Poster: Resource Allocation with Conflict Resolution for Vehicular Sidelink Broadcast Communications

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Background

- 3GPP introduced a new resource allocation concept for **vehicular broadcast communications** called V2V *mode-3*.
- eNodeBs only intervene in subchannel allocation.
- However, vehicles communicate directly with their counterparts in a **broadcast** manner.
- It is critical that vehicles transmit in orthogonal time resources to avoid conflicts and thus guarantee safety.

Objective

- Propose an approach that (i) maximizes the system sum-capacity and (ii) guarantees a conflict-free subchannel allocation for V2V *mode-3*.

System Model

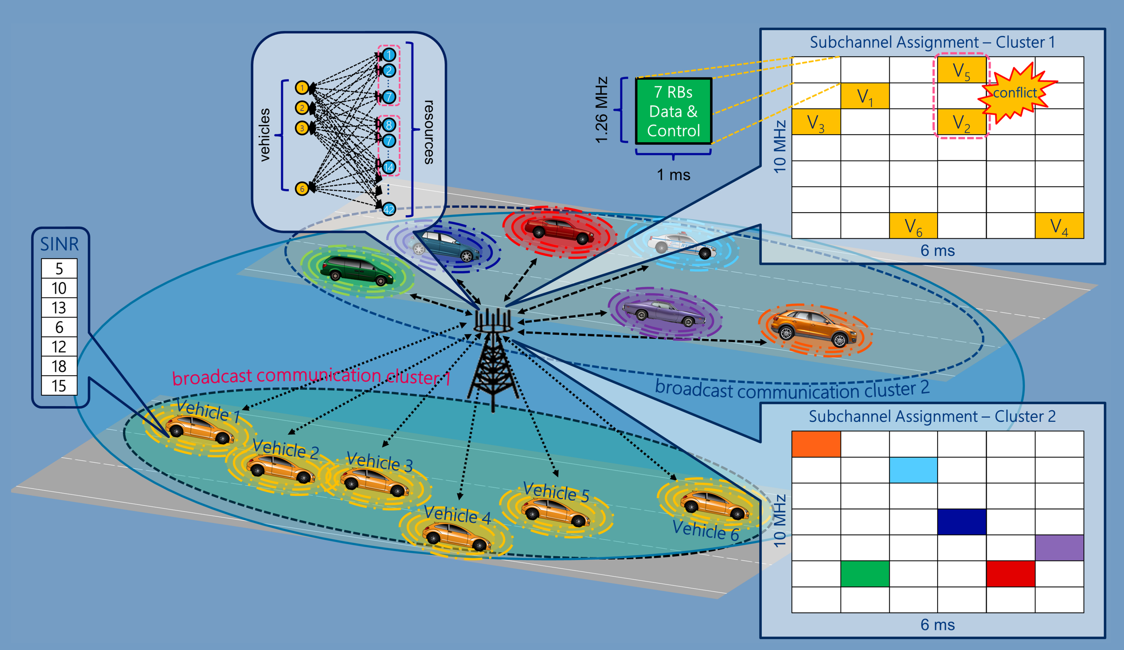


Figure 1: Vehicular broadcast communications via sidelink

Sidelink Subchannel Grid

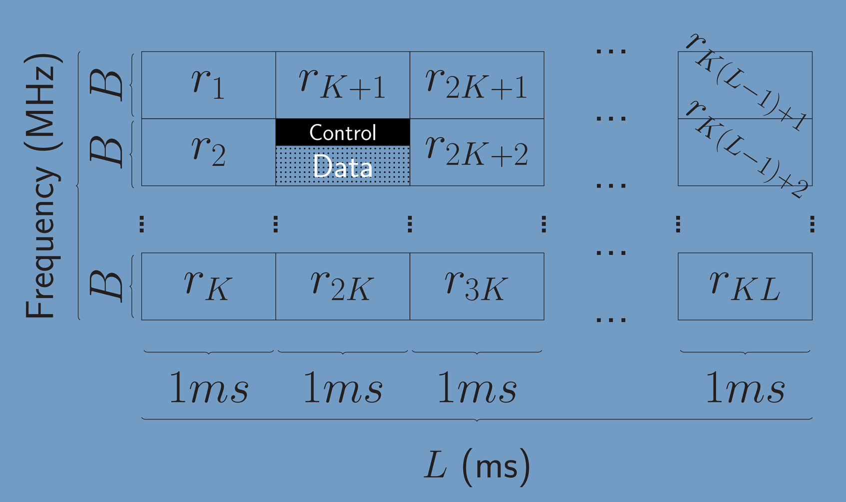


Figure 2: Channelization of sidelink resource blocks (RBs)

B: subchannel bandwidth. L: number of subframes. K: number of subchannels per subframe.

Example: Subchannel Allocation Conflict

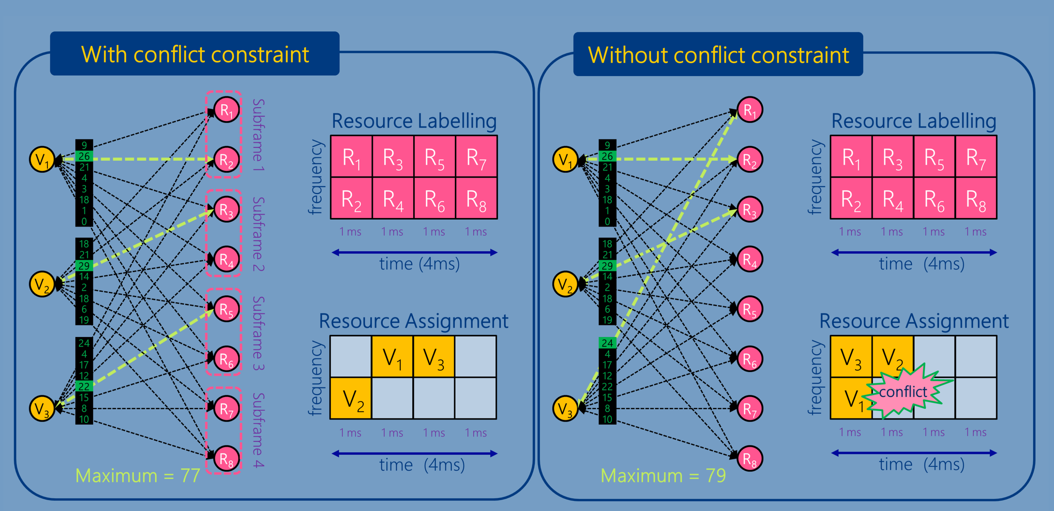


Figure 3: Resource allocation example

Simulation: Data Rate per Vehicle

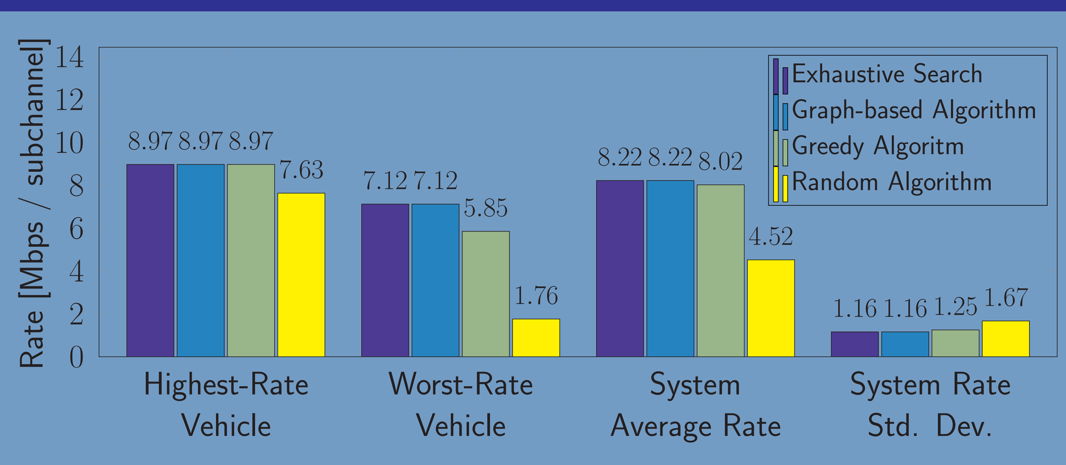


Figure 4: Vehicles data rate $/N = 100, K = 7$

Proposed Constrained Weighted Graph Matching

- Bipartite graph matching with conflict constraints

$$\max \mathbf{c}^T\mathbf{x}$$
$$\text{subject to } \underbrace{\begin{bmatrix} \mathbf{I}_{N\times N} \otimes \mathbf{1}_{1\times L} \\ \mathbf{1}_{1\times N} \otimes \mathbf{I}_{L\times L} \end{bmatrix}}_{\mathbf{A}} \otimes \mathbf{1}_{1\times K}\ \mathbf{x} = \mathbf{1}$$

$\mathbf{x} = [x_{1,1}, \dots, x_{N,NKL}]^T$: solution vector
$\mathbf{c} = [c_{1,1}, \dots, c_{N,NKL}]^T$: capacity vector
$c_{ij} = B\log_2(1 + \text{SINR}_{ij})$: j-th subchannel capacity
N: number of vehicles

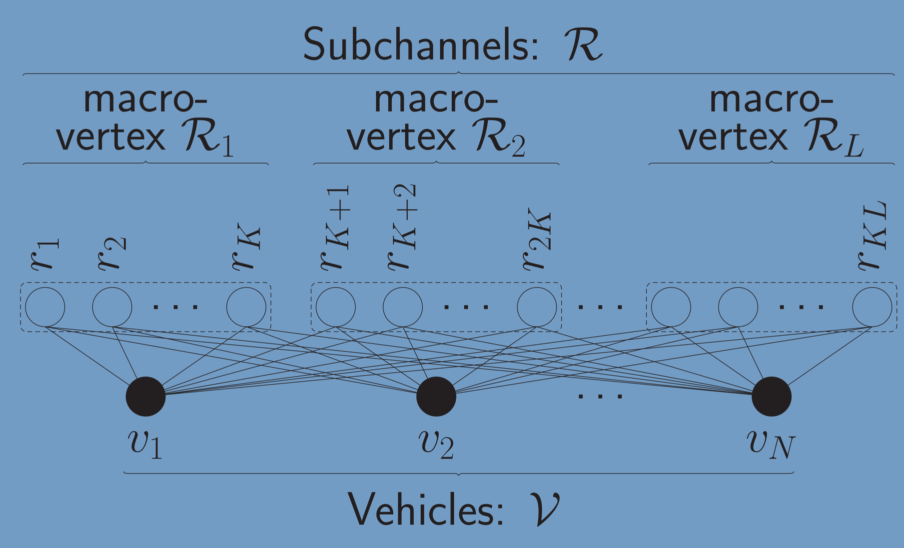


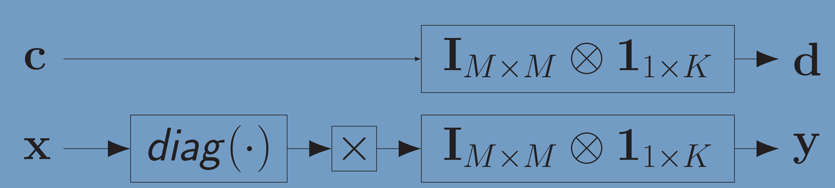
Figure 6: Constrained weighted bipartite graph

- Complexity via exhaustive search: $\mathcal{O}(|\mathcal{R}|!/(|\mathcal{R}| - |\mathcal{V}|)!)$

Simplified Weighted Graph Matching

- Equivalent Problem

$$\max \mathbf{d}^T\mathbf{y}$$
$$\text{subject to } \underbrace{\begin{bmatrix} \mathbf{I}_{N\times N} \otimes \mathbf{1}_{1\times N} \\ \mathbf{1}_{1\times N} \otimes \mathbf{I}_{N\times N} \end{bmatrix}}_{\mathbf{A}} \mathbf{y} = \mathbf{1}.$$

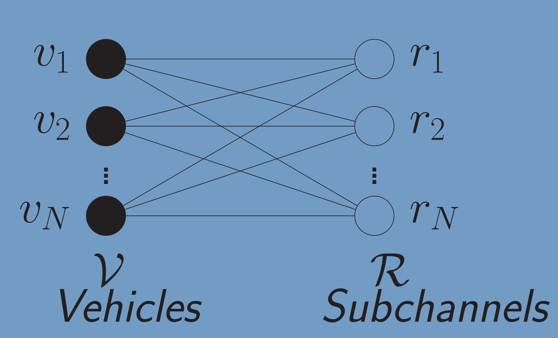


- To remove the dependence of $\mathbf{y}$ on $\mathbf{x}$,

$$\mathbf{d} = \lim_{\beta\to\infty} \frac{1}{\beta} \overset{\circ}{\log}\left\{(\mathbf{I}_{M\times M} \otimes \mathbf{1}_{1\times K}) e^{\circ \beta \mathbf{c}}\right\}$$

$\overset{\circ}{\log}\{\cdot\}$: element-wise natural logarithm
$e^{\circ\{\cdot\}}$: Hadamard exponential.

- This is equivalent to



- Complexity via Kuhn-Munkres: $\mathcal{O}(\max\{|\mathcal{V}|, |\mathcal{R}|/K\}^3)$

Simulation: Data Rate Statistics Comparison

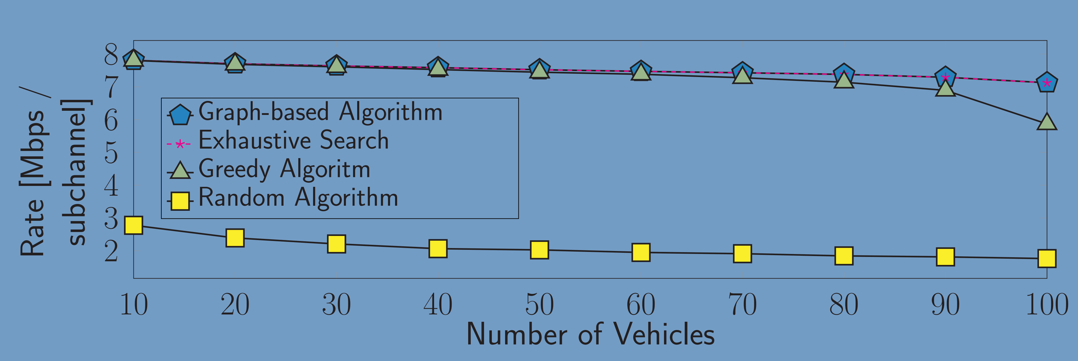


Figure 7: Worst-rate vehicle $/N = 100, K = 7$

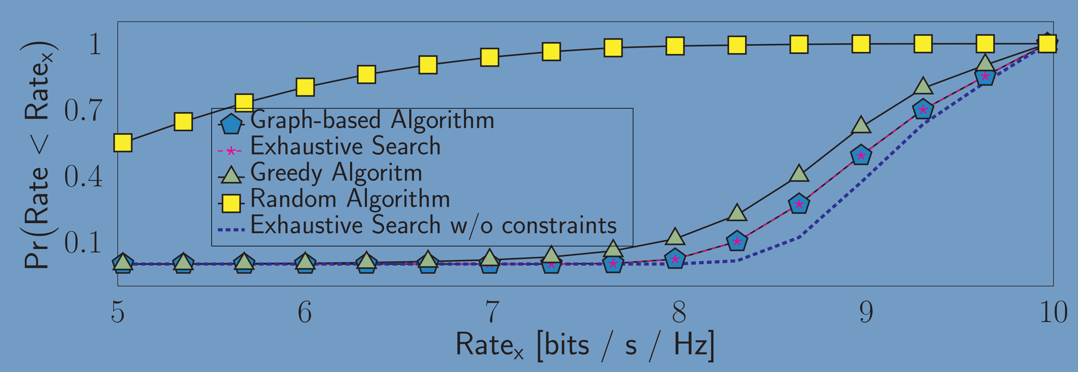


Figure 8: Cumulative distribution function $/N = 100, K = 7$

Matching Algorithm

Algorithm 1: Matching Algorithm

Input: A bipartite graph $\widetilde{G}^{(j)} = (\mathcal{V}^{(j)}, \widetilde{\mathcal{R}}, \widetilde{\mathcal{E}}^{(j)})$ for each cluster, such that $|\mathcal{V}^{(j)}| = |\widetilde{\mathcal{R}}|$.

Output: A set of perfect matchings $\mathcal{M}^{(j)}$, $j = 1, \dots, J$.

begin

for $j = 1 : J$ **do**

Step 1a: Generate an initial feasible labeling l_j.

Step 1b: Compute the equality subgraph $G_l^{(j)} = \{e_{vr} \mid l_j(v) + l_j(r) = d_{vr}\}$ for $\exists v \in \mathcal{V}^{(j)}, \exists r \in \widetilde{\mathcal{R}}, e_{vr} \in \widetilde{\mathcal{E}}^{(j)}$.

Step 1c: Find an arbitrary matching $\mathcal{M}^{(j)}$ in $G_l^{(j)}$.

Step 2: Terminate the algorithm if the matching $\mathcal{M}^{(j)}$ is perfect.

Step 3: Find a vertex $v' \in \mathcal{V}^{(j)}$ that has not been matched in $\mathcal{M}^{(j)}$ and set $\mathcal{S}^{(j)} = \{v'\}, \mathcal{T}^{(j)} = \{\emptyset\}$.

Step 4: Go to *Step 6* if $N(\mathcal{S}^{(j)}) \neq \mathcal{T}^{(j)}$.

Step 5a: Compute the labeling l'_j, $\forall$ vertex z

$$l'_j(z) = \begin{cases} l_j(z) - \varepsilon, \text{ if } z \in \mathcal{S}^{(j)} \\ l_j(z) + \varepsilon, \text{ if } z \in \mathcal{T}^{(j)} \\ l_j(z), \text{ otherwise} \end{cases}$$

where

$$\varepsilon = \min_{\substack{v\in\mathcal{S}^{(j)} \\ r\in\widetilde{\mathcal{R}}\setminus\mathcal{T}^{(j)}}} \{l_j(v) + l_j(r) - d_{vr}\}$$

Step 5b: Compute the equality subgraph $G_l'^{(j)}$.

Step 5c: Update the equality subgraph and labeling: $G_l^{(j)} \leftarrow G_l'^{(j)}$, $l_j \leftarrow l'_j$.

Step 6a: Find a vertex $r \in N(\mathcal{S}^{(j)}) \setminus \mathcal{T}^{(j)}$.

Step 6b: Perform $\mathcal{S}^{(j)} \leftarrow \mathcal{S}^{(j)} \cup \{u\}$, $\mathcal{T}^{(j)} \leftarrow \mathcal{T}^{(j)} \cup \{r\}$ and go to *Step 4* if $\exists e_{ur} \in \mathcal{M}^{(j)}$ such that $u \in \mathcal{V}^{(j)}$.

Step 7a: Find an alternating path $\langle e_{\hat{v}_0\hat{r}_0} \mapsto e_{\hat{v}_1\hat{r}_1} \mapsto \dots \mapsto e_{\hat{v}_m\hat{r}_m} \rangle$ such that $\hat{v}_n \in \mathcal{V}^{(j)}$, $\hat{r}_n \in \widetilde{\mathcal{R}}$, $\hat{r}_m = r$, $e_{\hat{v}_n\hat{r}_n} \in \{G_l^{(j)} \setminus \mathcal{M}^{(j)}\}$ for $n = 0, 1, \dots, m$, $e_{\hat{v}_n\hat{r}_{n-1}} \in \mathcal{M}^{(j)}$ for $n = 1, 2, \dots, m$.

Step 7b: Augment the previous matching $\mathcal{M}^{(j)} \leftarrow \{\mathcal{M}^{(j)} \cup \{e_{\hat{v}_n\hat{r}_n}\}_{n=0}^{n=m}\} \setminus \{e_{\hat{v}_n\hat{r}_{n-1}}\}_{n=1}^{n=m}$.

Step 7c: Go to *Step 2*.

Contributions

- We formulated a maximum sum-capacity conflict-free subchannel allocation scheme for V2V *mode-3* which was first solved via exhaustive search.
- The proposed scheme is recast as a bipartite graph matching problem.
- The complexity of the resultant scheme was reduced by means of graph vertex aggregation.
- The resultant scheme was then solved via Kuhn-Munkres algorithm.
- The new scheme can attain the same performance as exhaustive search.

Conclusions

- We have presented a novel subchannel allocation algorithm for V2V *mode-3* communications considering conflicts avoidance without neglecting capacity.
- We were able to transform the original problem into a simplified form without altering optimality.
- Although not explicitly enforced, the proposed scheme is capable of providing a high degree of fairness to all vehicles.

Simulation: One-shot Subchannel Allocation Comparison ::: Rate Distribution among Vehicles

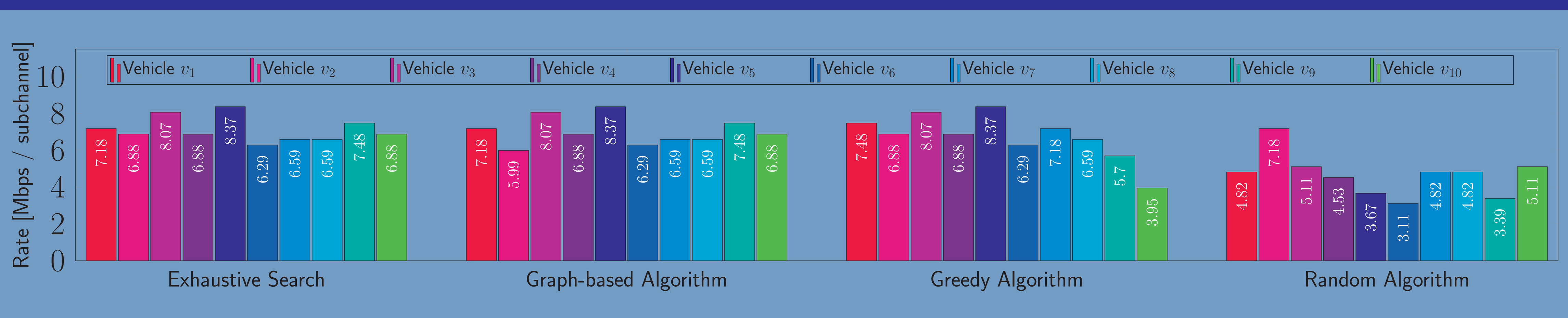


Figure 5: One-shot simulation for different approaches $/N = 10, L = 10, K = 3$

References

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[4] J. Munkres, "Algorithms for the Assignment and Transportation Problems", Journal of the Society for Industrial and Applied Mathematics, Vol. 5, No. 1, pp. 32-38, 1957.