Design of Routing Protocols and Overlay Topologies for Topic-based Publish/Subscribe on Small-World Networks

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Pub/Sub

• Many applications and standards
  – Online social networks, financial data dissemination, application integration, RSS feed distribution, business process management
  – MQTT, XMPP, etc.

• Industrial adoptions
  – IBM Internet of Things (IoT) Foundation
  – Google GooPS
  – Yahoo PNUTS
  – Facebook
  – Twitter
2 major directions for pub/sub

Overlay topologies
Construction of overlay topologies such that network traffic is minimized

Routing protocols
Design of routing protocols which disseminate messages efficiently atop overlay
2 major directions for pub/sub

Overlay topologies

Routing protocols
Merely one is NOT enough
Merely one is NOT enough

Routing only
- Difficult to scale
- Sophisticated matching
- Large forwarding tables
Merely one is NOT enough

Overlay only
• Structured
  heavy *routing overhead*, i.e., irrelevant messages forwarding
• Unstructured
  topic-connected overlay (TCO) with unbounded node degrees

Routing only
• Difficult to scale
• Sophisticated matching
• Large forwarding tables
Our contributions

• Combine both routing and overlay for pub/sub
• Achieve the best of both worlds
  – Overlay: small-world and interest-close
  – Routing: efficient w.r.t. overhead and latency
Small-world and interest-close overlay
Small-world networks for pub/sub

- $V$ node set, $T$ topic set, $I$ interest function
- Each $v \in V$ has unique id from $[0, |V|)$
- Each $v \in V$ maintains $\theta(\log |V|)$ small-world fingers, its $i$-th finger links to a node in the $i$-th small-world phase

$$v.swFinger[i] \in \left[ v + 2^i, v + 2^{i+1} \right), i \in \left[ 0, \log |V| \right), v \in \left[ 0, |V| \right)$$
Small-world networks for pub/sub

\[ v_{\text{swFinger}}[i] \in [v + 2^i, v + 2^{i+1}), i \in [0, \log |V|), v \in [0, |V|) \]
Interest-close: beyond small-world

• One drawback of typical small-world networks heavy routing overhead, # irrelevant messages

• Another desirable: interest closeness nodes with similar interests are close to each other
Small-world and interest-close overlay

Problem statement

Obj. maximize interest-closeness
s.t. the overlay is a small-world network
Greedy heuristic for small-world and interest-close overlay

GrSwico

Input: \((V, T, I)\)
Output: \(E\)

1. \(E \leftarrow \emptyset\)
2. while \(E\) does not form small-world network
3. greedily add to \(E\) the most cost-effective edge
4. return \(E\)
Greedy heuristic for small-world and interest-close overlay

GrSwico

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Routing: nearest subscribers and matched fingers (NSMF)
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msg \([1,10]\)

1.nearestSub(t)
Routing: nearest subscribers and matched fingers (NSMF)

msg \([1,10)\)

phase 0

phase 1

phase 2

phase 3

1. nearestSub(t)

1. nearestSub(t)
Routing: nearest subscribers and matched fingers (NSMF)

msg \([1,10)\)

phase 0

msg \([7,10)\)

msg \([5,7)\)

1.\texttt{nearestSub}(t)
Routing: nearest subscribers and matched fingers (NSMF)
Evaluation – pub/sub workloads

- Number of nodes $|V|$: [1000, 10,000]
- Number of topic $|T|$: [1000, 10,000]
- Subscription size on average: 20
- Topic popularity
  - Uniform: [Chockler et al., 2007]
  - Zipf: news feed in RSS [Liu et al., 2005]
  - Exponential: stock in NYSE [Tock et al., 2005]
Evaluation – comparison baselines

• Chord
  a DHT that always selects the finger as the first node in each small-world phase
  \[ v_{swFinger}[i] = v + 2^i, i \in [0, \log|V|), v \in [0,|V|) \]

• RandomSW
  a small-world network that randomly chooses the finger in each small-world phase
Evaluation

(a) Routing overhead

(b) Average path length

(c) TCO support ratio
Evaluation

Reducing $\geq 30\%$ of the costs in
- routing overhead
- message latency

(a) Routing overhead

(b) Average path length

(c) TCO support ratio
Conclusion

- Incorporate basic principles of small-world networks and TCOs into practical design for pub/sub systems
- Important and beneficial to combine routing and overlay for pub/sub
- Great potential to improve both routing protocols and overlay qualities
Backup slides
Topic-connected overlay (TCO)

An overlay $G$
Topic-connected overlay (TCO)

An overlay $G$ with one $TC$-component $G^{(a)}$ is topic-connected with one $TC$-component.
Topic-connected overlay (TCO)

An overlay $G$ is topic-connected with one $TC\text{-component}$.

$G^{(b)}$ is NOT topic-connected with two $TC\text{-components}$.
TCO support ratio

\[ TcoSuppR = \frac{TCC(\phi) - TCC(E)}{TCC(\phi) - TCC(K)} \]

#TCCs that have been reduced by adding E

#TCCs that should be reduced to achieve a TCO