TOMP: Opportunistic Traffic Offloading Using Movement Predictions

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Outline

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Motivation (1)

- **Cellular traffic** (e.g. UMTS, HSDPA) is rapidly increasing
  - Cisco\(^1\): No. of mobile Internet users double every year until 2015
  - Ericsson\(^2\): Smartphone traffic will increase by factor 10 until 2016
  ➤ Cellular networks will soon reach their **critical limit**

- What are possible **solutions**?
  - Reduction of network cell size ➔ big manual effort
  - Going back to volume-based pricing ➔ not very attractive for users
  - Utilizing ad-hoc communication techniques ➔ **Opportunistic traffic offloading**

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Motivation (2)

- **Opportunistic Traffic Offloading** tackles this problem for multicast communication patterns
  - Data from the infrastructure is sent to only a *subset* of receivers
  - Devices use ad-hoc communication (e.g. Wifi-Direct, Bluetooth) to forward data opportunistically

Requires suitable strategies for cellular receiver selection for optimal performance
Contributions

- We propose an **opportunistic traffic offloading approach**…
  - that only utilizes **device positions** for receiver selection
  - that uses position based **coverage predictions** for receiver selection

- We show that …
  - our approach **reduces the cellular message load** by up to 40%
  - the additional **message delay** that is introduced by this approach is negligible
System Model

• Mobile devices
  ◦ Position sensor (e.g. GPS)
  ◦ Ad-hoc comm. interface with range $r_{adhoc}$
  ◦ Cellular network interface

• Server
  ◦ Knowledge of road graph
  ◦ Cellular network interface

• Cellular Communication
  ◦ $\tau_s$: Estimated message delay for message of size $s$
  ◦ But: Real time guarantees on delay cannot be given
Problem Statement

- **Given**
  - Message $m$
  - Message delivery time $t_d$
  - Set of mobile devices $R$ to receive $m$

- **Goal**
  1. Deliver $m$ to all devices in $R$ before $t_d$
  2. Minimize data transfer on the cellular layer

- **Problem**
  - To which subset $R' \subseteq R$ of devices should $m$ be sent to minimize cellular traffic?
Naïve Approach

- Server broadcasts $m$ to all devices in $R$
  \[ \rightarrow \text{Current situation in cellular networks} \]

- No ad-hoc forwarding of message
- Cellular networks load is maximized:

\[
\text{network load} = |R| \times \text{size}(m)
\]
Opportunistic Extension

- Server sends $m$ to only subset of devices $R' \subseteq R$
- Cellular networks load reduced to: $|R'| \times \text{size}(m)$

**General Approach:**

1. Determine $R'$ (see upcoming slides)
2. Send $m$ to all devices in $R'$
3. Devices forward $m$ to other devices until $t_d$
4. Devices send ACK to server when $m$ is received
5. At time $t_d - \tau_s$:
   - Server sends $m$ to missing devices
Determine $R'$: Static Coverage

- To reduce cellular traffic, $R'$ should be selected in a way that number of ad-hoc messages exchanges is maximized.
- Assumption: Server knows position of devices at $t_{start}$.
- Idea: Find minimum subset of devices that can cover all other devices with an ad-hoc broadcast $\rightarrow$ Set-Coverage-Problem (NP-hard).

Determine $R'$: Prediction-based Coverage

- Static coverage only considers device position at time $t_{\text{start}}$
- However: Devices can exchange $m$ until $t_d$ and therefore reach more other devices than indicated by the static coverage:

\[
|R'| = 2 \quad \text{After } i \text{ time steps} \quad |R'| = 1
\]

- However: Future movement path of a device is unknown at $t_{\text{start}}$
  → Selection of $R'$ is based on prediction of future movement of devices
Future Coverage Prediction

- Use fraction of overlapping future path as heuristic for coverage
- Project all possible paths with length $s_{max}$ on graph

$$s_{max} = v_{max} \times (t_d - t_{start})$$

$$\text{coverage}(n_i, n_j) = \frac{\text{overlappingPath}(i, j)}{\text{path}(i) + \text{path}(j)}$$

- Extend greedy set-covering algorithm to find $R'$ (see paper)
- Use coverage-metric to identify devices with largest coverage
Evaluation – Setup

- Simulation in ns-2 on road graph of Stuttgart (4 km²)
- CanuMobiSim mobility traces (pedestrian speed)
- Message size: 1 MB
- Communication networks:
  - Ad-hoc forwarding: Bluetooth, range: 10 meters
  - Cellular network: HSDPA, 16 base stations
- Comparison of different approaches:

<table>
<thead>
<tr>
<th>Approach</th>
<th>Reference As</th>
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</thead>
<tbody>
<tr>
<td>1 Broadcast message to all devices in $R$</td>
<td>NAIVE</td>
</tr>
<tr>
<td>3 Choose $R' \subseteq R$ on base of the static coverage</td>
<td>STATIC</td>
</tr>
<tr>
<td>4 Choose $R' \subseteq R$ on base of the predictive coverage</td>
<td>PREDICTION</td>
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Evaluation – Results (1)

→ Number of cellular messages decrease by up to 40%

→ Additional message delay concerns only small fraction of devices
Evaluation – Results (2)

→ Prediction approach chooses the smallest receiver set $R'$

→ Prediction approach maximizes number of ad-hoc message exchanges
Related Work

• Cellular Traffic Offloading
  ◦ [Balasubramanian et al. 2010], *Augmenting Mobile 3G Using WiFi*
  ◦ [Dimatteo et al. 2011], *Cellular Traffic Offloading Through WiFi Networks*
    → No opportunistic message forwarding, only stationary WiFi-APs

• Opportunistic Traffic Offloading
  ◦ [Han et al. 2010], *Cellular Traffic Offloading Through Opportunistic Communication: A Case Study*
    → Selection of $R'$ based on social contact history of devices → privacy critical
  ◦ [Whitbeck et al. 2010], *Relieving the Wireless Infrastructure: When Opportunistic Networks Meet Guaranteed Delays*
    → Selection of $R'$ based on device density, size of $R'$ is fixed → not considering actual coverage relations
Conclusion and Future Work

Conclusion

• Opportunistic traffic offloading reduces the cellular network load by up to 40%
• Additional delay of the system is negligible small
• Use of movement predictions results in an appropriate receiver set, that shifts most of the communication to the ad-hoc network

Future Work

• Investigate further heuristics for the receiver set selection
• Implement an adaption mechanism that redistributes $m$ over time, depending on the number of received ACK-messages
Thanks for your attention

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