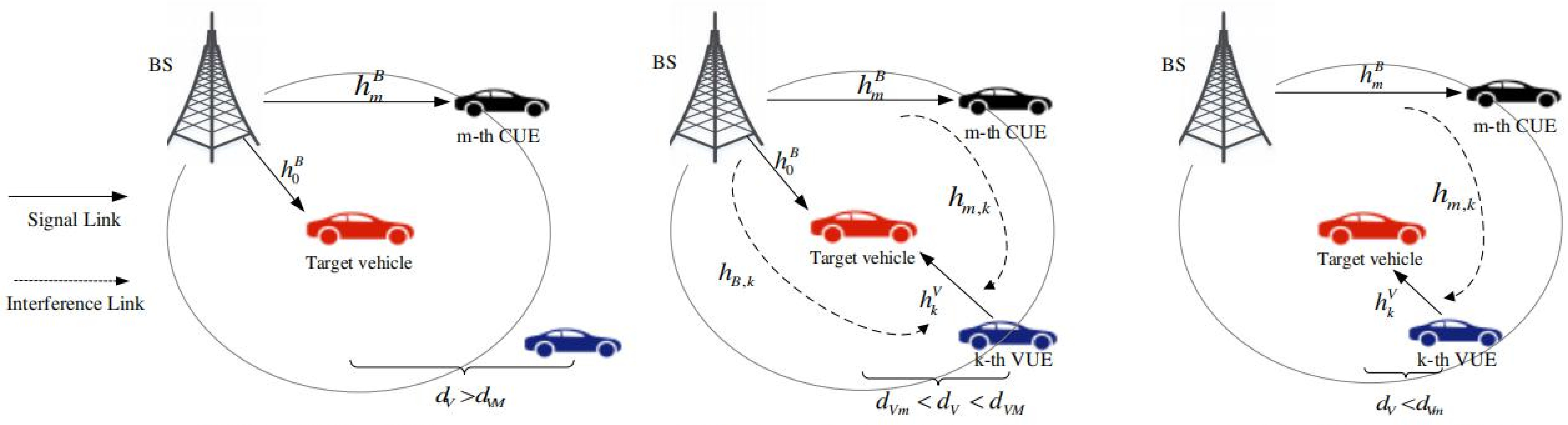
A. Scenario

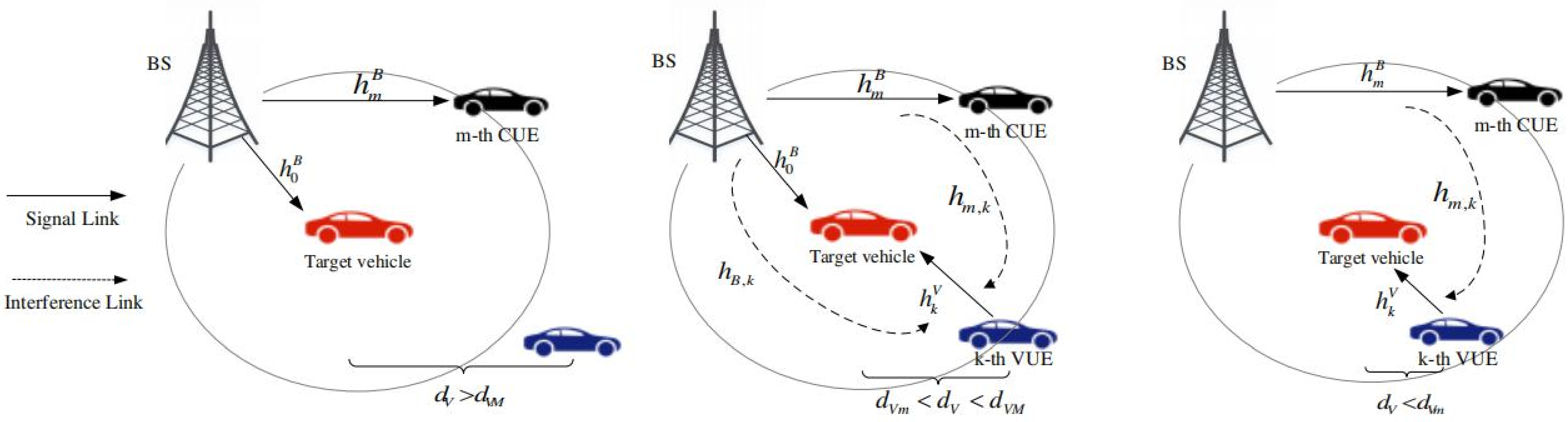
- VUEs： the blue vehicle group —— stored the required HD map data
- The red one ： the target vehicle of the HD map request.
- CUEs： M vehicles are performing V2I communications



(a) Mode 1 : V2I transmission only (b) Mode 2 : cooperative V2X transmission (c) Mode 3 : V2V transmission only

A. Scenario

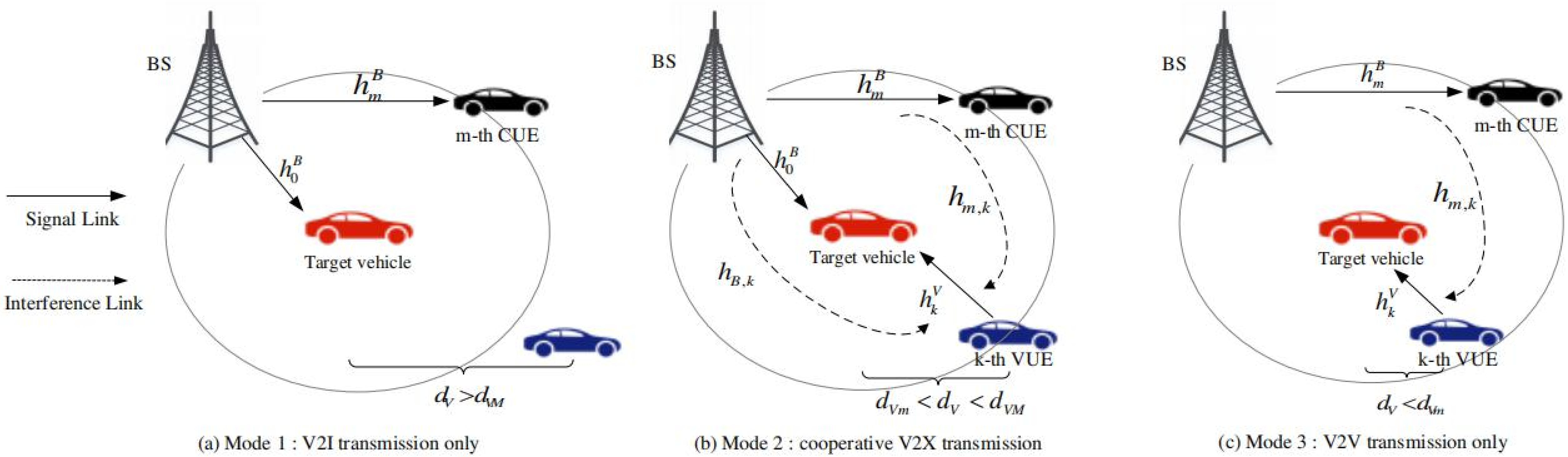
- The BS and each VUEs can simultaneously transmit different data blocks of the original content according to the network condition.
- Different V2I and V2V communication links are permitted to access the same downlink resources for their individual data transmission.



(a) Mode 1 : V2I transmission only (b) Mode 2 : cooperative V2X transmission (c) Mode 3 : V2V transmission only

B. System Model

three cases of transmission modes —— based on the position relationship of the two vehicles



P^V_k: the transmit power of the k-th VUE

P^B_m: the transmit power of the BS

$X_{m,k}$: spectrum reusing indicator

d: the distance between the two vehicles

h^B_m: channel power gain from the BS to the m-th CUE

Similarly, **h^V_k , $h_{B,k}$, $h_{m,k}$**

C. Transmission Model

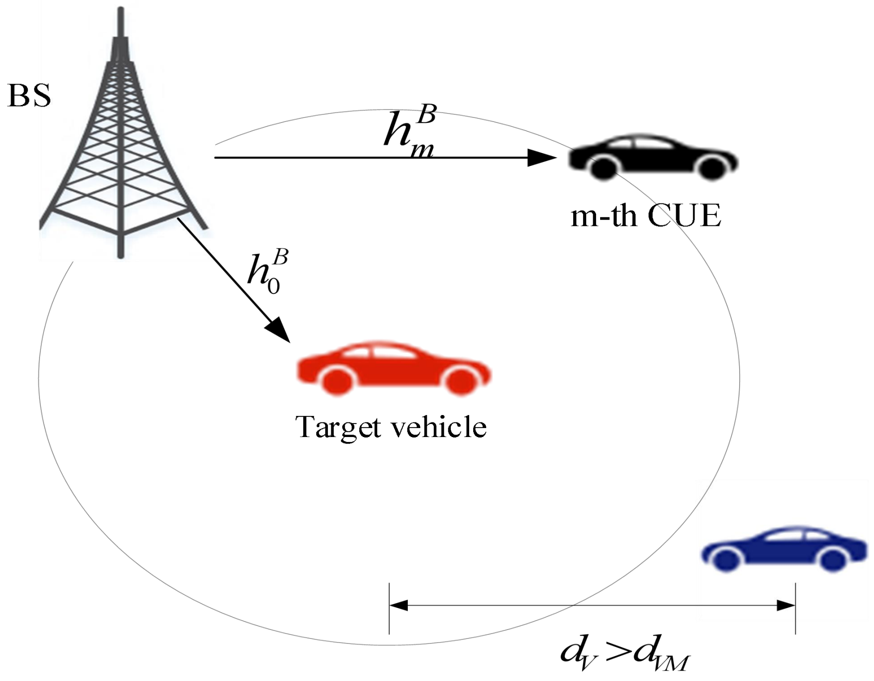
Definition 1 (V2I/V2V Contact Duration):

- Assume that the target vehicle moves into the communication coverage of BS or the k-th VUE at time $t_e^{(k)}$, and leaves at $t_p^{(k)}$, the V2I/V2V contact duration can be expressed as $\mathrm{T}_{V2I/V2V} = t_p^{(k)} - t_e^{(k)}$.

- It is demonstrated that the V2I/V2V Contact Duration obeys an exponential distribution.
- The probability density function of T_{V2I} and T_{V2V} follows the exponential distribution, which can be written as $f_{\mathrm{T}_{V2I}}(x)=\lambda_{V2I}e^{-\lambda_{V2I}x}, \quad f_{\mathrm{T}_{V2V}}(x)=\lambda_{V2V}e^{-\lambda_{V2V}x}$

C. Transmission Model

In Mode 1, when d ≥ dVM
HD map information is only transmitted by BS



- The transmission rates of BS for HD map

$$r_B^{(1)} = B_B \log_2(1 + \rho_B^{(1)})$$

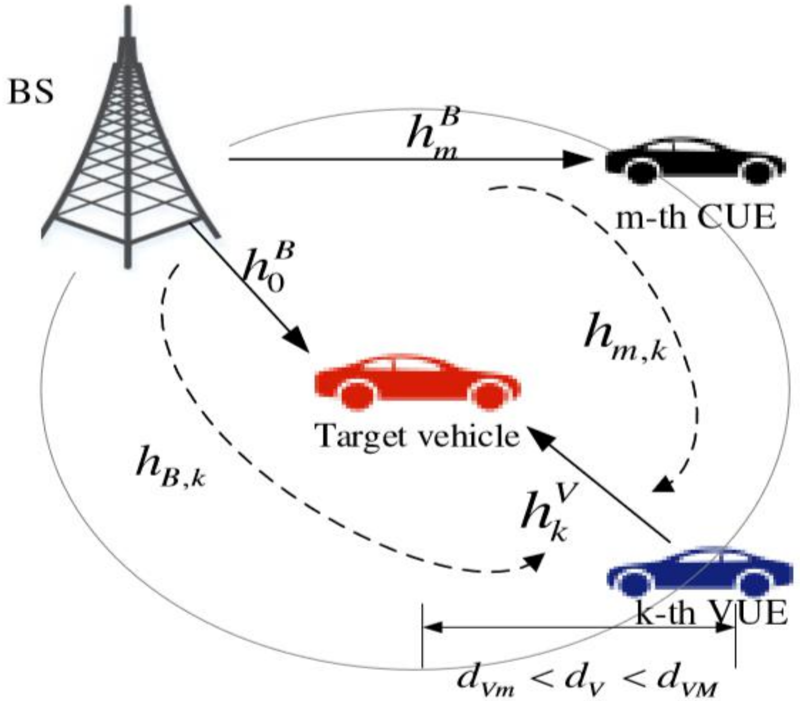
- the transmission delay of delivering HD map data between BS and the target vehicle

$$t_{V2I}^{(1)} = \frac{L}{r_B^{(1)}}$$

Under this case, when the CUEs spectrum resource is not currently reused by any other V2V pairs, it will not suffer the interference from V2V pairs.

C. Transmission Model

In Mode 2, when dvm ≤ d ≤ dVM,
HD map data is divided into k+1 data blocks,
transmitted by both BS and k VUEs.



the transmission rates of BS and k-th VUEs

$$r_{Vk}^{(2)} = \sum_{m \in \mathcal{M}} B_V \log_2(1 + \rho_{Vk}^{(2)})$$

$$r_B^{(2)} = B_B \log_2(1 + \rho_B^{(2)})$$

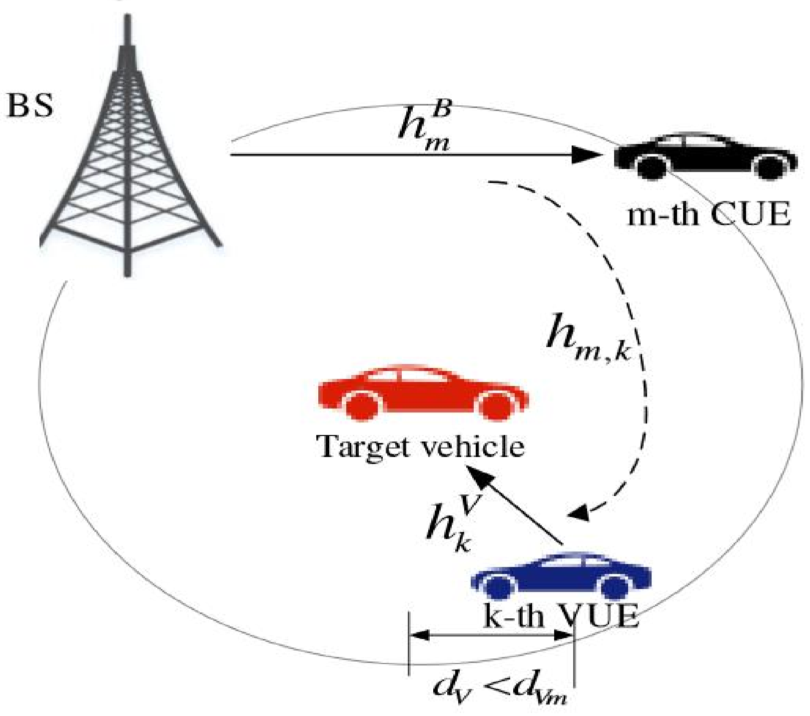
transmission delay of BS and k-th VUEs

$$t_{V2V}^{(2),k} = \frac{s^{(2)}}{r_{Vk}^{(2)}} \quad , \quad t_{V2I}^{(2)} = \frac{s^{(2)}}{r_B^{(2)}},$$

- the interference between V2V pair and the CUE is incurred.
- the V2V pair also suffer the interference from the link between the BS and target vehicle.

C. Transmission Model

In Mode 3, d ≤ dvm
HD map data is divided into k data blocks transmitted only by k VUEs.



the sum data rate of CUE m and V2V pair k over their allocated spectrum resource

$$R_m^c = \lambda_1 \log_2(1+\rho_c^{(1)}) + \lambda_2 \sum_{k \in \mathcal{K}} x_{m,k}^{(2)} \log_2(1+\rho_c^{(2)}) + \lambda_3 \sum_{k \in \mathcal{K}} x_{m,k}^{(3)} \log_2(1+\rho_c^{(3)}),$$

$$R_k^V = \lambda_2 \sum_{m \in \mathcal{M}} x_{m,k}^{(2)} \log_2(1+\rho_{Vk}^{(2)}) + \lambda_3 \sum_{m \in \mathcal{M}} x_{m,k}^{(3)} \log_2(1+\rho_{Vk}^{(3)}).$$

- In this mode, the V2V pair will suffer the interference from the CUEs when they share downlink spectrum resources

D. Problem Formulation

Resource Management

- mode selection
- spectrum assignment
- power control

$$\max_{x_{m,k}, P_m^B, P_k^V} \{\sum_{k\in\mathcal{K}} R_k^V + \sum_{m\in\mathcal{M}} R_m^c\}$$

$$s.t. \quad \lambda_1 + \lambda_2 + \lambda_3 = 1,\ \lambda_1, \lambda_2, \lambda_3 \in \{0,\ 1\}$$

$$0 \le P_m^B \le P_{max}^B,\ \forall m \in \mathcal{M}$$

$$0 \le P_m^B \le P_{max}^V,\ \forall k \in \mathcal{K}$$

$$\sum_{k\in\mathcal{K}} x_{m,k} \le 1,\ x_{m,k} \in \{0,\ 1\},\ \forall k \in \mathcal{K}$$

$$\sum_{m\in\mathcal{M}} x_{m,k} \le 1, x_{m,k} \in \{0,\ 1\},\ \forall m \in \mathcal{M}$$

$$\lambda_1 P_{V2I}^1 + \lambda_2 \prod_{k\in\mathcal{K}} P_{V2I}^2 \cdot P_{V2V}^{2,k} + \lambda_3 \prod_{k\in\mathcal{K}} P_{V2V}^{3,k} \le \varepsilon.$$

- **network capacity**
- **reliability requirement**

Cooperative V2X transmission scheme

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A. Optimal Power Allocation

Interpolation Search

Obtain optimal power allocation according to the constraints in different modes

$$P_{V2I}^{1} \leq \varepsilon,$$

$$\prod_{k \in \mathcal{K}} P_{V2I}^{2} \cdot P_{V2V}^{2,k} \leq \varepsilon,$$

$$\prod_{k \in \mathcal{K}} P_{V2V}^{3,k} \leq \varepsilon.$$

- Consider a particular spectrum reusing pair of the k-th VUE and the m-th CUE, which implies that the k-th VUE suffers interference only from the m-th CUE, and vice versa.
- The SINR of the k-th VUE and the m-th CUE are then functions of P Bm and $P^{V}{}_{k}$ the objective function is given by

$$R_{k,m}^{V}(P_k^V, P_m^B) = \log_2(1 + \frac{P_k^V h_k^V}{P_m^B h_{m,k} + P_0^B h_{B,k} + \sigma^2})$$

$$R_{m,k}^{c}(P_k^V, P_m^B) = \log_2(1 + \frac{P_m^B h_m^B}{P_k^V h_{m,k} + \sigma^2})$$

B. Pairing optimization

Kuhn-Munkras a best matching problem with weighted bipartite graph

- From the previous subsection, we have derived the optimal power allocation for all possible spectrum reusing pairs.
- The remaining work is to find the optimal spectrum reusing combination by determining $x_{m,k}$

$$\max_{x_{m,k}} \sum_{m \in \mathcal{M}, k \in \mathcal{K}} R^*(P_k^{V*}, P_m^{B*})$$

- can be efficiently solved by the KuhnMunkras method in polynomial time

finds the optimal power allocation for
each reusing pair and the best spectrum sharing among all
possible reuse pairs.

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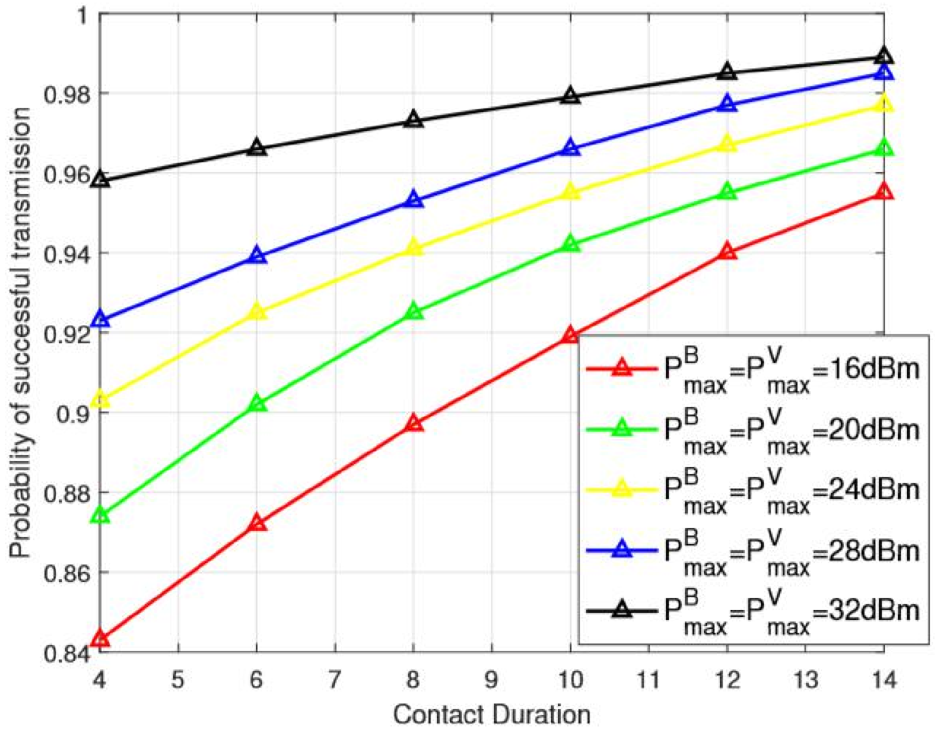
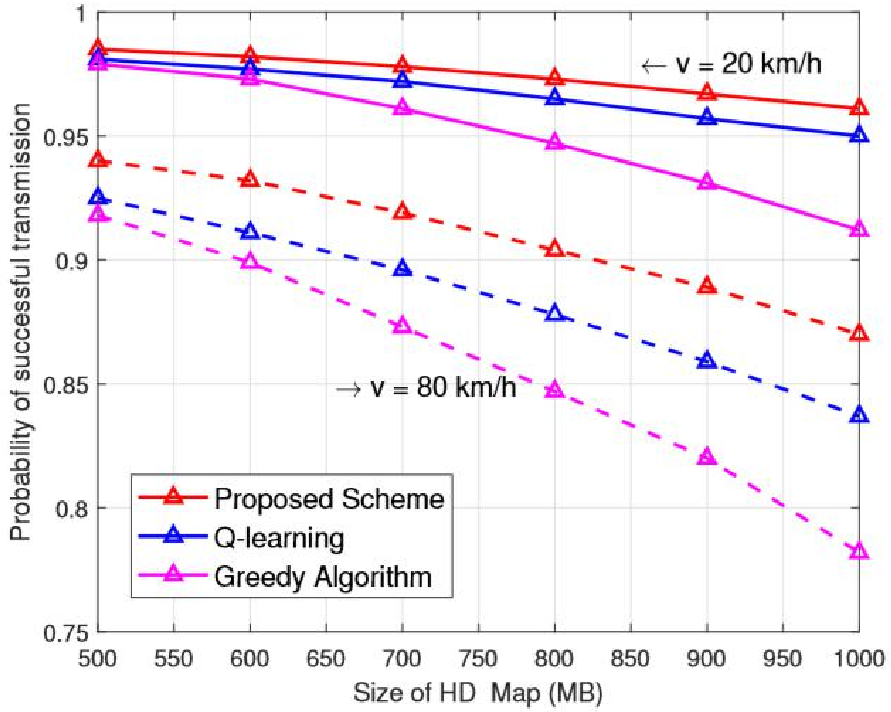
4 Numerical Results

Probability of successful transmission with varying Contact Duration



- With the increasing average CD, the latency requirement of the HD map transmission becomes less stringent, so that the probability of successful transmission increases.
- The data reception of the target vehicle is less sensitive to CD when P^{V}_{max} , P^{B}_{max} increases, which can guarantee the requisite low-latency information transmission.

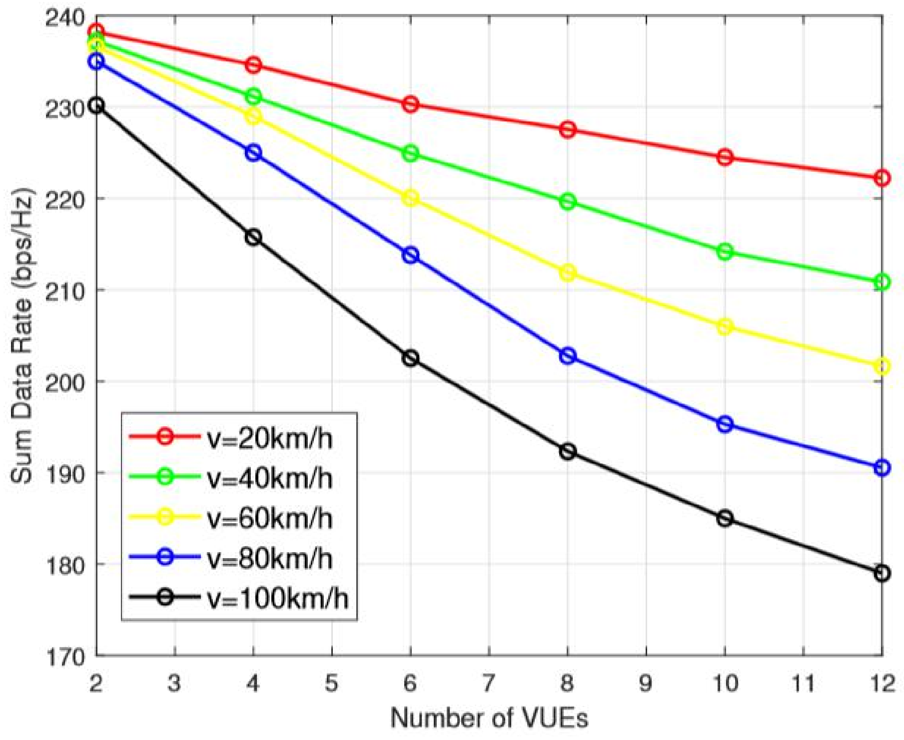


Probability of successful transmission with varying size of HD map

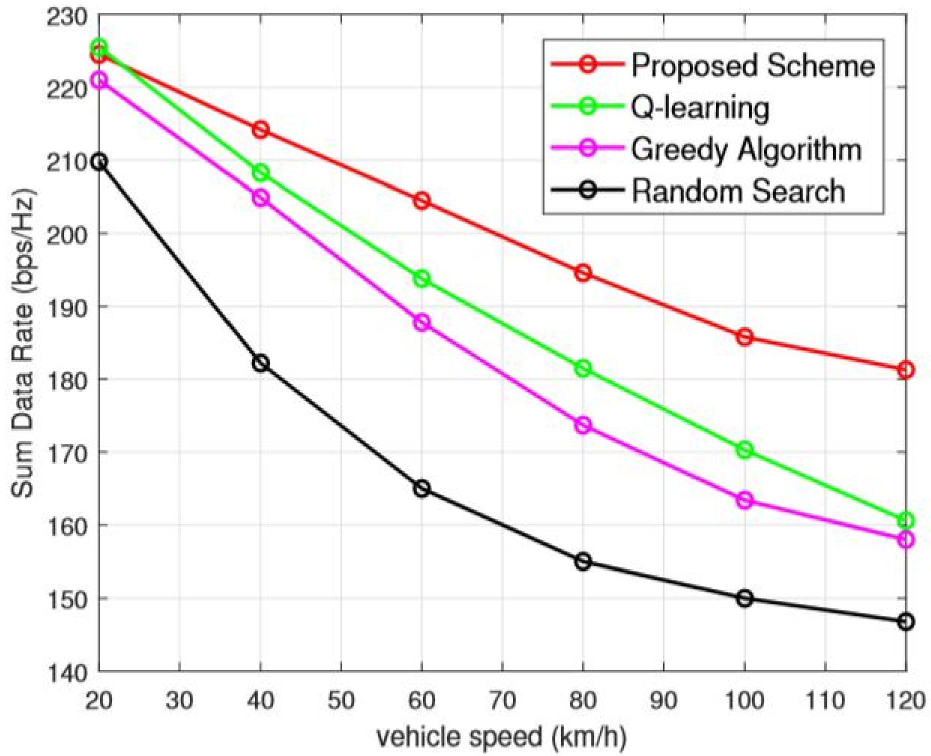
- The performance of all approaches reduces as the increase size of HD map.
- The topology of the vehicular network becomes more stable with reducing vehicle speed, and thus the probability of successful transmission increase.

4 Numerical Results

Sum data rate with varying number of VUEs



- The sum data rate performance reduces as the increase number of VUEs.
- Faster speeds has a more significant impact on performance.



Performance comparison of three different schemes with varying vehicle speed

- As the vehicle speed increases with high uncertainties, our proposed approach can still maintain the sum data rate at a considerable level and outperforms Greedy Algorithm which lack of global cosiderations.

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5 Conclusion

HD map dissemination problem in V2X-assisted automated driving

mode selection

power control

spectrum allocation

probability of successful transmission

the sum capacity

numerical results

The proposed scheme is an efficient way to address the challenges in HD map dissemination.

Thank you ！

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