C^2RC: Channel Congestion-based Re-transmission Control for 3GPP-based V2X Technologies

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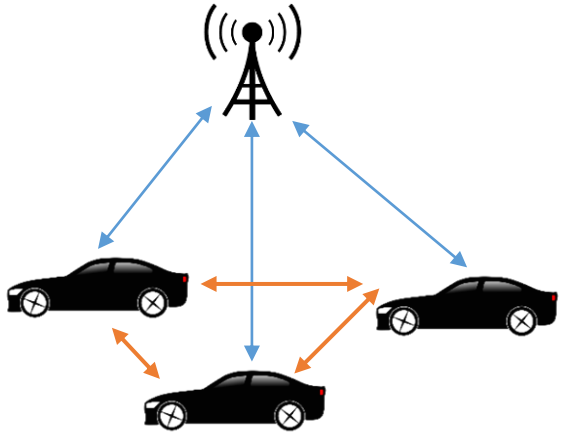
Outline

- Cellular V2X
  - Sidelink mode 4
  - Packet re-transmissions
- Need for re-transmission control
  - Why do re-transmissions (sometimes) fare poorly?
- C^2RC: Channel Congestion-based Re-transmission Control
  - Optimization of C^2RC parameters
- Conclusions

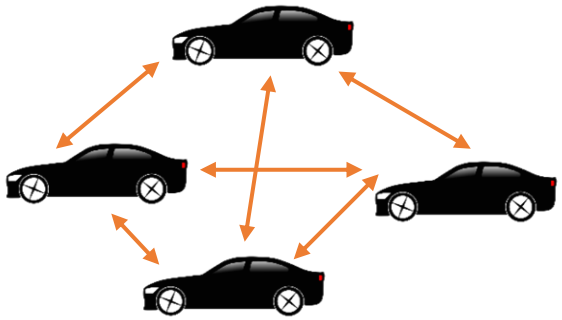
Cellular Vehicle-to-Everything (C-V2X)

- C-V2X is a radio access technology that enables V2X communications
  - Standardized in 2017 by the 3GPP in its Release 14
  - PHY and MAC layers based on LTE
  - New Radio V2X coming soon in Release 16
- The “sidelink” interface

C-V2X sidelink Mode 3
Cellular coverage



C-V2X sidelink Mode 4
No cellular coverage



- Cellular coverage may be unreliable
- We focus on sidelink mode 4

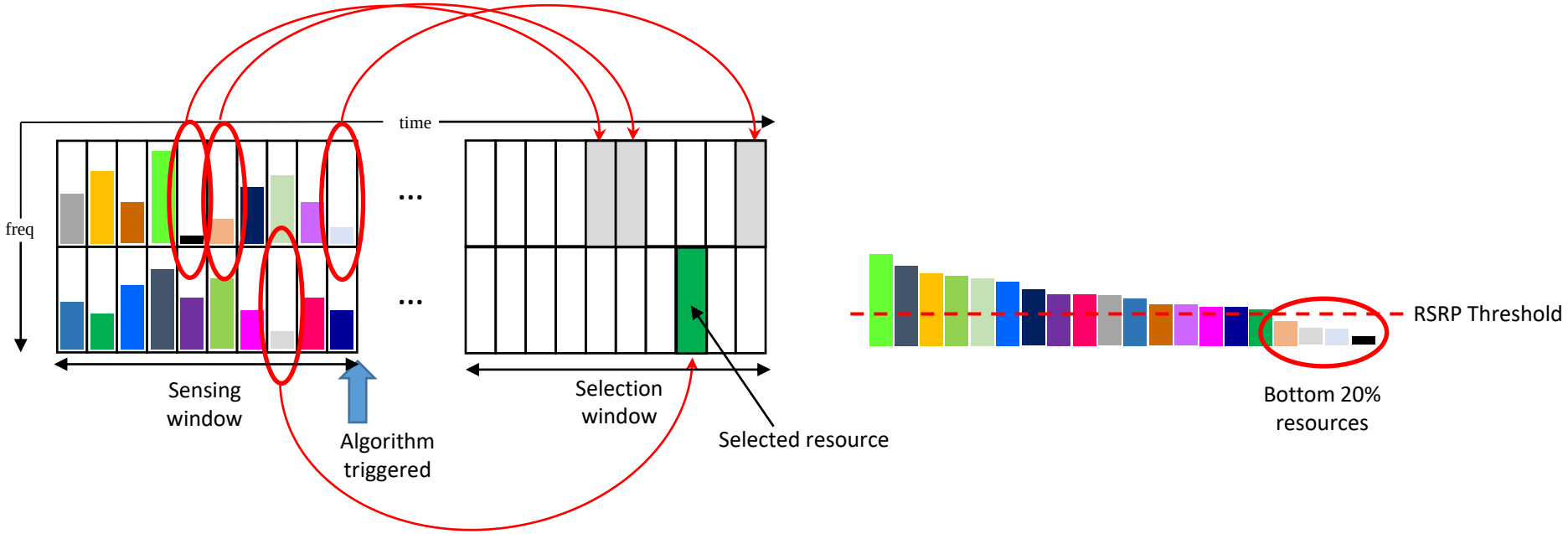
Resource management (uplink/downlink)
Vehicular communication (sidelink)

3GPP – 3rd Generation Partnership Project
LTE – Long Term Evolution

C-V2X sidelink mode 4

- No assisting infrastructure implies vehicles must perform resource selection themselves
  - 3GPP has defined a resource selection and reservation algorithm

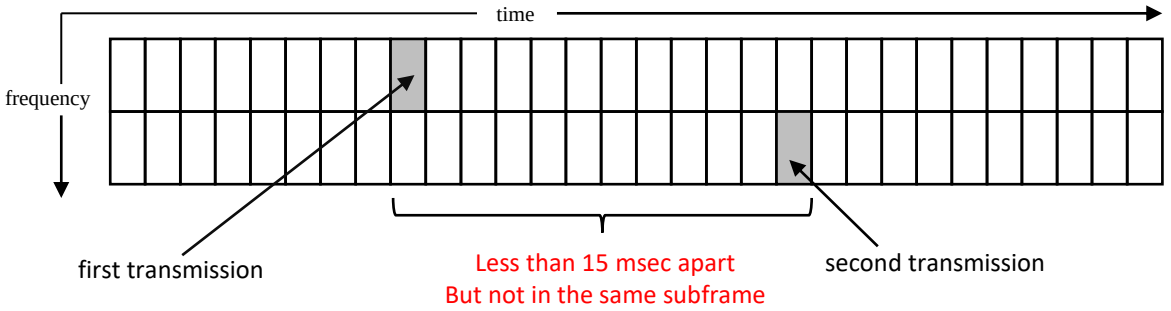
1. Monitor past resources
2. Rank on energy
3. Adjust RSRP Threshold
4. Pick bottom 20% resources
5. Select one resource at random



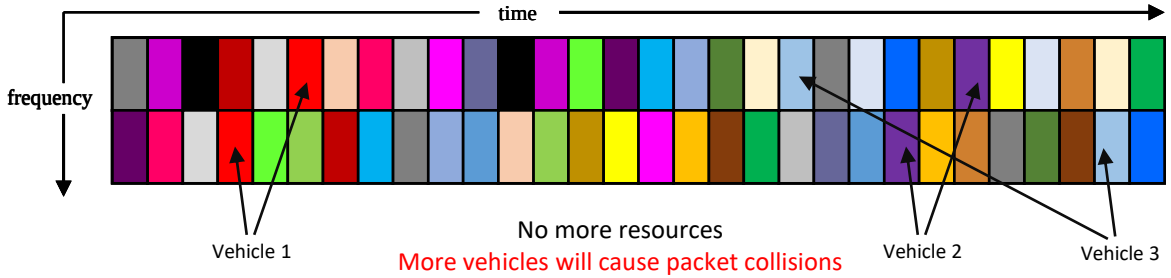
- Salient features
  - Fully distributed: no infrastructure required
  - Semi-persistent scheduling: period packets
  - Packet re-transmissions: increased reliability

Packet re-transmissions

- 3GPP Rel. 14 allows up to two transmissions per packet



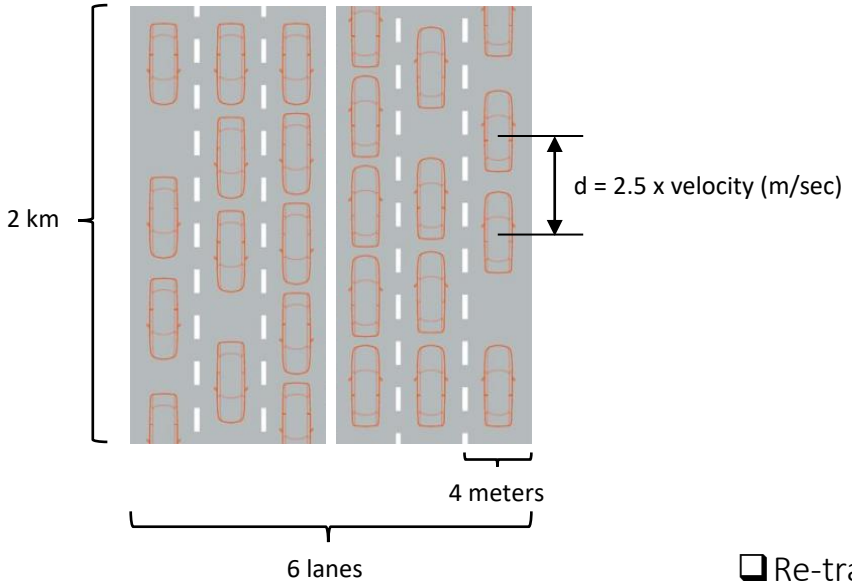
- Beneficial from the PHY layer perspective
  - Frequency and time diversity: probability of both resources being *bad* becomes smaller
- Also beneficial from the MAC layer perspective
  - Especially at small densities: unused resources are utilized
  - Can overwhelm the MAC layer beyond certain traffic density



Need for Re-transmission Control

Simulation setup

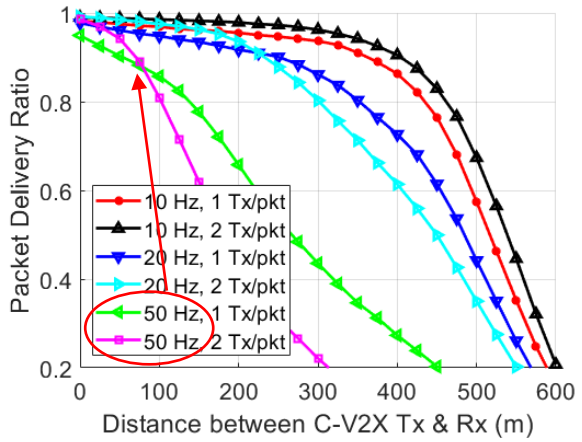
Highway environment



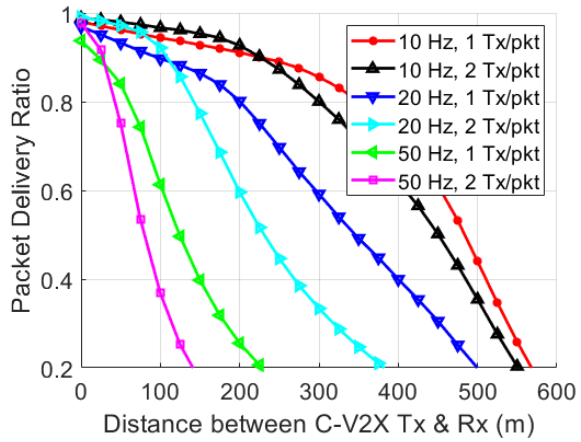
Two *standard* cases

Parameter	Highway Fast	Highway Slow
Velocity	140 km/hr	70 km/hr
# vehicles	120	240
Vehicle separation (d)	100 meters	50 meters

Highway Fast (120 vehicles)



Highway Slow (240 vehicles)



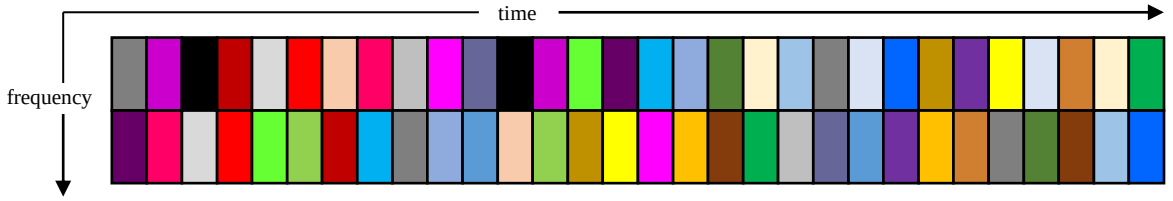
- ❑ Re-transmissions are beneficial at low densities
- ❑ As the transmission rate increases,
  - re-transmissions fare worse beyond a certain distance
  - crossover point shifts left (smaller Tx-Rx distance)

- ❑ As vehicle density increases,
  - re-transmissions fare worse beyond a certain distance
  - crossover point shifts left (smaller Tx-Rx distance)

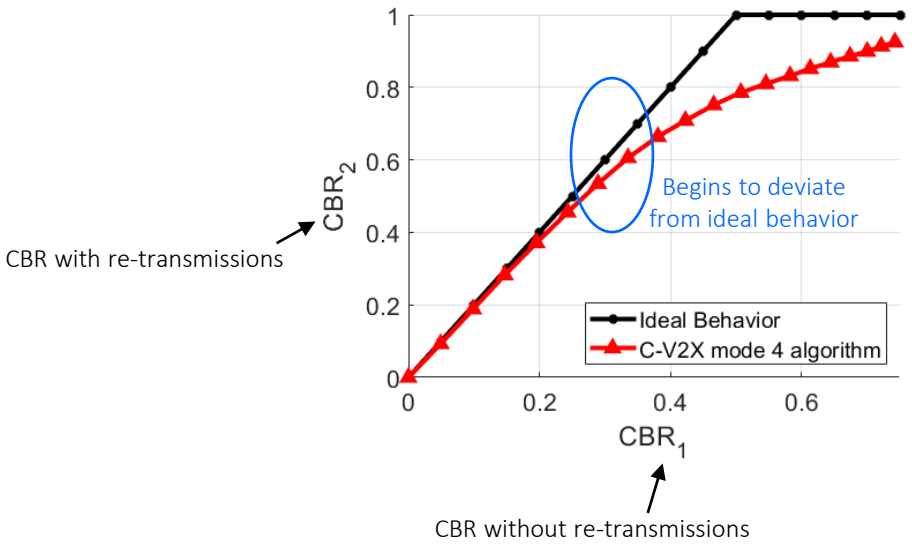
Re-transmissions deteriorate system performance as transmission rate AND/OR vehicle density increases

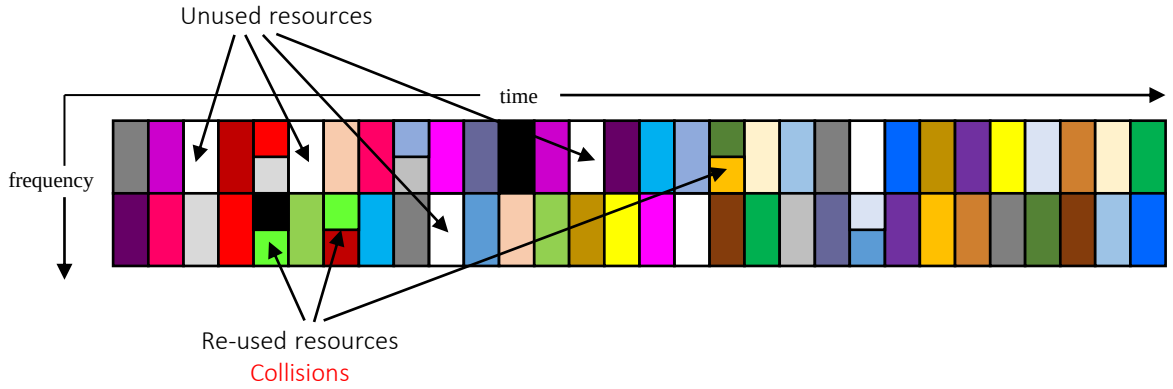
Why do re-transmissions (sometimes) fare poorly?

- Channel congestion



- Inefficient utilization of resources
  - Channel Busy Ratio (CBR): fraction of resources *busy* in the last 100 msec





Some resources are re-used by the SPS algorithm even as others are left idle

C^2RC: Channel Congestion-based Re-transmission Control

- Basic idea: Observe the CBR and decide whether to re-transmit or not

- Each vehicle observes the *local CBR,* CBR_{obs}
- Enables re-transmissions with "re-transmission probability" -- $p_{re\text{-}tx}$

- How do we select $p_{re\text{-}tx}$?
  - $p_{re\text{-}tx}$ must be be a non-increasing function of CBR_{obs}
  - The rate at which $p_{re\text{-}tx}$ drops from 1 to 0 must be configurable

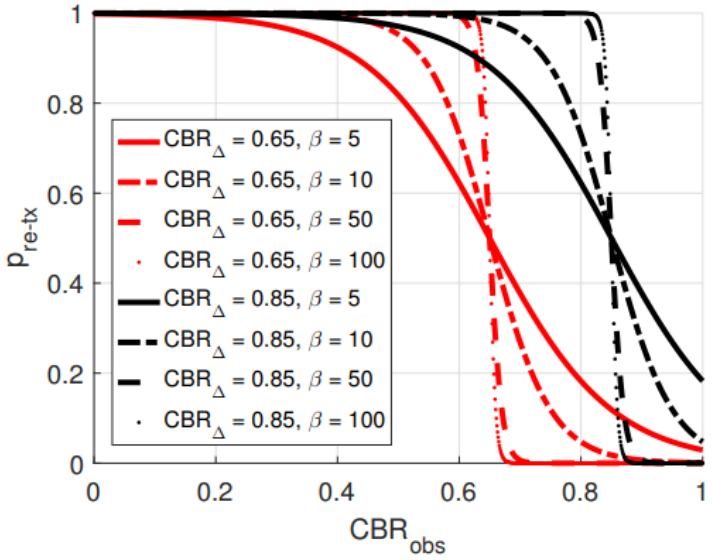
- We select

$$p_{\text{re-tx}} = 1 - \frac{1}{1 + e^{-2\beta(\text{CBR}_{\text{obs}} - \text{CBR}_{\Delta})}}$$

β and CBR_{Δ} are configurable parameters, which we will optimize

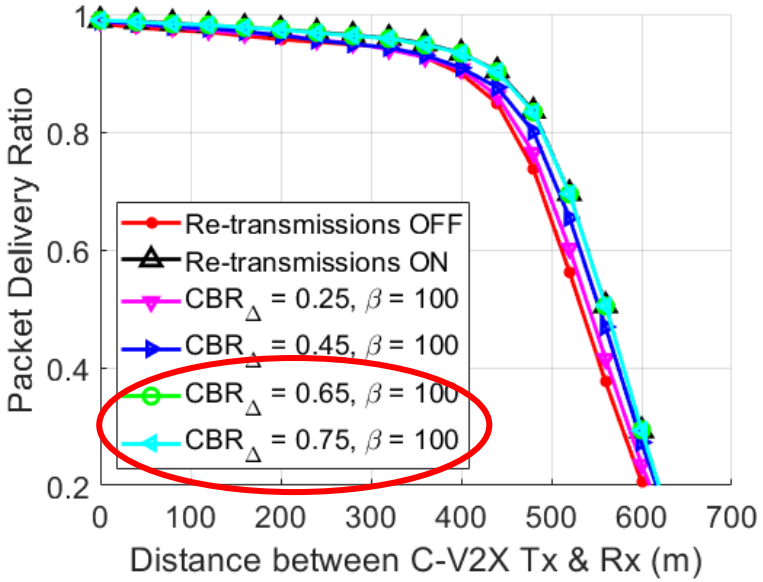
CBR_{Δ} signifies the CBR_{obs} at which $p_{re\text{-}tx}$ = ½

β controls the rate at which pre-tx drops to 0



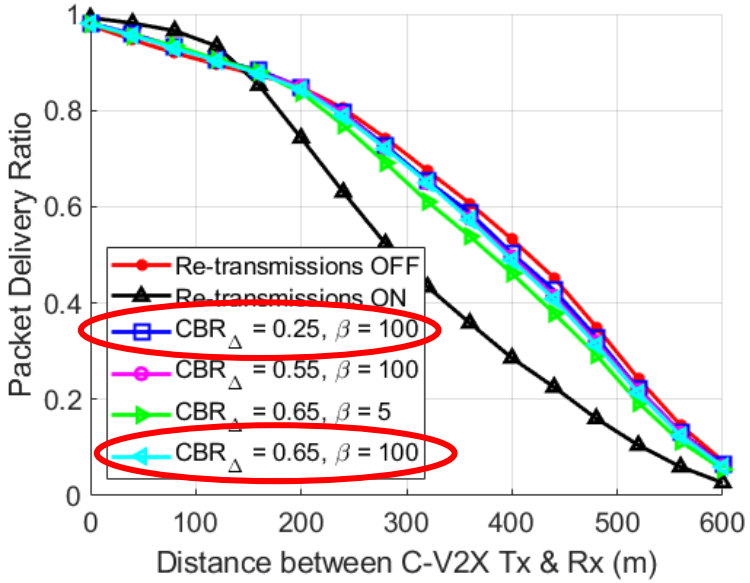
Optimization of C^{2}RC parameters

Lightly loaded
(100 vehicles, 10 Hz)



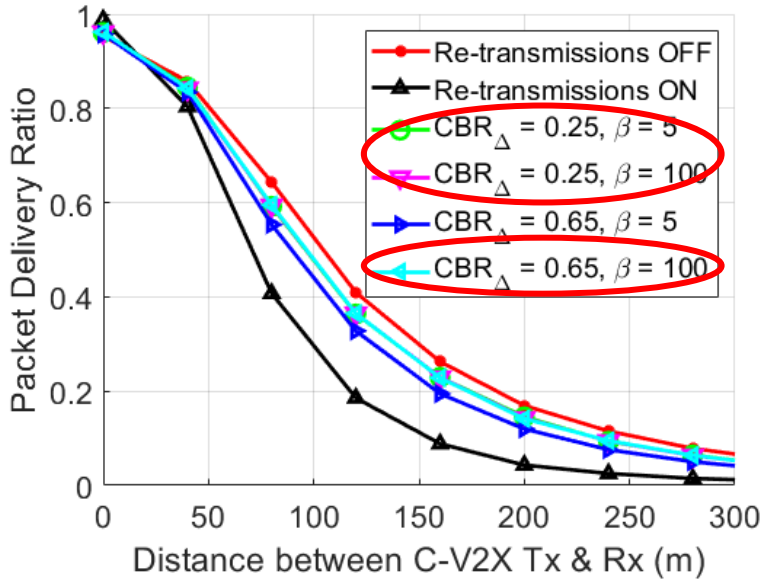
- Re-transmissions improve performance at low densities
- Higher values of CBR_Δ achieve superior performance (similar to re-transmissions ON)

Moderately loaded
(200 vehicles, 20 Hz)



- As load increases, re-transmissions begin to hurt performance
- Best performance is at low values of CBR_Δ with high β
- However, as long as β is high, increasing CBR_Δ has marginal impact on performance

Heavily loaded
(300 vehicles, 50 Hz)



- As load further increases, re-transmissions severely hurt performance
- At this point, CBR_{obs} is very high (~0.9). Any reasonable choice of CBR will do.
- But β should be high.

$CBR_\Delta = 0.65$ and $\beta = 100$ achieves a balance between performance at high, moderate and low densities

Conclusions

- Re-transmissions in C-V2X are important in improving system performance
- This feature is likely to be re-used in NR V2X as well

- However, simply switching re-transmissions ON or OFF is inefficient
  - At low densities, the static OFF configuration underutilizes the channel
  - At high densities, the static ON configuration leads to congestion

- A re-transmission control mechanism is needed
- We show that a probabilistic re-transmission control mechanism---C^2RC---is effective at improving C-V2X performance in low, moderate, and high traffic conditions

Thank you!