Opportunistic WiFi Offloading in a Vehicular Environment: Waiting or Downloading Now?

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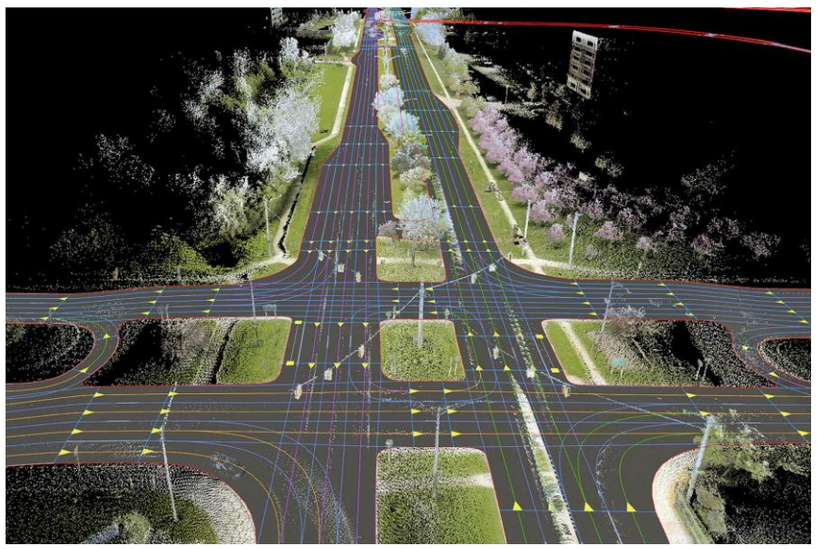
Agenda

- Motivation
- Model and problem formulation
- Theoretical analysis
- The idea of the proposed algorithm
- Performance evaluations

Motivation

- Data downloading during the driving
  - Self-driving vehicles
    - Traffic and safety information
    - High-resolution digital maps
  - On boarding applications
    - Video, music, social networks
    - ……



android auto

Apple CarPlay

Related works

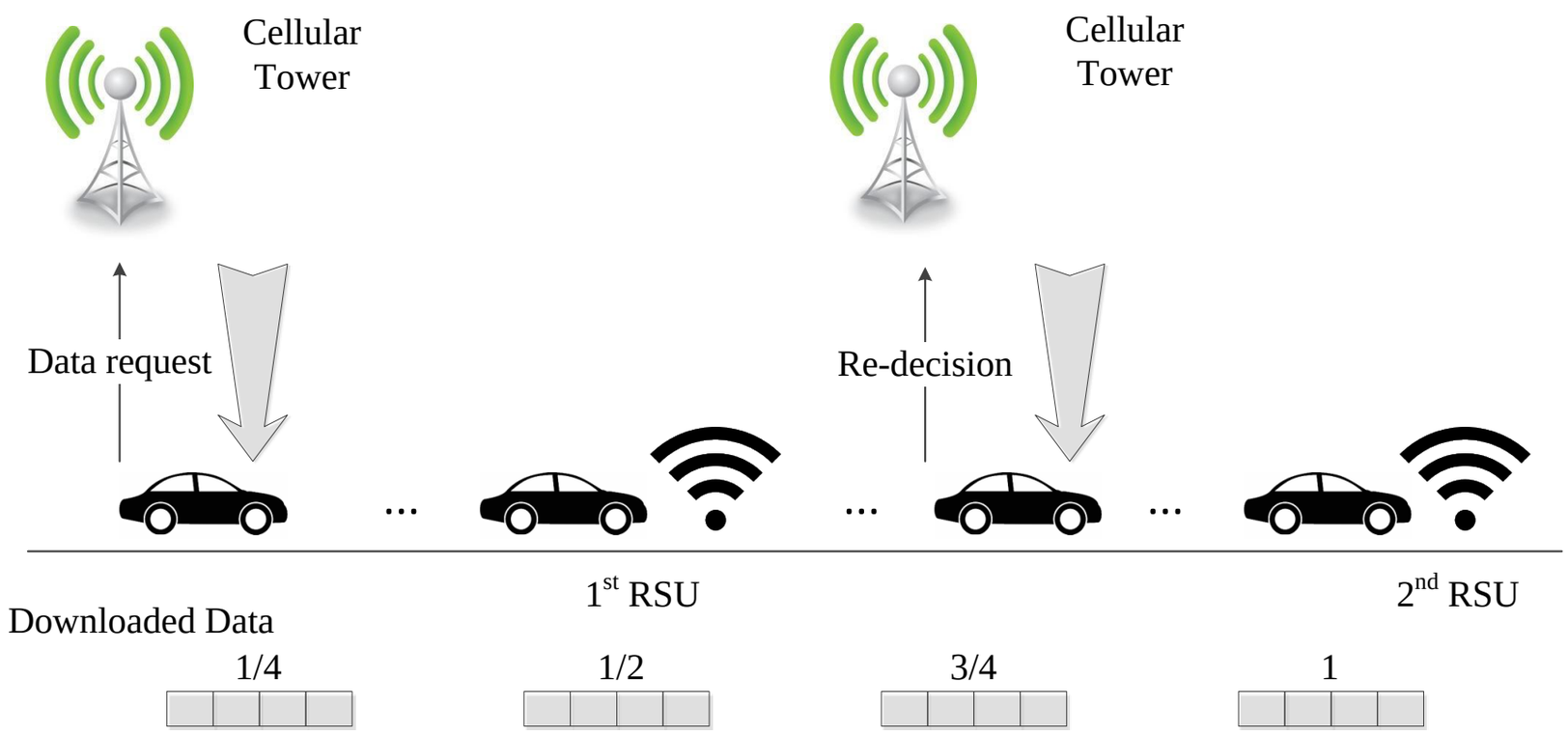
- Opportunistic offloading
  - Mobile Data Offloading through Opportunistic Communications and Social Participation. (TMC 2012)
- User's satisfaction decay with time
  - Toss: Traffic offloading by social network service-based opportunistic sharing in mobile social networks (INFOCOM 2014)
- Roadside Units deployment
  - On-road ads delivery scheduling and bandwidth allocation in vehicular cps (INFOCOM 2013)

Motivation

- **A hybrid network**
  - Roadside Units with WiFi (RSUs).
    - Limited coverage, high bandwidth, cheap
  - Cellular network
    - Full coverage, low bandwidth, expensive.
- **Delay-sensitive data downloading**
  - Delay sensitive data
    - Incoming call, safety information update
  - Delay non-sensitive data
    - Music, social network update, etc.

Network model and Problem

- With the increasing of data size
  - A trade-off between the cost and delay
    - **from the Cellular netwo**rk: No risk but lead to a high cost.
    - **from the RSUs network** : Risk, high delay, but cheap



Network model and Problem

- Maximize the user's satisfaction
  - If the cost is high, the user's satisfaction will be low.
  - If the delay is large, the user's satisfaction will be low.

- Utility model

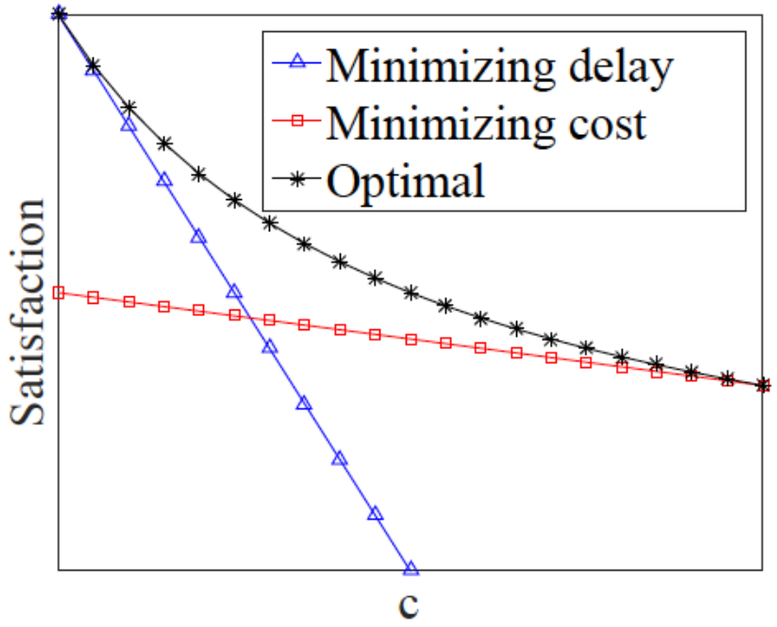
$$U_t = U_0 - at$$

The sensitivity to the delay

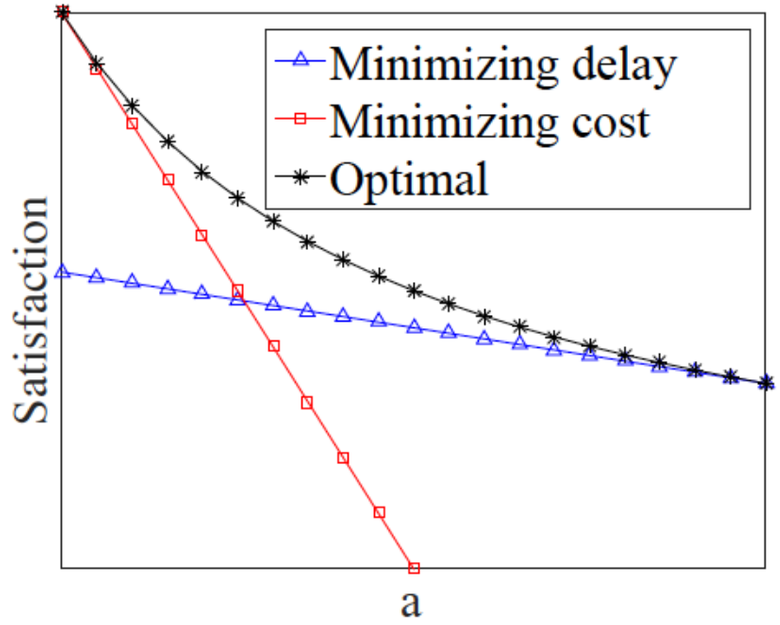
- Cost model
  - The price of downloading from cellular networks is c higher per bit than the price of downloading from RSUs.

Challenges

- Simple downloading strategies.
  - only get good result in certain scenarios.



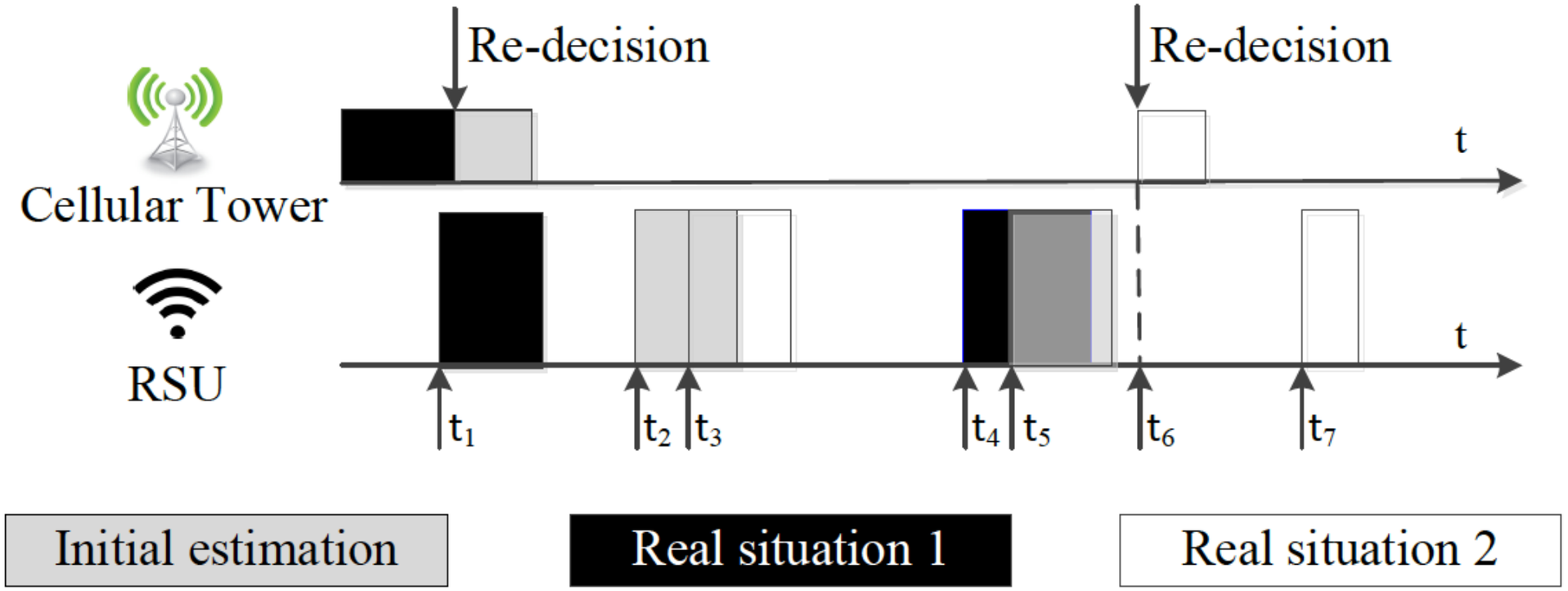
(a) Different data downloading cost



(b) Different data utlity decay speed

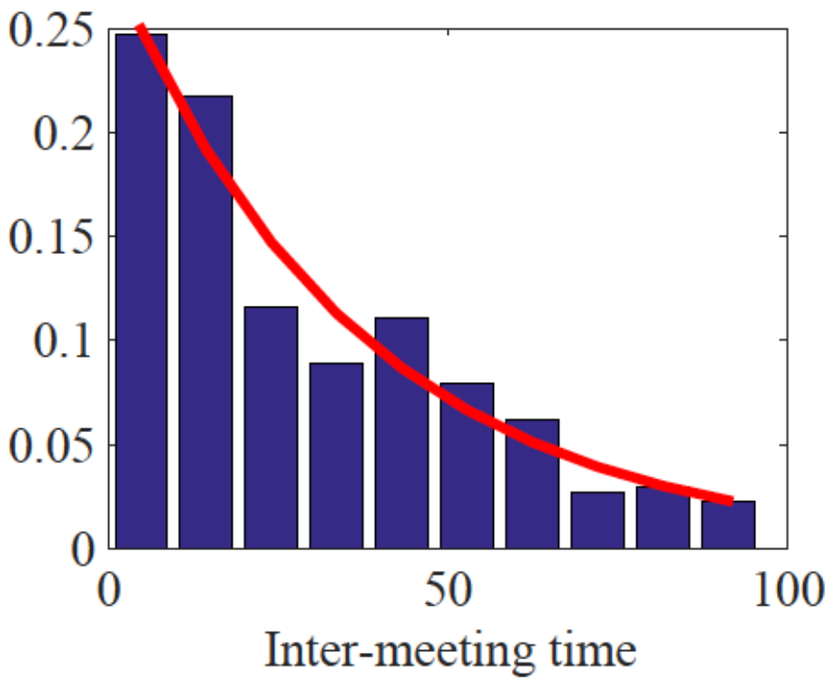
Challenges

- How to predict the expected utility through RSUs?
- When to adjust your downloading strategy?

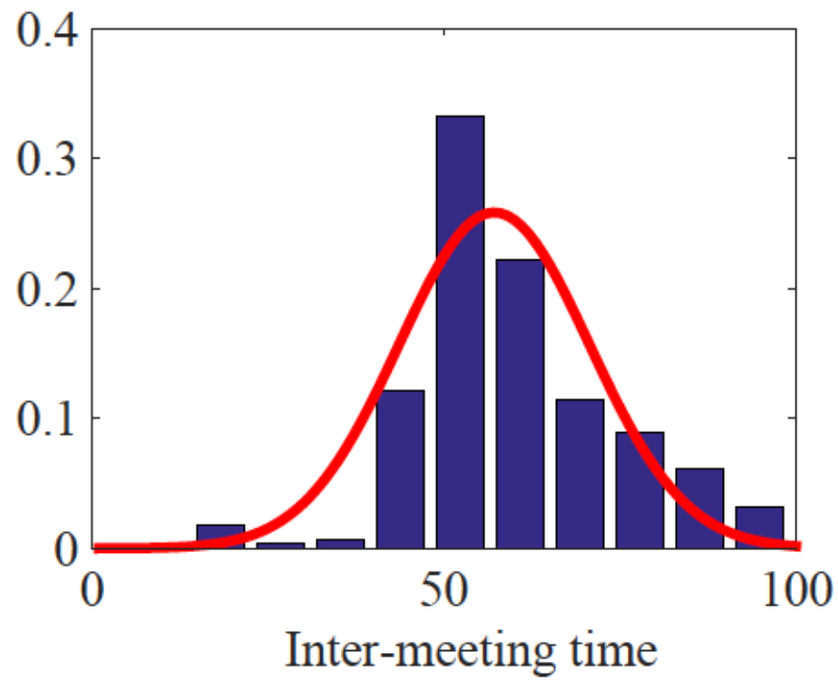


Real trace

- Inter-meeting distribution between a vehicle and RSUs in Diesel Bus Dataset:



(a) No.3204 bus



(b) No.5676 bus

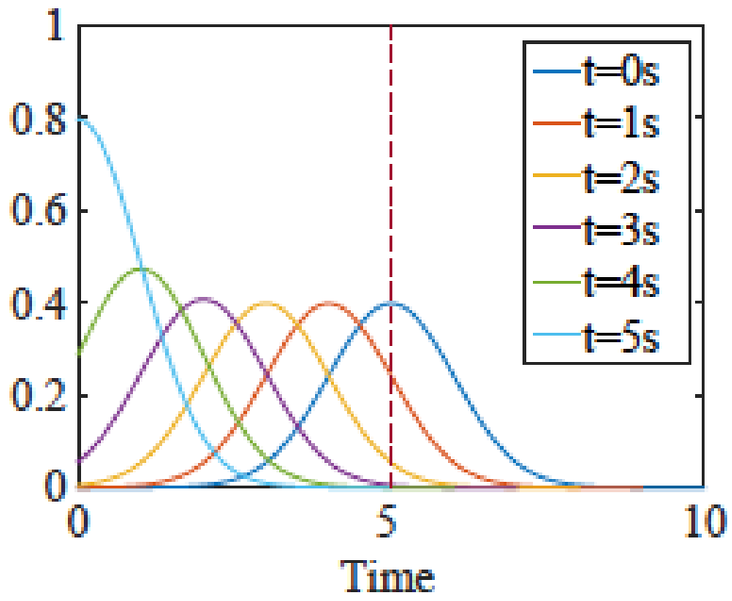
One RSU

- Exponential inter-meeting distribution
  - Memoryless property

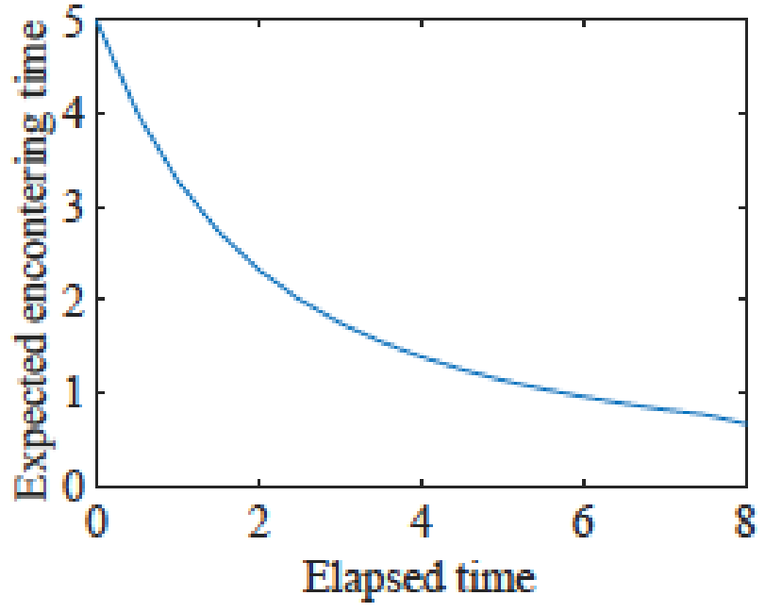
- Theorem: For exponential distribution of the encountering time between the vehicle and RSUs, the vehicle only needs to do the decision once: download from the cellular network right now, or never. The criterion of choosing the cellular network right now is $a/2\lambda > c$.

One RSU

- Gaussian inter-meeting distribution



(a) Probability density function



(b) Expected enountering time

- Theorem: For Gaussian distribution of the encountering time between the vehicle and RSUs, the criterion for choosing the cellular network right now is $\frac{(T^e)^{\beta+1}a}{\beta} > c.$

multiple RSUs

- Dependent inter-meeting time in RSUs
  - Meet one RSU earlier (later), high probability to meet the following RSUs earlier (later)

$$f(t_1, t_2, \ldots, t_k) = \frac{1}{q} \cdot f_1(t) * f_2(t) \cdots * f_k(t),$$

- Theorem: the expected meeting time with kth RSUs will not change, however the estimation uncertainty will increase $\sqrt{k}$ times.

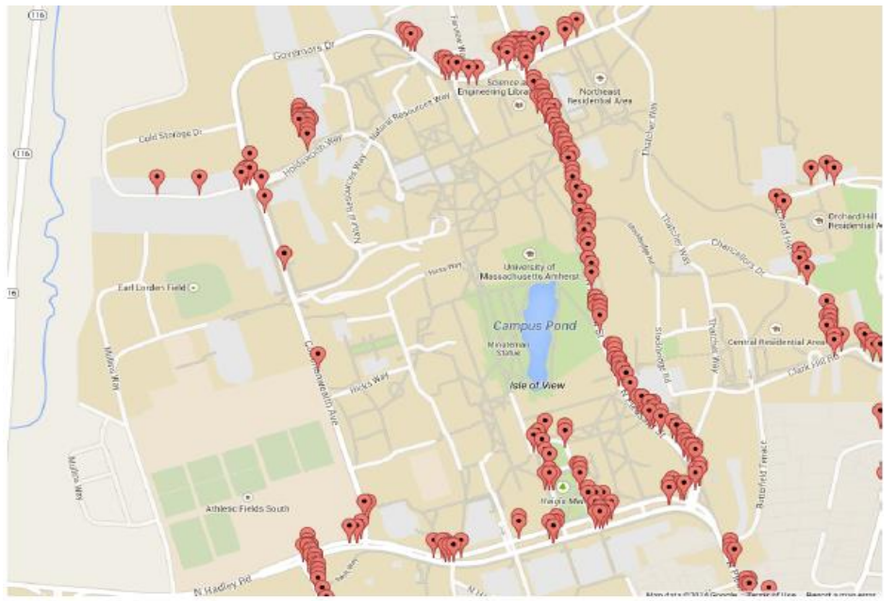
Proposed solution

- Adaptive algorithm
  - RSUs meeting prediction by historical information.
  - Jointly consider the expected meeting time with RSUs and the uncertainty to do downloading strategy.
  - Re-decision based on the actual situation.

Performance evaluation

- Trace information
  - Synthetic trace
  - UMass Diesel Trace
    - 40 Buses
    - 47 RSUs
- Experiment setting
  - Average data size 6MB
  - Different cost setting
  - Different decay speed

bandwidth	Cellular	RSUs
Kbps	20	100

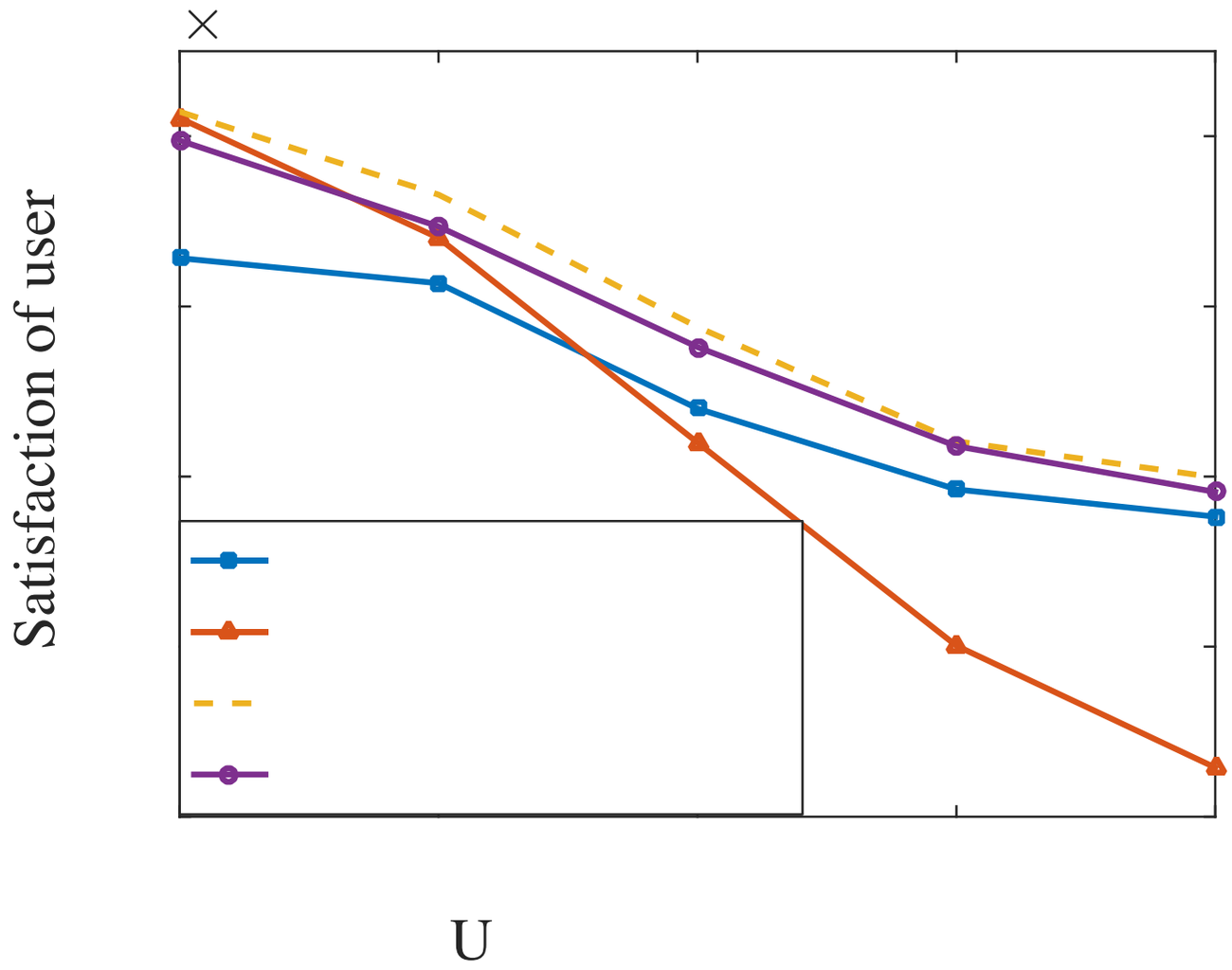


- Meeting positions of a bus with RSUs in Diesel data trace, where the red marker represents the contact records between a vehicle and RSUs

Algorithm comparison

- Algorithms:
  - Minimizing delay: Keep downloading data from cellular network.
  - Minimizing cost: Always wait for the RSUs
  - Optimal solution through brute-force
  - Proposed algorithm

Experiment result



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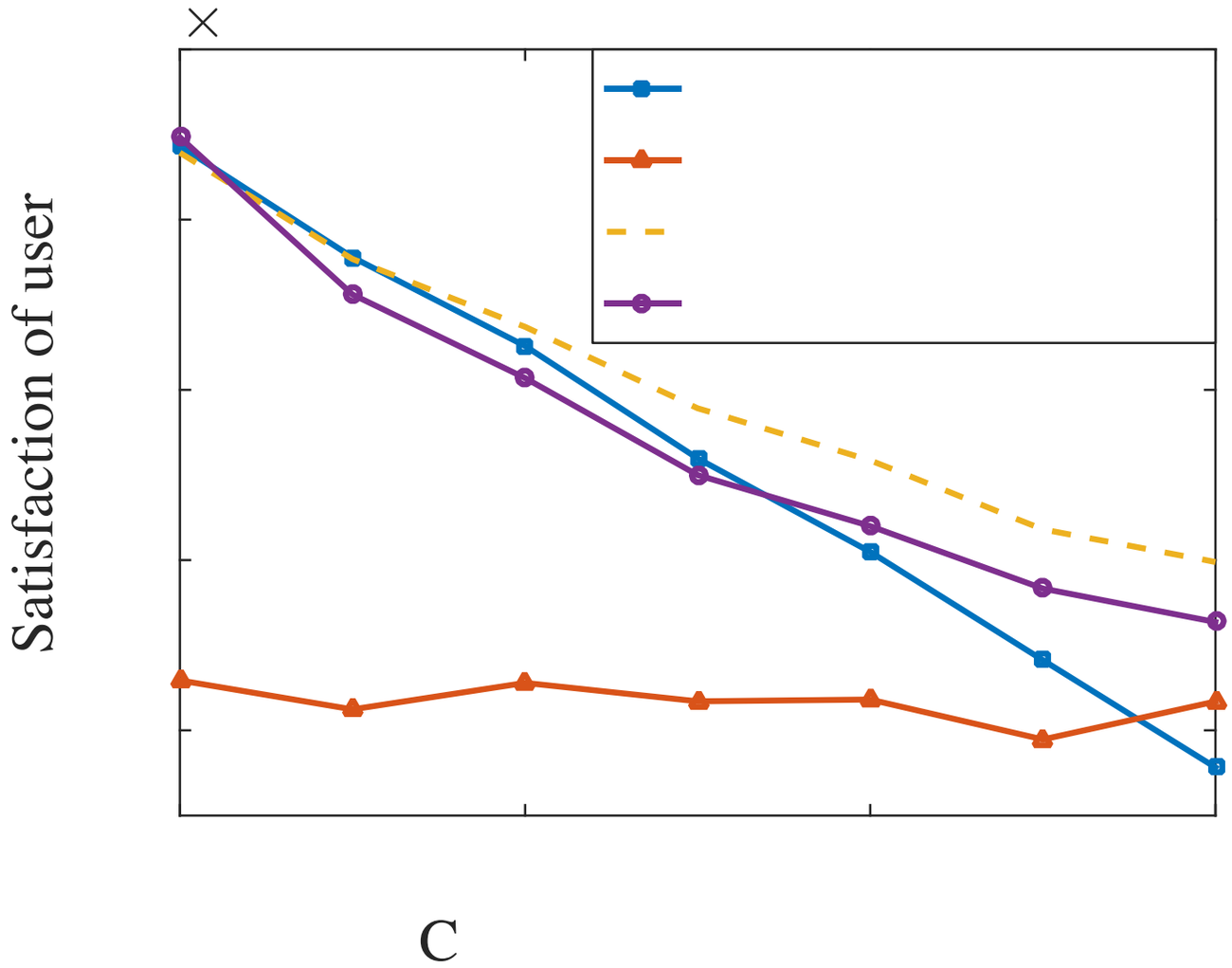
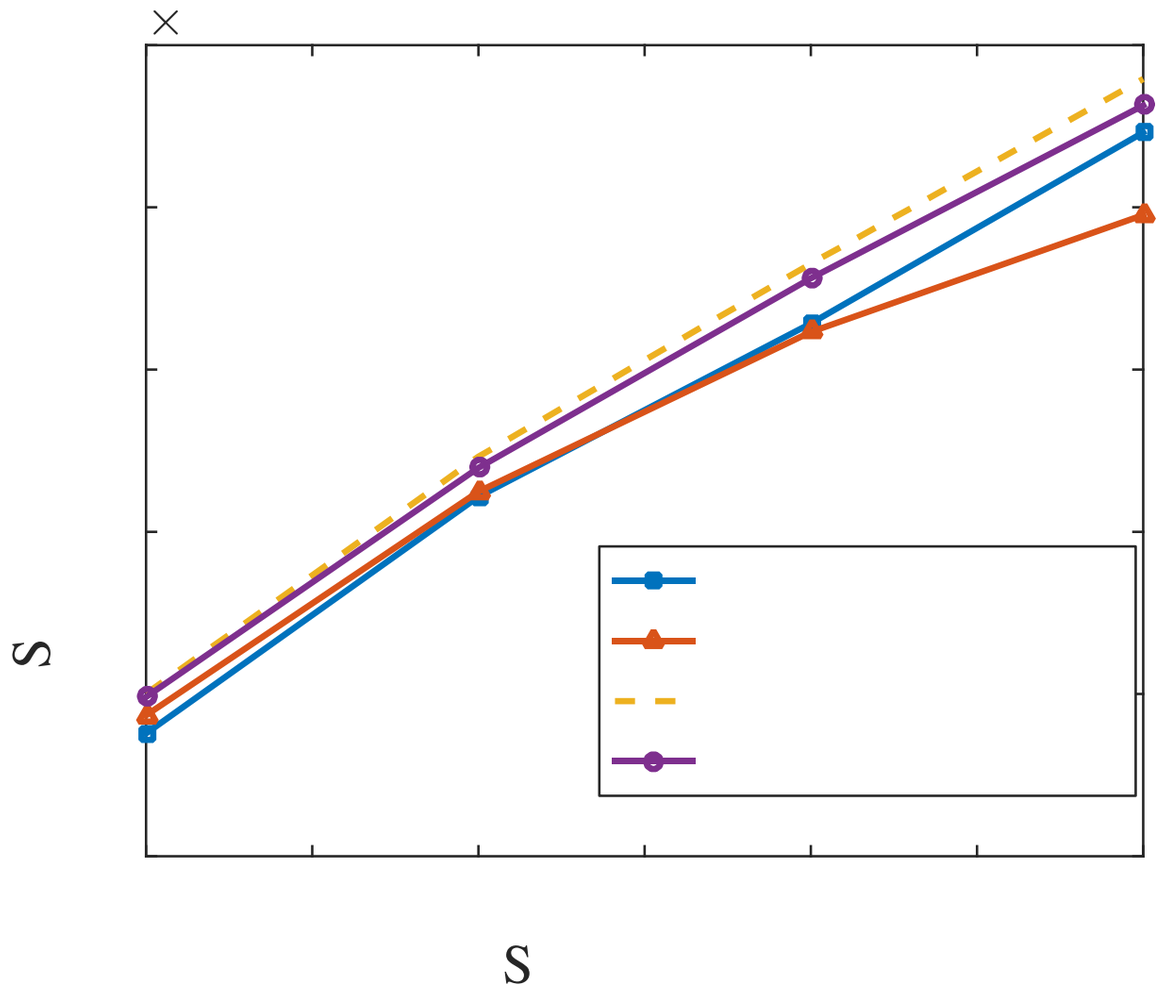


Experiment result



Conclusions

- We investigate the data downloading strategy from a hybrid network (RSUs and Cellular networks), considering the downloading cost and delay.
- We analyze two theoretical meeting distributions and propose an adaptive scheme.
- RSUs inter-meeting prediction.
  - Inter-meeting time and uncertainty

Future work: the content sharing between vehicles

Thank you!

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