Adaptive Mediation for Data Exchange in IoT Systems

Andrew Chio[1], Georgios Bouloukakis[1], Cheng-Hsin Hsu[2], Sharad Mehrotra[1], Nalini Venkatasubramanian[1]

UC Davis, CA, December 10, 2019

ARM 2019

[1]Donald Bren School of Information and Computer Science, UC Irvine, USA

[2]Department of Computer Science, National Tsing Hua University, Taiwan

Motivation: Smart Cities and IoT Applications

IoT Devices

Gas Sensor

Camera

Bluetooth Beacon

Motion Sensor

"IoT-Sensorized"

IoT Applications and Services

Temperature Regulator

IoT Analytics

Quality of Life

The Firefighting Scenario

?

Flashover

Building occupants

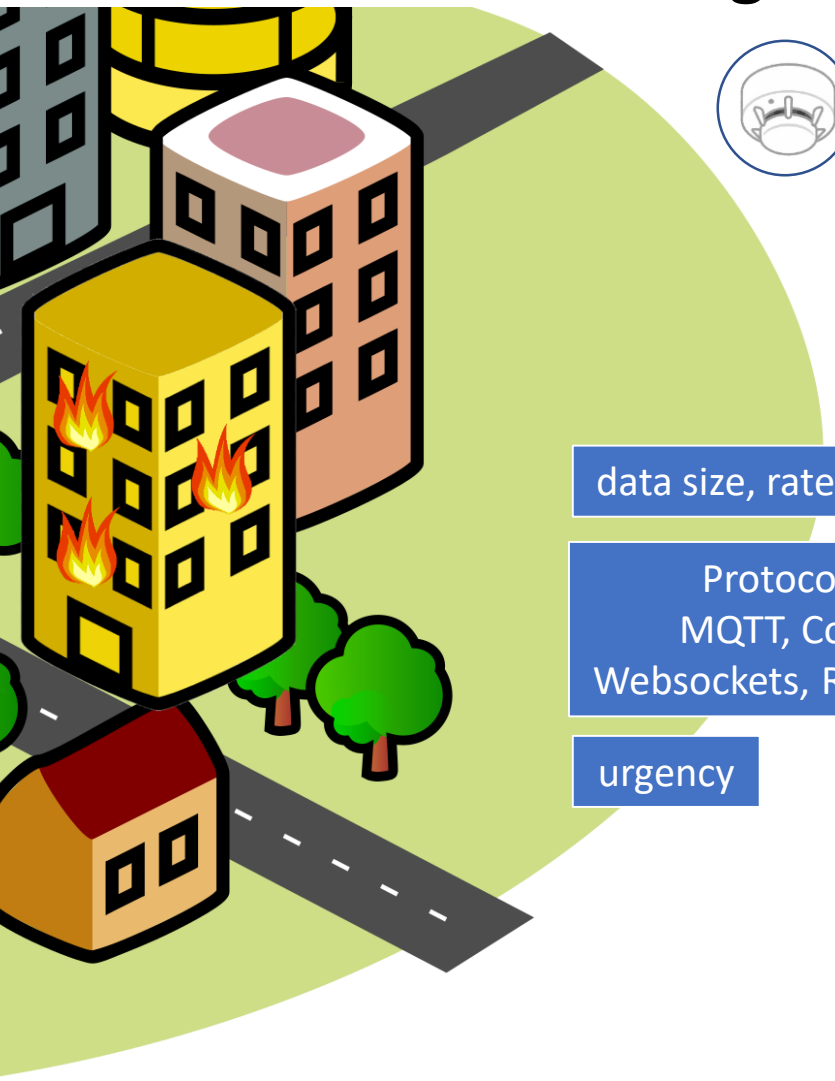
Fire fighters & Equipment

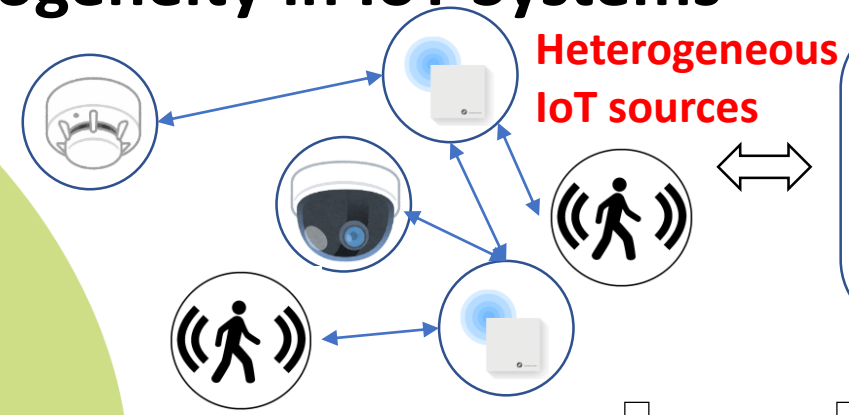
IoT Devices

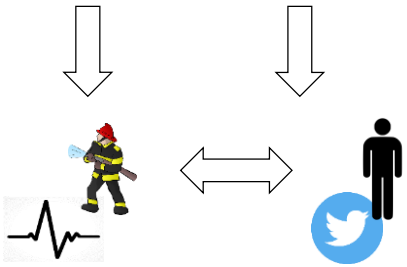
IoT Applications and Services

Dashboard

Heterogeneity in IoT Systems







data size, rates & format

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

urgency

Problem: Can we enable interoperability in an efficient manner?

Existing Solutions to Heterogeneity

Cloud Platform

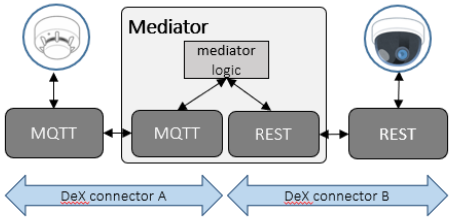
thingworx

nimbit
A PreSonus™ Company

SensorCloud™
Powered by LORD Sensing

Mediating Adapters/ Connector Wrappers

Mediator Synthesizer[1]



Can we utilize the Edge to become faster?

Raspberry Pi

Edge Server

Where should we deploy this code?

[1]G. Bouloukakis, N. Georgantas, P., Ntumba, V., Issarny, *Future Generation Computer Systems*, 2019

IoT Devices

t_1
$p(t_1) = CoAP$
$l(t_1) = (2, 1)$
$r(t_1) = 5\ Mbps$

t_2
$p(t_2) = MQTT$
$l(t_2) = (4, 4)$
$r(t_2) = 3\ Mbps$

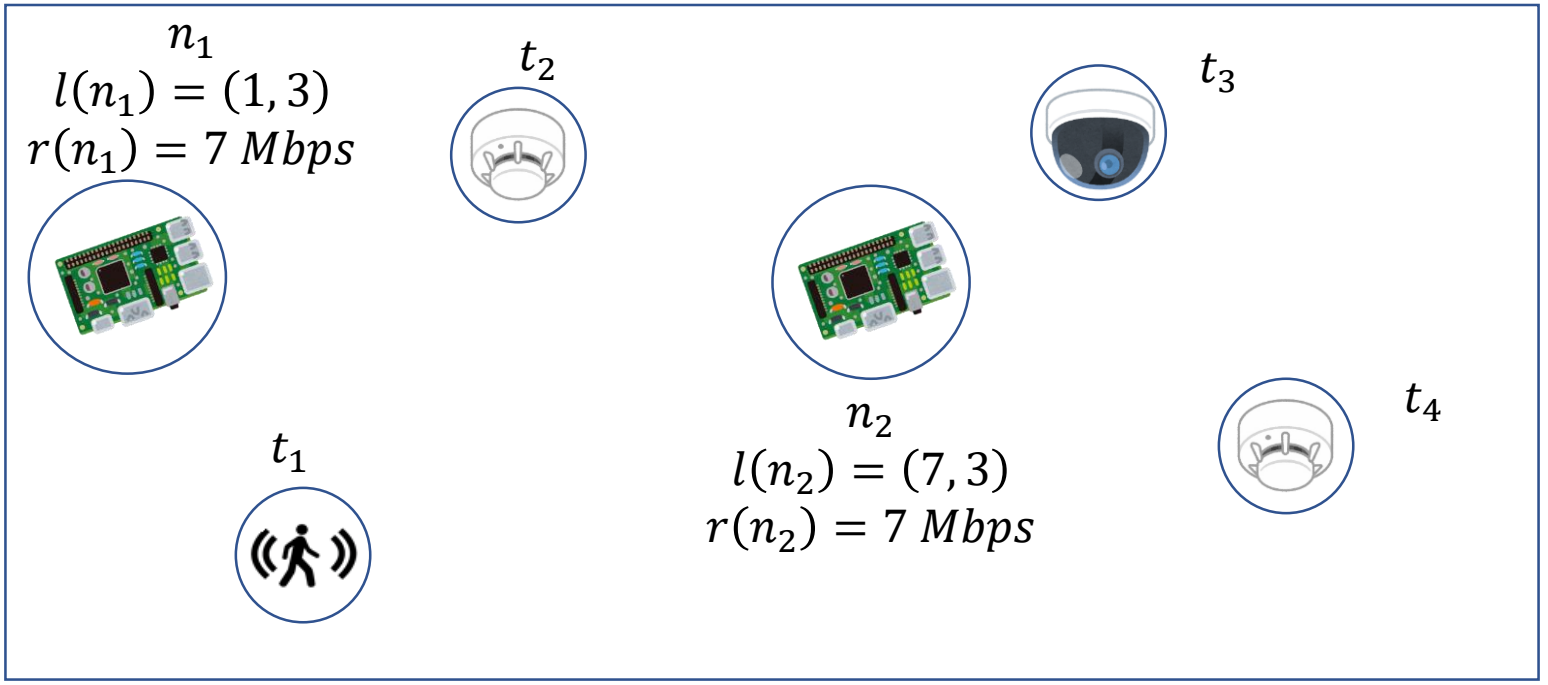
t_3
…

t_4
…

Dashboard

t_5
…

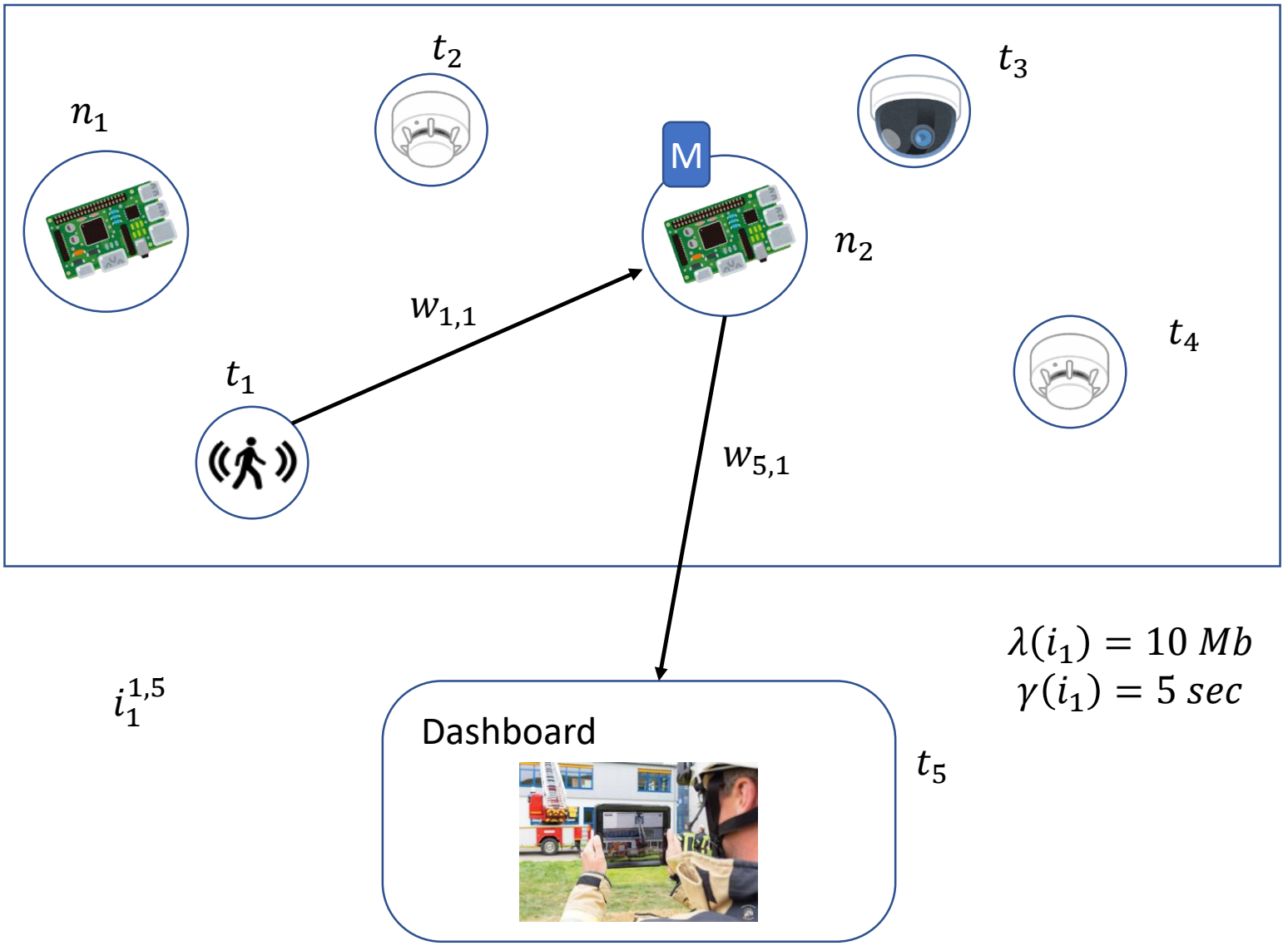
Nodes



Dashboard

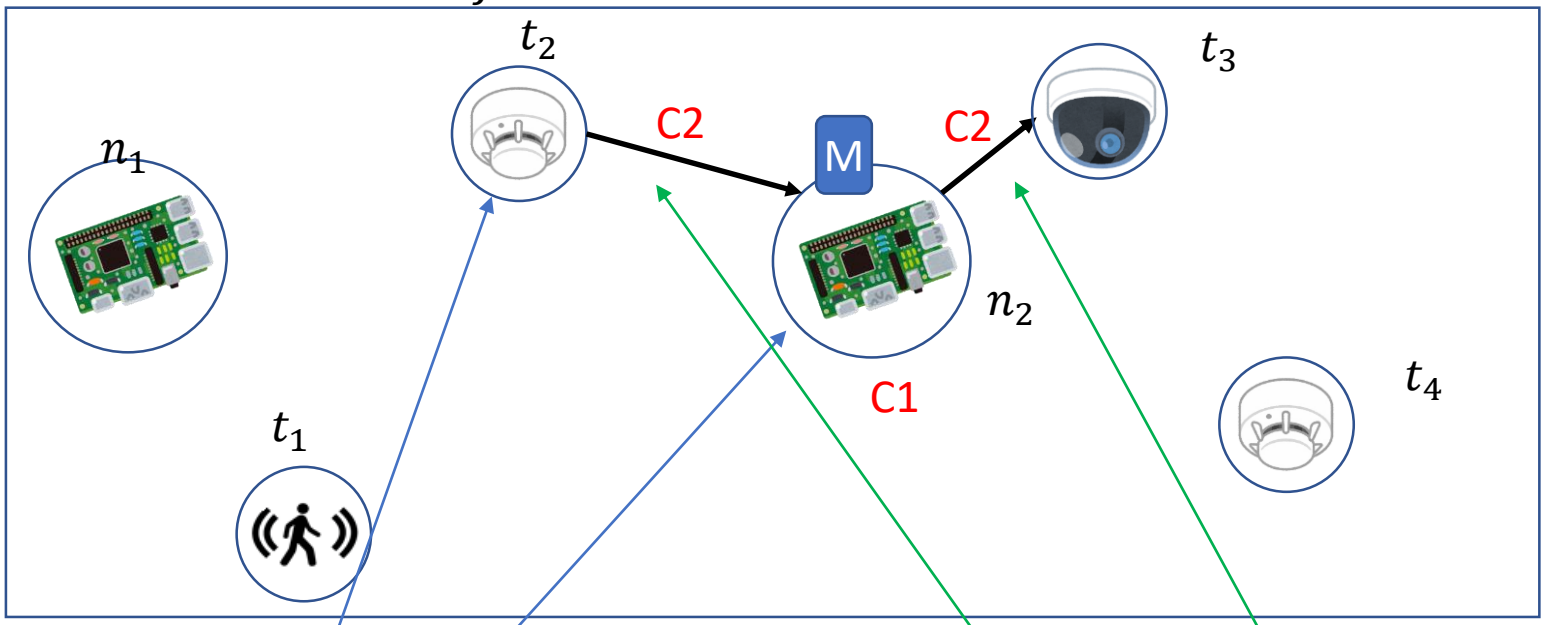
t_5

Interactions



Mediator Placement Problem

$$\min \Delta_{E2E} = \Sigma_{i_j^{k,l}} \Delta^j_{trans} + \Delta^j_{prop} + \Delta^j_{proc} + \Delta^j_{queue}$$



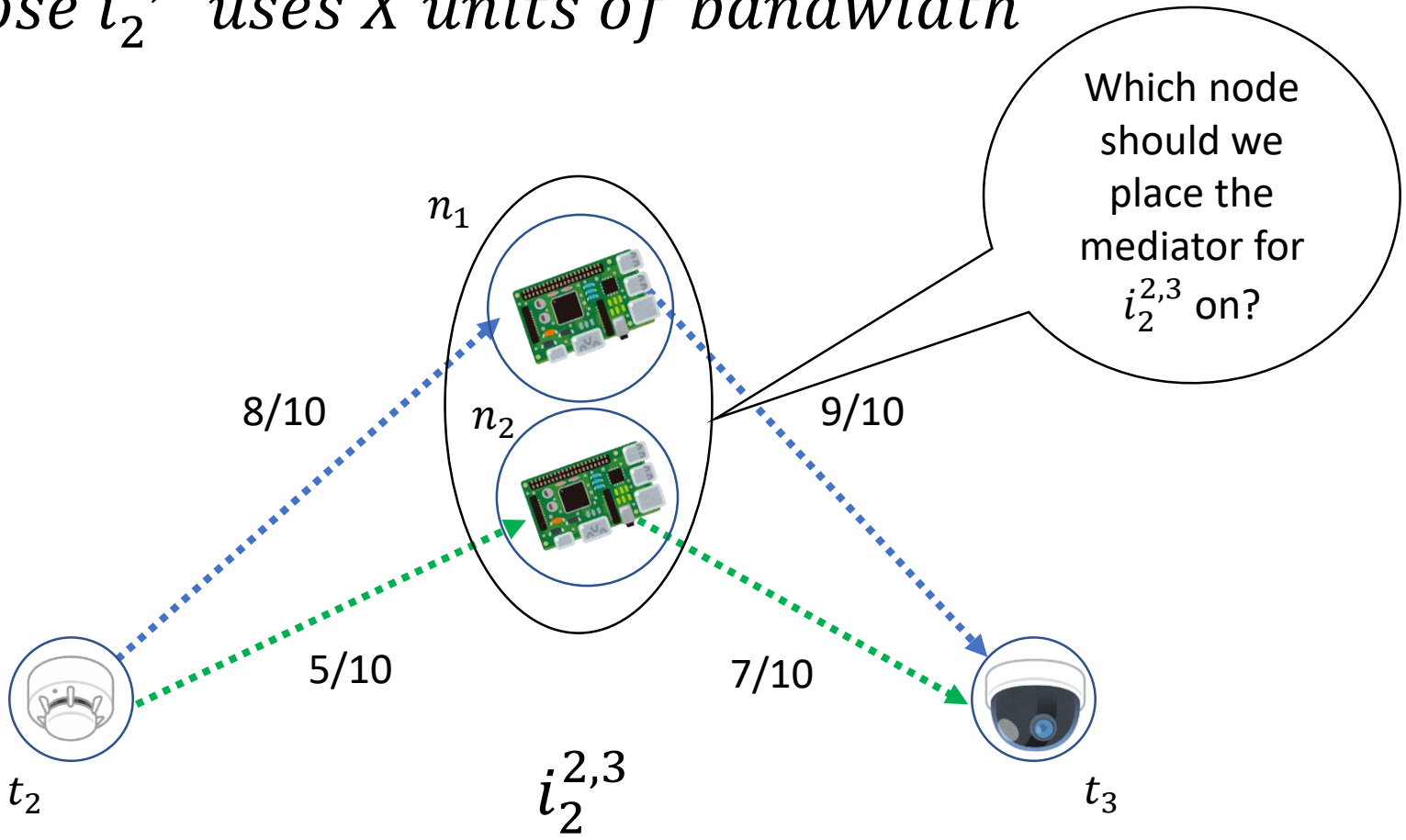
$$\Delta^2_{trans} = \frac{\lambda(i_2)}{r(t_2)} + \frac{\lambda(i_2)}{r(n_2)} \qquad \Delta^2_{prop} = \frac{|l(t_2) - l(n_2)|}{c} + \frac{|l(n_2) - l(t_3)|}{c}$$

Constraints:

- C1 [Mapping constraint]: A mediator is assigned one node. .
- C2 [Bandwidth constraint]: Bandwidth used on each link cannot be greater than Bandwidth capacity

Algorithms: Sample Topology

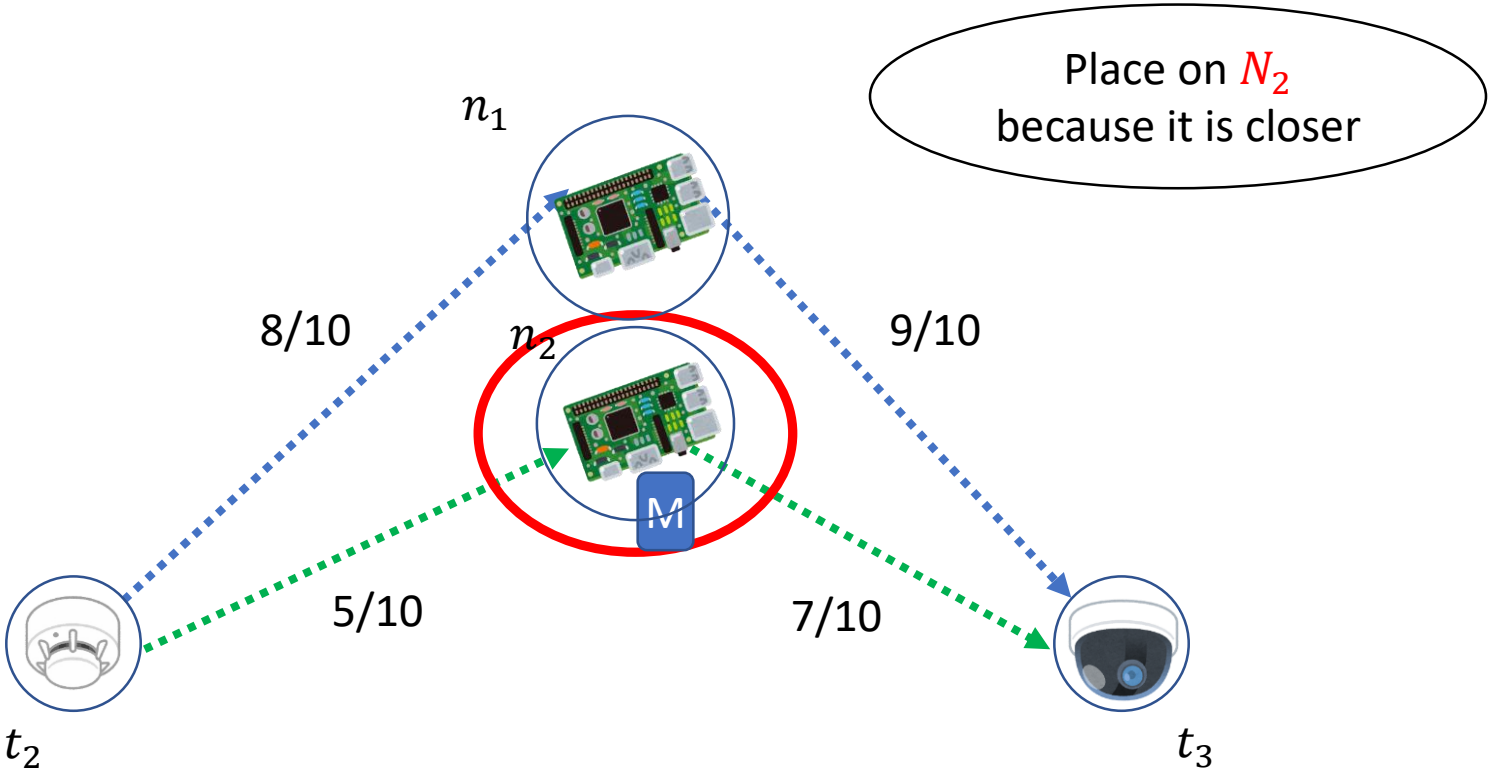
$Suppose\ i_2^{2,3}\ uses\ X\ units\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Greedy Distance Placement

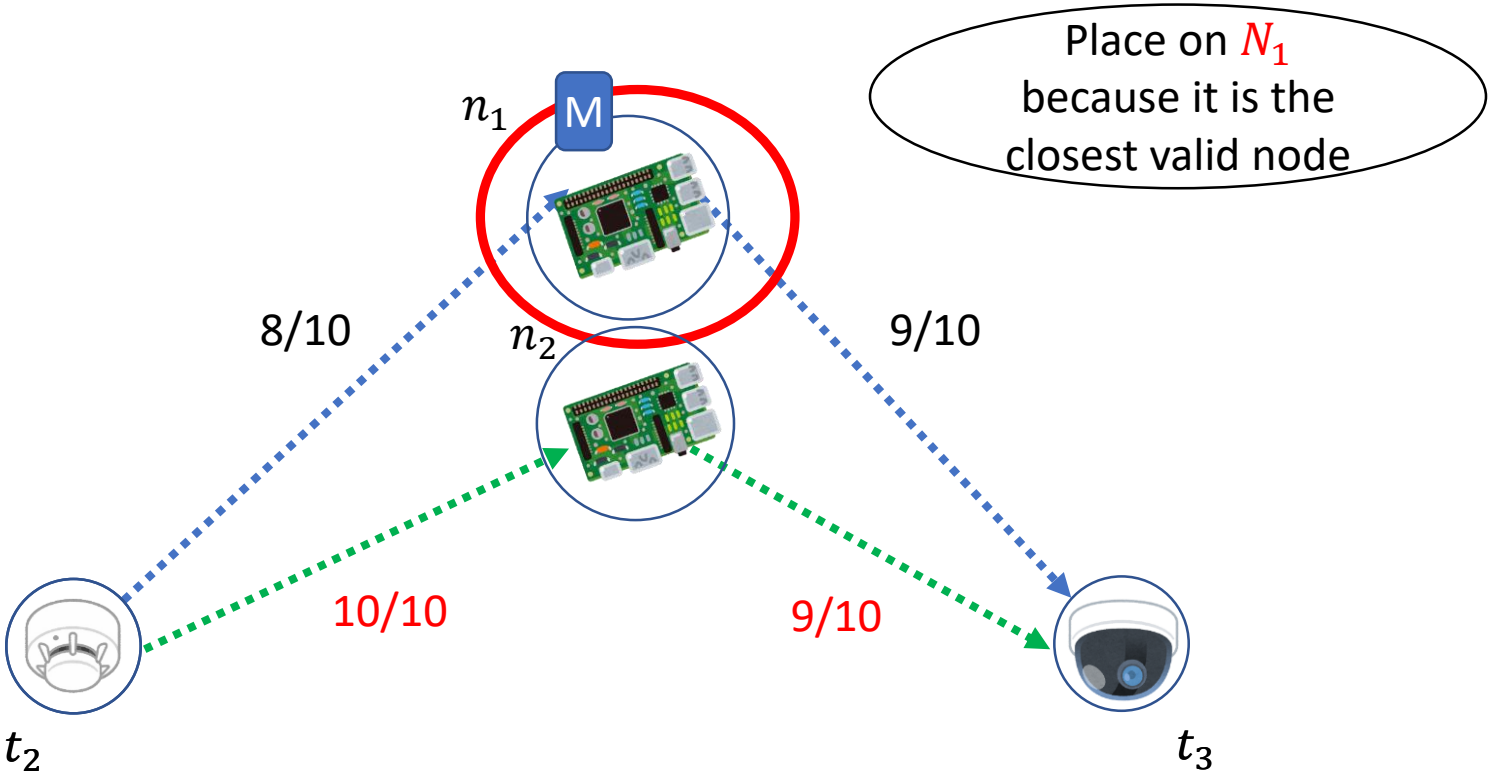
$Suppose\ i_2^{2,3} uses\ 1\ unit\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Greedy Distance Placement

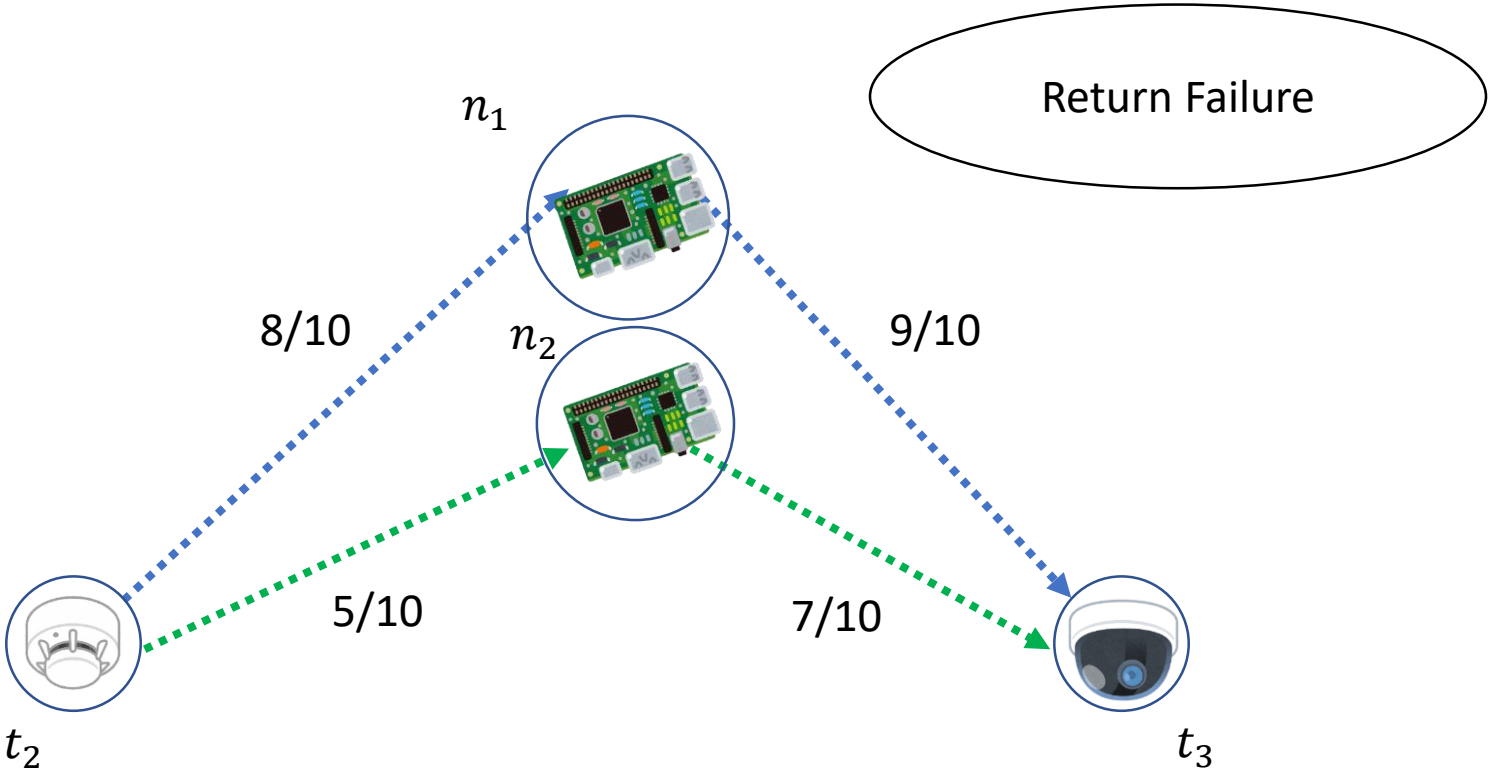
$Suppose\ i_2^{2,3}\ uses\ 1\ unit\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Greedy Distance Placement

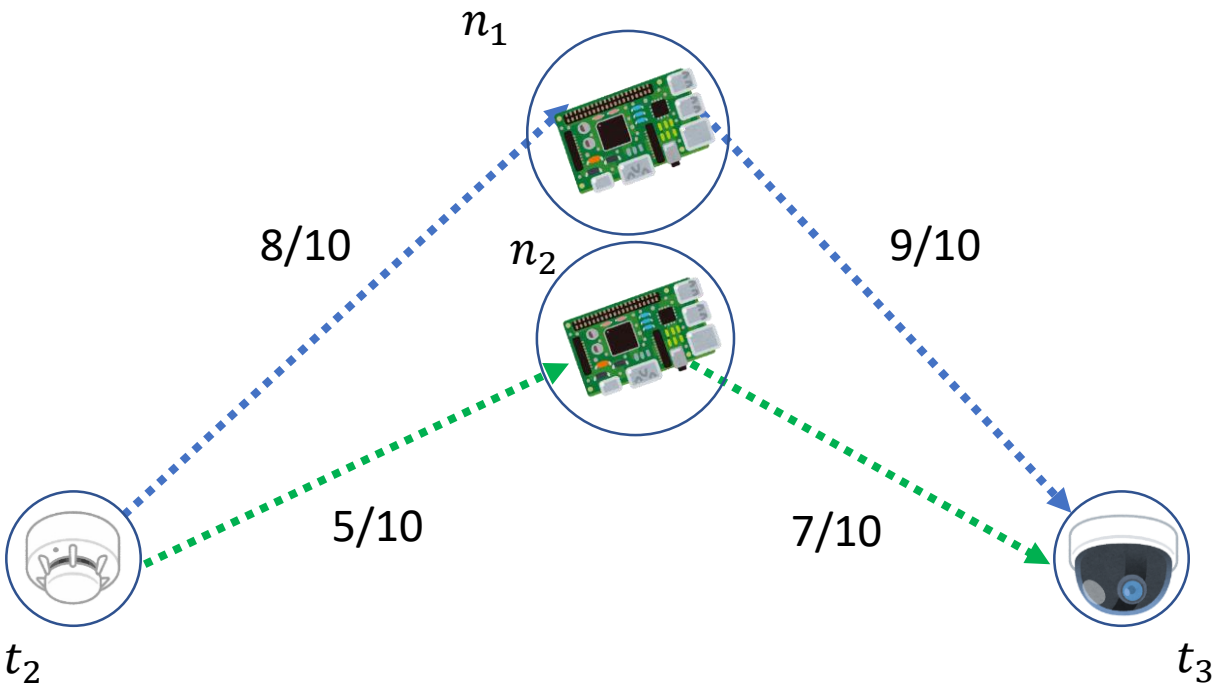
$Suppose\ i_2^{2,3} uses\ 4\ units\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Best Fit Decreasing Bandwidth Placement

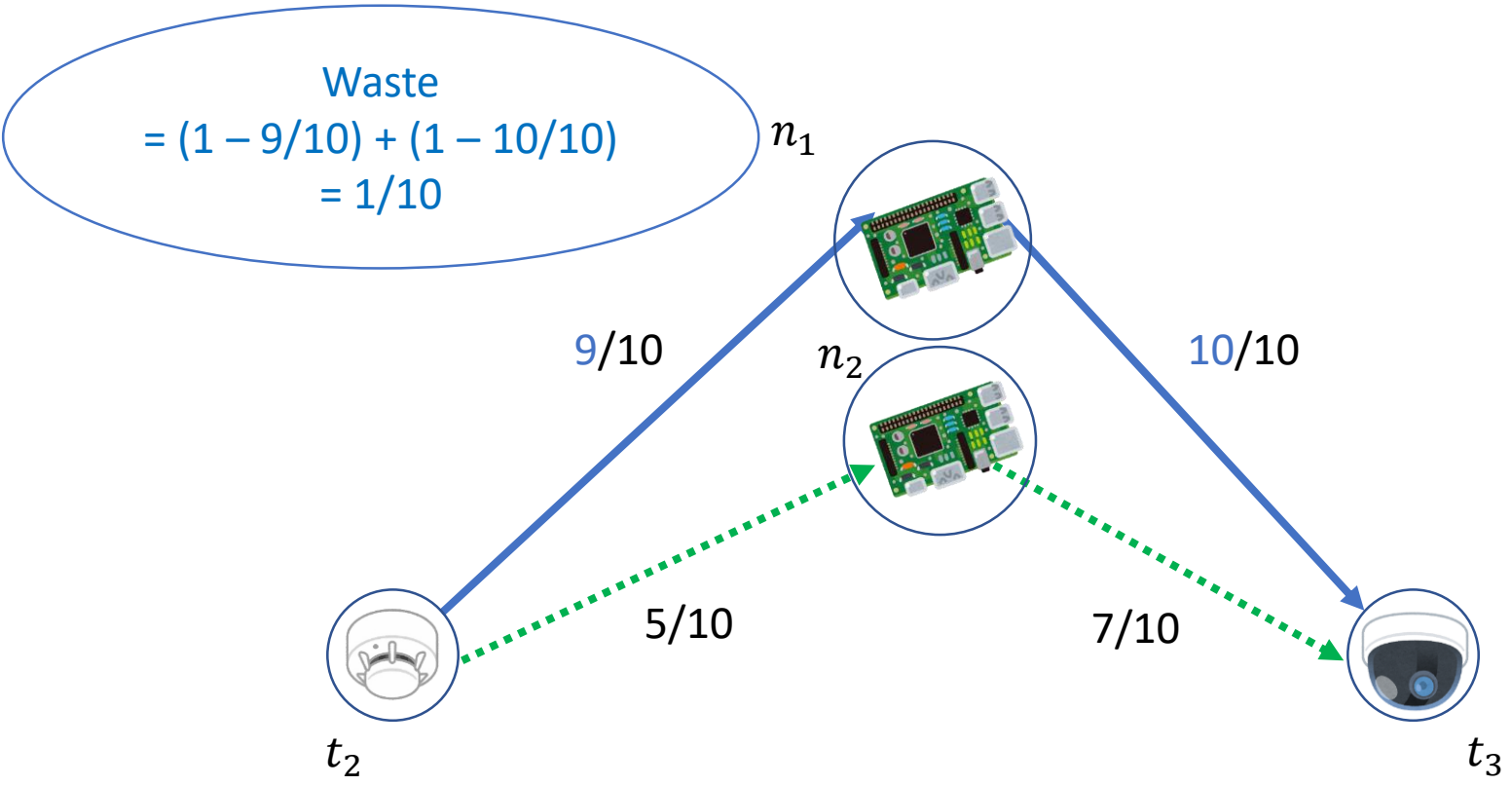
$Suppose\ i_2^{2,3}\ uses\ 1\ unit\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Best Fit Decreasing Bandwidth Placement

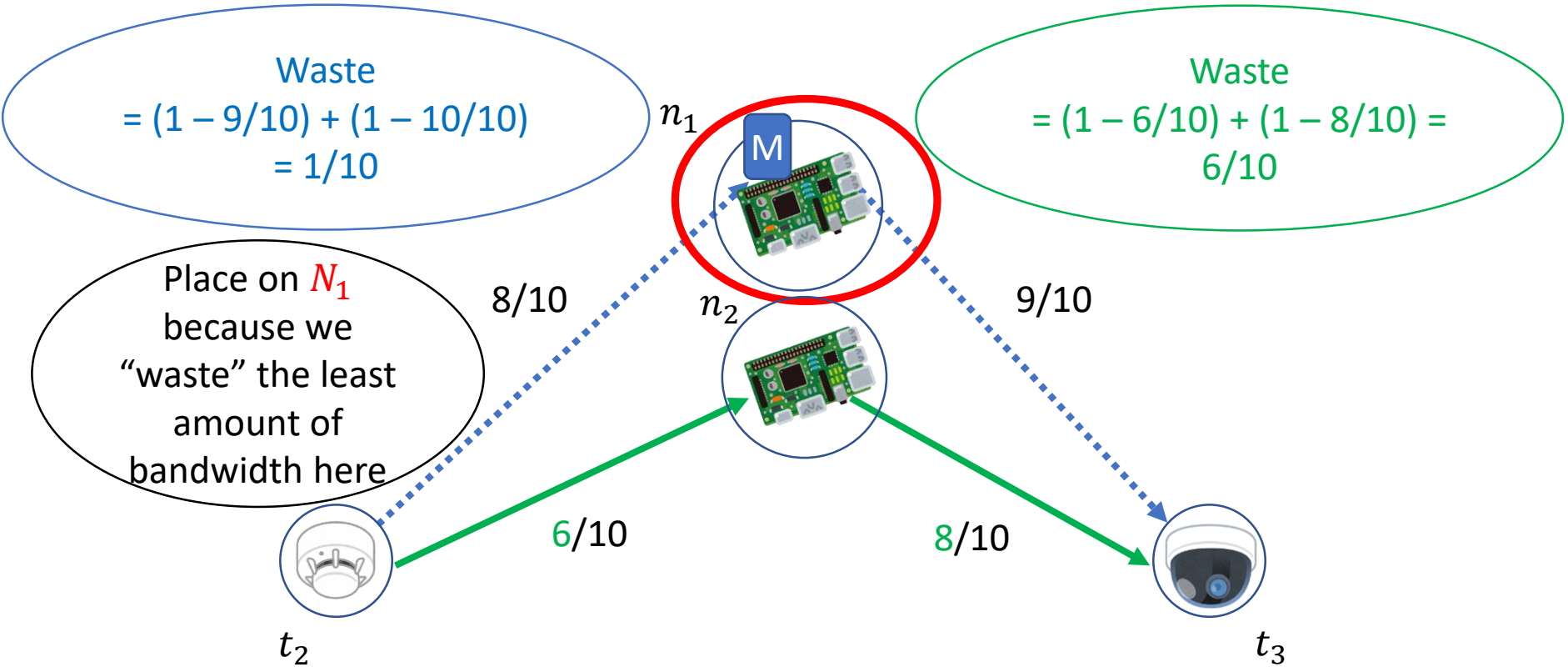
$Suppose\ i_2^{2,3}\ uses\ 1\ unit\ of\ bandwidth$



Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: Best Fit Decreasing Bandwidth Placement

$Suppose\ i_2^{2,3}\ uses\ 1\ unit\ of\ bandwidth$



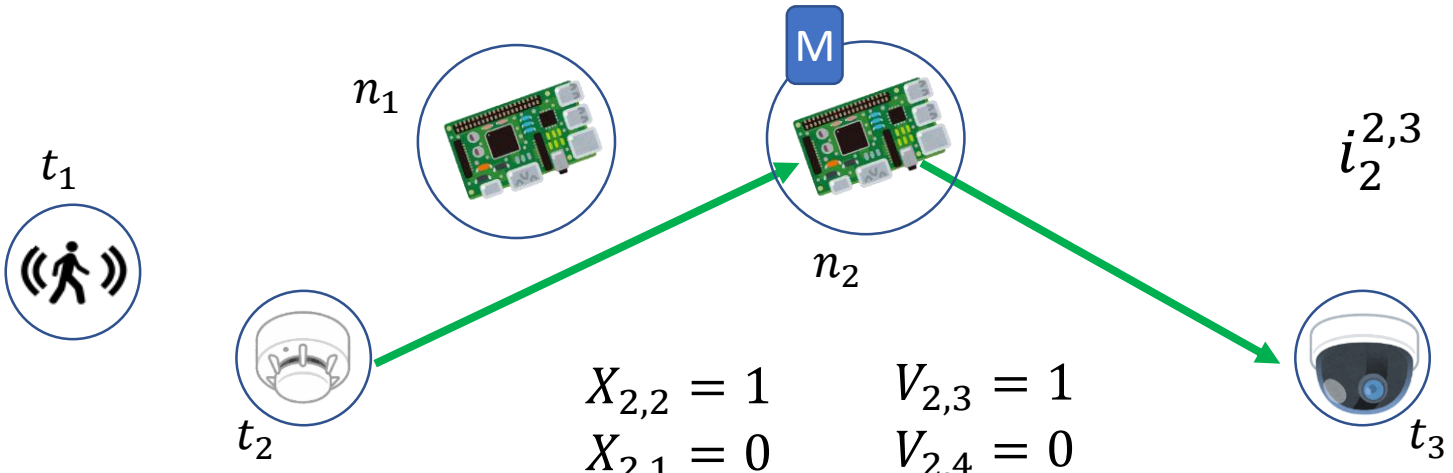
Let **u/c** represent **(used_bandwidth) / (capacity_of_bandwidth)**

Algorithms: ILP Placement

Define the following:

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

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



Algorithms: ILP Placement

$$\min \Delta_{E2E} = \Sigma_{i_j^{k,l}} \Delta_{trans}^{j} + \Delta_{prop}^{j}$$

subject to:

$$\forall\, i_j\ \Sigma_{n_i} X_{ji} = 1 \qquad (1)$$

$$\forall t_p \forall n_q\ \ \Sigma_{i_j}\ V_{jp} * X_{jq} * \lambda(i_j) * \gamma(i_j) \leq w_{pq} \qquad (2)$$

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

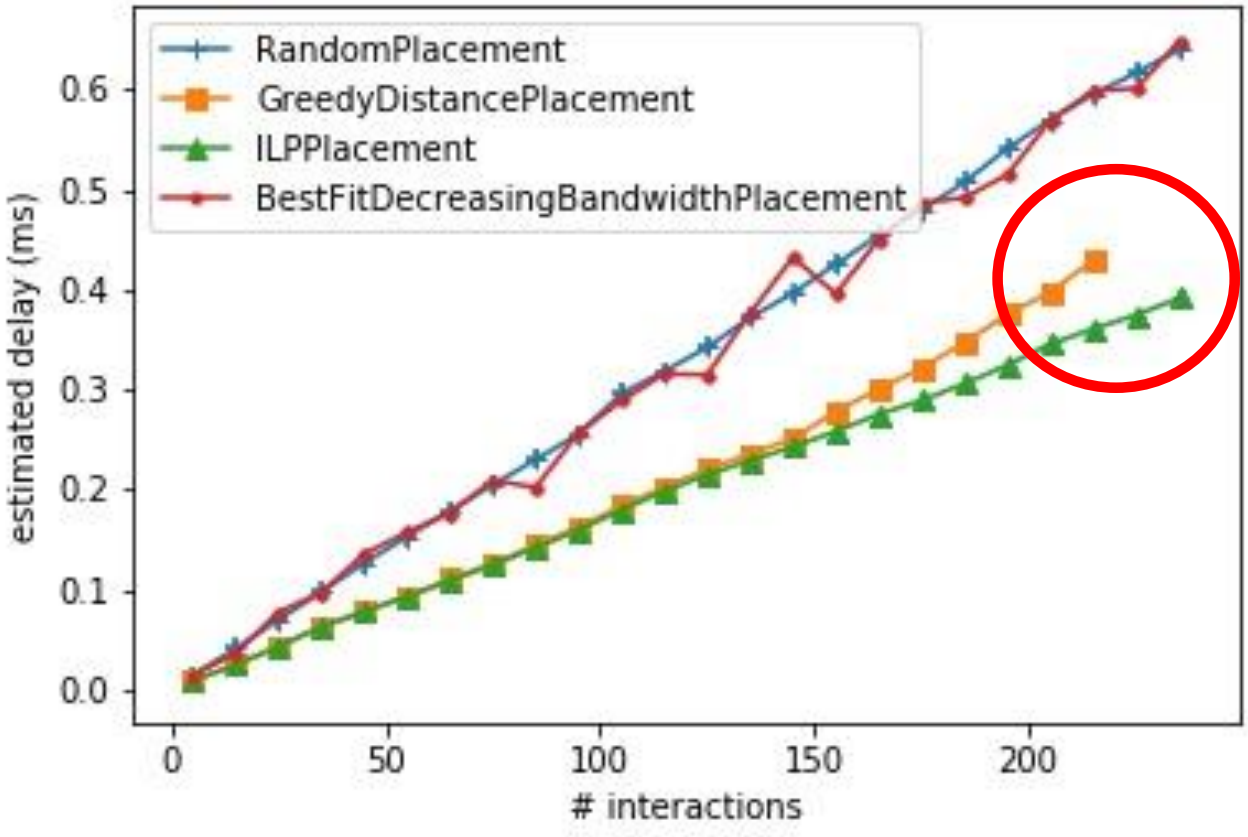
Experimental Setup

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

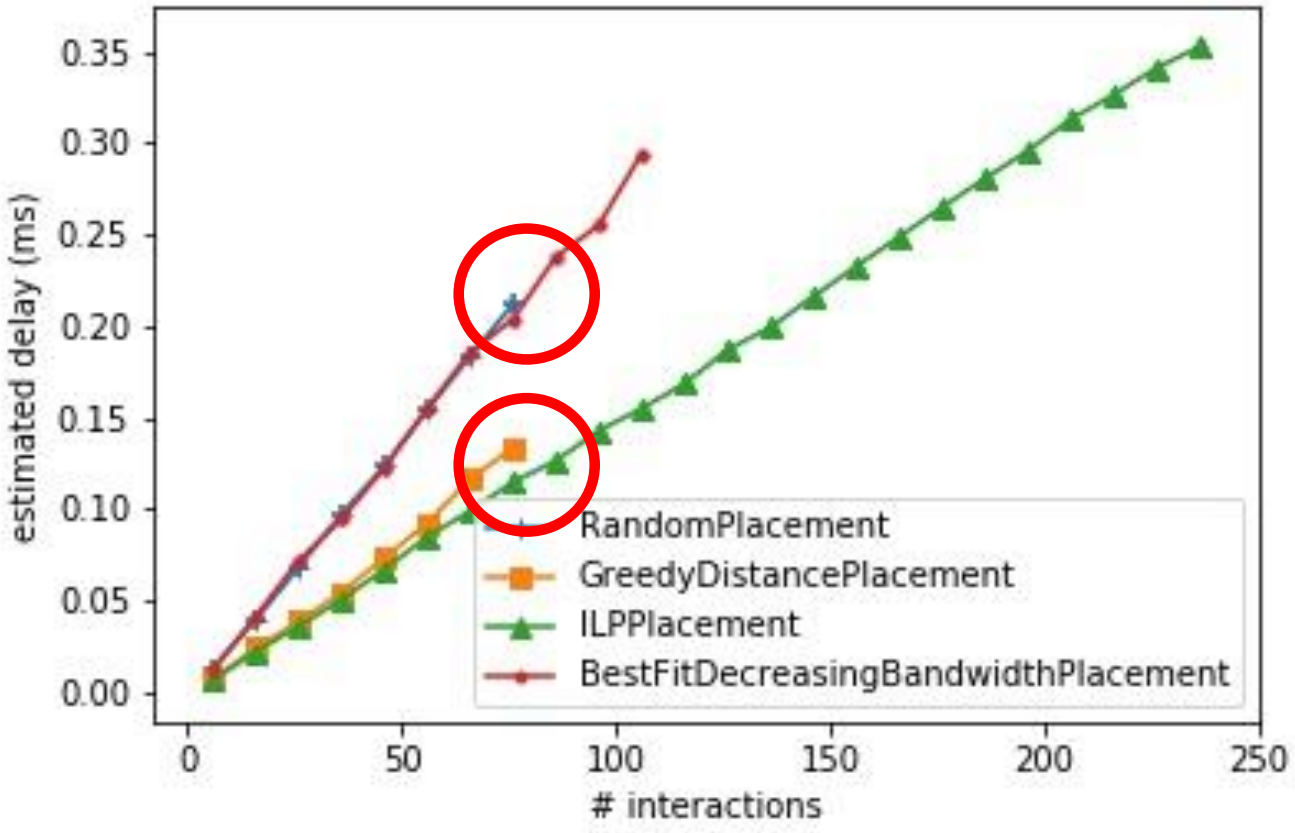
- Parameters chosen uniformly at random in some range

- We measure Δ_{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