Enhancing Mobile Data Offloading with Mobility Prediction and Prefetching

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Motivation and objectives

• Investigate mobile data offloading gains from
  – Mobility prediction:
    • Human mobility patterns, vehicular route selection
  – Data prefetching:
    • Proactively cache data at WiFi hotspots

• Sensing capabilities of smartphones
  – Real-time travel data from crowd-sourcing: location & time
  – Can be used for best route selection (e.g. OptiPath app)
  – Can also collect real-time mobile & WiFi throughput information

Mobility and throughput information
Motivation and objectives (cont.)

• Consider both delay tolerant & delay tolerant traffic
  – Delay tolerant: increase percentage of offloaded traffic
  – Delay sensitive: reduce transfer delay
• Evaluation
  – When are there gains and how much gains
  – How gains depend on mobile/WiFi throughput, data object size, time & throughput errors

Relation to prior work

Prior work:
• Cellular and WiFi throughput is predictable
• Throughput prediction can be used to improve media streaming quality
• Delay tolerance can improve mobile data offloading
• Prefetching is possible and can improve video streaming/reduce network load

Our work:
• Develop and evaluate procedure to exploit mobility & throughput prediction and prefetching for mobile data offloading
• Specific procedures adapted to delay tolerant and delay sensitive traffic
• Robustness to location/time & throughput estimation errors
OptiPath: Optimal Route Selection Based on Location Data Collected from Smartphones

- Exploit sensing capabilities of smartphones
  - Real-time travel data: location & time
  - Collect data in central server (crowd-sourcing)
- Select route with shortest travel time
  - Obtain alternate routes from Google maps
  - Use real-time travel data to estimate travel time
- Consists of Android client & centralized server
Application to mobile data offloading

- Client-server system (crowd-sourcing) similar to systems that build database with GPS and network access & throughput information

Travel data (location & time)

Intelligent mobile offloading procedure

WiFi location, mobile & WiFi throughput

Mobility and throughput information
Mobility and throughput information

<table>
<thead>
<tr>
<th>Segment</th>
<th>Access</th>
<th>Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>mobile</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>WiFi</td>
<td>12</td>
</tr>
<tr>
<td>3</td>
<td>mobile</td>
<td>32</td>
</tr>
<tr>
<td>4</td>
<td>WiFi</td>
<td>149</td>
</tr>
<tr>
<td>5</td>
<td>mobile</td>
<td>157</td>
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<tr>
<td>6</td>
<td>WiFi</td>
<td>227</td>
</tr>
<tr>
<td>7</td>
<td>mobile</td>
<td>233</td>
</tr>
</tbody>
</table>

Route is assumed to be known (e.g. provided by a route selection app)

Intelligent mobile offloading

- Offloading mobile data to WiFi already used today
- Can we achieve/how much better performance in terms of
  - increased percentage of offloaded traffic?
  - reduced transfer delay?
- Different handling of delay tolerant and delay sensitive traffic
Intelligent mobile offloading for delay tolerant traffic

- Delay tolerant: transfer data within given delay threshold
- Objective: reduce data transferred over mobile network
- Approach:
  - Use mobility and WiFi throughput prediction to estimate **max amount of data that can be offloaded to WiFi**
  - Compute **minimum mobile throughput** required to transfer remaining data
  - Above defines a **schedule for data transfer**

Behavior without prediction/prefetching

- Slope of mobile segment smaller than WiFi segment because mobile throughput lower than WiFi throughput
Illustration of gains from mobility & throughput prediction

- Smaller slope of mobile segments when prediction used indicates larger amount of offloaded data

Intelligent mobile offloading: prefetching

- Mobility and throughput prediction can be used to prefetch data in WiFi hotspots that will be encountered along route
- Gains if backhaul throughput of WiFi hotspot to Internet smaller than WiFi throughput
Illustration of gains from prefetching

![Graph showing gains from prefetching]

• Smaller slope of mobile segments and higher height of WiFi segments indicate larger amount of offloaded data

Intelligent mobile offloading for delay sensitive traffic

• Objective: minimize data transfer delay
• Approach:
  – Always use **maximum mobile throughput**
  – Use mobility and throughput prediction can be used to **prefetch** data in **WiFi hotspots** that will be encountered along route
Illustration of prefetching to reduce delay for delay sensitive traffic

- Prefetching increases height of WiFi segments: increases amount of data transferred over WiFi, hence reduce delay

Evaluation

- Numerically compute data transfer for different parameter values
- Consider empirical measurements obtained using the OptiPath applications for a journey between two locations in Athens, Greece
  - *When and how much do we gain from using prediction and prefetching*
  - *Investigate robustness to time and throughput estimation errors*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data object size</td>
<td>10, 20 (default for delay sensitive), 30 (default for delay tolerant), 40, 50 MB</td>
</tr>
<tr>
<td>Mobile throughput</td>
<td>1 Mbps (average)</td>
</tr>
<tr>
<td>WiFi throughput</td>
<td>10 Mbps (average)</td>
</tr>
<tr>
<td>Backhaul throughput</td>
<td>2.5, 5 (default), 7.5 Mbps</td>
</tr>
<tr>
<td>Time error</td>
<td>10% (default), 20%, 30%, 40%</td>
</tr>
<tr>
<td>Throughput error</td>
<td>20% (default), 40%, 60%</td>
</tr>
</tbody>
</table>
Delay tolerant traffic: influence of data object size

![Chart showing the influence of data object size on offloaded traffic for different backhaul throughputs and prediction/prefetching scenarios.]

Delay tolerant traffic: influence of backhaul throughput

![Chart showing the influence of backhaul throughput on offloaded traffic for different backhaul throughputs and prediction/prefetching scenarios.]
Delay tolerant traffic: influence of time errors

- Time errors: errors in estimating when and for how long WiFi connectivity will be available

**Diagram:**
- Offloaded traffic vs. Time error
- Mobile & WiFi, +prediction, +prefetching, without prediction

Delay tolerant traffic: influence of throughput errors

- Throughput errors: errors in estimating mobile and WiFi throughput

**Diagram:**
- Offloaded traffic vs. Throughput error
- Mobile & WiFi, +prediction, +prefetching, without prediction
Delay sensitive traffic: influence of data object size

Delay sensitive traffic: influence of time errors
Cache requirements for prefetching

Conclusions

- Investigated procedures to exploit mobility & throughput prediction and prefetching for mobile data offloading
  - Delay tolerant and delay sensitive traffic
  - Robustness to location/time and throughput errors
- Type of mobility and throughput information determines how this can be used
  - Mobility prediction assumed route is known
  - Different approach if route not known but information on probabilities for possible next hops is known => paper in Information Centric Networking (ICN) workshop @ SIGCOMM 2012