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SOLA: A Decentralized Communication Middleware Developed with ns-3

WNS3 2023, June 28–29, 2023, Arlington, VA, USA
Motivation
The world is changing...

Supply Bottlenecks

Pandemic

Mass Production

Customized Products

Flexibility
Transparency
Functionality
Robustness
Scalability
(Re-)Configuration

[Btv14], [LDE22], [Sta20]

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[Btv14], [LDE22], [Sta20]
Paradigm Shift
From centralized towards decentralized control
Autonomous Mobile Robots

Example Fraunhofer evoBOT™

Robotic System are becoming more and more versatile

Robot-Robot-Collaboration is coming more into focus
Organization of Communication
Publish-Subscribe [SMD19]

Central organized Communication

Decentral organized Communication

Number of Connection Links:
- Participant: $O(1)$
- Broker: $O(N)$

Number of Connection Links:
- Worst-Case: $O(N)$

Star-Topology: Either the broker or the sender has $O(N)$ connection links

No approach just works on a subset, e.g., $O(n)$ mit $n \ll N$
SOLA: A decentralized communication framework

Overview

Decentralization on application layer

Management Overlay
- Logical network overlay connecting peers
- Enables lookup for other peers

Event Dissemination
- Topic-based Publish-Subscribe
- \((m:n)\)-Broadcast on application layer
A closer look

Simple API

Modular components

SOLA

Application

start/stop
set_cb_recv_data

add/update/remove/find services

send_data

publish/subscribe to/unsubscribe from event

event updates/recv_data/search results

Management Overlay
(Structured Peer-to-Peer Network and Service/Peer Discovery)

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Event Dissemination
(Publish-Subscribe)

SOLA Network Interface
SOLA: Management Overlay

Management Overlay:

- Minimal height tree overlay network (MINHTON) [LDB23]
- Tree overlay network with fixed fanout m
- Allows searching for other peers with predicate/ query like $\phi_1 > 42$ [DGB22]

Join (Hops): $O(m \cdot \log_m N)$

Leave (Hops): $O(m \cdot \log_m N)$

Peer Discovery (Hops):
Insert/Update/Delete: $O(1)$
Search: $O_{BC}(2 \cdot |DSN|)$

Other structures and protocols could be used as well

[LDB23] Laskowski, Patrick; Detzner, Peter; Bondorf, Steffen: Tree-structured Overlays with Minimal Height: Construction, Maintenance and Operation. In: 17th ACM International Conference on Distributed and Event-based Systems, 2023 (will be presented tomorrow :)

SOLA: Event Dissemination

Costs to subscribe/unsubscribe related to MINHTONs costs

Not sending duplicates (in theory assuming no node failures :-)

Event Dissemination:

- Deterministic message distribution with Unicasts (Application Layer Multicast)
- Uses MINHTON structure for each topic
- Creates spanning trees for every initial sender

Other structures and protocols could be used as well

Subscribing to a topic

1. **Peers View**
   - **subscribe Topic A**
     - search for peer having key topicA
     - result: None
   - **insert data into own node topicA=<IP from A>**

2. **Global View**
   - **Topic A**

**Management Overlay**
**Event Dissemination**
SOLA
Development with ns-3

Key requirements/features:

- Reproducibility and easy debuggability
- Easy configurable application setup
- Testing scalability
- Validating results
- Allow running in simulation or in real-world (using abstractions)
SOLA
Implementation and Integration with ns-3

Key requirements/features:

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Validation and Verification

Logging

- Data is scattered around the network
- Using SQLite in ns-3 simulation
- Using deferred logging
- Abstraction to use other logger mechanisms as well
- Logging for all parts (MO, ED) and on different layers (application, networking)

Scenario Configuration

- Using YAML configuration file
- Passing application and simulation specific configurations
- Automatic parallel execution of different setups
Validation and Verification

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<th>Scenario Configuration</th>
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SOLA
ns-3 network structure

Layer

Transport
- UDP
- No node failure and package loss

Internet
- Separate IP subnets
- Static IP routing

Link
- ns-3 CSMA model
- ns-3 wireless model
- Using pre-filled ARP tables [MAD19]

Communication topology:
- Application layer: decentralized
- Link layer: star-topology (centralized)

Use Case: Self-Organized Material Flow

Initial Setup

Precedence Graph with 9 Transport Orders

Temporal Constraints (Deadlines)

Heterogenous AMRs
Use Case: Self-Organized Material Flow

System Design

Icons and Figures: Fraunhofer IML
Use Case: Self-Organized Material Flow
Visualization with NetSimulyzer [BGR21]

Use Case: Self-Organized Material Flow

Solution Space

Icons and Figures: Fraunhofer IML
Use Case: Self-Organized Material Flow
Messages sent and received

Management Overlay

(m:n) Event Dissemination

(1:1)-Communication

Icons: Fraunhofer IML, Figures: own work
Conclusion

Decentral organized communication SOLA

Fully developed and integrated with ns-3

Proof-Of-Concept with Self-Organized Material Flow
Future Work

Tested and verified protocols and layers

Wi-Fi Handover

More Layer-7 applications and evaluations

Simplified documentation

Deployment in real-world

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(Cost reduction: Peer Discovery, exploiting local view, …)

Connecting to other simulations, e.g., ROS2, NVIDIA, …

Optimization


Image: Adobe, ns-3 Logo: www.nsnam.org
Thank you for your attention!
Questions?

https://github.com/iml130/sola