A Distributed Protocol for Crowd Counting in Urban Environments

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Introduction & motivation

- Focus on a specific class of distributed tasks
  - Crowd counting in urban environments
  - Each node periodically broadcasts its crowd size estimate
  - Received crowd size estimates are integrated into the own estimate

- Decentralized counting of current crowd size in an area
  - Dispensation with cameras (quality, privacy)
  - Nodes = moving pedestrians with mobile phones
  - Device-to-device (D2D) communication for disseminating crowd size estimates
A Distributed Protocol for Crowd Counting

- Objective: each node calculates local estimate of crowd size

- Requirements
  - Each node has to keep track of the estimates of other nodes
    - Shared nodes: nodes that one got to know about
    - Left nodes: nodes that left
  - No (shared/left) node may be counted more than once
    - Bit vectors (1=node there/left, 0=node not there/left)?
      - 1 1 1 0 0 0 0 0 0 0 0 0
      - 0 0 1 0 0 0 0 0 0 0 0 0
  - Each bit vector position represents
  - Memory-efficient storage of crowd size estimates
    - Messages to be sent are size-limited
    - Devices may have limited storage capabilities
    - There may be restrictions on the memory to be used
      - Compressed representation of bit vectors = D-GAP
A Distributed Protocol for Crowd Counting

- Mobility scenarios are characterized by (among other things)
  - **Node arrival rate** $\lambda$: nodes arrive with $\lambda$ in an area of size $A$
  - **Node lifetime** $T$: nodes stay in an area for some time $T$
  - **Crowd density** $\rho$: $\rho = T \cdot \lambda / A$ (Little's law)
Selected mobility scenarios for evaluation

- (a) Outdoor urban scenario (Östermalm, central Stockholm)
  - Active area: 5872 m², different arrival rates $\lambda$
- (b) Indoor scenario (two-level subway station)
  - Active area: 1921 m², fixed arrival rate $\lambda$

- Based on realistic mobility traces (http://crawdad.org/kth/walkers/)
Simulation setup

- All nodes carry devices
- All nodes keep track of two compressed bit vectors
  - Shared nodes: nodes that one got to know about
  - Left nodes: nodes that left

- Opportunistic content distribution system implemented in OMNeT++ modeling framework MiXiM
- Simulation runs are executed in synchronous rounds of 0.6 s
- Nodes broadcast at the beginning of each round
  - Broadcast transmissions are distributed uniformly at random $\mathcal{U}(0; 0.5)$ s to avoid collisions
- Transmission range is set to 10 m
Selected simulation results: effect of arrival rate $\lambda$

- Realistic outdoor urban scenario (Östermalm, central Stockholm) with different arrival rates $\lambda$

- Local estimates of all nodes:

<table>
<thead>
<tr>
<th></th>
<th>Arrival rate $\lambda$ [nodes/s]</th>
<th>Node lifetime $T$ [s]</th>
<th>Crowd density $\rho$ [nodes/m²]</th>
<th>Nodes in the area on average</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>0.42</td>
<td>327</td>
<td>0.02</td>
<td>137</td>
</tr>
<tr>
<td>(b)</td>
<td>0.98</td>
<td>318</td>
<td>0.05</td>
<td>312</td>
</tr>
<tr>
<td>(c)</td>
<td>2.1</td>
<td>293</td>
<td>0.1</td>
<td>614</td>
</tr>
</tbody>
</table>
A Distributed Protocol for Crowd Counting in Urban Environments

\( \lambda = 0.42 \text{ s}^{-1} \)

\( \lambda = 0.98 \text{ s}^{-1} \)

\( \lambda = 2.1 \text{ s}^{-1} \)

\( \rho \geq 0.1 \text{ nodes/m}^2 \)

Accuracy \( \geq 95\% \)
Selected simulation results: effect of arrival rate $\lambda$

- Realistic indoor scenario (subway) for arrival rate $\lambda = 0.15$ nodes/s

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</thead>
<tbody>
<tr>
<td>0.15</td>
<td>195</td>
<td>0.1</td>
<td>205</td>
</tr>
</tbody>
</table>

Accuracy $\geq 93\%$
Summary

● **Contribution:** A new distributed protocol for mobile crowd counting in urban environments

● High accuracy in environments with high node mobility & churn while preserving privacy

● Simulation results for synthetic and realistic mobility
  - Minimum required crowd density 0.1 nodes/m²
  - Not shown in presentation: synthetic mobility (city square model)
    - At least 98 % accuracy for up to 2400 nodes
  - Shown in presentation: realistic mobility (Östermalm, subway)
    - At least 93 % accuracy for up to 1035 nodes

● Outlook
  - Evaluation as real application implementation in a realistic testbed
Thank you for your attention!

Questions?