Graph-based Namespaces and Load Sharing for Efficient Information Dissemination in Disasters

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ICNP 2019
Information dissemination in disasters

• Communication and information dissemination key in disaster management
  • Many-to-many, according to roles (e.g., instruction to all firefighters)
  • Many actors interacting with complex & dynamic relationships
  • Non-uniform demand: traffic concentration and congestion
• Timeliness, relevance, coverage are important requirements
  • Timeliness: Information delivered in a timely manner
  • Relevance: Information delivered to the relevant people
  • Coverage: Information delivered to everyone who needs it
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• POISE: Information dissemination for disaster management
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- **POISE**: Information dissemination for disaster management enabling role-based pub/sub, supporting graph-based namespaces, with automatic load splitting
Graph-based namespace for disaster management

- Information flow organization
- Multi-dimensional structure
- Nodes are names. Edges are name relationships
Graph-based namespace for disaster management

- Information flow organization
- Multi-dimensional structure
- Nodes are names. Edges are name relationships
- “NJ Fire” denotes all fire-related tasks in New Jersey
- “NJ FE1” (NJ fire engine 1) is a higher-level authority than “F.Fighter2” (fire fighter 2)
Graph-based namespace for disaster management

- Many different sub-namespaces
  - Organizations, incidents
- New names/roles for an incident can be added
  - Incident X sub-namespace added

Diagram:

- Regular organization
  - Geo-Location
  - First Response
    - Police
    - Fire
    - NJ Fire
      - NJ FE3
      - NJ FE2
      - NJ FE1
      - Driver 1
      - F. Fighter 1
      - F. Fighter 2
  - Incident-specific organization
    - Incident X
      - Inc. X Fire
      - Inc. X EMS
      - Fire Fighting
      - Survival Search
Graph-based namespace for disaster management

- Many different sub-namespaces
  - Organizations, incidents
- New names/roles for an incident can be added
  - Incident X sub-namespace added
- Edges can be added/removed
  - “NJ FE2” and “F. Fighter 2” dispatched for “Fire Fighting” in Incident X
Graph-based namespace for disaster management

• First responders subscribe to (“listen to”) names
  • Roles they are associated with
    • FM3 subscribe to/responsible for “F.Fighter 1”
  • At appropriate level of granularity
  • They will receive publications to those name whenever published

• Incident commanders (or any users) “publish” to names
  • Publications to “F. Fighter 1” will reach FM3 and FM4

• Recipient-based pub/sub (CNS[ICN’16]), but w graphs
Graph-based namespace for disaster management

• Name expansion
  • Publishing to a name: implicitly publishing to all its descendants as well

Publish to “NJ Fire” [Content]

Will receive publication

<table>
<thead>
<tr>
<th>Location</th>
<th>First Response</th>
<th>Incident X</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>Police</td>
<td>Inc. X Fire</td>
</tr>
<tr>
<td>NJ</td>
<td>Fire</td>
<td>Inc. X EMS</td>
</tr>
</tbody>
</table>

Insert diagram here
Graph-based namespace for disaster management

- Without name expansion, one separate publication for every name in the sub-graph should be generated, with same content

- Too many messages; too many duplications

Will receive publication
Graph-based namespace for disaster management

• Name expansion
  • Publishing to a name: implicitly publishing to all its descendants as well

Publish to “NJ Fire” [Content]
Graph-based namespace for disaster management

• Name expansion
  • Publishing to a name: implicitly publishing to all its descendants as well
  • Subscribing to a name: implicitly subscribing to all its ancestors as well
Graph-based namespace for disaster management

• Name expansion
  • Publishing to a name: implicitly publishing to all its descendants as well
  • Subscribing to a name: implicitly subscribing to all its ancestors as well
  • Greatly decreases subscription & publication messages (network resources and user load)
  • Need to support in the network
Support graph-based namespaces in the network

• Need support in network (multicast) for efficient delivery
• IP multicast is feasible but has issues
  • Flat IP address space, cannot capture multicast-group inter-relationship
• Information-Centric Networking (ICN) enables name-based multicast
  • However, state-of-the-art supports hierarchical naming in the network: Named Data Networking (NDN)
Graph-based pub/sub using traditional ICN

ICN Layer

Strictly hierarchical namespace

Hierarchical name-based forwarding

Convert to hierarchy

FIIB entries

/IncidentX/IncXFire/F.Fighting/F.Fighter2
/FirstResponse/Fire/NJFire/NJFE1/F.Fighter2
/Geo-Location/NJ/NJFire/NJFE1/F.Fighter2
...

Routing
Graph-based pub/sub using traditional ICN

Geo-Location

CA
NJ

First Response
Police
Inc. X Fire
Inc. X EMS

Geo-Location

NJ Fire
Fire Fighting
Survival Search

Geo-Location

NJ FE1
NJ FE2
NJ FE3

F. Fighter 2
Driver 1
F. Fighter 1

Convert to hierarchy

ICN Layer

Strictly hierarchical namespace

Hierarchical name-based forwarding

“F. Fighter 2” appears as three separate entries in the FIB

To publish to “F. Fighter 2”, three publications need to be made

“F. Fighter 2” appears three times in the hierarchical equivalent

Adding a child to “F. Fighter 2” requires three modifications

/IncidentX/Inc.XFire/F.Fighting/F.Fighter2
/FirstResponse/Fire/NJFire/NJFE1/F.Fighter2
/Geo-Location/NJ/NJFire/NJFE1/F.Fighter2

...
Support graph-based namespaces in the network

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• IP multicast is feasible but has issues
  • Flat IP address space, cannot capture multicast-group inter-relationship
• Information-Centric Networking (ICN) enables name-based multicast
  • However, state-of-the-art supports hierarchical naming in the network: Named Data Networking (NDN)
    • Will have to convert complex namespace graph to its hierarchical equivalent first
    • Issues: too many duplications, large FIB sizes, not very flexible with frequent namespace churning
• POISE: decouple ICN layer to Information Layer (namespace management) and Service Layer (name-based forwarding)
Graph-based pub/sub using POISE
Information dissemination procedure

- Rendezvous Points (RPs) are distribution nodes for parts of the namespace

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- Rendezvous Points (RPs) are distribution nodes for parts of the namespace.

- Geo-Location:
  - CA
  - NJ

- First Response:
  - Police
  - Fire

- Incident X:
  - Inc. X Fire
  - Inc. X EMS

- NJ Fire:
  - NJ FE1
  - NJ FE2
  - NJ FE3

- Drivers:
  - Driver 1
  - F. Fighter 1
  - F. Fighter 2

- Rendezvous Points (RPs):
  - RP1
  - RP2
  - RP3
  - R1
  - R2
  - R3
  - R4
  - R5
  - R6
Information dissemination procedure

- RP1 and RP2 each maintain a (disjoint) subset of the namespace.
- Name-RP mapping resolves names to RP id.
  - Similar to group-to-RP mapping typical in multicast.

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NAME-RP Mapping
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MAP NAME RP
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Information dissemination procedure

• RPs also act as the core of multicast trees for their names
• Subscribers (firemen 1-5) join the multicast trees
Information dissemination procedure

- Incident Commander wants to publish content (e.g., instructions) to “Fire Fighting”
Information dissemination procedure

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  - Resolved to RP2 (look up by first-hop router R4)
Information dissemination procedure

- At RP
  - **Multicast** to name and descendants on the same RP
Information dissemination procedure

- At RP
  - **Multicast** to name and descendants on the same RP
  - **Unicast** to name if on another RP
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**Commander**

**To: NJ FE2**

[Content]
Information dissemination procedure

- **At RP**
  - **Multicast** to name and descendants on the same RP
  - **Unicast** to name if on another RP

- All subscribers of “Fire Fighting” and all its descendants receive the publication
Load splitting

• Different RPs experience different workloads
  • One RP may become a “hot spot” (RP1)
Load splitting

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**POISE provides**
- A workload-driven graph partitioning algorithm to find a balanced partitioning
- A seamless, reliable namespace migration
Graph partitioning

- Workload at RP represented as a labeled directed namespace graph
  - Nodes (names) initially labeled with explicit incoming request count in recent time window
Graph partitioning

- Workload at RP represented as a labeled directed namespace graph
  - Nodes (names) initially labeled with explicit incoming request count in recent time window
    - Example: “d” publications sent to name “D”
  - Goal: find a “good” partitioning to cut the namespace graph to two segments
Graph partitioning

- Prepared (partitionable) graph with multicast workloads added
Graph partitioning

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  - Node weights = # of messages to be multicasted for subscribers of node (e.g.: C)
    - Includes explicit publications to “C” plus publications to ancestors of “C”
  - Edge weights = # of messages going towards the child nodes

From “C” will be multicasted publications to “A”, “B”, and “C”
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Many ways to partition the graph
Graph partitioning

- Many ways to partition the graph
- Partitioning decision affects node weights
  - In Partitioning 1, weight of “C” is counting input from “A” once, twice in Partitioning 2
  - Two paths from A to C: both contained in one segment vs. both going across the cut
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- “Chicken and egg problem”
  - Objective function is a complex function of partitioning itself → Complex Objectives
  - State-of-the-art graph partitioners, such as METIS, fall short
    - METIS: Graph partitioner, high quality and fast; “gold standard in partitioning”
- POISE: hybrid graph partitioning: heuristic (METIS) + meta-heuristic (Tabu Search)
Graph partitioning

1. Prepare weighted graph (diffusion method)
2. Provide initial solution using METIS
3. Tabu search and report best solution found before stop
   • Objective: Minimize weighted function $F(G_1, G_2)$ for two segments $G_1$ and $G_2$
   • $F(G_1, G_2) = \alpha \cdot |TC(G_1) - TC(G_2)| + \beta \cdot \max(TC(G_1), TC(G_2)) + \gamma \cdot (UC(G_1) + UC(G_2))$
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     • Minimize imbalance of total workload (#total messages)
     • Minimize the maximum total workload of either segment
     • Minimize total unicast workload (inter-RP communication)
Graph partitioning

- **POISE: METIS+Tabu** outperforms other choices, on a graph G(50,84) *
  - METIS-only
  - Tabu-only
  - Random

- Impact of # of refinement iterations on quality of solution

*Input graphs from repository at “www.graphdrawing.org/data.html”*
Graph partitioning

- POISE: METIS+Tabu outperforms other choices, on a graph G(50,84)
  - METIS-only
  - Tabu-only
  - Random
- Impact of # of refinement iterations on quality of solution
- Evaluate with different graphs
  - METIS+Tabu (POISE) consistently better quality than METIS

**Objective:**

\[ F(G_1,G_2) = \alpha |TC(G_1) - TC(G_2)| + \beta \max(TC(G_1), TC(G_2)) + \gamma (UC(G_1) + UC(G_2)) \]

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Core migrations

• Goal: seamless and reliable core migration
• Example: migrate a tree from RP1 to RP2
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- New multicast tree at RP2 established
Experimental results

• Network simulation: evaluate the impact of POISE’s design on latency, traffic and queuing

• Simulation setup
  • Topology with 277 routers
  • Namespace: disaster management from Wikipedia
    • 489 nodes, 732 edges (hierarchical equivalent: 1,468 nodes)
  • Subscribers: 6 per name, randomly placed
  • Publications: 514,620 pubs with Poisson distribution
    • Increasing rate: 1,500pkt/s – 2,000pkt/s
      • Increasing as disaster events unfold and more people involved
  • Notification latency and aggregate network traffic are key metrics
Experimental results

• Hierarchical namespace-based approach sees huge latency due to more publications caused queueing on the RP (red line)

• Graph namespace (even w/o RP partitioning) does a lot better (blue line)

• Graph namespace has low notification latency (<100ms) with low rate, but queueing is still observed when publication frequency gets higher
Experimental results

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- Graph namespace (even w/o RP partitioning) does a lot better (blue line)
- Graph namespace has low notification latency (<100ms) with low rate, but queueing is still observed when publication frequency gets higher
- Our solution (POISE) reduces the latency with sensible RP splitting
Experimental results

- Average latency of POISE is many orders of magnitude smaller
- Aggregate network traffic
  - Our solution (POISE) introduced a slightly higher traffic (<1%), to get the very low notification latency
  - Graph namespace reduces network traffic (by 41.41%) compared to hierarchical name-based approach

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<tr>
<th>Solution</th>
<th>Avg. Notification Latency (s)</th>
<th>Aggregate Network Traffic (Gb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hierarchical name-based</td>
<td>247.742</td>
<td>866.27</td>
</tr>
<tr>
<td>Graph w 1 RP</td>
<td>2.741</td>
<td>483.08</td>
</tr>
<tr>
<td>Graph w RP splitting (POISE)</td>
<td>0.018</td>
<td>492.39</td>
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Experimental results

• Intensify the publication workload
  • To observe the difference in extreme traffic
  • 514,620 pubs with increasing rate:
    1,500 pkt/s – 2,000 pkt/s
    1,500 pkt/s – 3,500 pkt/s

• Compare choice of graph partitioning
  • METIS
  • POISE: METIS+Tabu
    • Better queue size balance between two RPs
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    • Better notification latency
      • Average: 0.396s vs. 0.583s
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    • Better queue size balance between two RPs
    • Better notification latency
      • Average: 0.396s vs. 0.583s

• Using this hybrid graph partitioning,
  POISE enables a load sharing with smaller latency and better balance
Summary

• POISE: Information dissemination enabling role-based pub/sub, supporting graph-based namespaces, with automatic load splitting --- use case: disaster management
  • POISE’s Graph-based pub/sub outperforms hierarchical name-based pub/sub
  • POISE’s graph partitioning outperforms METIS
  • POISE’s RP migration is seamless and reliable