DOVE: Data Offloading through Spatio-temporal Rendezvous in Vehicular Networks

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Outline

- Motivation
- DOVE framework & operations
- DOVE algorithm
- Evaluation
- Conclusion

Background

- Vehicular networks
  - Promising research area to support the driving safety
    - i.e., vehicle collision avoidance
- Communication module for vehicular networks
  - Dedicated Short Range Communications (DSRC)
    - IEEE 802.11p (WAVE)
  - Embedded cellular connectivity systems
    - GM, Toyota, Hyundai…
- In-vehicle data services
  - By the help of DSRC and cellular connectivity system
    - Real time services (e.g., road traffic information)
    - Software update for car system
    - RSS services (as non-real time applications) for car dash screen
      - E.g., news headlines and audio/video clips for entertainment

delay-insensitive service!

Motivation (1/3)

- Traffic explosion in mobile environments
  - The increasing mobile traffic is becoming a serious concern for mobile network providers
  - In-vehicle data service will worsen the problem

Mobile Data Traffic 2014-2019

Motivation (2/3)

- How to reduce the mobile traffic?
  - Data offloading
    - One of solutions to resolve traffic explosion problem
    - Offloading the traffic from cellular networks to other networks
      - E.g., WiFi hotspots, femtocells
  - Reducing redundant traffic
    - Request for some popular videos account for the majority of all the requests [1]
    - A significant amount of cellular traffic is redundant [2]

➔ We focus on the data offloading for redundant traffic caused by in-vehicle data services

[1] M. Cha, H. Kwak, P. Rodriguez, Y.-Y. Ahn, and S. Moon, "I Tube, You Tube, Everybody Tubes: Analyzing the Worlds Largest User Generated Content Video System," in Proc. of ACM IMC, 2007.
[2] S. Woo, E. Jeong, S. Park, J. Lee, S. Ihm, and K. Park, "Comparison of caching strategies in modern cellular backhaul networks," in Proc. of ACM MobiSys, 2013.

Motivation (3/3)

- Research question?
  - How to design an offloading framework utilizing components of vehicular networks for delay-insensitive data services, while minimizing the usage of cellular links

- Let's focus on features of vehicular networks
  - Vehicles
    - Multiple communication devices (DSRC, 3G, 4G-LTE)
    - GPS navigator, storage
  - Predictable mobility
    - Constrained roadways, navigation paths (vehicle trajectories)
  - Vehicular infrastructure
    - Relay Nodes (RNs) can be used for data offloading

Proposed Idea Overview (1/2)

- Target scenario
  - Reducing cellular traffic for vehicles by offloading the redundant traffic (of popular files) to vehicular networks
- Target content files
  - Popular files for delay-insensitive in-vehicle data services
    - Update files for software in car system
    - Popular multimedia files (e.g., headline news, music files, and YouTube video clips)
- Goal
  - Selecting effective offloading positions (OPs) that minimize the aggregated usage of cellular links for vehicles
    - i.e., the amount of data downloaded through cellular networks

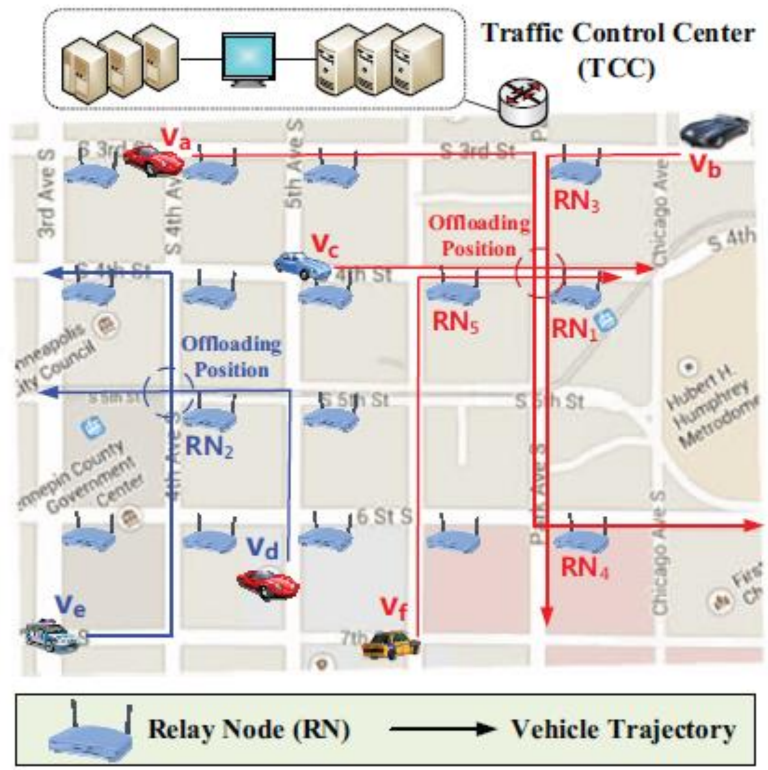
Proposed Idea Overview (2/2)

- DOVE: data offloading through vehicular networks
  - Using vehicle infrastructures (i.e., RNs) as *offloading positions (OPs)* for offloading purposes
  - Offloading the cellular traffic to OPs (in vehicular networks) by exploiting vehicle trajectories

- Contributions
  - Proposing a data offloading framework (called DOVE) by using the components of vehicular networks
  - Formulating the selection of OPs as a set-covering problem
  - Proposing a time-prediction based set-covering algorithm (called DOVE algorithm) to select OPs

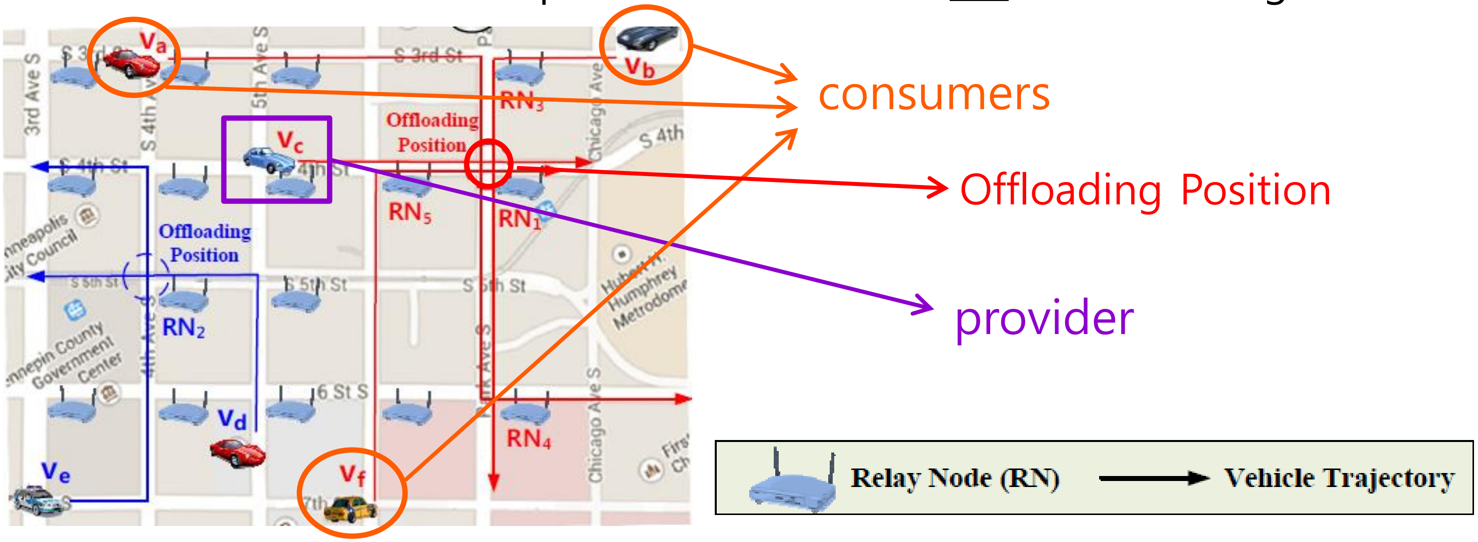
DOVE Framework (1/2)

- DOVE components
  - Traffic control center (TCC)
    - Traffic management node
    - Maintaining vehicle trajectories
    - Collecting content requests from vehicles
  - Relay node (RN)
    - Wireless packet holder for the reliable forwarding
    - Equipped with DSRC, storage
    - Usually deployed in vehicular networks for the driving safety
    - Role of offloading position (OP)
  - Vehicles
    - GPS navigator, DSRC, cellular communication device



DOVE Framework (2/2)

- Concept of offloading in DOVE
  - Given trajectories, finds RNs where trajectories are overlapped
    - Candidates for OPs
  - Selects appropriate OPs (i.e., RN) for data offloading
  - Decides provider and consumers
    - Provider
      - downloads the file using cellular links and stores it into the RN
    - Consumers
      - retrieve the requested file from the RN without using cellular links



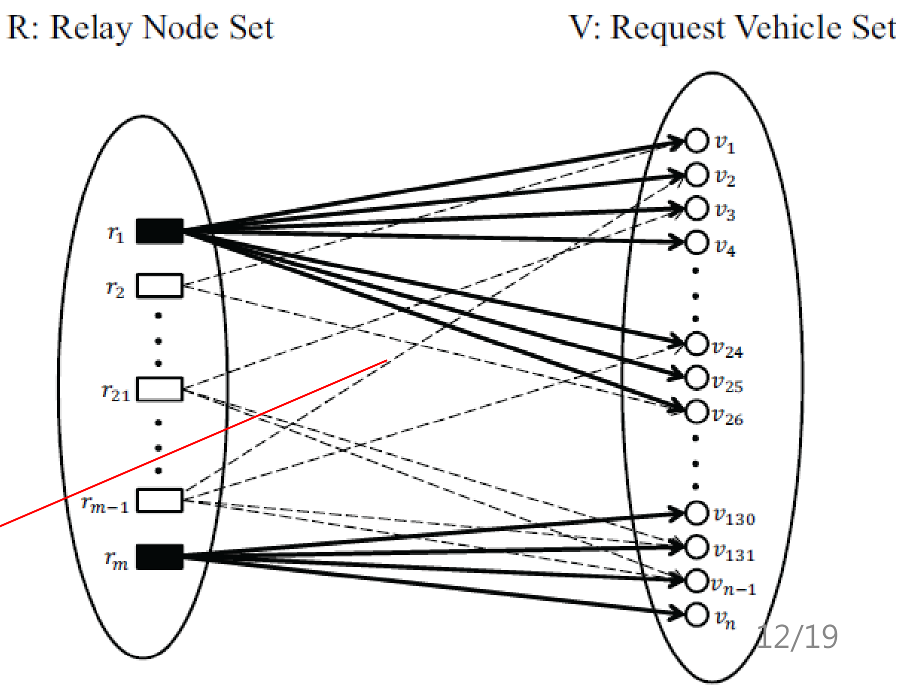
DOVE Operation

- Traffic control center (TCC)
  - 1. TCC collects the content requests and the trajectory from each vehicle
  - 2. TCC decides the OPs (i.e., selected RNs) and provider for data offloading
    - Using **DOVE algorithm**
  - 3. TCC sends the offloading information to vehicles

- Vehicles
  - 4. Vehicles obtain the offloading information from TCC
  - 5. Providers (first arrival vehicles at the RN) download a file using cellular traffic and put the file at the RN
  - 6. Consumers can retrieve the file from RNs and thus they can reduce the cellular traffic

DOVE Algorithm (1/3)

- Formulate <u>selection of RNs</u> as a <u>set-covering problem</u>
  - Definition
    - V : set of request vehicles requesting the same content
    - R : set of relay nodes (RNs) where trajectories of vehicles in V are overlapped
    - S_i : set of request vehicles covered by an RN_i
      - 'cover' means that vehicles in S_i can get the content from the RN_i
    - F: family of the subsets of V
  - Goal
    - Finding a minimum set-cover C^* of RNs as follows:
      - $C^* \leftarrow \arg\min_{C \subseteq F} |C|$ where $V = \cup_{S_i \in C} S_i$



A line means that the vehicle will traverse the RN

DOVE Algorithm (2/3)

- DOVE algorithm (RN selection)
  - Using greedy approach
    - known as the best possible polynomial time approximation algorithm
  - Time-prediction based set-covering algorithm

Algorithm 1 DOVE Algorithm (R, V, F)

$I \leftarrow R$
$U \leftarrow V$
$P \leftarrow \emptyset$
while $U \neq \emptyset$ **do**
  update $S_i^* \leftarrow S_i$ for $i \in I$ by **pruning** unsatisfied vehicles v such that $\hat{t}_{p_v,i} < \gamma$ or $t_{p_v,i} > \delta$ where $v \in S_i$.
  select a $S_i^* \in F$ that maximizes $|S_i^* \cap U|$ for $i \in I$
  select a provider $d_i \in S_i^*$ whose arrival time at RN i is minimum
  $U \leftarrow U - S_i^*$
  $I \leftarrow I - \{i\}$
  $P \leftarrow P \cup \{(i, d_i)\}$
end while
return P

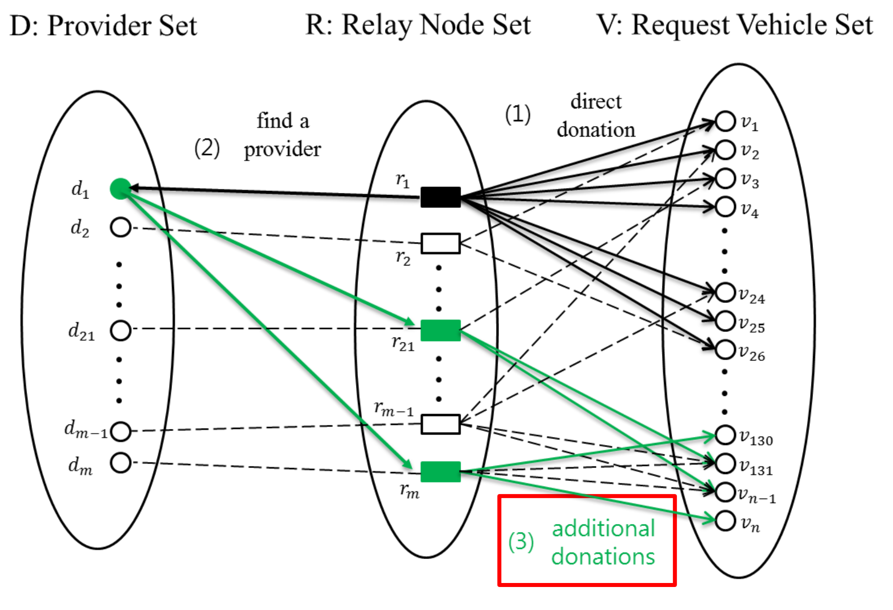
Considering vehicles' travel time

RN selection

Provider selection

DOVE Algorithm (3/3)

- DOVE⁺ algorithm (using multiple donations)
  - Enhanced DOVE algorithm to further reduce # of providers
    - (1) Select an S_i^* to decide an OP that directly covers the maximum vehicles
    - (2) Find a provider that is the first vehicle reaching the selected OP
    - (3) Find additional consumers using RNs where a provider will pass (multiple donations)
    - (4) Repeat the steps (1)-(3)

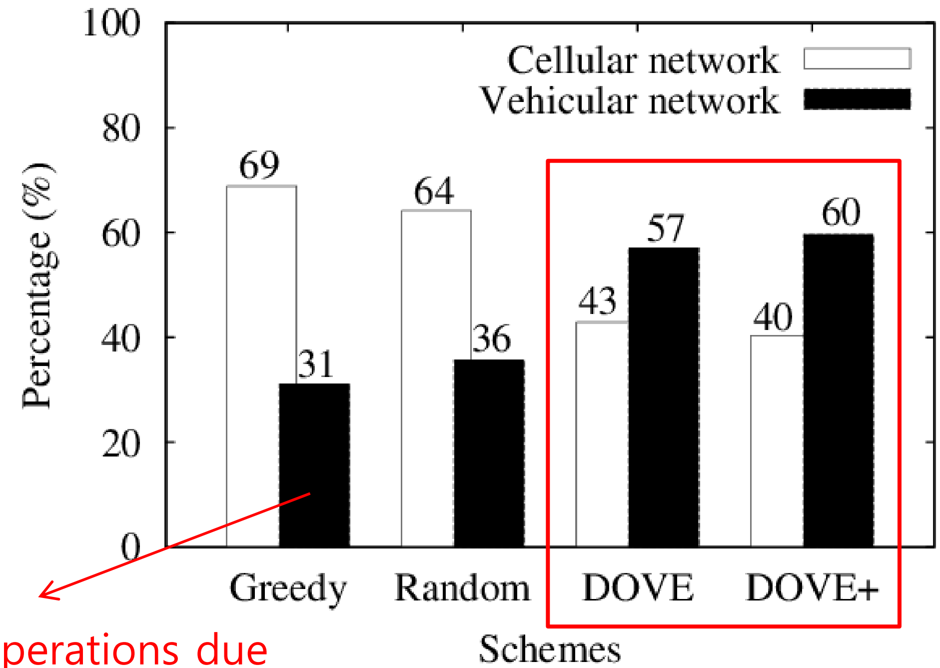


Simulation Environments

Simulation configuration	
Road network	The number of intersections is 49. The area of the road map is 8.25km×9km.
Communication range of DSRC [4]	Communication range R = 200 meters. Bandwidth of the DSRC = 25 Mbps.
Number of vehicles (N)	The number of vehicles moving within the road network. The default N is 300.
Vehicle speed (v)	$v \sim N(\mu_v, \sigma_v)$ where μ_v = {20, 25, ..., 60} MPH and σ_v = 5 MPH. The default (μ_v, σ_v) is (40, 5) [5,6].
Deployment ratio (a)	The ratio a of the number of deployed RNs to the total number of intersections. The default a is 1.
Tolerance time (δ)	The maximum (tolerable) delay of vehicles. The default δ is 600 sec (i.e., 10 min) [7].
Cellular Communication	Cellular BW =2.1 Mbps, file size = 12MB Cellular downloading time γ is 47.9 sec.
Comparison (RN selection algorithm)	DOVE algorithm, DOVE$^+$ algorithm, Random selection, Greedy selection

Simulation Results (1/3)

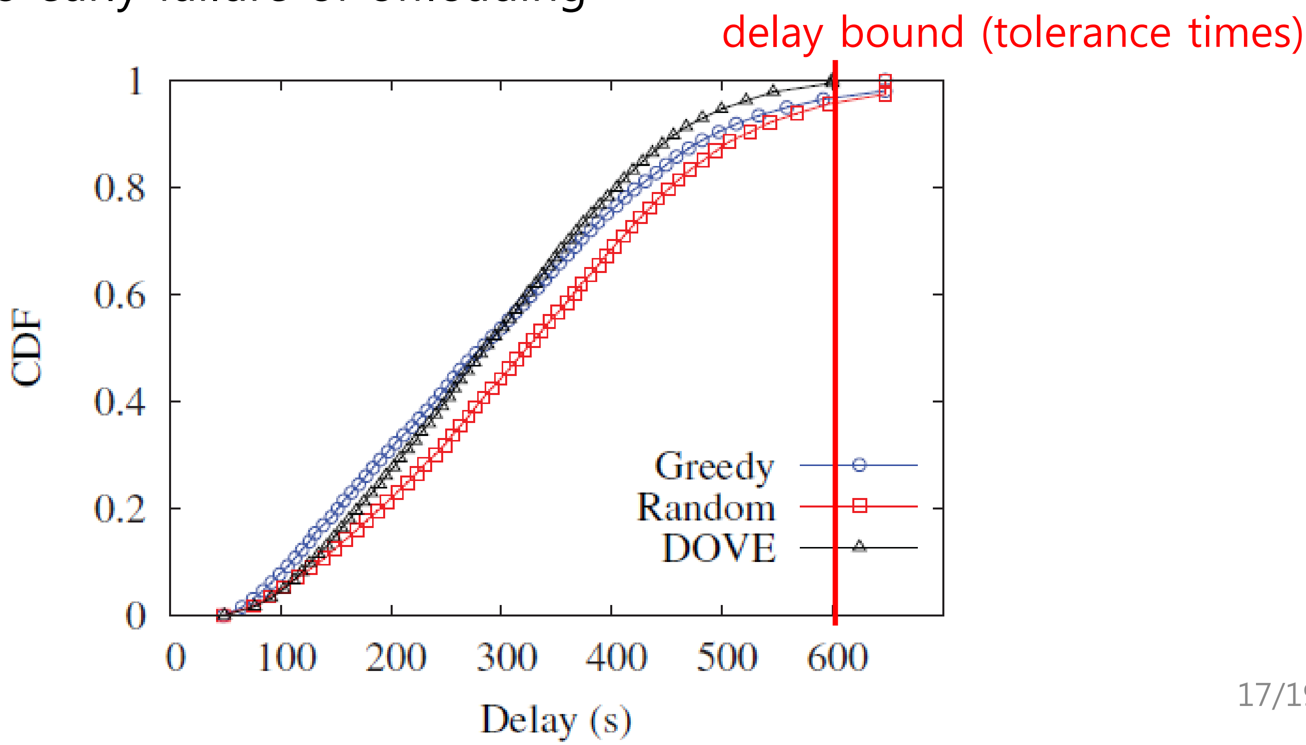
- The percentage of offloading vehicles
  - In DOVE (DOVE⁺), more than half (i.e., 57%/60%) offload their traffic from the cellular network to the vehicular network
    - Only 31% (Greedy) and 36% (Random) of request vehicles take advantage of data offloading
  - DOVE selects more effective OPs compared to Greedy and Random.



Failure of offloading operations due to absence of time consideration

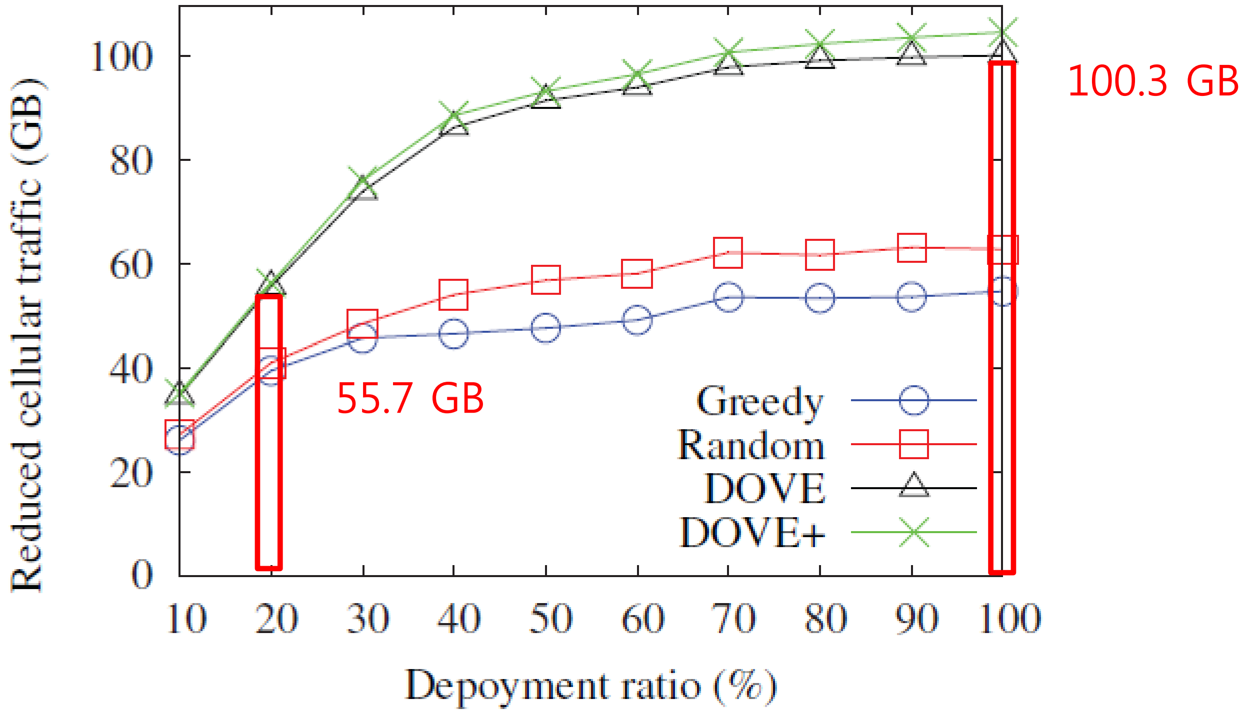
Simulation Results (2/3)

- The content retrieval time
  - All the consumers using DOVE obtain the file within the delay bound(i.e., 600 seconds)
    - But, Greedy and Random show the non-negligible portion of consumers that exceed the delay bound
  - Greedy and Random show shorter content retrieval delay
    - Due to early failure of offloading



Simulation Results (3/3)

- Partial deployment
  - The higher deployment ratio leads to the less usage of cellular links (all algorithms)
  - RNs in only 20% of intersections can reduce about half of traffic reduction in the full deployment



Conclusion

- We propose data offloading framework (DOVE) for redundant traffic caused by in-vehicle data services
  - Utilizing vehicle trajectories
  - Formulating the selection of OPs as a set-covering problem
  - Proposing a DOVE algorithm to select OPs

- DOVE can provide cost effective offloading service with infrastructure nodes for the driving safety
  - DOVE reduces 57% of cellular link usage via OPs
  - DOVE can be used as one of solutions to resolve the mobile traffic explosion

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- [1] M. Cha, H. Kwak, P. Rodriguez, Y.-Y. Ahn, and S. Moon, "I Tube, You Tube, Everybody Tubes: Analyzing the Worlds Largest User Generated Content Video System," in Proc. of ACM IMC, 2007.
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- [7] Y. Im *et al.*, "Amuse: Empowering users for cost-aware offloading with throughput-delay tradeoffs," in *Proc. of IEEE INFOCOM*, 2013.

Q&A

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