Adaptive Mediation for Data Exchange in IoT Systems

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Motivation: Smart Cities and IoT Applications

“IoT-Sensorized”

Quality of Life

IoT Devices
- Gas Sensor
- Camera
- Bluetooth Beacon
- Motion Sensor

IoT Applications and Services
- Temperature Regulator
- IoT Analytics
The Firefighting Scenario

IoT Devices

IoT Applications and Services

Dashboard

Flashover

Fire fighters & Equipment

Building occupants

?
Problem: Can we enable interoperability in an efficient manner?

Heterogeneity in IoT Systems

Heterogeneous IoT sources

Protocols: MQTT, CoAP, Websockets, REST, etc.

People

data size, rates & format

Dashboard

urgency
Existing Solutions to Heterogeneity

Cloud Platform

Mediating Adapters/Connector Wrappers

Mediator Synthesizer

Can we utilize the Edge to become faster?

Where should we deploy this code?

Raspberry Pi  Edge Server

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IoT Devices

$t_1$
- $p(t_1) = CoAP$
- $l(t_1) = (2, 1)$
- $r(t_1) = 5 \text{ Mbps}$

$t_2$
- $p(t_2) = MQTT$
- $l(t_2) = (4, 4)$
- $r(t_2) = 3 \text{ Mbps}$

$t_3$

$t_4$

Dashboard

$t_5$

...
Nodes

$n_1$

$l(n_1) = (1, 3)$

$r(n_1) = 7 \text{ Mbps}$

$n_2$

$l(n_2) = (7, 3)$

$r(n_2) = 7 \text{ Mbps}$

Dashboard
Interactions

\[
\lambda(i_1) = 10 \text{ Mb} \\
\gamma(i_1) = 5 \text{ sec}
\]
Mediator Placement Problem

$$\min \Delta_{E2E} = \sum_{i,j,l} \Delta_{trans}^j + \Delta_{prop}^j + \Delta_{proc}^j + \Delta_{queue}^j$$

Constraints:
- C1 [Mapping constraint]: A mediator is assigned one node.
- C2 [Bandwidth constraint]: Bandwidth used on each link cannot be greater than Bandwidth capacity
Suppose $i_{2,3}^2$ uses $X$ units of bandwidth

Which node should we place the mediator for $i_{2,3}^2$ on?

Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$
Algorithms: Greedy Distance Placement

Suppose $i_{2,3}^2$ uses 1 unit of bandwidth

Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$

Place on $N_2$ because it is closer
Suppose $i_{2,3}^2$ uses 1 unit of bandwidth

Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$
Algorithms: Greedy Distance Placement

Suppose $i_{2,3}^2$ uses 4 units of bandwidth

Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$
Algorithms: Best Fit Decreasing Bandwidth Placement

Suppose $i_{2,3}^2$ uses 1 unit of bandwidth

Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$
Algorithms: Best Fit Decreasing Bandwidth Placement

Suppose \( i_{2,3} \) uses 1 unit of bandwidth

Let \( u/c \) represent \( \frac{\text{used_bandwidth}}{\text{capacity_of_bandwidth}} \)

Waste
\[ = (1 - \frac{9}{10}) + (1 - \frac{10}{10}) \]
\[ = \frac{1}{10} \]
Let $u/c$ represent $(\text{used\_bandwidth}) / (\text{capacity\_of\_bandwidth})$
Define the following:

\[ X_{pq} = \begin{cases} 1 & \text{if interaction } i_p \text{ uses node } n_q \\ 0 & \text{otherwise} \end{cases} \]

\[ V_{pq} = \begin{cases} 1 & \text{if interaction } i_p \text{ involves thing } t_q \\ 0 & \text{otherwise} \end{cases} \]

\[ X_{2,2} = 1 \quad V_{2,3} = 1 \]
\[ X_{2,1} = 0 \quad V_{2,4} = 0 \]
Algorithms: ILP Placement

\[ \min \Delta_{E2E} = \sum_{i,j}^{k,l} \Delta_{\text{trans}}^j + \Delta_{\text{prop}}^j \]

subject to:

\[ \forall i_j \sum_{n_i} X_{ji} = 1 \]  
(1)

\[ \forall t_p \forall n_q \sum_{i,j} V_{jp} \ast X_{jq} \ast \lambda(i_j) \ast \gamma(i_j) \leq w_{pq} \]  
(2)

(1) : Mapping constraint
(2) : Bandwidth constraint
Experimental Setup

• Two topologies used
  • 10 things, 10 nodes (Topology1)
  • 100 things, 10 nodes (Topology2)

• Parameters chosen uniformly at random in some range

• We measure $\Delta_{E2E}$, the total delay
Topology 1 – 10 Things, 10 Nodes
Topology 2 – 100 Things, 10 Nodes
Conclusion

• We define the Mediator Placement Problem

• We propose a hybrid algorithm based on our initial results:
  • Small numbers of interactions: Greedy
  • Larger numbers of interactions: ILP
Future Work: Extensions

• DAG representation of interactions

• Handling mobility

• In-depth experiments

• Queueing Theory as input to our algorithms
Discussion – Prioritization: Cloud vs Edge

• In our firefighting scenario, we assumed that all of the interactions were necessary and must be placed.

• Can we prioritize some of the interactions so that they will be placed on the Edge?

• Can we push irrelevant interactions to have mediators in the Cloud instead?
Discussion – Graceful Degradation

• In the firefighting scenario, it is possible for the IoT devices and nodes to break.

• How can we gracefully degrade?
Thank you for your time