Intelligent Resource Allocation For D2D Communication In 5G Heterogeneous Networks

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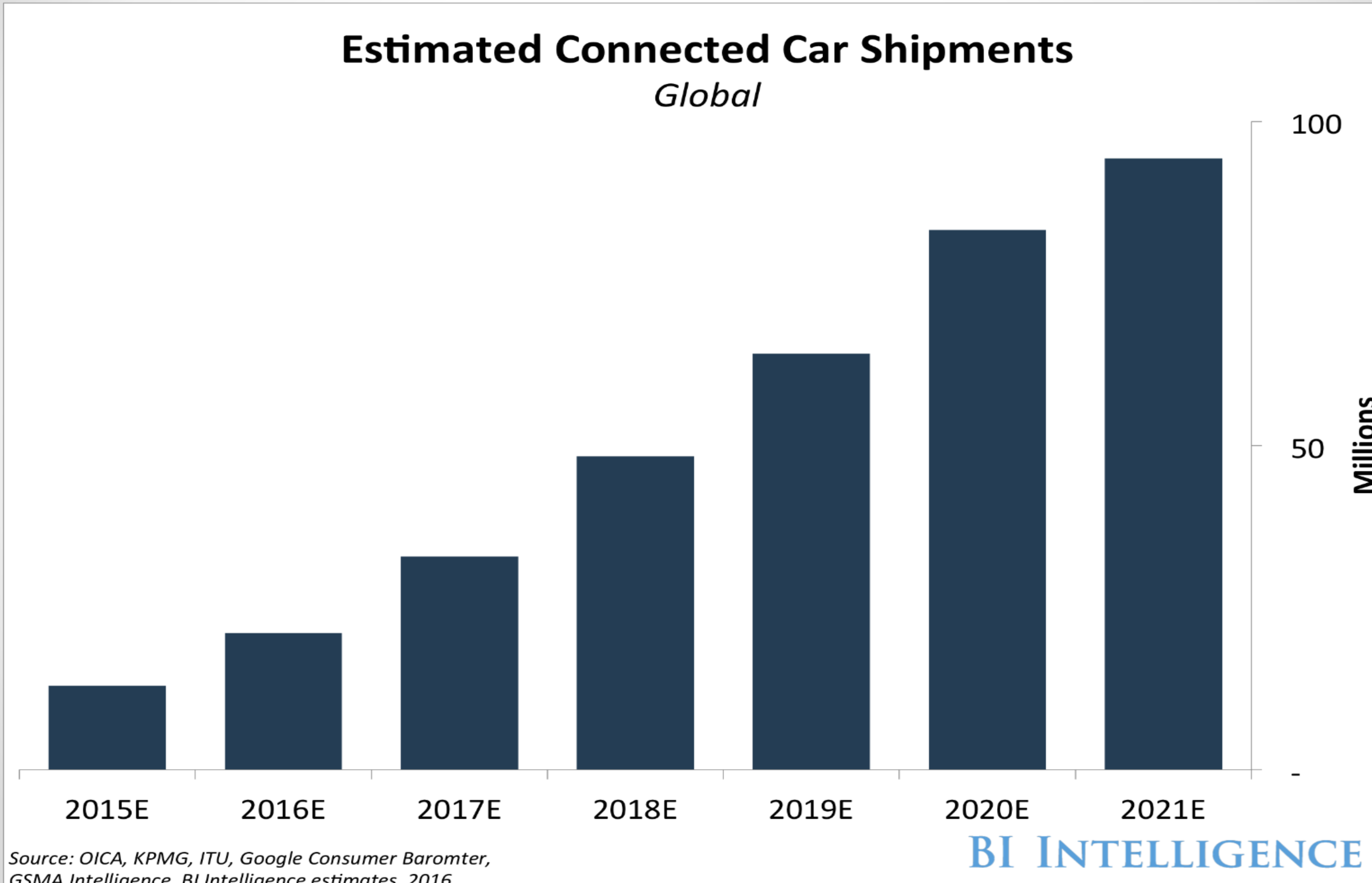
Agenda

- **Introduction on Vehicular Networks**
- **Fifth Generation and Device-to-Device (D2D)**
- **Network Model and Problem Formulation**
- **Power Allocation Mechanisms**
- **Analytical Model for V2V/V2I.**
- **Three Proposed Algorithms**
- **Simulation Results**
- **Conclusion and Future Work**

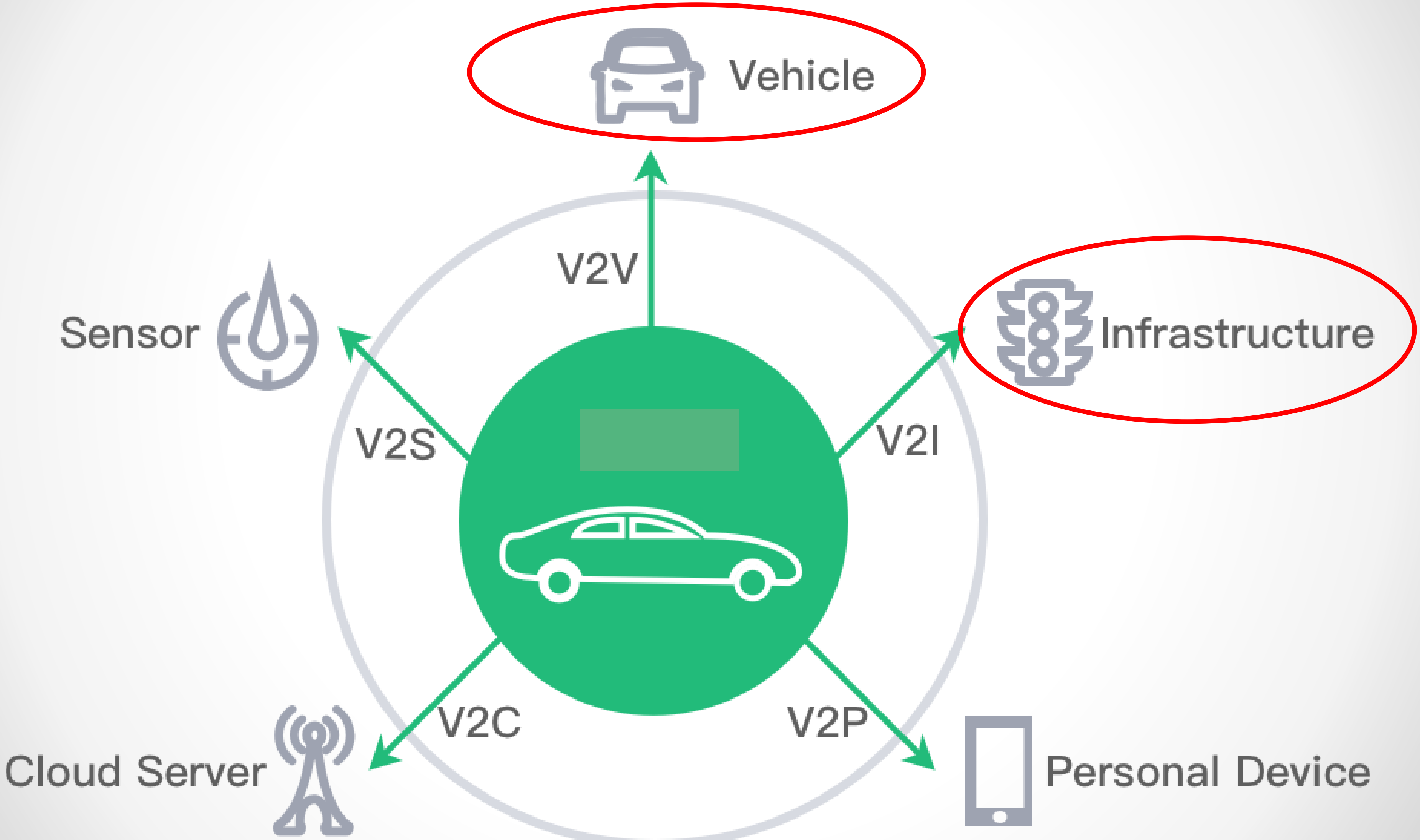
Vehicular Network



Vehicular Network Advantages

- Smarter ground transportation system.
- Real time traffic Information
- Less traffic blocks
- Driver & Passenger Safety
- ADAS (Advanced Driver Assistance Systems).

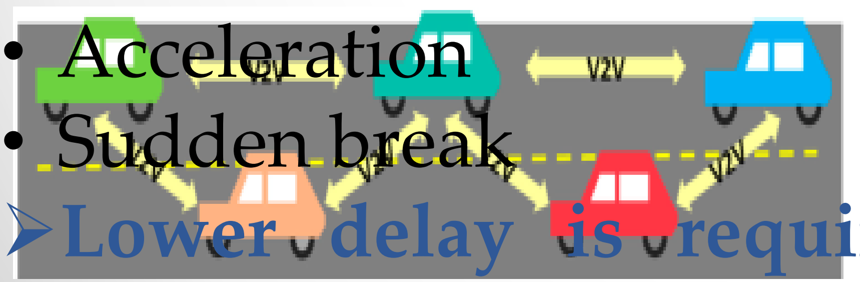
V2X connectivity types



V2X

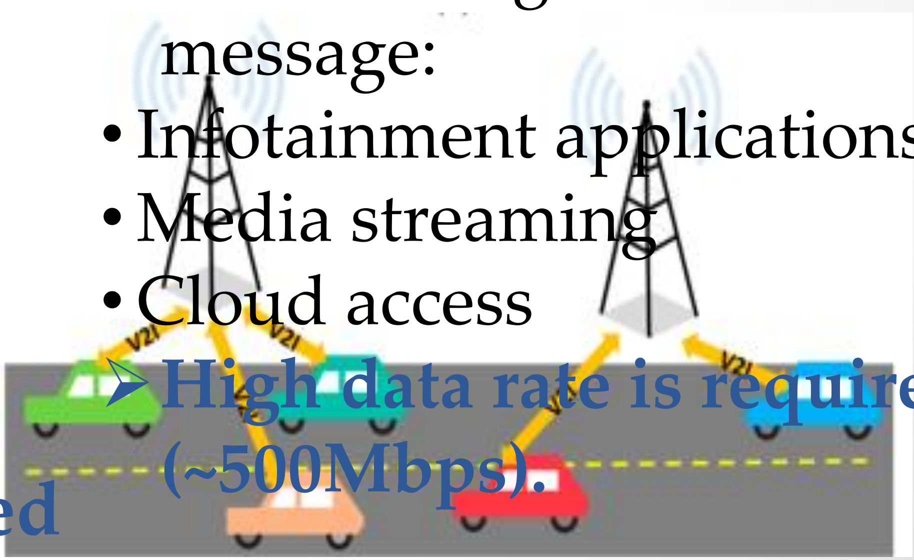
V2V

- ➢Exchange short messages:
  - Locations
  - Speed
  - Inter vehicle distance
  - Acceleration
  - Sudden break
- ➢**Lower delay is required (~5ms).**



V2I

- ➢Deliver high data rate message:
  - Infotainment applications
  - Media streaming
  - Cloud access
- ➢**High data rate is required (~500Mbps).**



Vehicular Network challenges

Support:

- different types of links.
- high coverage range.
- high mobility.
- high data rate.
- low end-to-end delay.

Technology	DSRC	ZigBee	Bluetooth	UWB	WiFi Direct	5G
Standardization name	IEEE 802.11p	802.1504	Bluetooth SIG	802.1503 a	802.11a	3GPP LTE-A Rel12 5G
Transmission distance (max)	~200m	~100m	~100m	~10m	~200m	~1km
Data rate (max)	~27Mb/s	~1250kb/s	~24Mb/s	~480Mb/ s	~250Mb/s	~1Gb/s
Frequency band	5.86-5.92 GHz	868/915 MHz 2.4 GHz	2.4 GHz	3.1-10.6 GHz	2.4/5 GHz	Licensed Band
Supporting mobility	Up to 60 Km/h	Low	Very low	Very low	Low	Up to 350 Km/h
V2I comm.	Availabl e	Available	Available	Availabl e	Available	Through eNB
V2V comm.	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Ad hoc	Through D2D

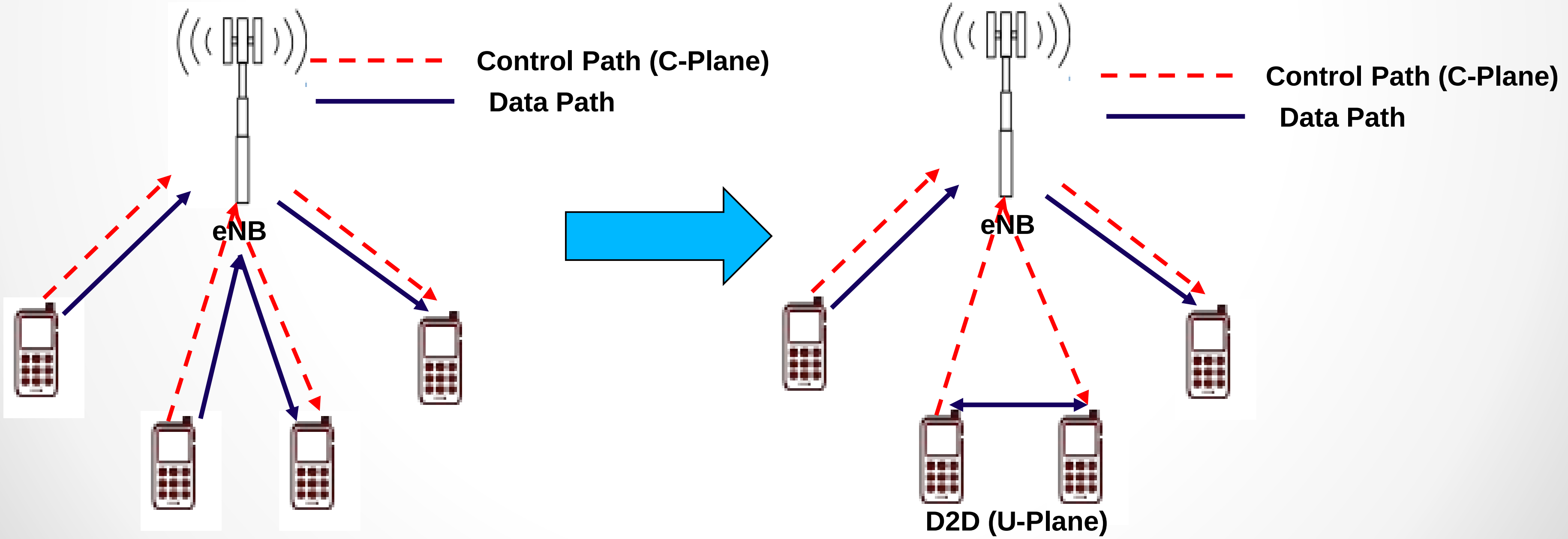
What is Fifth Generation (5G)?

Data rates	1-10Gbps (resp. 100s of Mbps)
Capacity	36TB/month/user (resp. 500 GB)
Spectrum	Higher frequencies & flexibility
Energy	~10% of today's consumption
Latency reduction	~ 1ms (e.g. tactile internet)
D2D capabilities	NSPS, ITS, resilience, ...
Reliability	99.999% within time budget
Coverage	>20 dB of LTE (e.g. sensors)
Battery	~10 years
Devices per area	300.000 per access node

What is D2D communication?

➢ ***D2D Definition:***

"Direct communication between two devices without using the eNB or core network"



Lien, S. Y., et. al. (2016). 3GPP device-to-device communications for beyond 4G cellular networks. IEEE Communications Magazine, 54(3), 29–35.

D2D Advantages

- **D2D technology can gain V2X more benefits:**
- Reducing latency
- Saving power
- Increasing capacity
- Raising spectrum utilizations.

Thus, 5G-D2D can be a strong candidate to achieve Vehicular network requirements

Main purposes

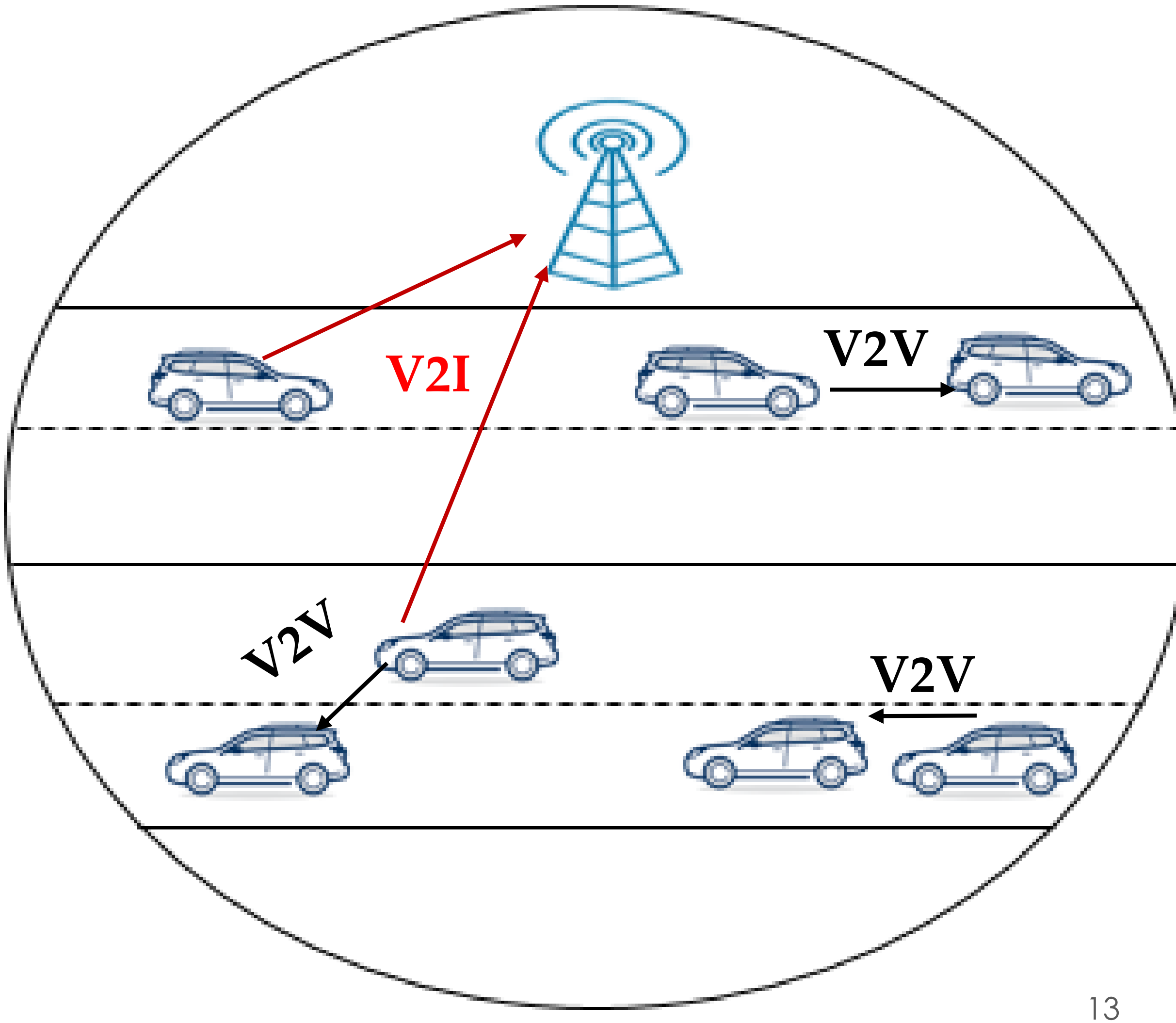
- Construct vehicular network based on 5G-D2D that supports both V2I and V2V links.
- Share resources between V2Vs and V2Is.
- Safe network (Avoid crashes).
- Support high mobility.

Network model and assumptions

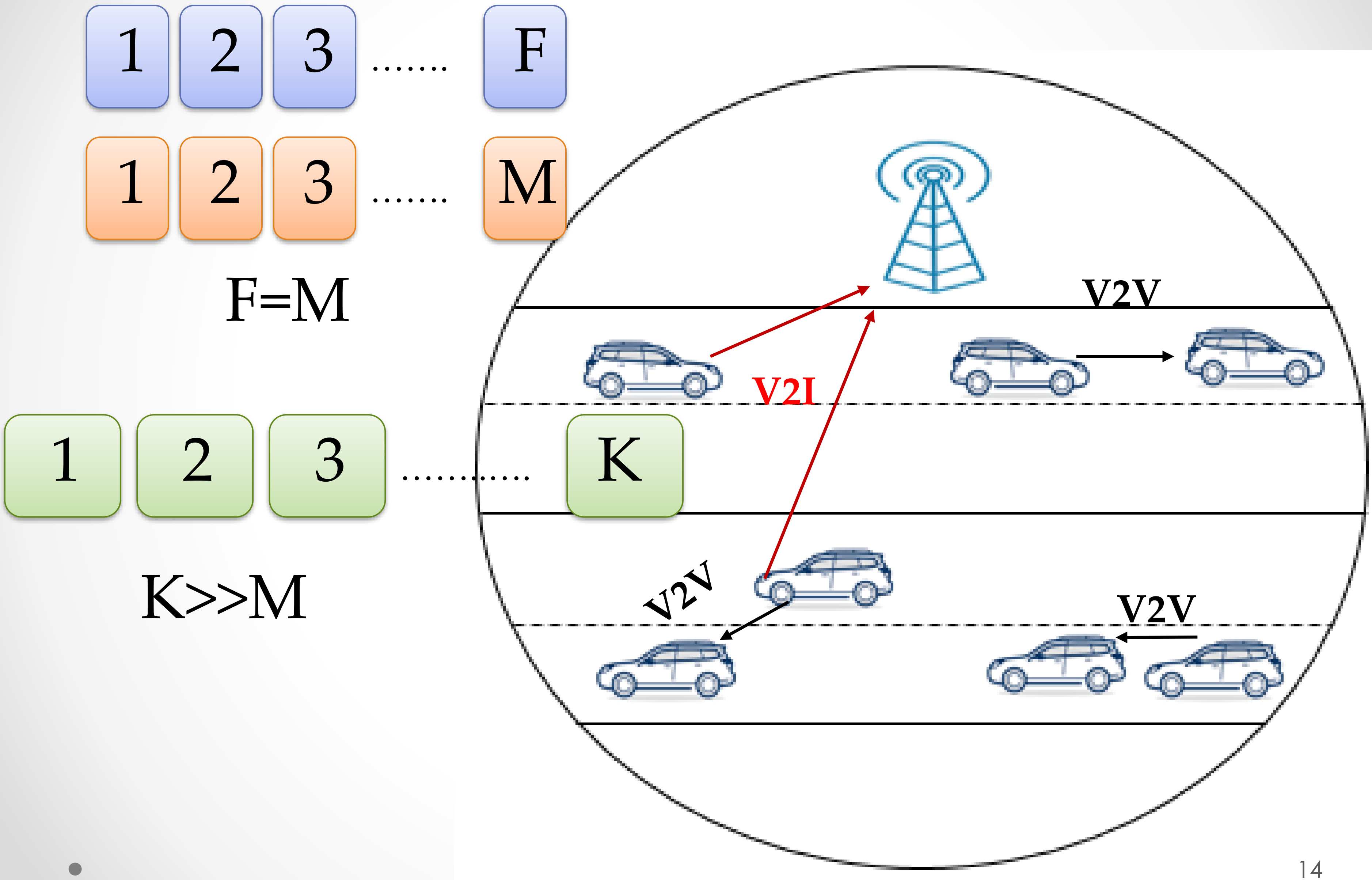
M cellular users ($m=\{1,2,\ldots..,M\}$), denoted as CUm.

K D2D Pair ($k=\{1,2,\ldots.,K\}$) , denoted as DU_k.

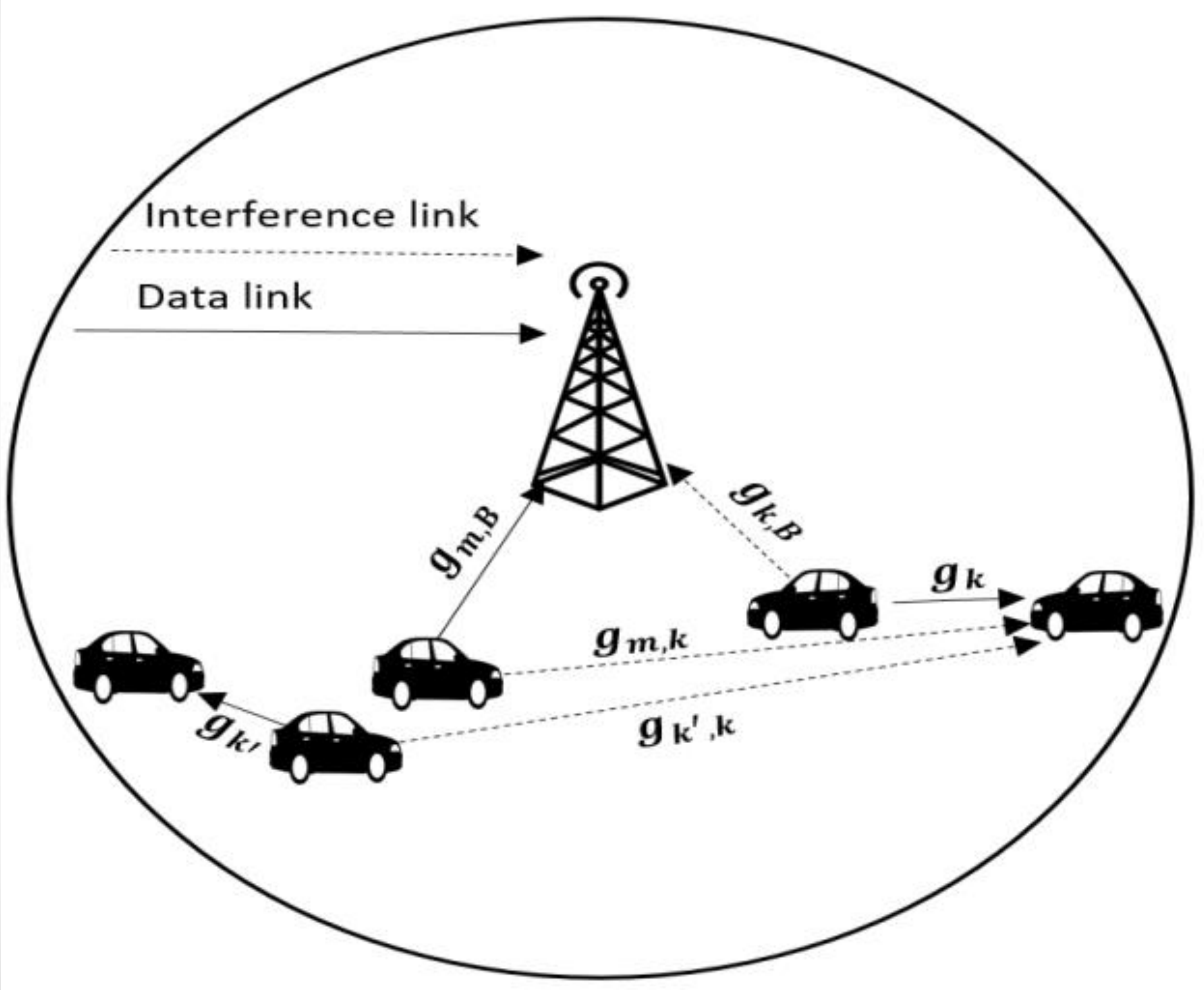
Uplink scenario is assumed.



Network model and assumptions



Network model



Network model

Parameter	Explanations
$g_{m,B}$	V2I channel gain from m^{th} CU to eNB
g_k	V2V channel gain among k^{th} DUs pair
$g_k{}'$	V2V channel gain among k'^{th} DUs pair
$g_{m,k}$	Interfere channel gain from m^{th} Tx to k^{th} DU Rx
$g_{k,B}$	Interfere channel gain from k^{th} Tx to eNB
$g_{k\prime,k}$	Interfere channel gain from k'^{th} DU Tx to other k^{th} DU RX

Signal to Noise Interference Ratio (SNIR)

SNIR form CU_m to eNB (γ_m^c) is obtained as

Received Power

$$\gamma_m^c = \frac{P_m^c g_{m,B}}{\sum_k P_k^d g_{k,B} + \sigma^2} \quad (1)$$

DU Interference

Thermal Noise

SNIR from DU_k to its pair (γ_k^d) is obtained as

Received power

$$\gamma_k^d = \frac{P_k^d g_k}{P_m^c g_{m,k} + \sum_{k\prime \neq k} P_{k\prime}^d g_{k\prime,k} + \sigma^2} (2)$$

Thermal Noise

CU Interference

DU Interference

Network problem formulation

- Maximize V2I's ergodic capacity.
- Guarantee V2Vs' reliability.
- Save energy

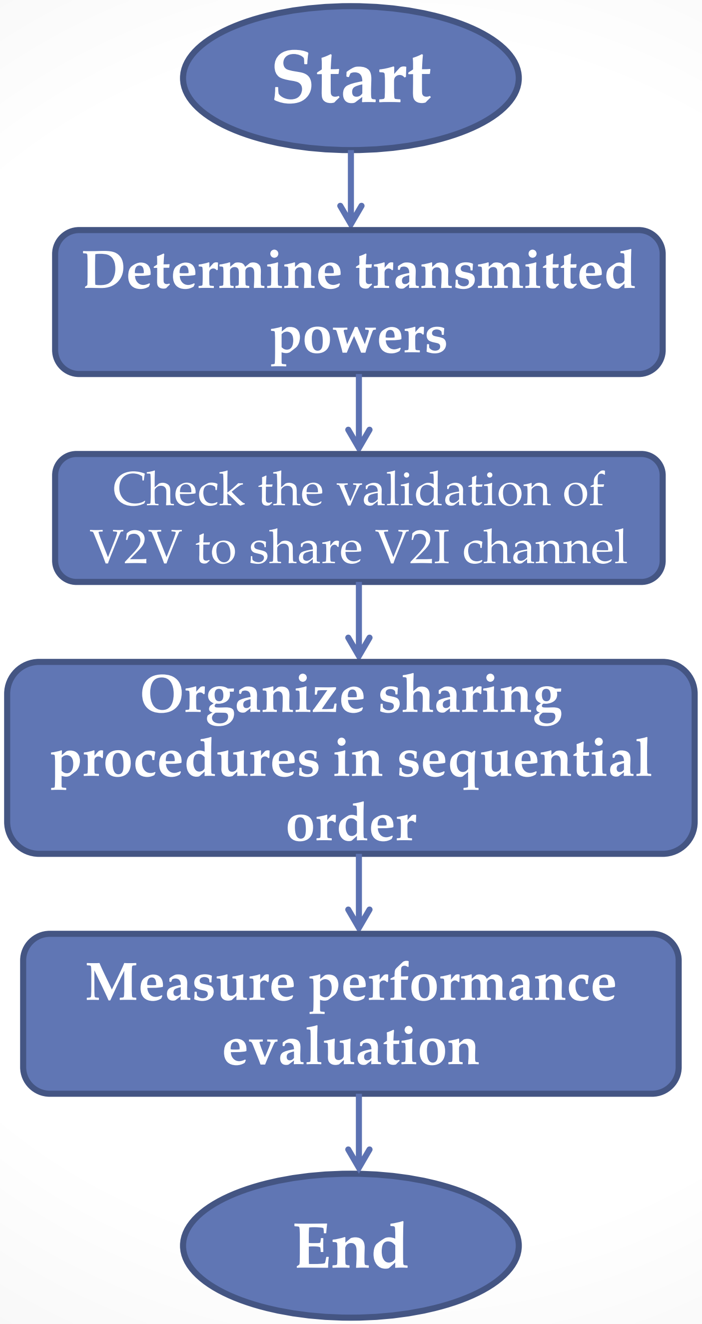
$$\max_{P_m^c, P_k^d} \mathrm{E}[\log_2(1+\gamma_m^c)] \quad (3)$$

$$s.t.\ \mathrm{E}[\log_2(1+\gamma_m^c)] \geq r_0 \quad (3a)$$

$$\Pr\{\gamma_k^d \leq \gamma_0^d\} \leq \rho_0 \quad (3b)$$

$$0 \leq P_m^c \leq P_{max}^c \quad (3c)$$

$$0 \leq P_k^d \leq P_{max}^d \quad (3d)$$


Start
Determine transmitted powers
Check the validation of V2V to share V2I channel
Organize sharing procedures in sequential order
Measure performance evaluation
End

Power Allocation mechanisms

- Two mechanisms have been suggested (MAX mechanism and OPT mechanism).

- These mechanisms are proposed to assign power levels for V2I and V2V transmitters in the network.

- **The main target:**

- Maximize ergodic capacity for V2I links.
- Guarantee reliability for V2V links based on (3b).
- Don't exceed max. power level (3c, 3d).

Max mechanism

- It assumes worst case scenario, where both CU_m and DU_k transmit data with their maximum power level P_{max}. It is assumed that P_{max}^{c}= P_{max}^{d}=P_{max}.

$$R_m^k = \frac{P_k^d}{P_m^c} = 1, \qquad (4)$$

OPT mechanism

- Transmitted power levels for CU and DU are specified based on optimization model.

1 V2V - 1 V2I

n V2V - 1 V2I

$$R_m^k = \frac{P_k^d}{P_m^c} = \frac{\gamma_o^d \alpha_{m,k}}{\alpha_k}\left[\frac{1-\rho_o}{\rho_o}\right] \begin{cases} \le 1\,;\ then\ \mathrm{P_m^c} = \mathrm{P_{max}}\ and\ P_k^d = f^{-1}(P_{max}) \\ > 1;\ then\ \mathrm{P_m^c} = f(P_{max})\ and\ P_k^d = P_{max} \end{cases} \quad (5)$$

$$[R_m^k]_{K\times 1} = \left[\frac{P_k^d}{P_m^c}\right]_{K\times 1} = [\,\emptyset^{-1}]_{\mathrm{K}\times K}\,\bar{\gamma}_{\mathrm{o}}\,[\alpha_{m,k}]_{\mathrm{K}\times 1}\,, \quad (6)$$

$$[\max([R_m^k]_{K\times 1})] = R_{max} \begin{cases} \le 1;\ then\ \mathrm{P_m^c} = \mathrm{P_{max}}\ and\ [P_k^d]_{K\times 1} = [\mathrm{R}_m^k]_{K\times 1}\,P_{max}, \\ > 1;\ then\ \mathrm{P_m^c} = \frac{P_{max}}{R_{max}}\ and\ [P_k^d]_{K\times 1} = [\mathrm{R}_m^k]_{K\times 1}\,\frac{P_{max}}{R_{max}}\,, \end{cases} \quad (7)$$

Analytical model

- Determine which V2V link(s) can share the same channel with V2I link.
- This model discards V2V links based on distance.

$$d_{k_{up},B} \geq d_{m,B} \left(R_m^{k_{up}}\right)^{1/\eta} \left(\frac{1}{\gamma_M} - \frac{1}{\gamma_m^c}\right)^{-1/\eta}, \qquad (8)$$

$$d_{k_{up},k} \geq d_{k,k} \left(R_k^{k_{up}}\right)^{1/\eta} \left(\frac{1}{\gamma_0^d} - \frac{1}{\gamma_k^d}\right)^{-1/\eta}, \qquad (9)$$

Any upcoming DU_k should satisfy constrains (8) & (9). Otherwise, this link will be dropped.

Algorithm 1: MAX mechanism

case CU_m only
    $P_m^c = P_{max}$, $P_k^d = 0$
    calculate γ_m^c
    if $\log_2(1 + \gamma_m^c) < r_0$
        break
    end if

CU only

case CU_m and multiple DU_k
    $P_m^c = P_k^d = P_{max}$, $R_m^k = 1$
    calculate γ_m^c and γ_k^d
    check (8) and (9)
end case

CU and DUs

Algorithm 2: OPT mechanism

case CU_m only
  $P_m^c = P_{max}$, $P_k^d = 0$
  calculate γ_m^c
  if $\log_2(1 + \gamma_m^c) < r_0$
    break
  end if
case CU_m and single DU_k
  perform (5)
  calculate γ_m^c and γ_k^d
  check (8) and (9)
case CU_m and multiple DU_k
  perform (6) and (7)
  calculate γ_m^c and γ_k^d
  check (8) and (9)
end case

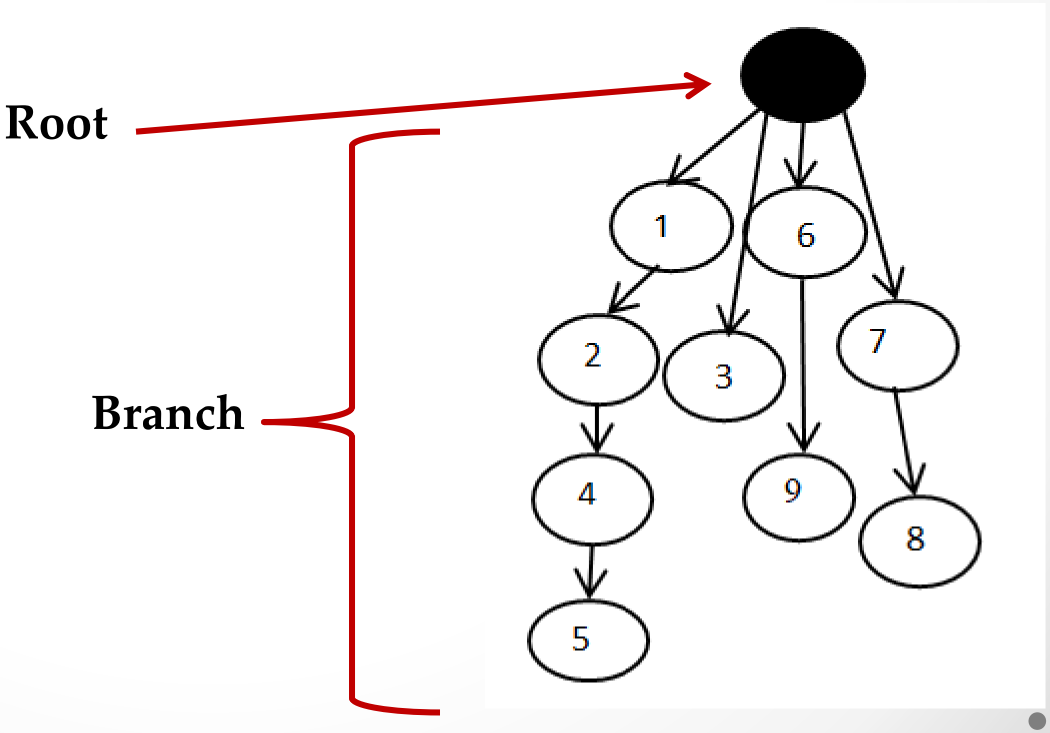
CU only

CU and DU

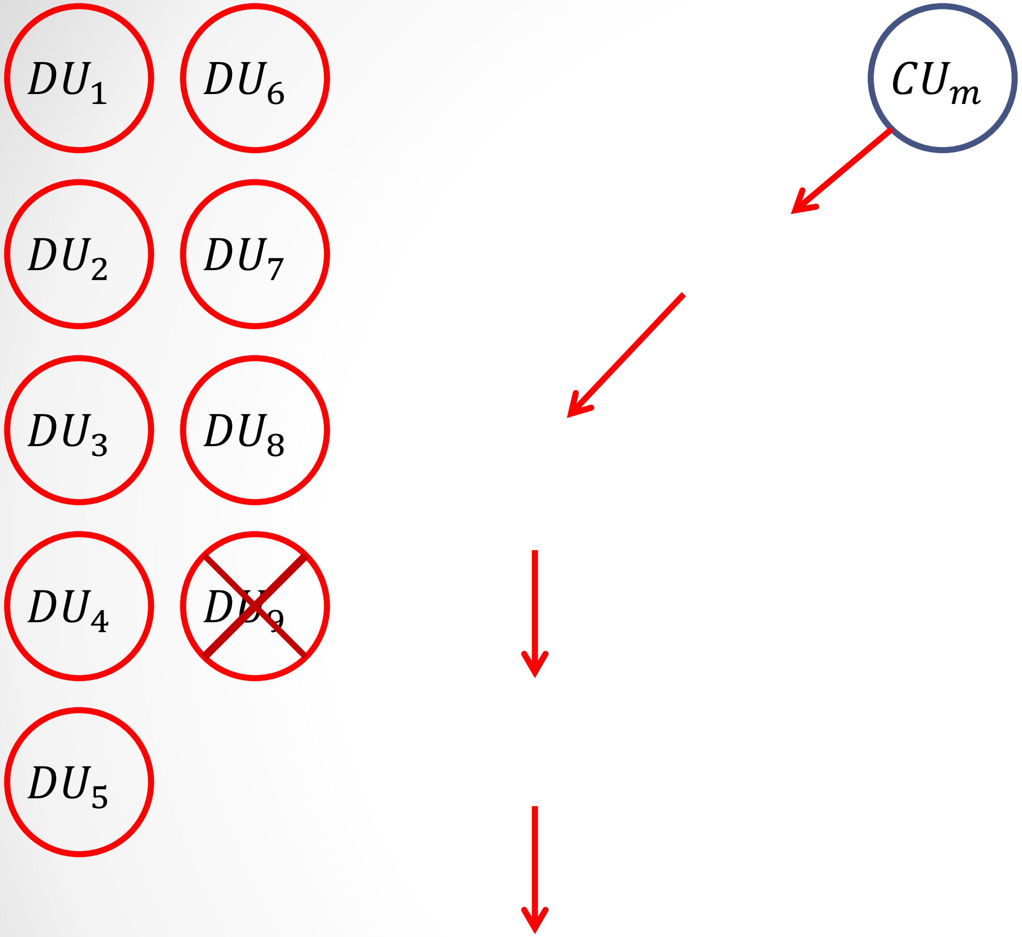
CU and DUs

Depth First Search Tree (DFST) Algorithm

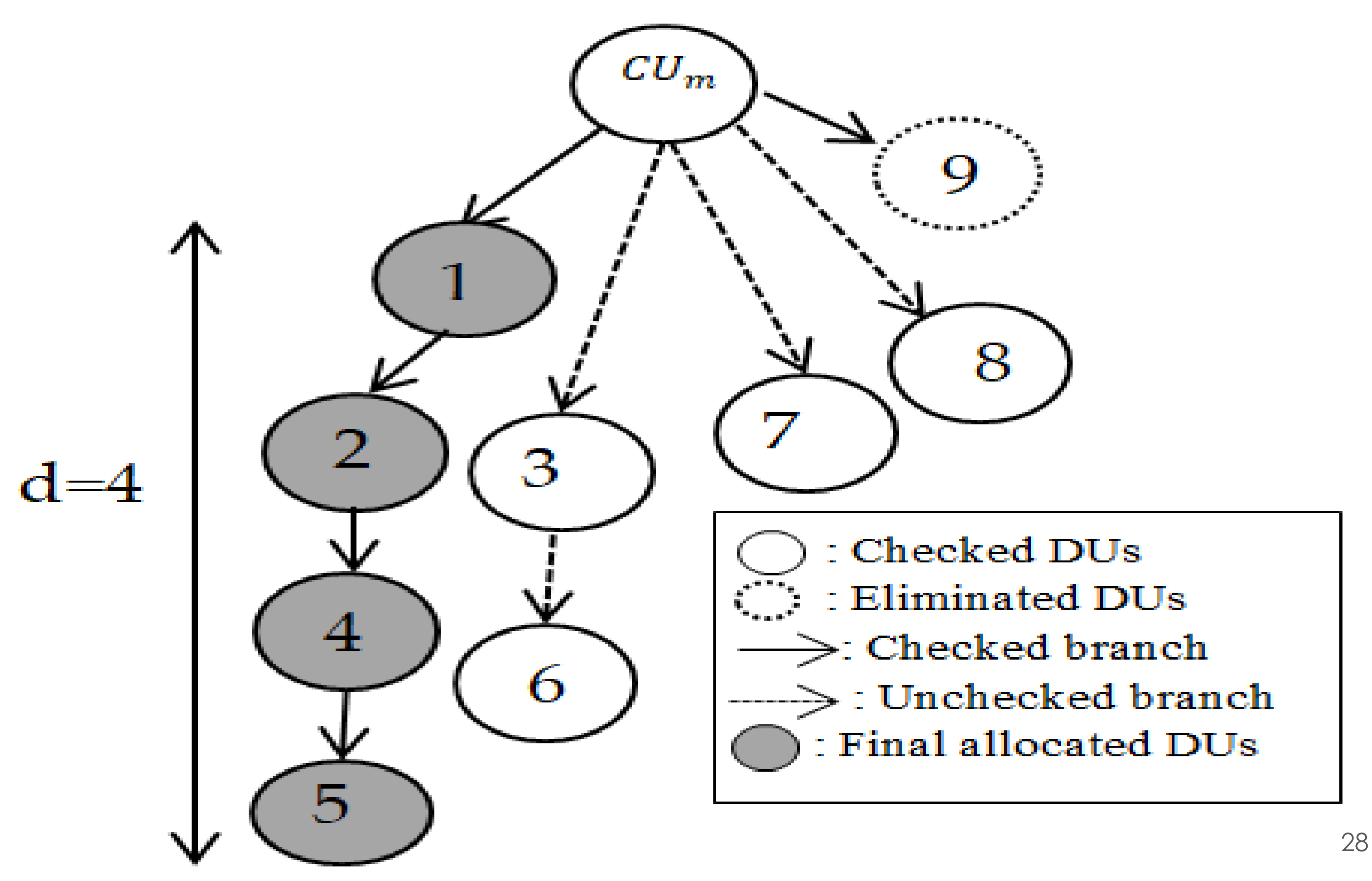
- Allocating V2V links over the same RB of V2I link in a sequential order is considered as a search problem.



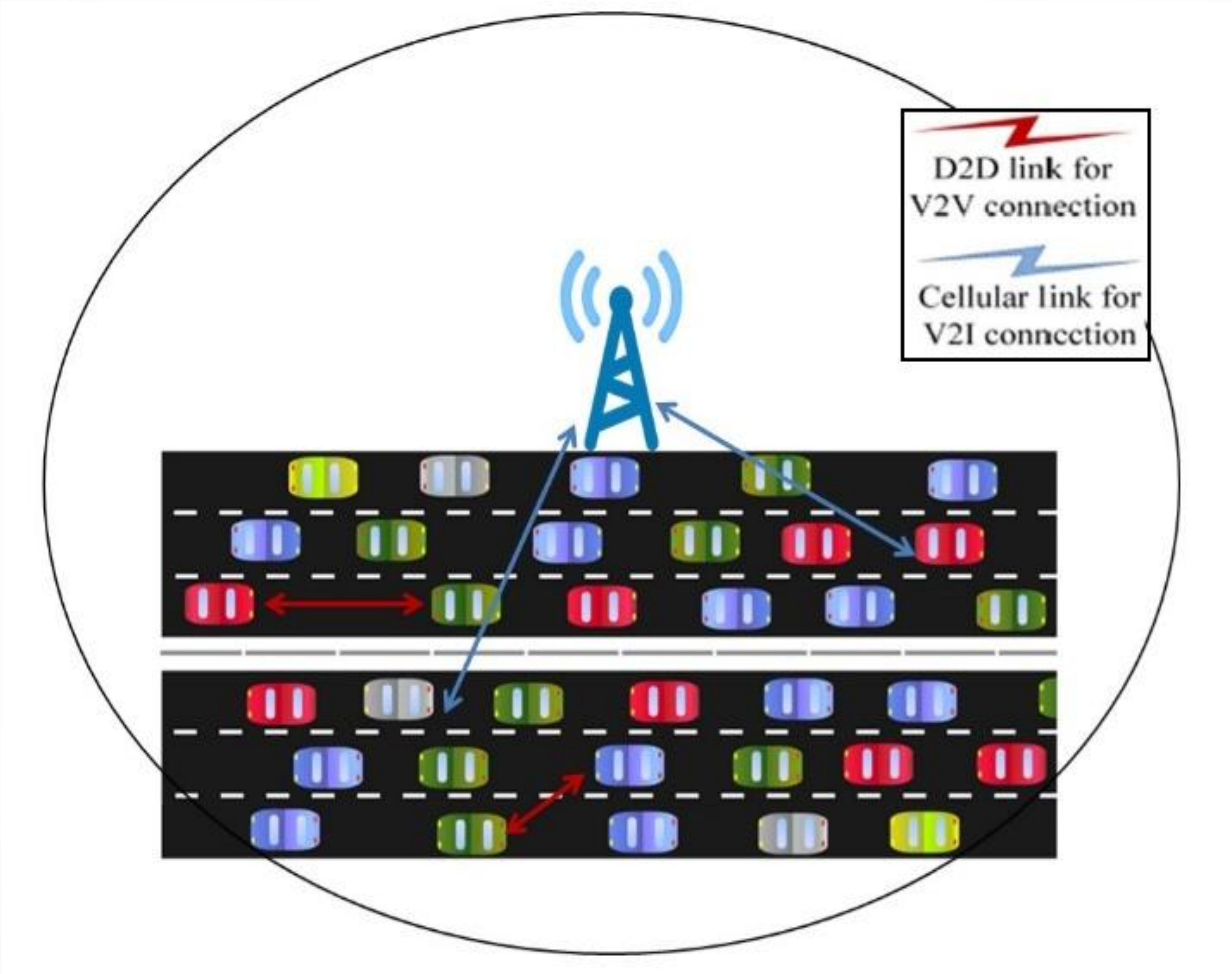
Depth First Search Tree (DFST) Algorithm



Depth First Search Tree (DFST) Algorithm



Simulation Results



Simulation Results (Cont'd)

Parameters	Value
Maximum transmit power for CUs P_{max}^{c}	23 dBm
Maximum transmit power for DUs P_{max}^{d}	23 dBm
Minimum SINR threshold for DUs γ_0^d	5 dB
DUs reliability ρ_0	0.01
Path loss exponent parameter η	2
Thermal noise power	-114 dBm
Minimum threshold capacity of CUs r_0	2 bps/Hz
Operating Frequency	2 GHz
Cell radius	500 meter
eNB antenna height	25 meter
eNB antenna gain	8 dBi
eNB Noise Figure	5 dB
Vehicle antenna height	1.5 meter
Vehicle antenna gain	3 dB
Vehicle receiver noise figure	9 dB
Fast fading	Rayleigh fading
Shadowing distribution	Log-normal
Shadowing standard deviation for V2V	3 dB
Shadowing standard deviation for V2I	8 dB

Simulation Results (Cont'd)

Parameters	Value
Vehicles model	Spatial Poisson model
Number of lanes	6 lanes (3 in each direction)
Lane width	4 meter
Distance from eNB to the highway road	35 meter
Average vehicle distance in road	2.5 v
Average vehicle speed	60 Km/hr

Simulation Results (Cont'd)

- **Liang17 Algorithm:**

➢ It studies spectrum sharing between V2I and V2V.

➢ The network connectivity based on D2D technology.

➢ A Hungarian method is applied to optimize the formulated problem that guarantees QoS needs.

➢ The algorithm allocates a best V2V link/V2I link that achieve the constrains.

Simulation Results (Cont'd)

- **Liang18 Algorithm:**

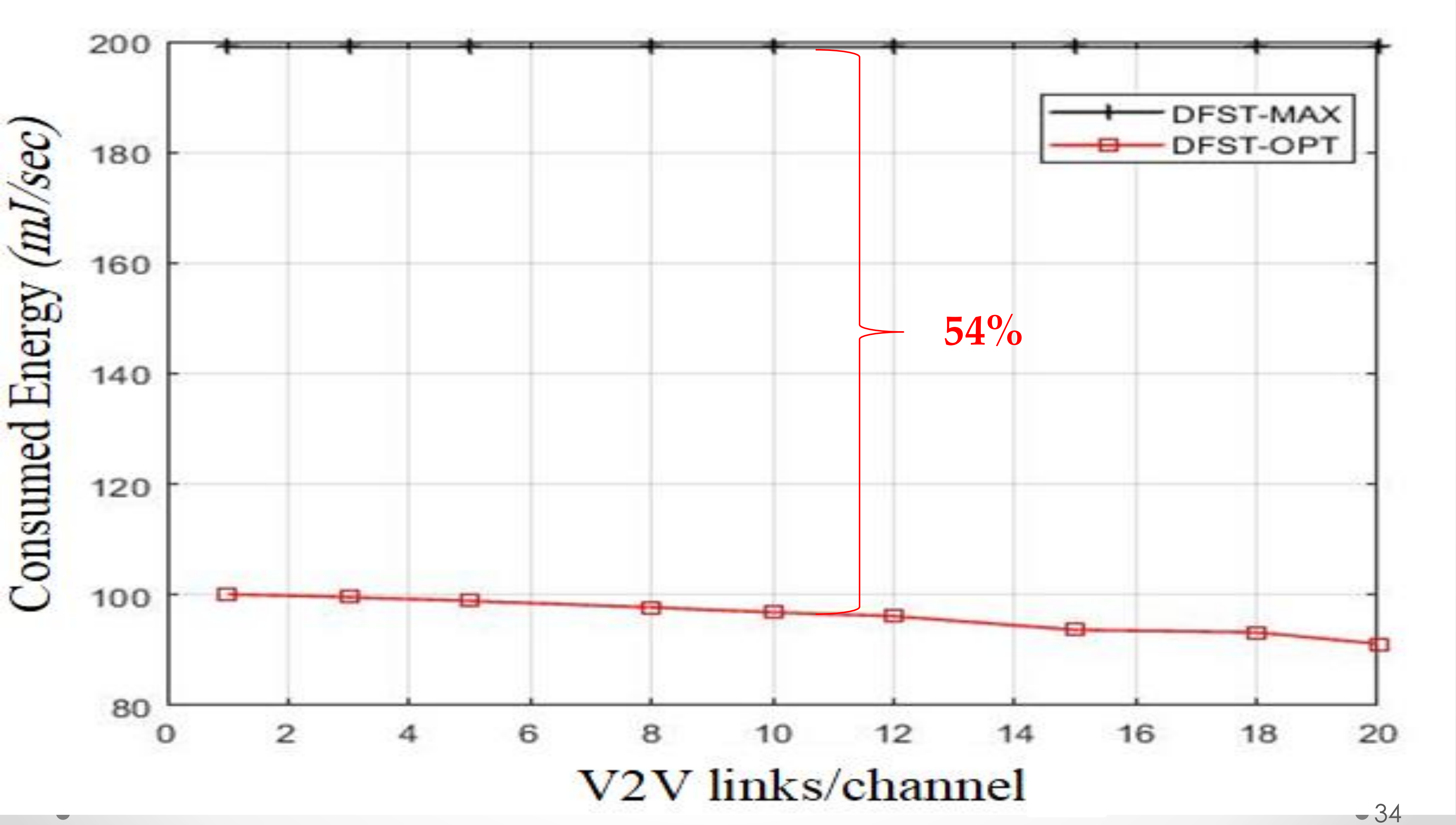
➢ It studies spectrum sharing between V2I and V2V.

➢ The network connectivity based on D2D technology.

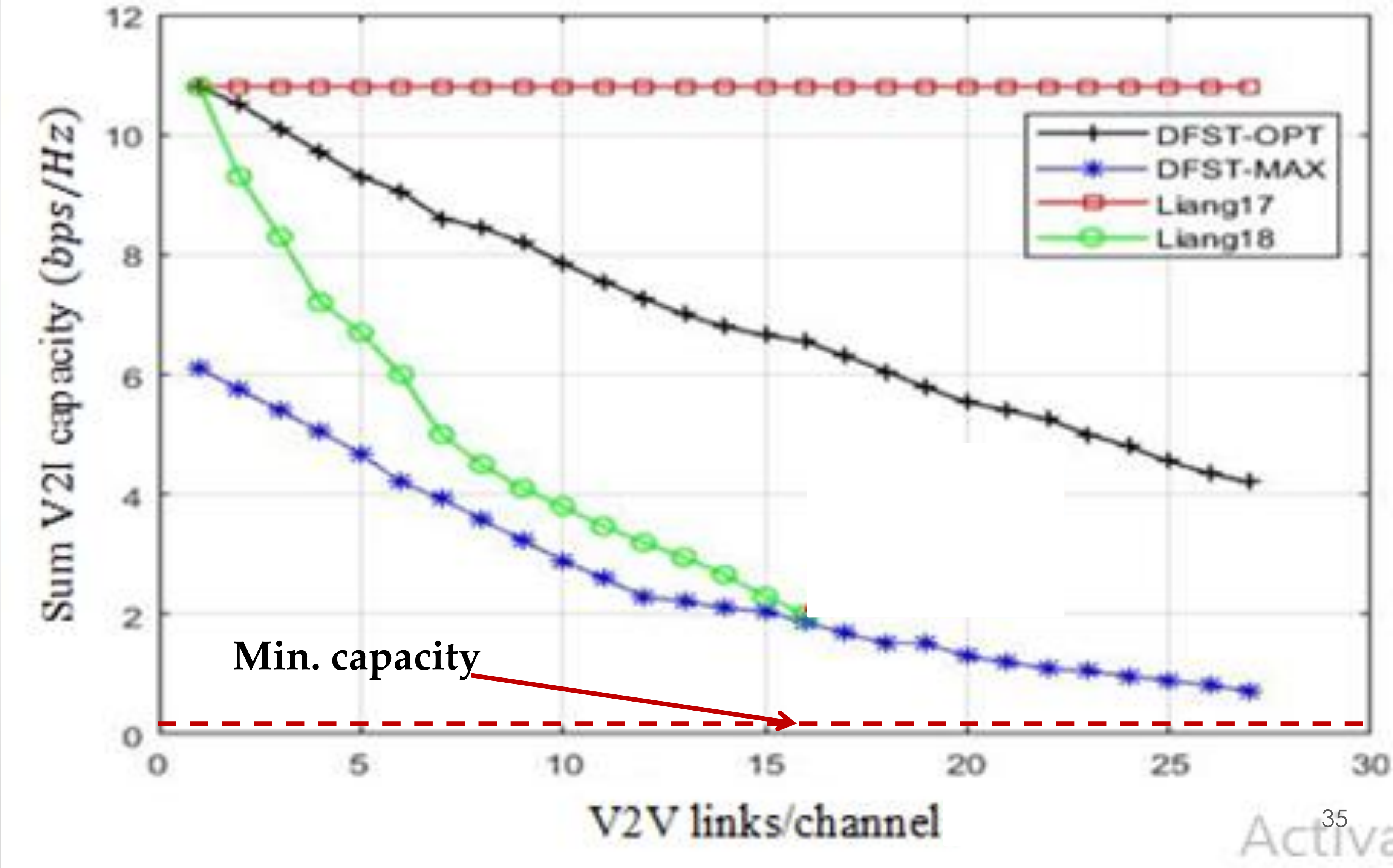
➢ A Graph portioning method is applied to optimize the formulated problem that guarantees QoS needs.

➢ The algorithm distributes all V2V links/V2I links based on mentioned constrains.

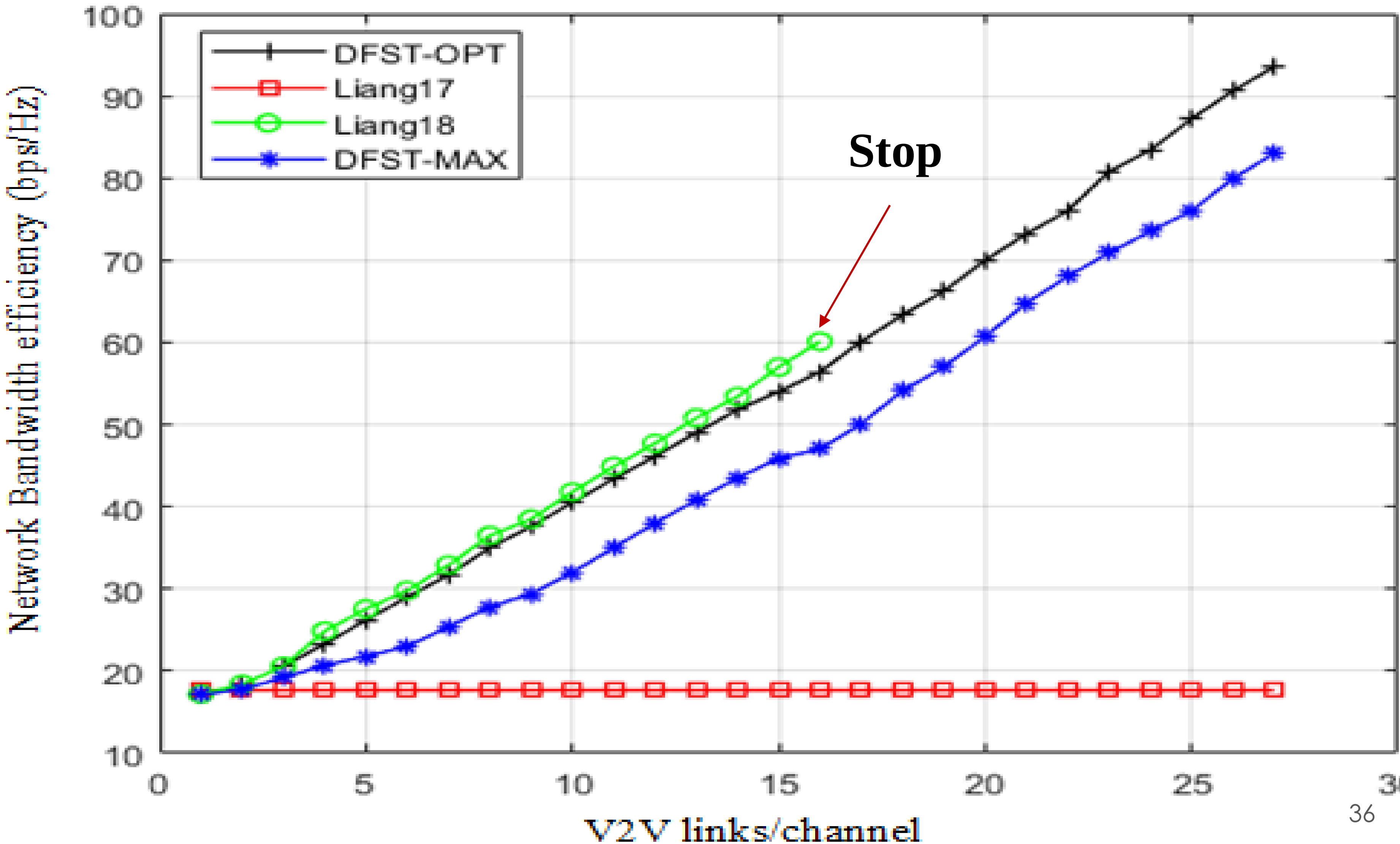
Energy consumption with varying number of V2V links



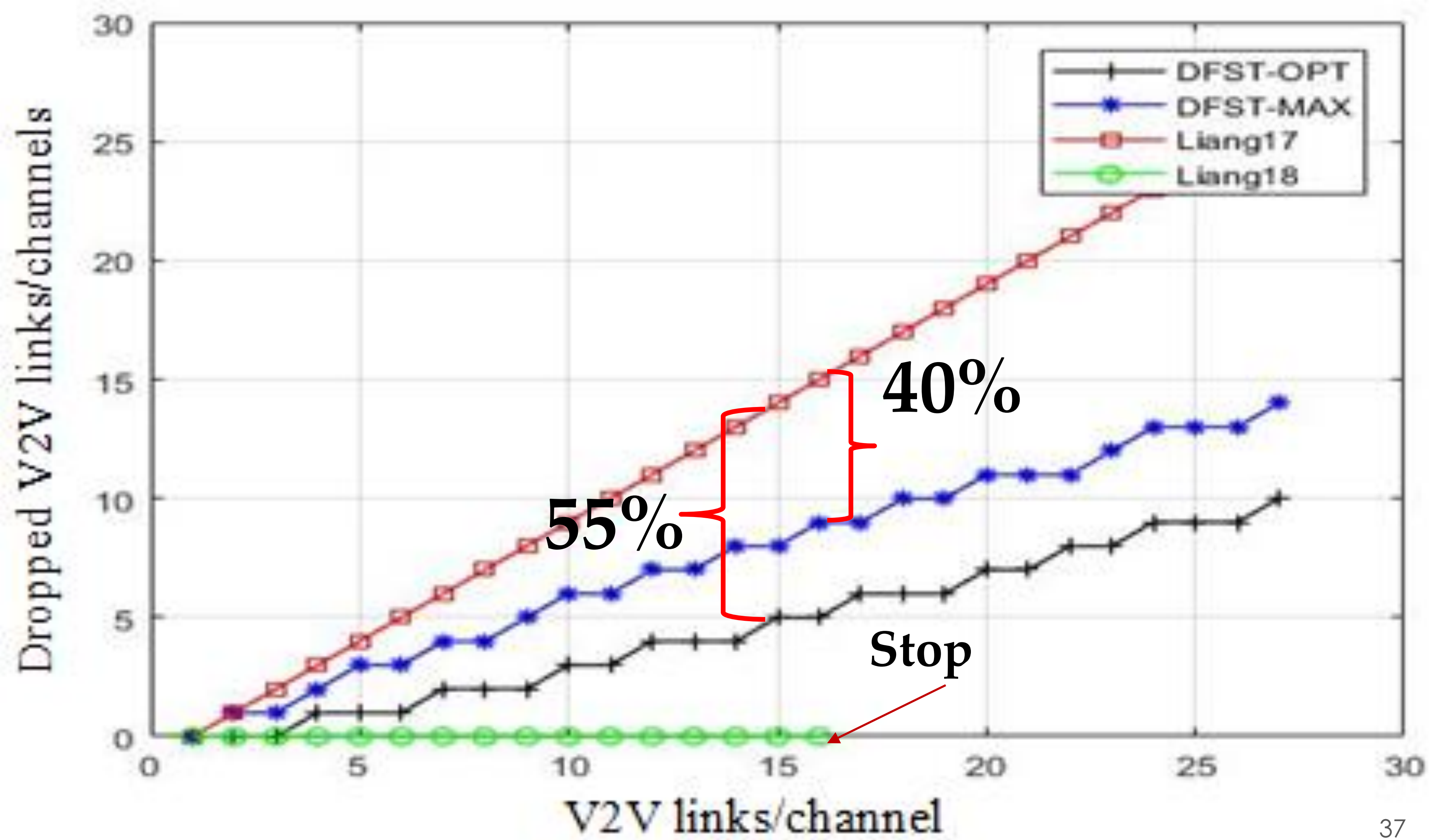
Sum V2I ergodic capacity with varying V2V links



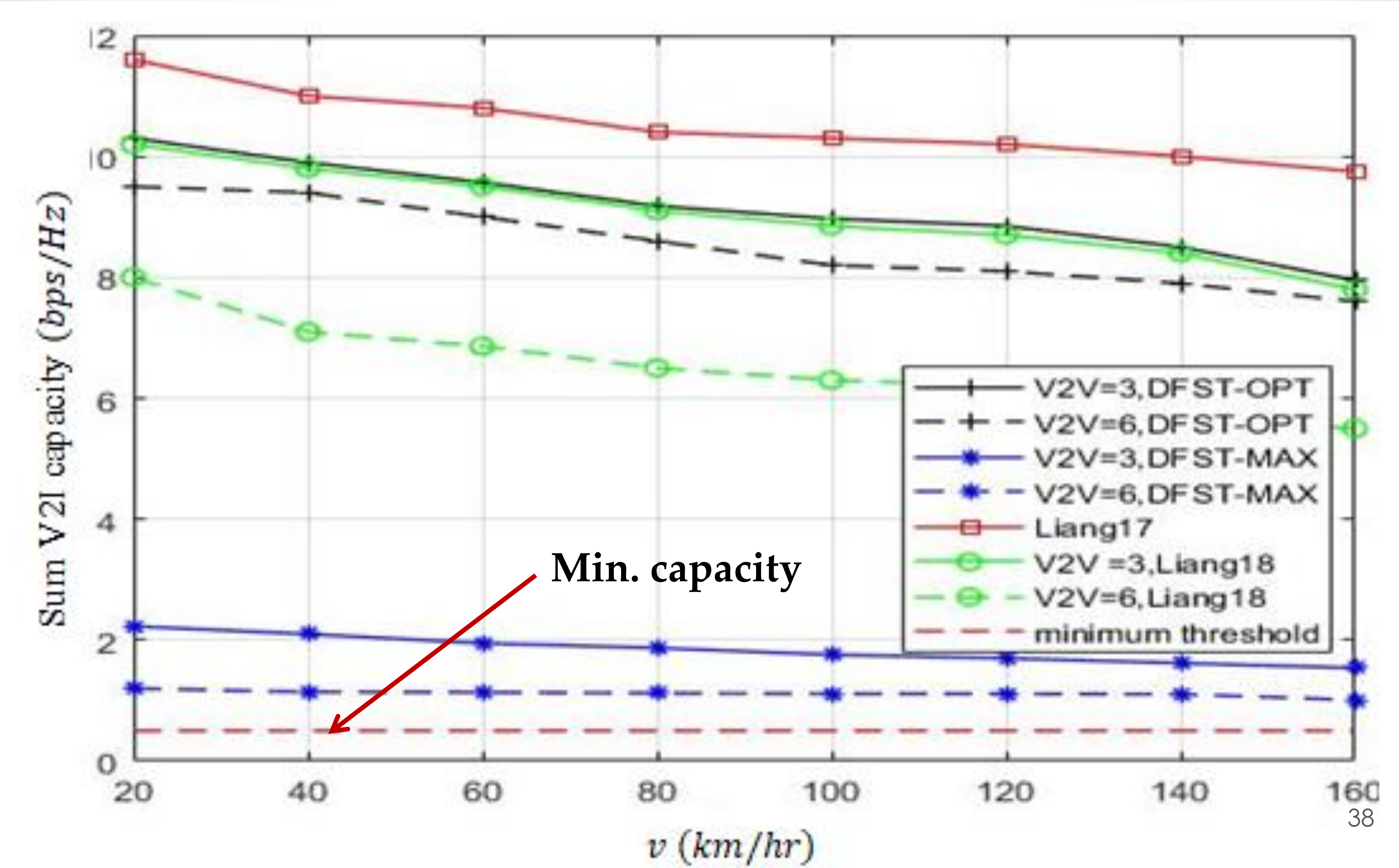
Network bandwidth efficiency with varying number of V2V links



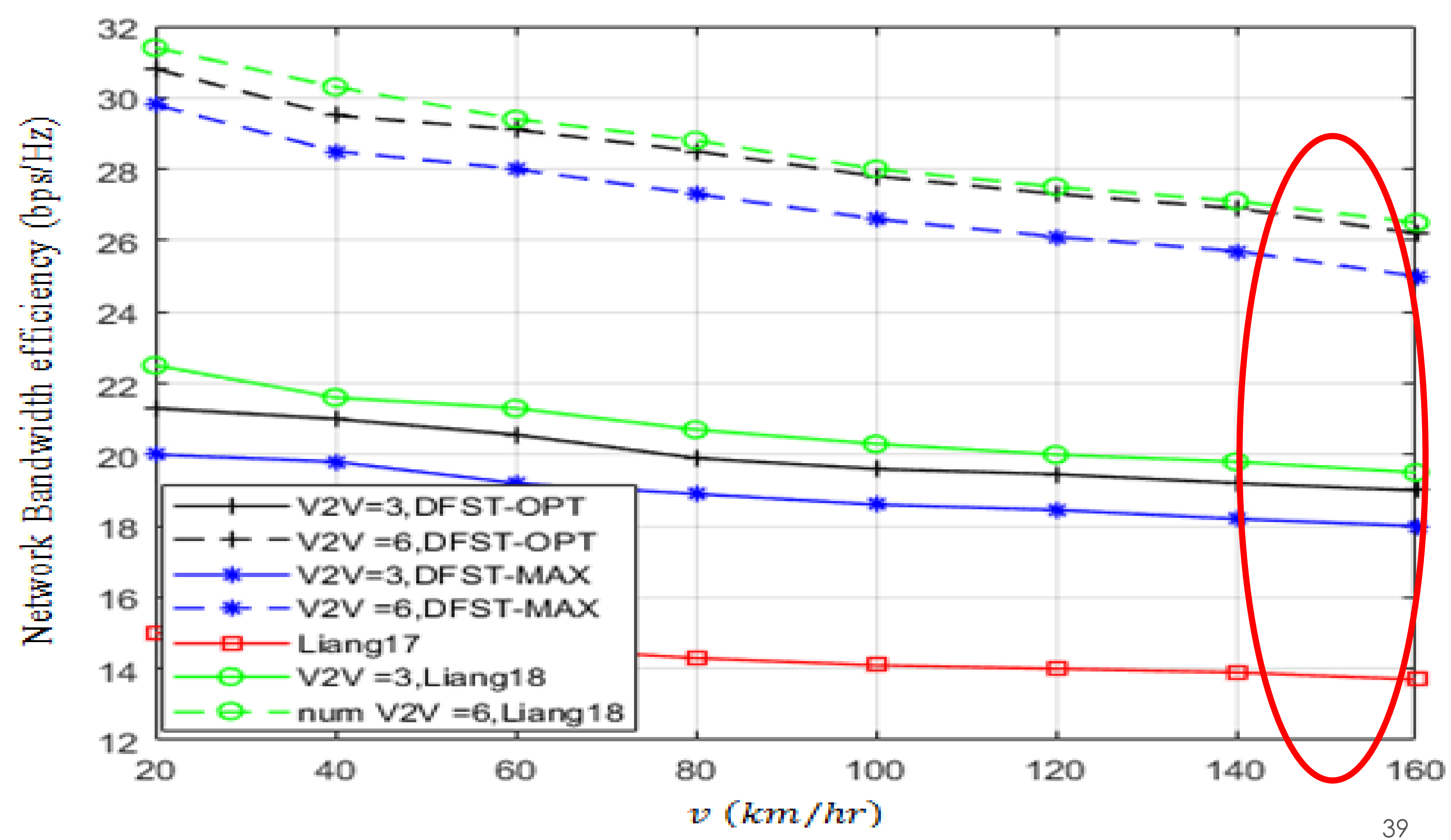
Dropped vehicles links with varying number of V2V links



Sum V2I capacity with varying average vehicles' speed



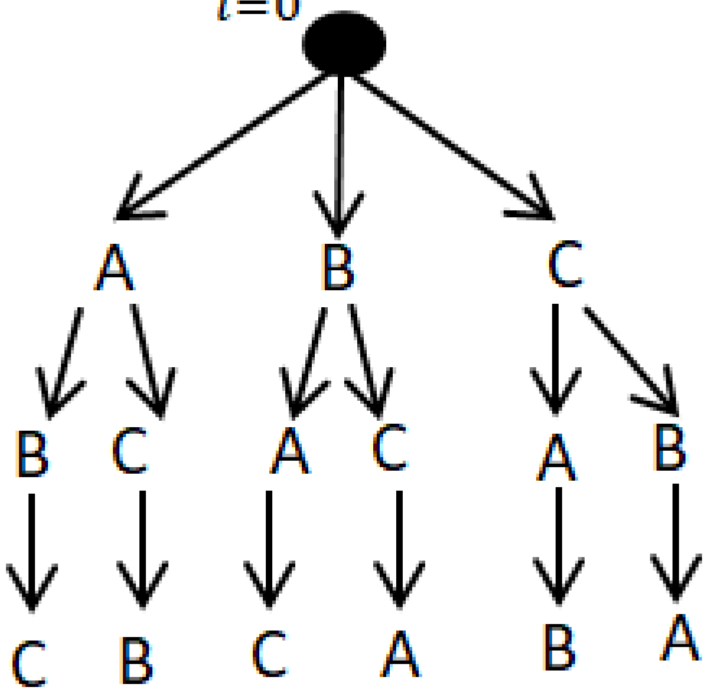
Network bandwidth efficiency with varying average vehicles' speed



Complexity

Liang18

$$\sum_{i=0}^{n} n_{p_i}$$



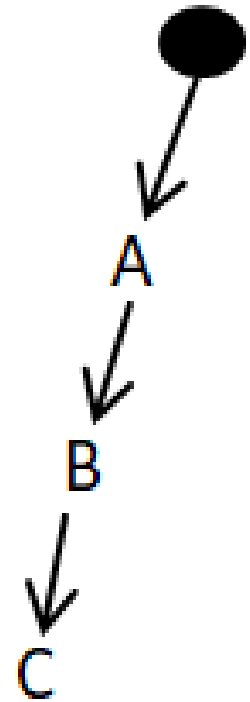
$$3_{p_1} = 3$$

$$3_{p_2} = 6$$

$$3_{p_3} = 6$$

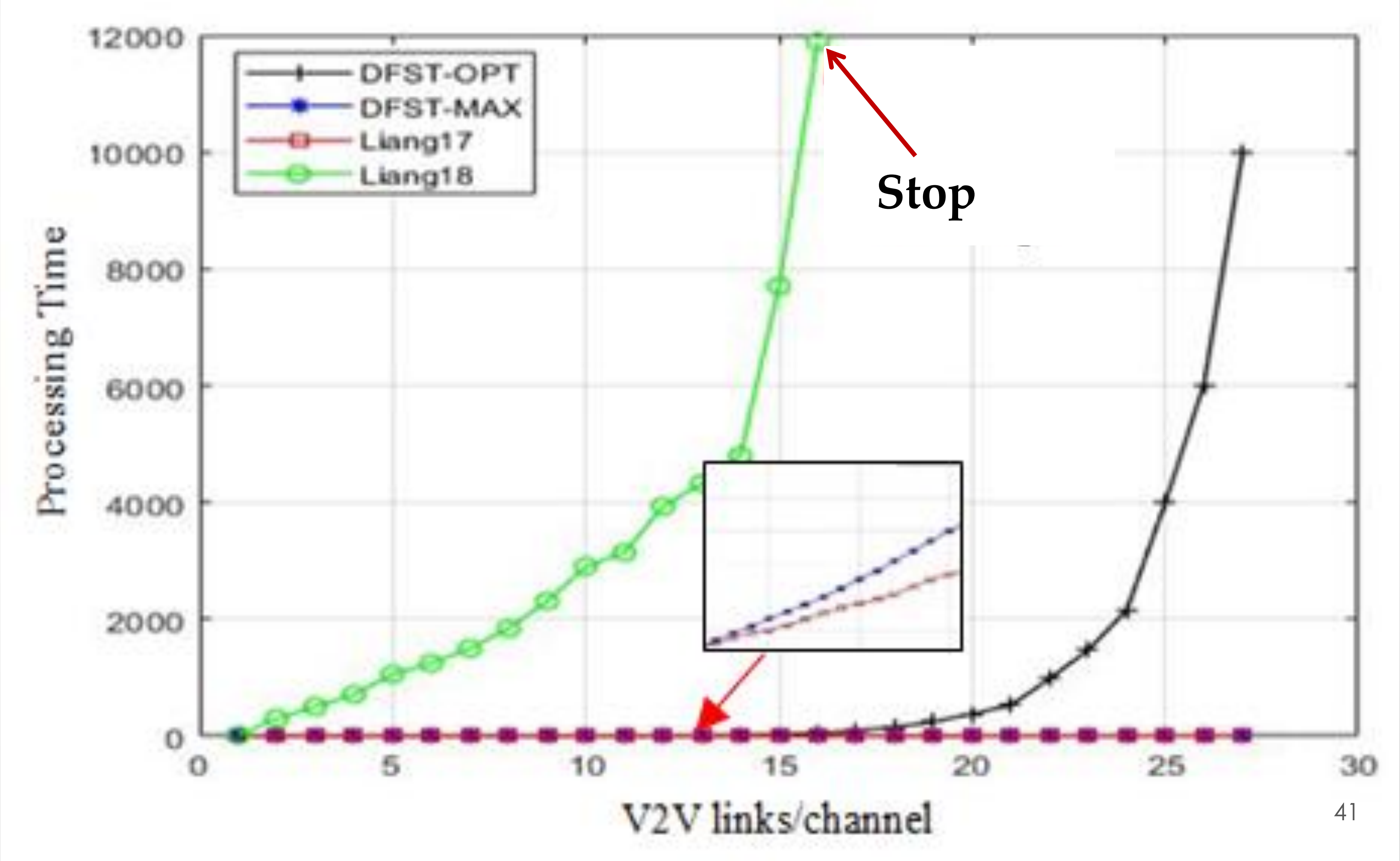
$\boldsymbol{O(n^n)}$

DFST

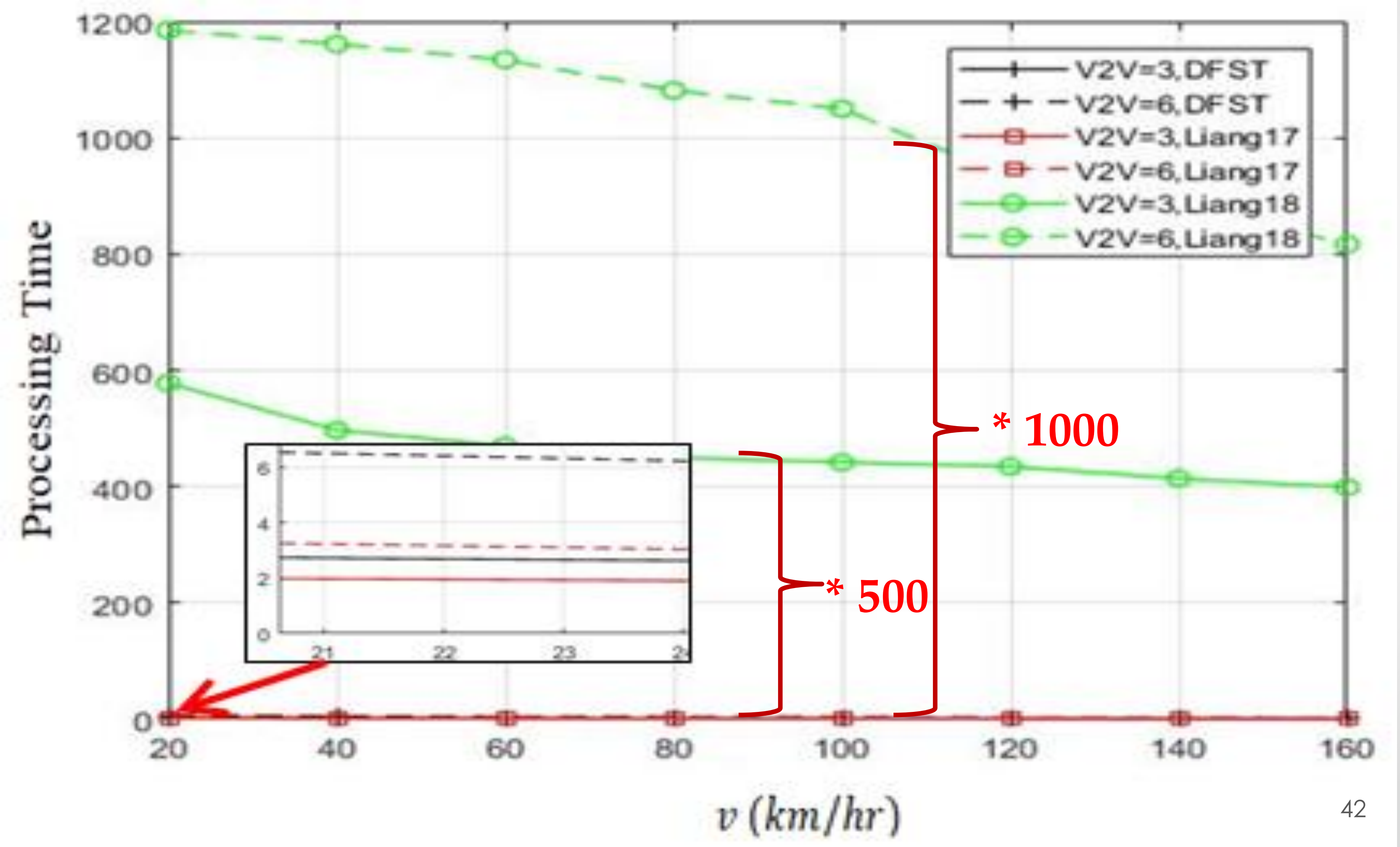


$\boldsymbol{O(n)}$

Network processing time with varying number of V2V links

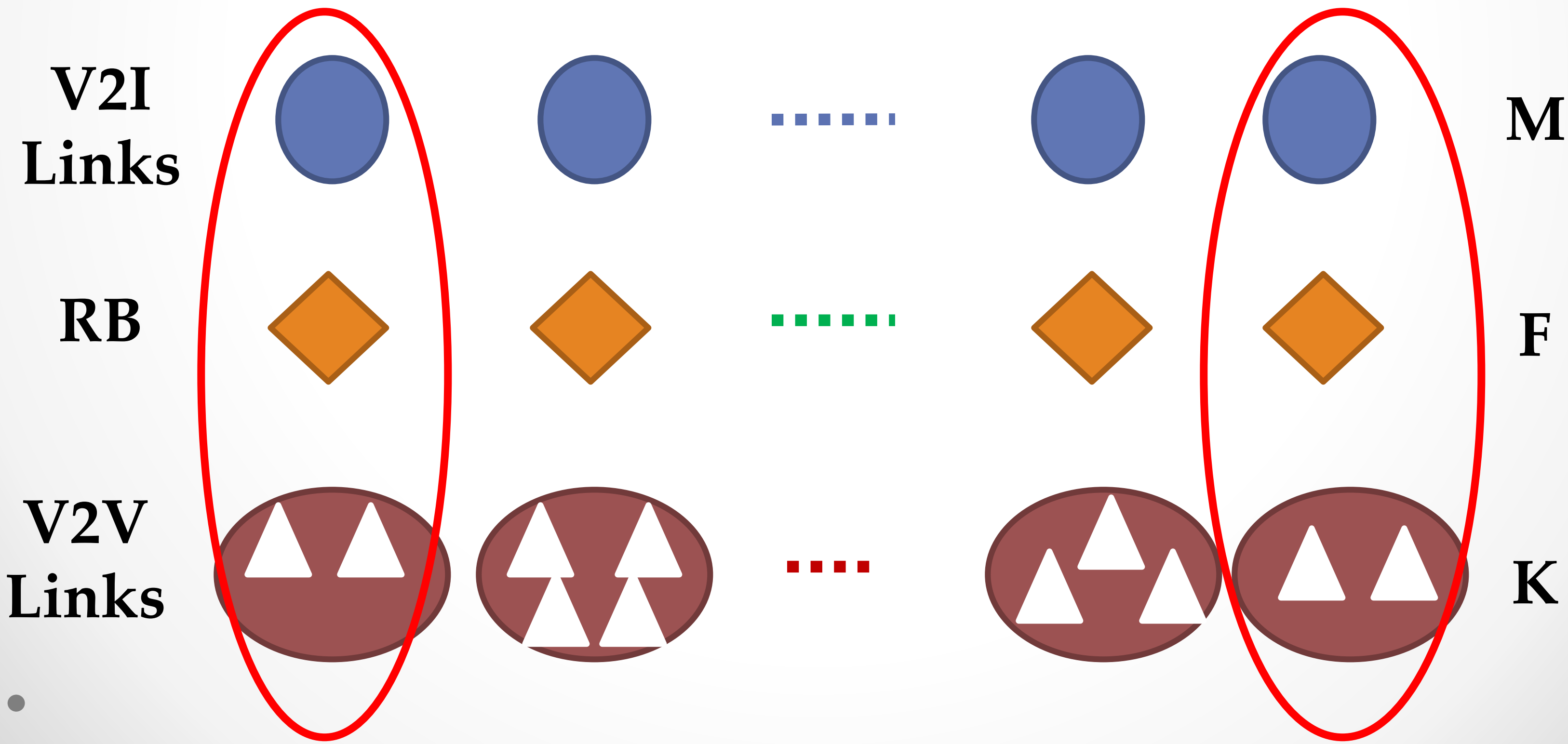


Network processing time with varying average vehicles' speed

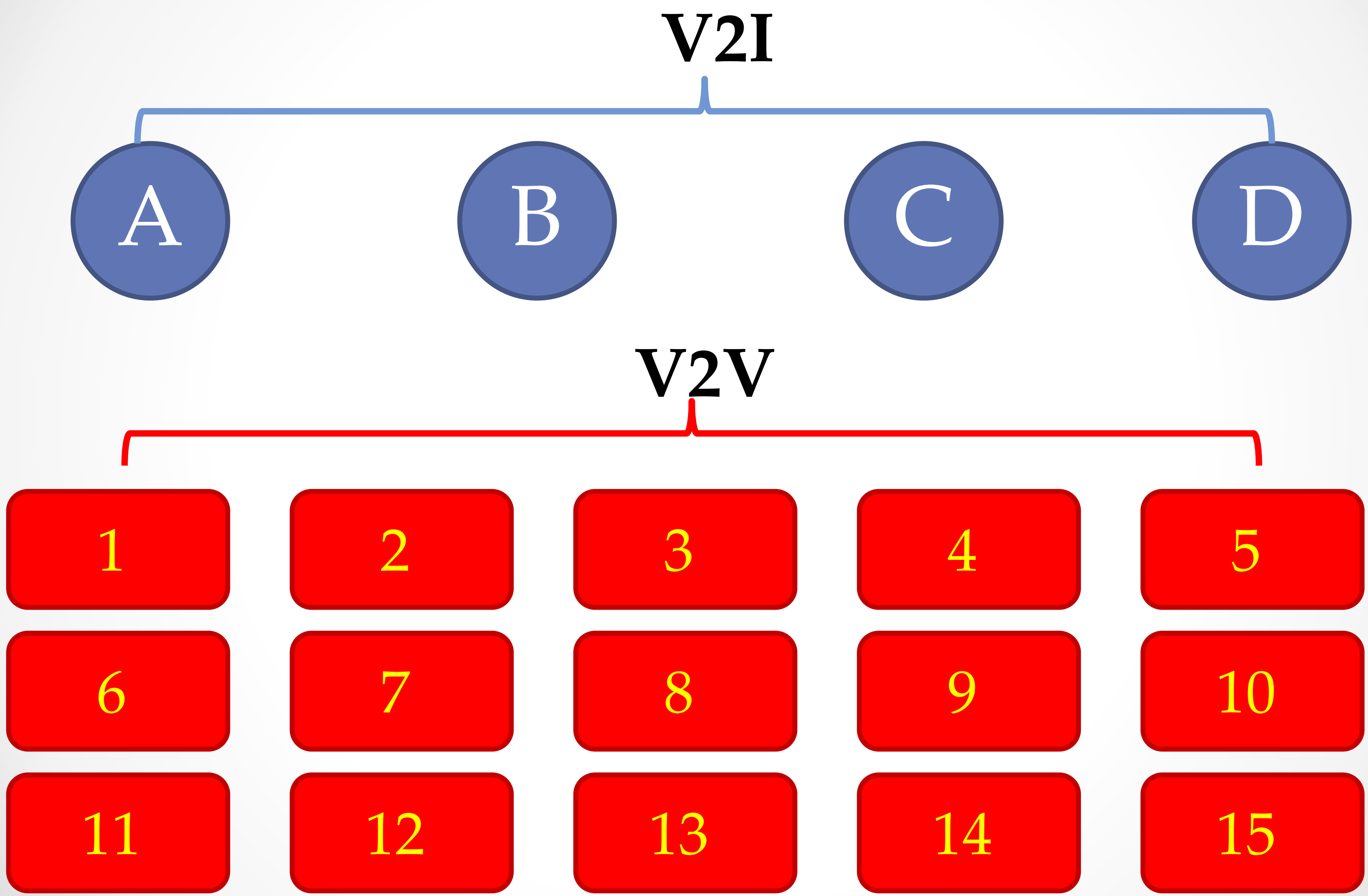


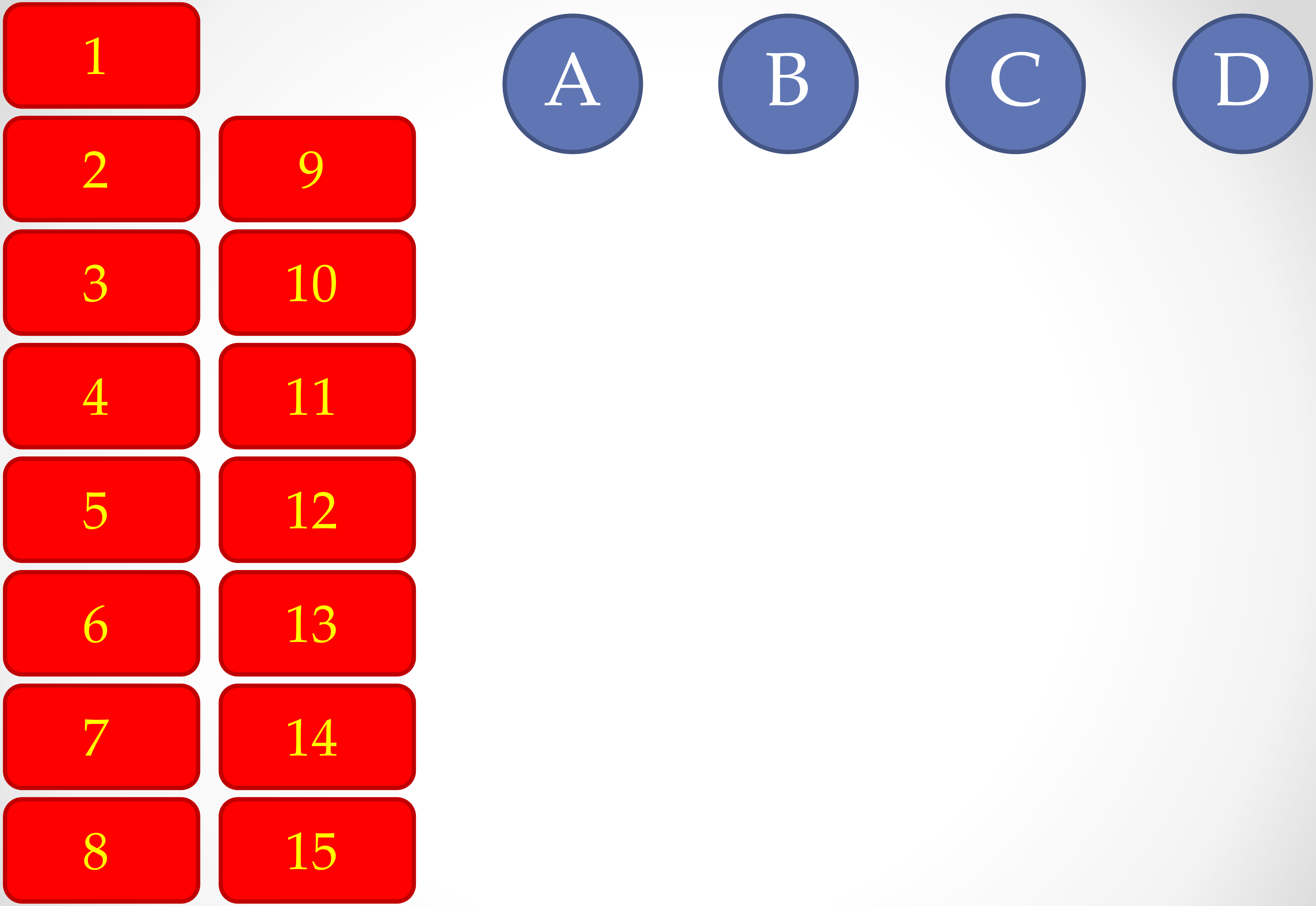
Clusters Generation

- Cluster is defined as a group of vehicles share the same channel, where each cluster has only one V2I link and group V2V links.



Example





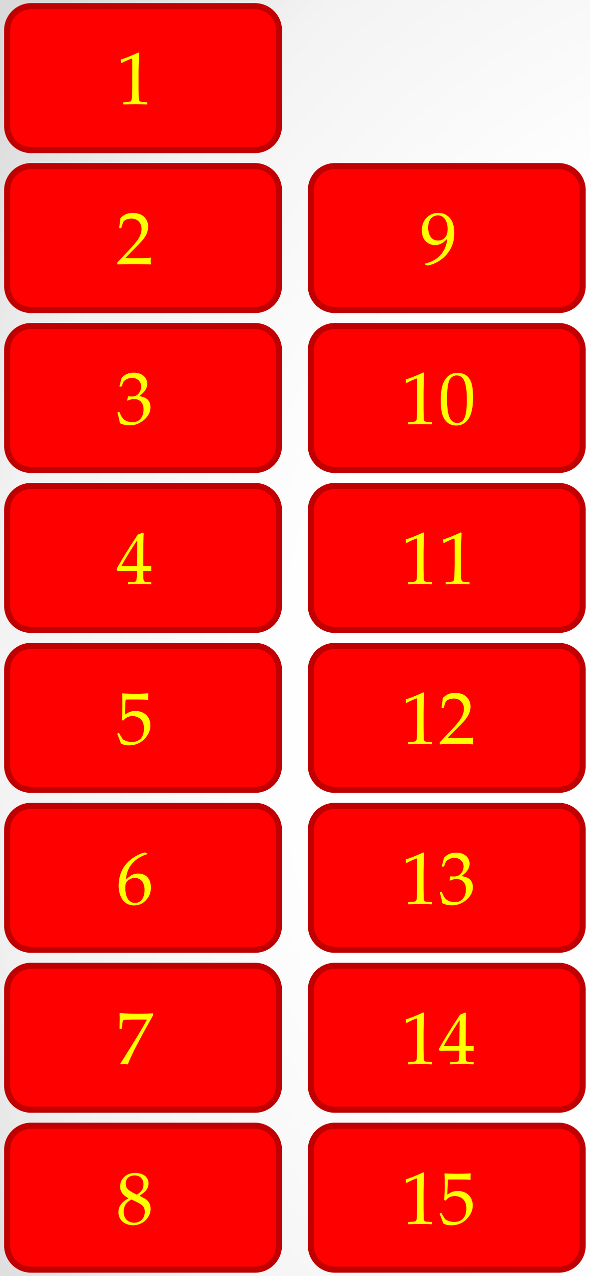
Largest-clustered

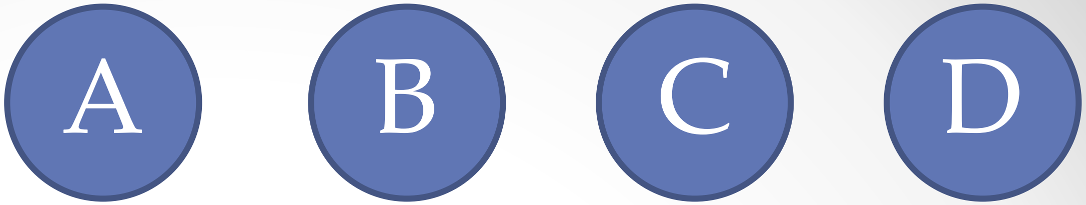
1	
2	9
3	10
4	11
5	12
6	13
7	14
8	15

A B C D

$$DL = \frac{K}{M}$$

Depth First Search Tree-Depth Length (DFST-DL)

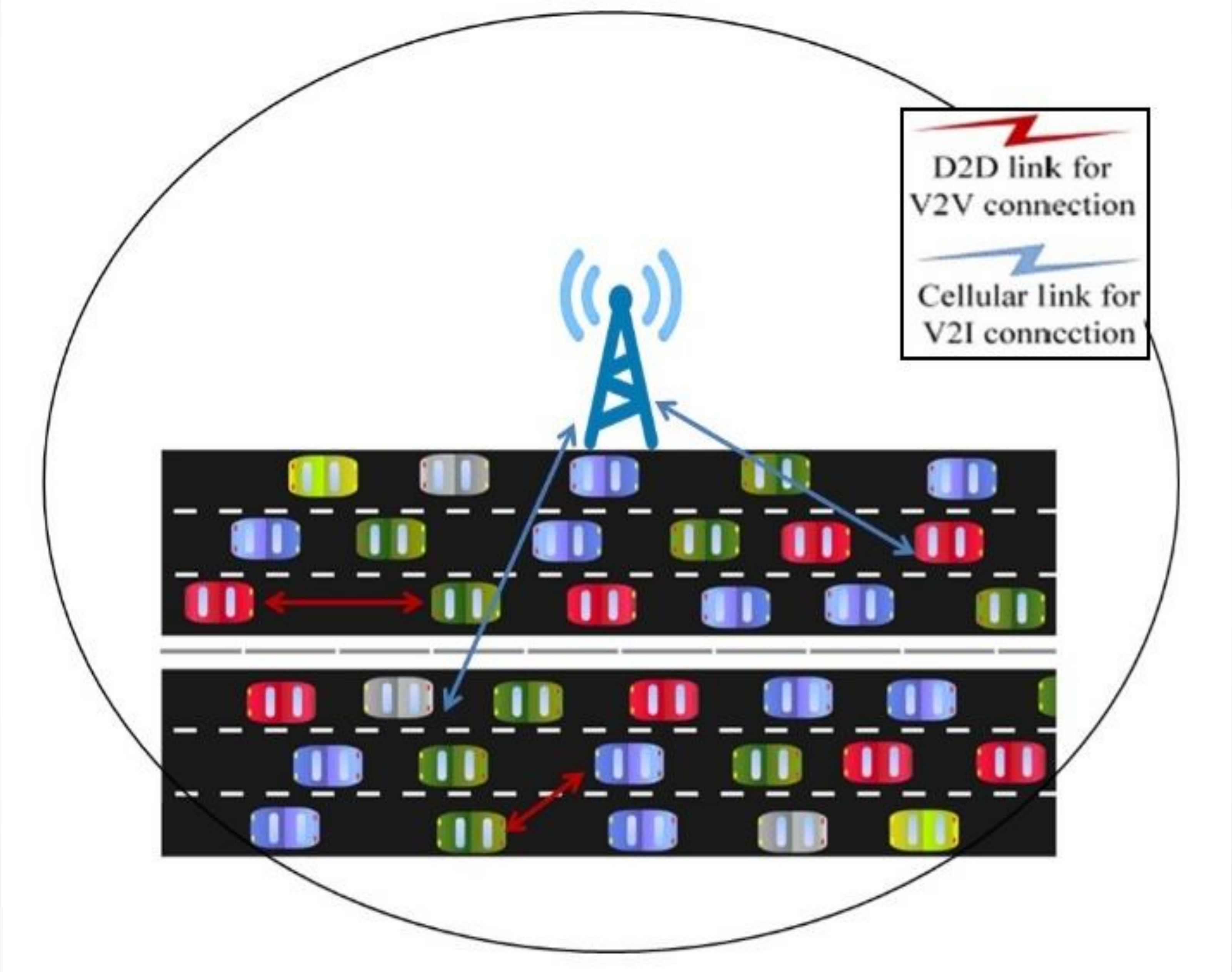




$$FF = \gamma_m^c + \sum_{k=1}^{k=K} \gamma_k^d$$

Round Robin with fitness function (RR-FF)

Simulation Results



Simulation Results (Cont'd)

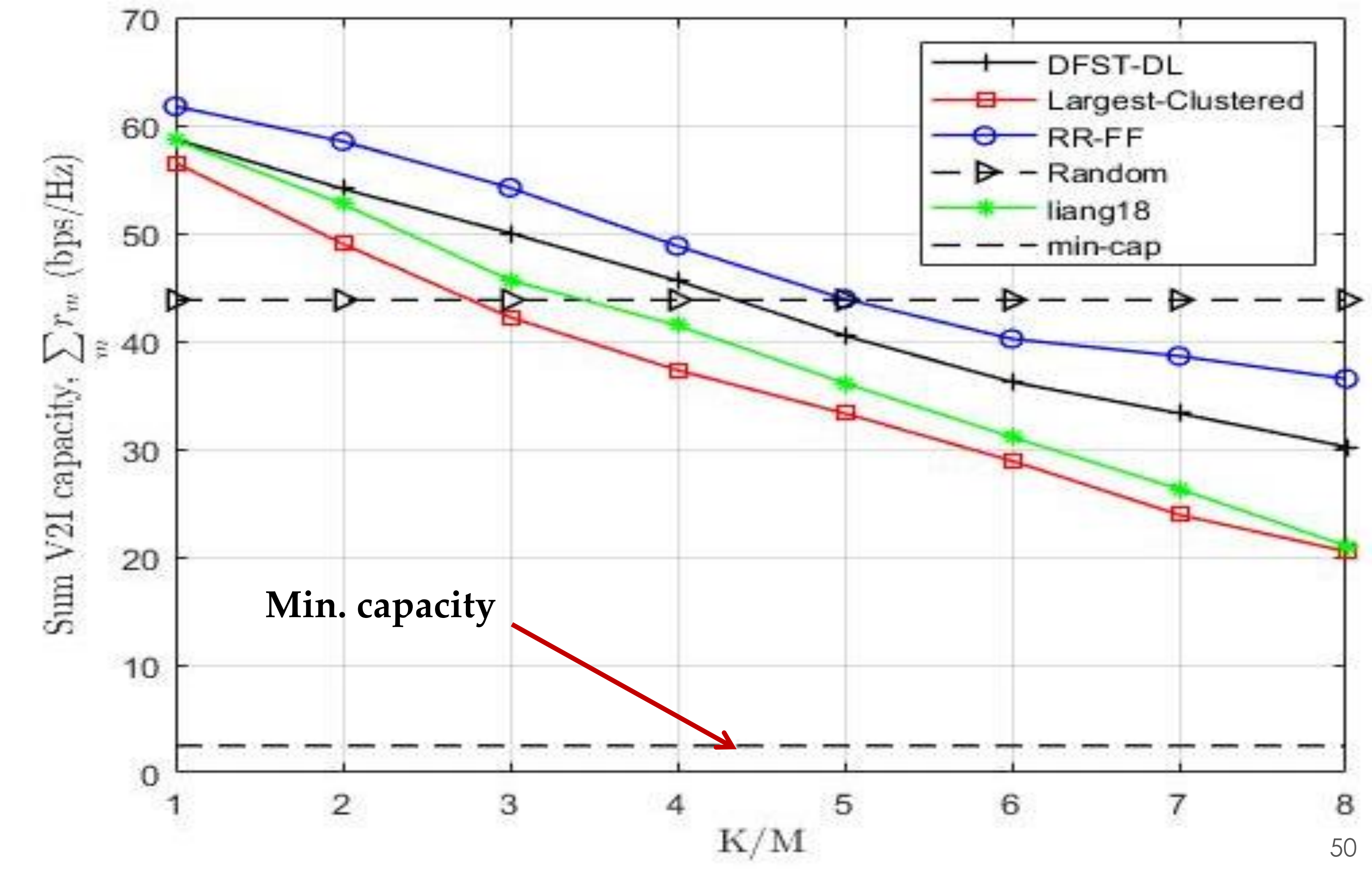
- **Random Algorithm:**

➢ It studies spectrum sharing between V2I and V2V.

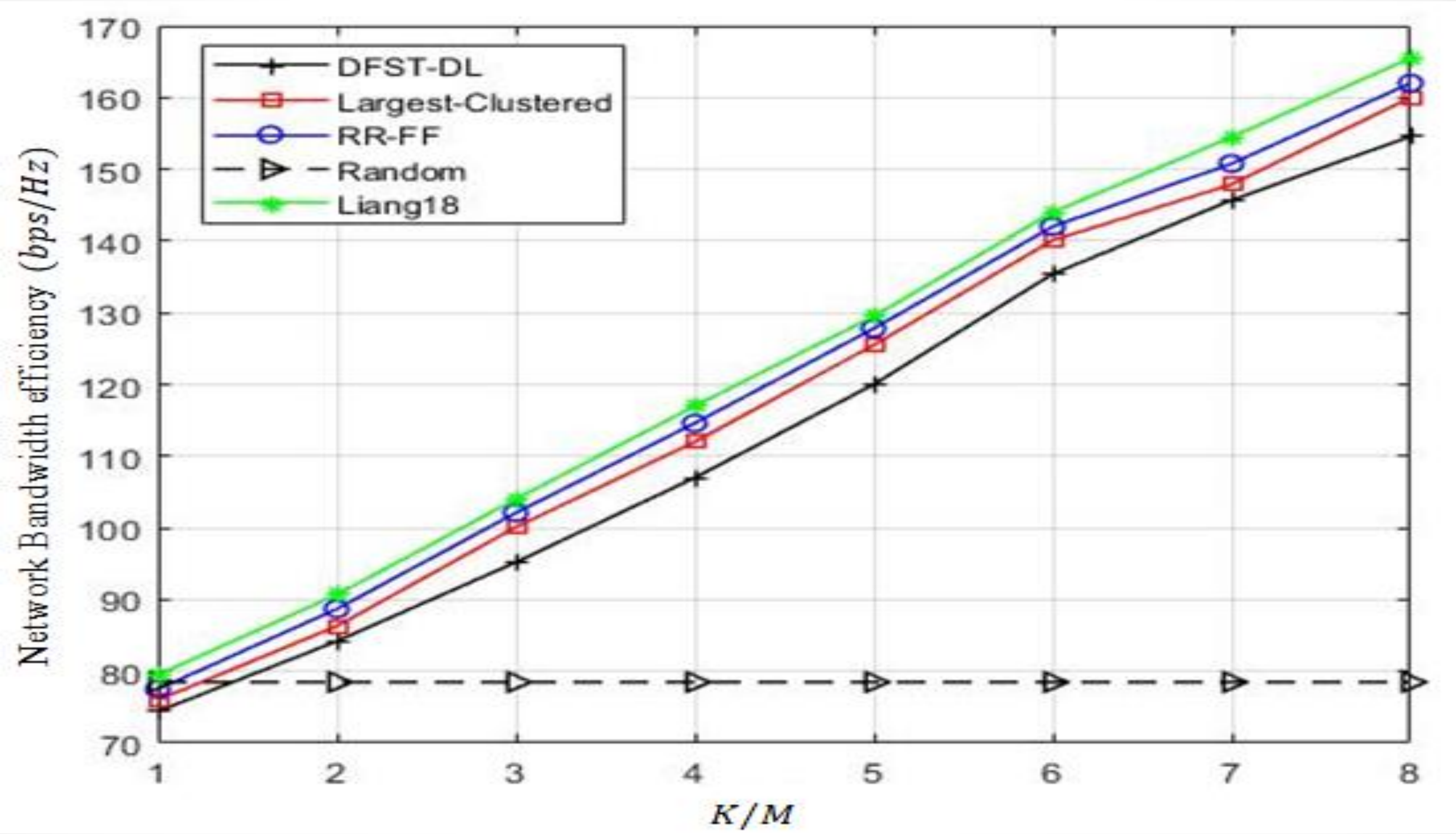
➢ The network connectivity based on D2D technology.

➢ The algorithm allocate random V2V link/V2I link.

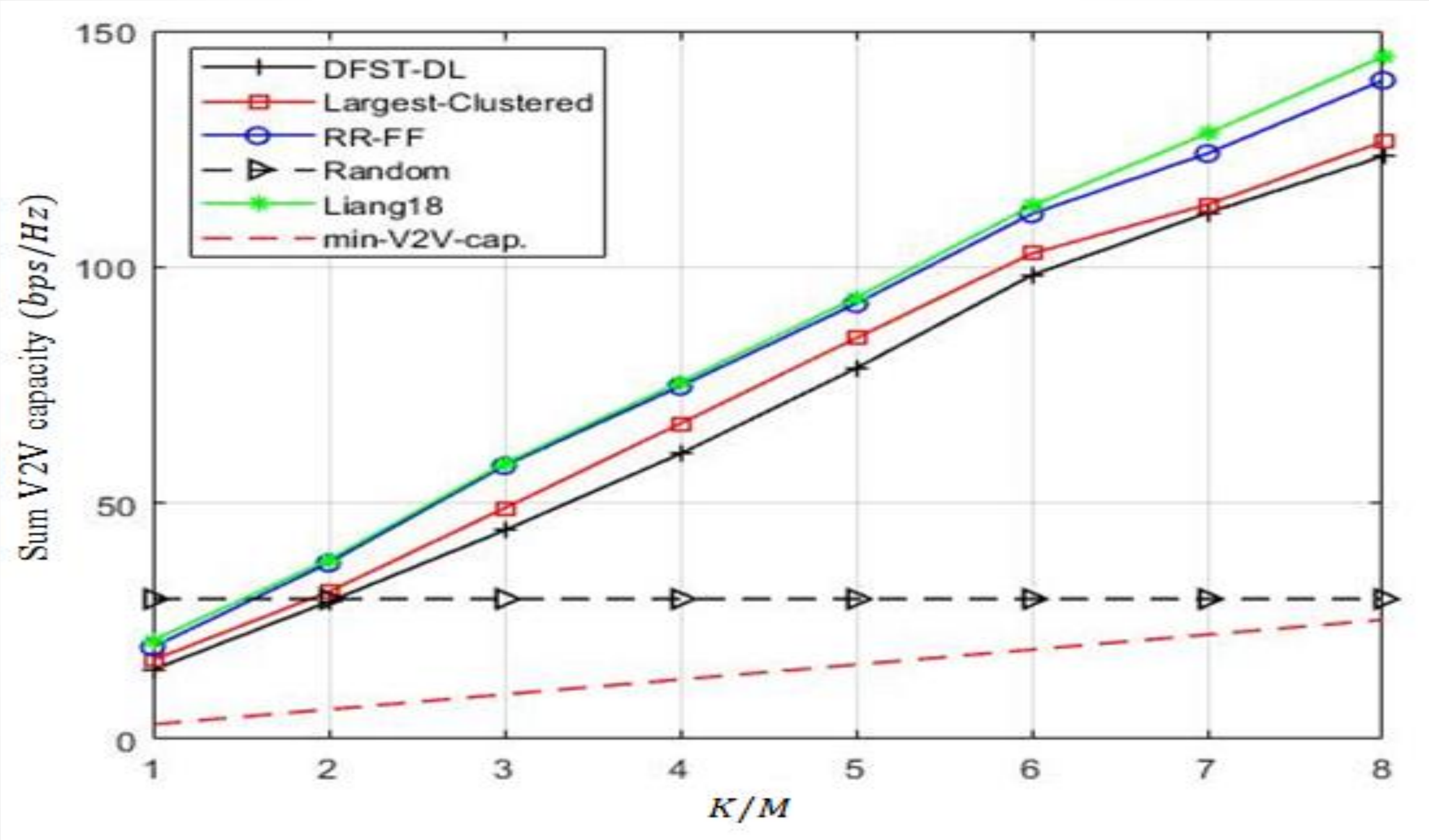
Sum V2I capacity with varying number of V2V links



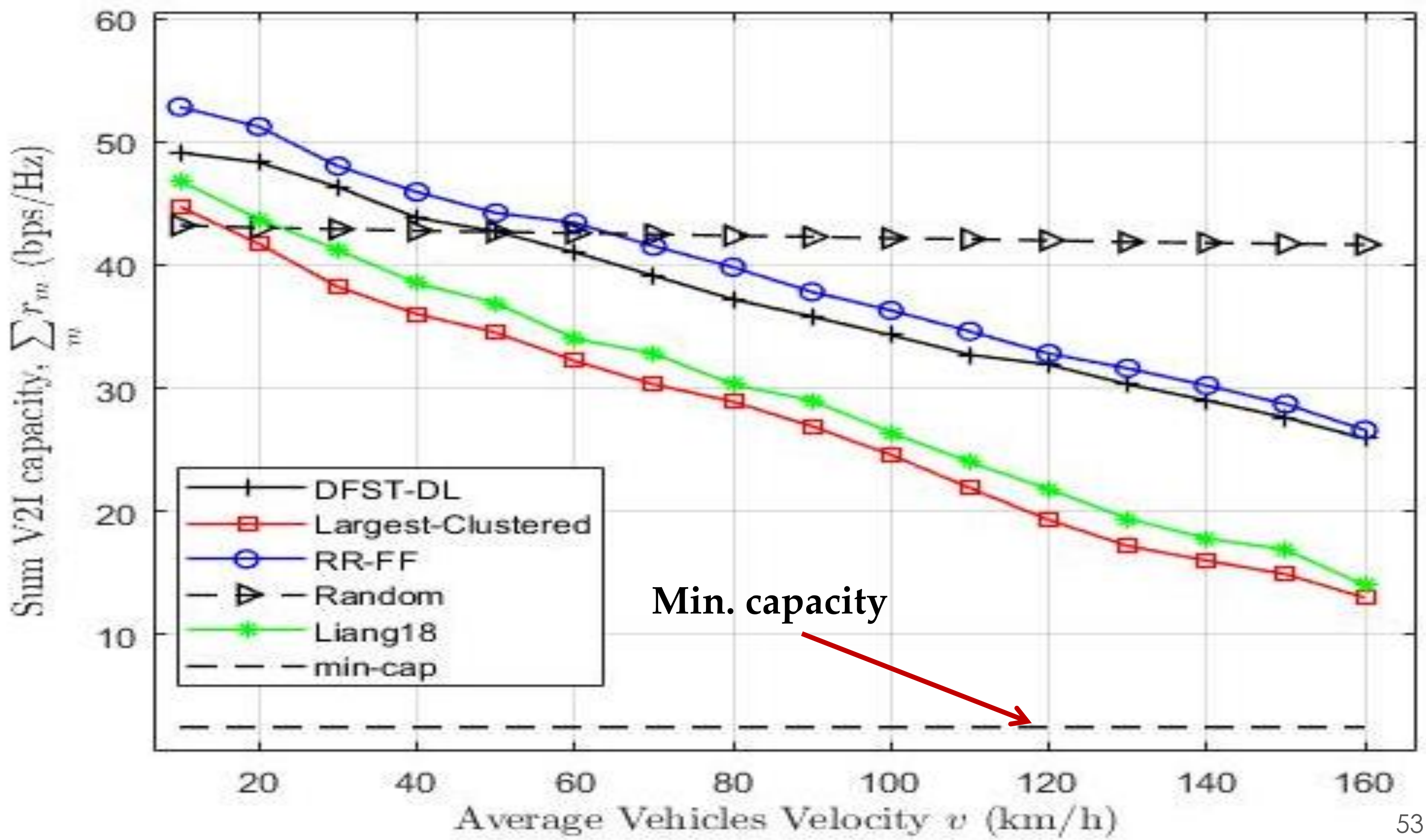
Network bandwidth's efficiency with varying number of V2V links



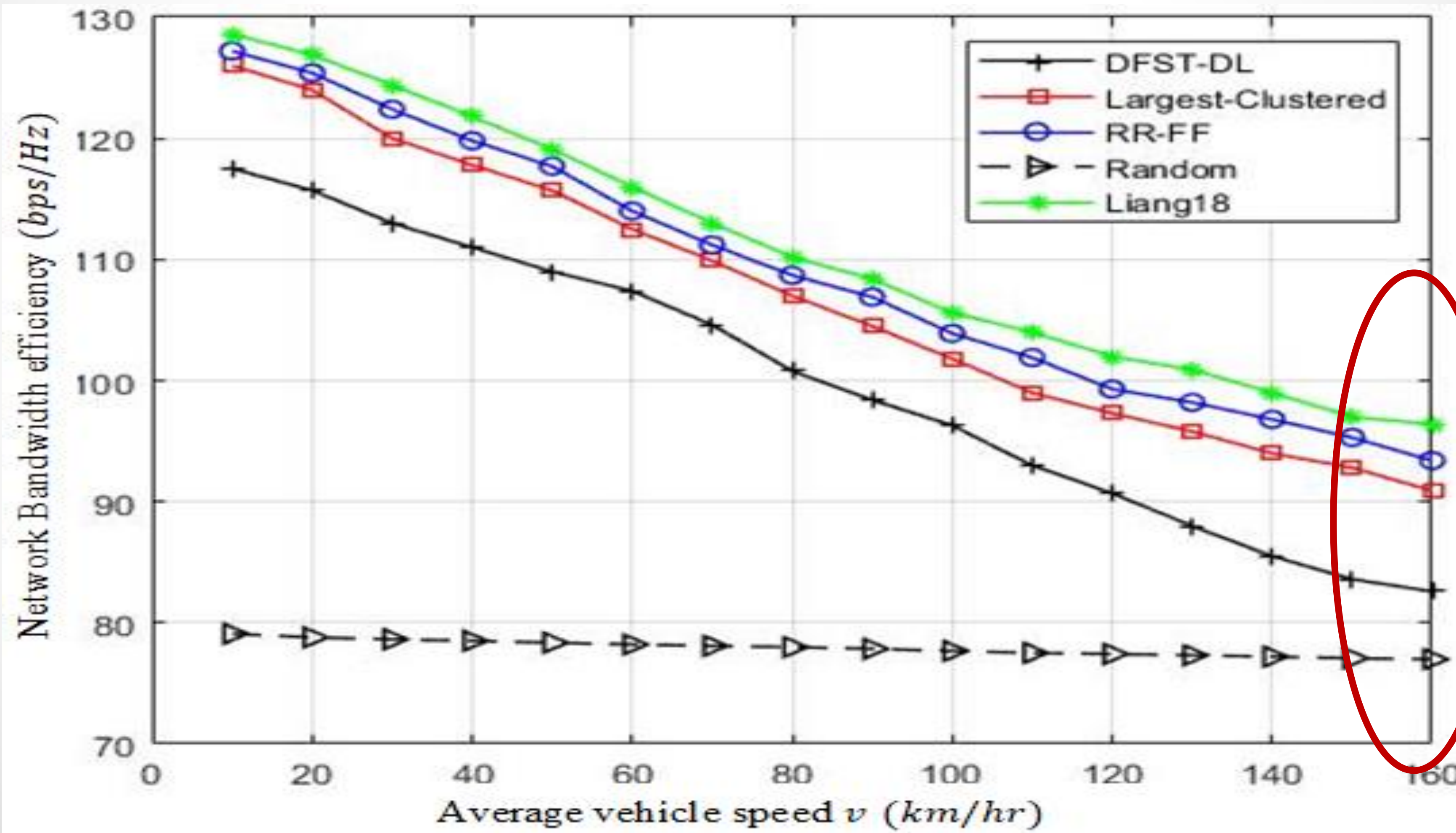
Sum V2V capacity with varying number of V2V links



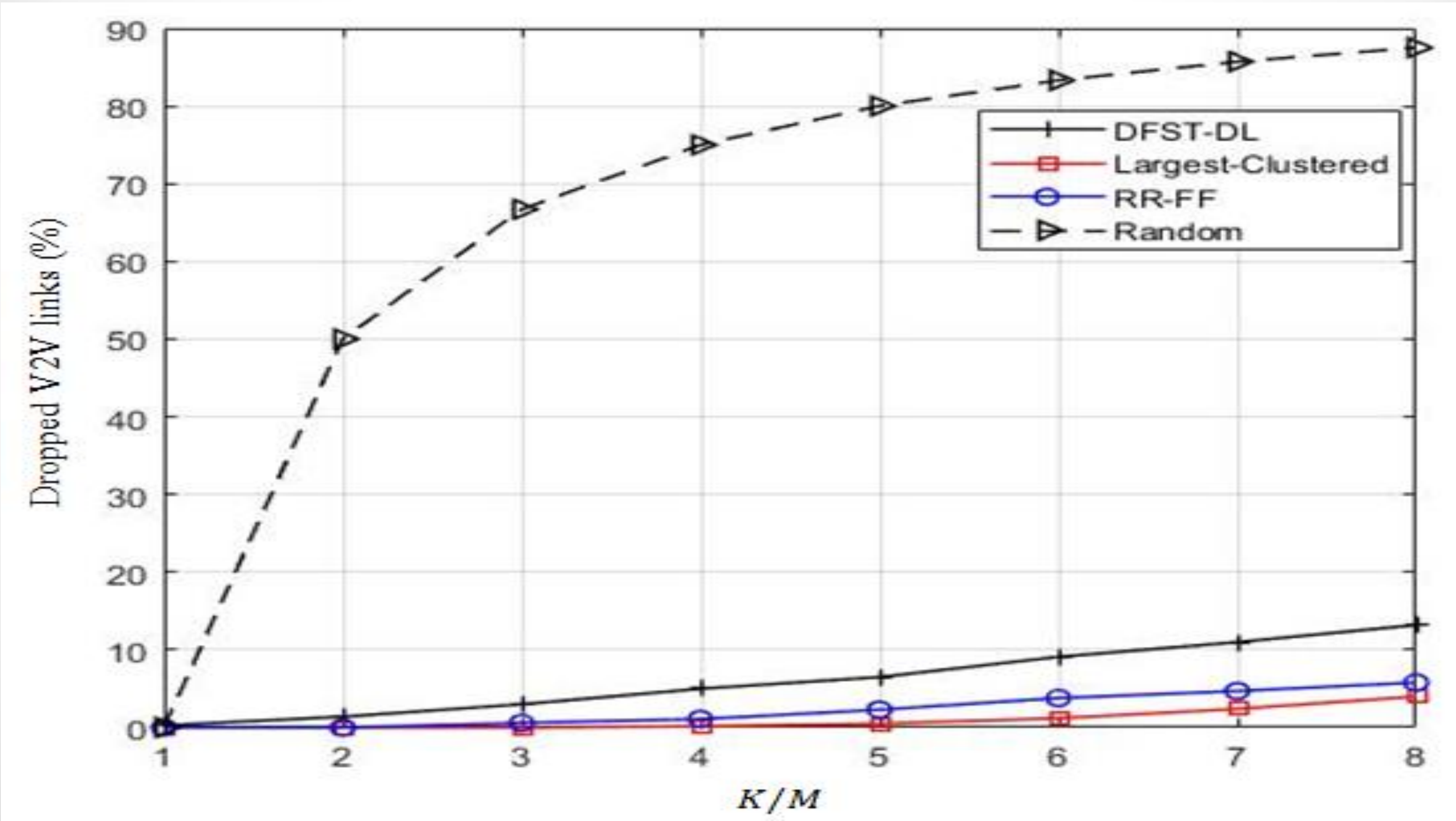
Sum V2I capacity with varying average vehicles' speed



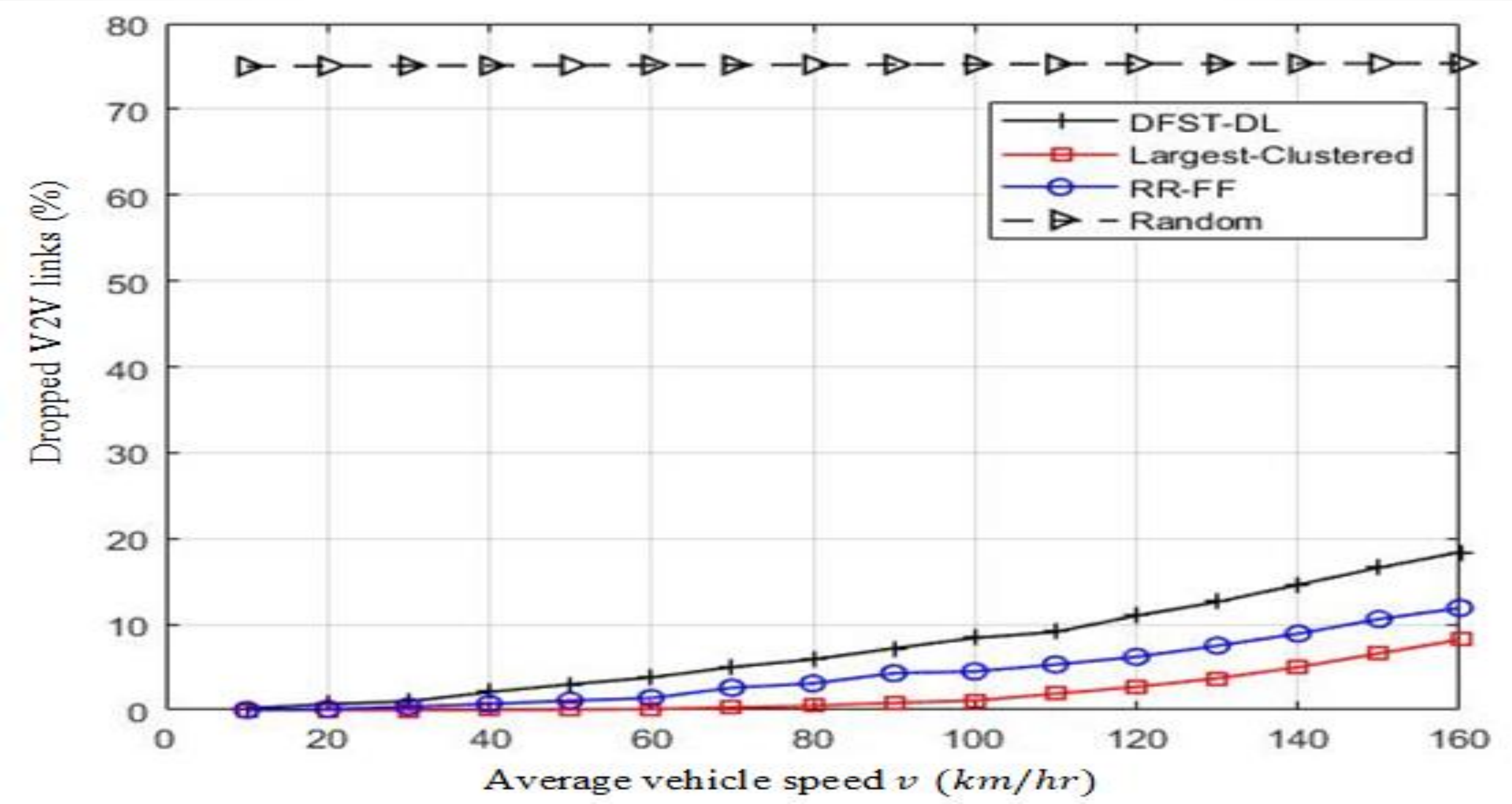
Network bandwidth's efficiency with varying average vehicles' speed



Dropped vehicles links with varying number of V2V links



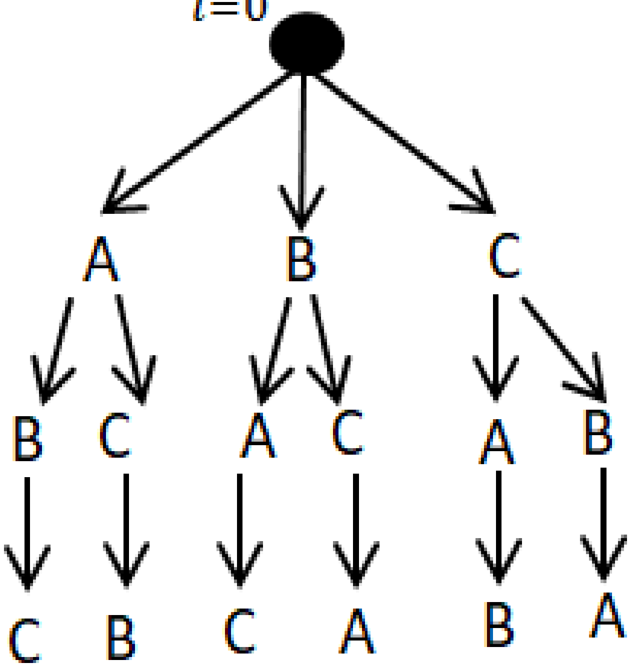
Dropped vehicles links with varying average vehicles' speed



Complexity

Liang18

$$\sum_{i=0}^{n} n_{p_i}$$



$$3_{p_1} = 3$$

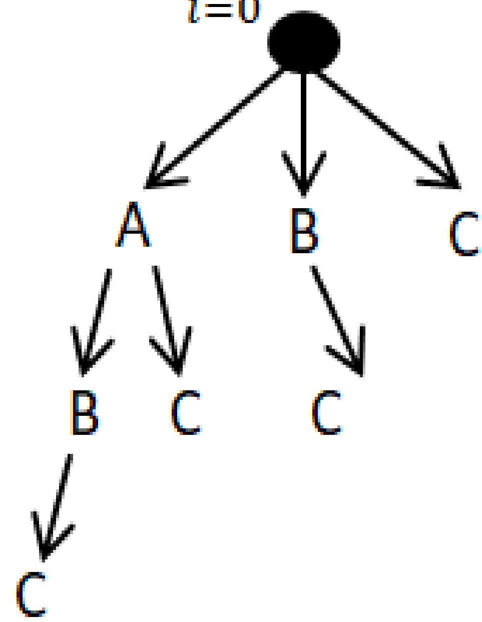
$$3_{p_2} = 6$$

$$3_{p_3} = 6$$

$$\boldsymbol{O}(\boldsymbol{n}^{\boldsymbol{n}})$$

RR-FF

$$\sum_{i=0}^{n} n_{c_i}$$



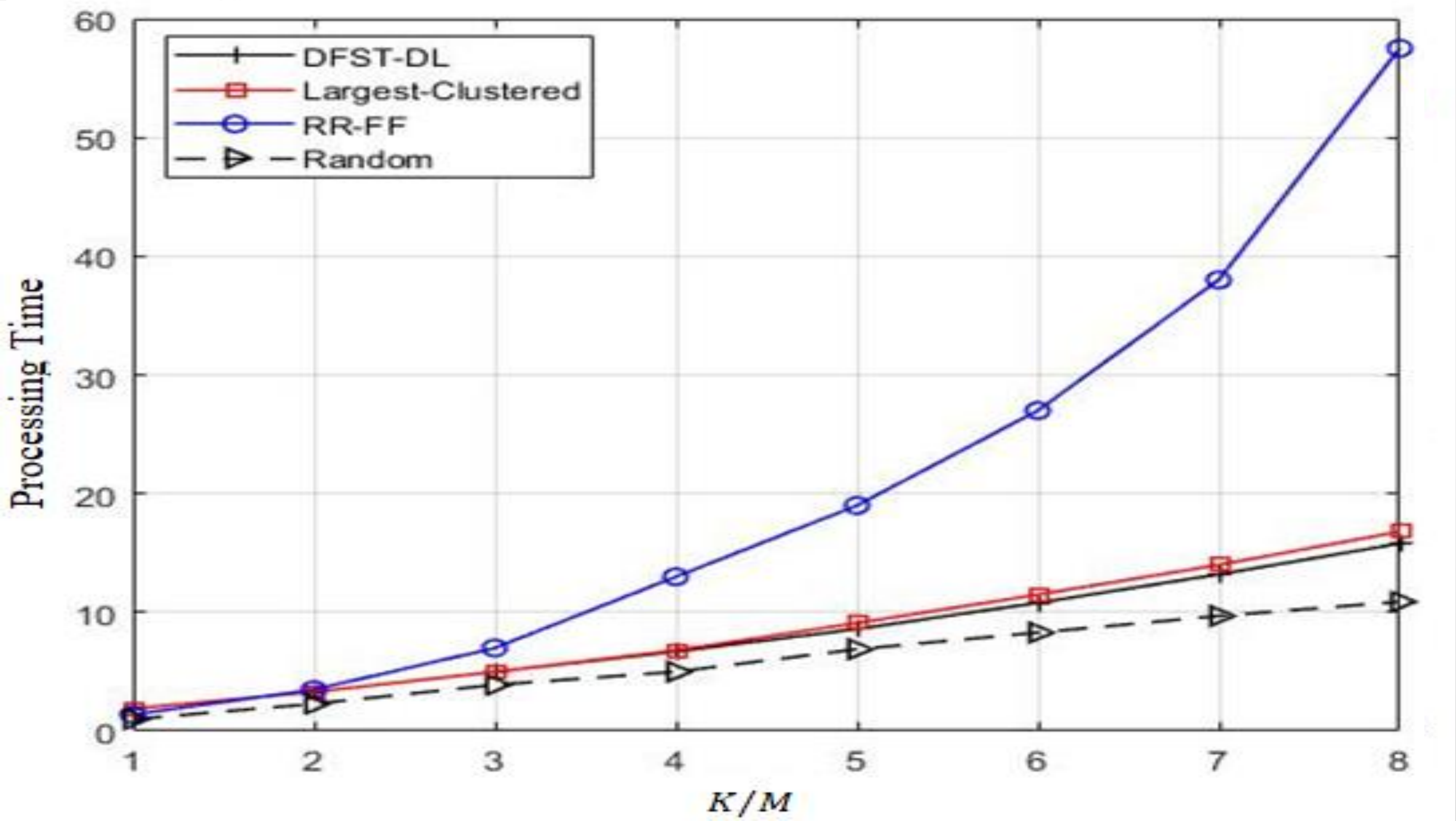
$$3_{c_1} = 3$$

$$3_{c_2} = 3$$

$$3_{c_3} = 1$$

$$\boldsymbol{O}\left(\left[\sqrt{2}\,\right]^{\boldsymbol{n}}\right)$$

Network processing time with varying number of V2V links



Conclusion

- Vehicular networks play a critical role in the intelligent transportation system.
- 5G-D2D is applied to enhance vehicular network's performance.
- Main targets:

- Maximize V2I's ergodic capacity.
- Guarantee V2Vs' reliability.
- Maximize network's utilization.
- Save energy

- MAX and OPT mechanisms are suggested, where **OPT mechanism** shows better energy efficiency than MAX mechanism within **54%** approximately.

Conclusion

- Analytical model is applied to maximize V2Vs' reliability and V2Is' ergodic capacity.
- DFST algorithm is used to enhance network's utilization.
- **OPT-DFST** algorithm shows better network's bandwidth efficiency with effective runtime. It is also capable of operation even if the number of V2V links increase per channel.
- Largest-clustered, DFST-DL, and RR-FF algorithms have been proposed.
- With guaranteeing lower bound of V2I's ergodic capacity, these algorithms show better network's bandwidth efficiency with effective runtime.

Conclusion

- **Largest-clustered** algorithm showed least **dropped vehicles**.
- **DFST-DL** algorithm has least **processing time**.
- **RR-FF** algorithm has highest **V2Is' data rate** and highest **network utilization**.
- In most applications except highly time critical ones like sudden brakes for crashes avoidance, **RR-FF algorithm** is preferred as it has the best results. For highly time critical cases, **Largest-clustered algorithm** is better to be applied due to its effective processing time and supporting most of V2V links with targeted QoS.

Future Work

- Different network scenarios can be built and tested (i.e. urban roads).
- Study and analyze different localization mechanism.
- Hardware implementation can be executed.

List of Publications

[1] (2019, November) Enhancing signal to noise interference ratio for device to device technology in 5G applying mode selection technique. In *2017 4th International Conference on New Paradigms in Electronics & information Technology (PEIT)* (pp. 187-192). **IEEE**.

[2](2019,September). Intensive Benchmarking of D2D communication over 5G cellular networks: prototype, integrated features, challenges, and main applications. Springer, Wireless Networks, 1-20 (**Q2, IF=2.66**).

[3] (2019, November). Internet of Vehicles (IoV) enabled 5G D2D technology using proposed resource sharing Algorithm. In *2019 5th International Conference on New Paradigms in Electronics & information Technology (PEIT)* (pp. 126-131). **IEEE**.

[4] (2020, January). Enabling Device-to-Device Technology in 5G Heterogeneous Networks. In *Fundamental and Supportive Technologies for 5G Mobile Networks* (pp. 187-212). IGI Global.

[5] (2020, October). Proposed localization scenario for autonomous vehicles in GPS denied environment. In International conference on advanced intelligent systems and informatics (pp. 608-617). **Springer**.

[6] (2021, May). Depth-First-Search-Tree Based D2D Power Allocation Algorithms for V2I/V2V Shared 5G Network Resources. Springer, Wireless Networks, vol. (27), (pp. 3179-3193) (**Q2, IF=2.66**).

[7] (2021, May). Multi V2X channels resource allocation algorithms for D2D 5G Network performance enhancement. Elsevier, Vehicular Communications, vol.(31), (pp. 1-12) (**Q1, IF=6.91**).

Thank you!

Any questions?