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
    - ....
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.
• **With the increasing of data size**

• **A trade-off between the cost and delay**

  • *from the Cellular network:* 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**

\[ U_t = U_0 - at \]

• **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 utility 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:

![Graphs showing inter-meeting time distribution for No.3204 bus and No.5676 bus.]](image)
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 $a / 2\lambda > c$. 
• **Gaussian inter-meeting distribution**

![Graphs showing probability density function and expected encountering time](image)

(a) Probability density function  
(b) Expected encountering time

• **Theorem:** For Gaussian distribution of the encountering time between the vehicle and RSUs, the criterion for choosing the cellular network right now is  

\[
\frac{(T^e)^{\beta+1} \alpha}{\beta} > c.
\]
multiple RSUs

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

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

• 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

<table>
<thead>
<tr>
<th>bandwidth</th>
<th>Cellular</th>
<th>RSUs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kbps</td>
<td>20</td>
<td>100</td>
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- 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

![Graph showing satisfaction of user (Y-axis) against a variable U (X-axis).]
Experiment result

Satisfaction of user vs C

Center for Networked Computing
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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