Efficient Social-aware Content Placement in Opportunistic Networks

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a delay - tolerant environment

A wireless network that is very sparse and partitioned

✓ disconnected clusters of nodes appear

• Nodes are highly mobile making the clusters change often over time
• No contemporaneous end-to-end path
graph representation of a DTN

A graph that stands for a DTN: add an edge between two nodes if

✓ the frequency of encounters
or
✓ the cumulative time of direct contact

exceeds a pre-defined threshold
approximate solution to the classic facility location problem

- **K-median problem**: given a fixed number of facilities, minimize the total service cost

\[
Cost(\mathcal{F}) = \sum_{n \in \mathcal{V}} w_n \cdot \min_{x_j \in \mathcal{F}} \{d(x_j, n)\}
\]

- \(d(k, n)\) : cost path between nodes \(k, n\)
- \(w_n\) : demand generated by node \(n\)

- To cope with constraints, use:
  1. Local topology info
  2. Local demand info

the R-balls heuristic*

- Solve the optimization problem within a limited neighborhood of selected facilities
- Implicit computation of the demand generated by outer nodes

content placement: a social-aware approach

1-Median Problem: Determine the physical location of content’s single host, in a way that a cost metric is minimized

- Instead of a large optimization problem, solve iteratively small-scale ones, on subgraphs $G^i \in G$,
  trying to reach the optimal
- Pick $G^i$ nodes around host $i$ according to a social-inspired criterion
- Criterion should achieve quantification of demand from nodes not included in $G^i$

assuming uniform demand
content placement: a social-aware approach

Betweenness Centrality \((u)\): portion of all pairs shortest paths of \(G\) that pass through node \(u\)

\[
BC(u) = \sum_{s=1}^{V} \sum_{t=1}^{V} \frac{\sigma_{st}(u)}{\sigma_{st}}
\]

Conditional Betweenness Centrality \((u, t)\): portion of all shortest paths of \(G\) from node \(u\) to target \(t\), that pass through node \(u\)

\[
CBC(u; t) = \sum_{s \in V, u \neq t} \frac{\sigma_{st}(u)}{\sigma_{st}}
\]

a measure of the importance of node's \(u\) social position: lies on paths linking others

a measure of the importance of node's \(u\) social position: ability to control information flow towards target node
content placement: a social-aware approach

CBC criterion

- small-scale 1-median solution derived from any cost-effective algorithm (i.e. approx., heuristic, enumeration)

Algorithm 1 Social-aware 1-median in $G(V,E)$
1. choose randomly node $s$
2. place CONTENT in $s$
3. $C_{current} \leftarrow \infty$
4. $\forall u \in G$ compute $CBC(u; s)$
5. let $G^o_s$ be $\alpha$% of $G$ nodes with top $CBC$ values
6. 1-median solution in $G^o_s \rightarrow$ node Host
7. $C_{next} \leftarrow C(\text{Host})$
8. while $C_{next} < C_{current}$ do
9. move CONTENT to Host
10. $C_{current} \leftarrow C_{next}$
11. $\forall u \in G$ compute $CBC(u; \text{Host})$
12. let $G^i_{\text{Host}}$ be $\alpha$% of $G$ nodes with top $CBC$ values
13. 1-median solution in $G^i_{\text{Host}} \rightarrow$ node NewHost
14. Host $\leftarrow$ NewHost
15. $C_{next} \leftarrow C(\text{NewHost})$
16. end while
content placement: a social-aware approach

• CBC criterion picks neighboring nodes to the host

• Selected nodes “stretching” in a certain direction

• Solution space moved by selection towards directions populated by capable nodes of transporting information efficiently

• “Socially significant” direction is valid under any demand model but exploited only under uniform demand hypothesis
Simulation Settings

• Generate both E-R and B-A random graphs of $N=100$ nodes
• 10 simulation runs for any chosen configuration
• Results presented are the averages over the runs
• Regenerate the graph for each simulation run
• Probability of a link to exist approximates the theoretical value of the target graph model
simulation results ($\frac{1}{3}$)

Mean normalized cost ratio $= f$ (percentage of nodes)

Standard Error associated with each mean:  $0.07\% \leq SE \leq 2.88\%$
simulation results (2/3)

- **Random policy**: place the content on a randomly selected node and serve demands

  - Test the most costly scenario: \( \max \beta_{\text{algorithm}}(\alpha) = \beta_{\text{algorithm}}(0.1) \)

\[
\beta_{\text{algorithm}}(\alpha) = E\left[ \frac{C_{\text{algorithm}}}{C_{\text{optimal}}} \right] \\
\beta_{\text{random}} = E\left[ \frac{C_{\text{random}}}{C_{\text{optimal}}} \right]
\]

SOCIO-AWARE 1-median VS SIMPLE RANDOM PLACEMENT

<table>
<thead>
<tr>
<th>E-R graphs</th>
<th>B-A graphs</th>
</tr>
</thead>
<tbody>
<tr>
<td>max. ( \beta_{\text{algorithm}} )</td>
<td>max. ( \beta_{\text{algorithm}} )</td>
</tr>
<tr>
<td>( \beta_{\text{random}} )</td>
<td>( \beta_{\text{random}} )</td>
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<tr>
<td>1.0938</td>
<td>1.0366</td>
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<tr>
<td>1.2736</td>
<td>1.4953</td>
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</tbody>
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simulation results (3/3)

Demand mapping

• New demand model for the small-scale optimization to improve performance
• Mapping between CBC values of subgraph $G^i$ and incoming demand load
• When the percentage of participating nodes $\to 1$, we solve a different problem
future work

✓ study whether such mechanisms can be effectively applied

✓ consider the threshold-based mapping of contacts to static graphs

✓ expand this work to include non-uniform demand patterns
Questions ?