Migrating IoT Processing to Fog Gateways

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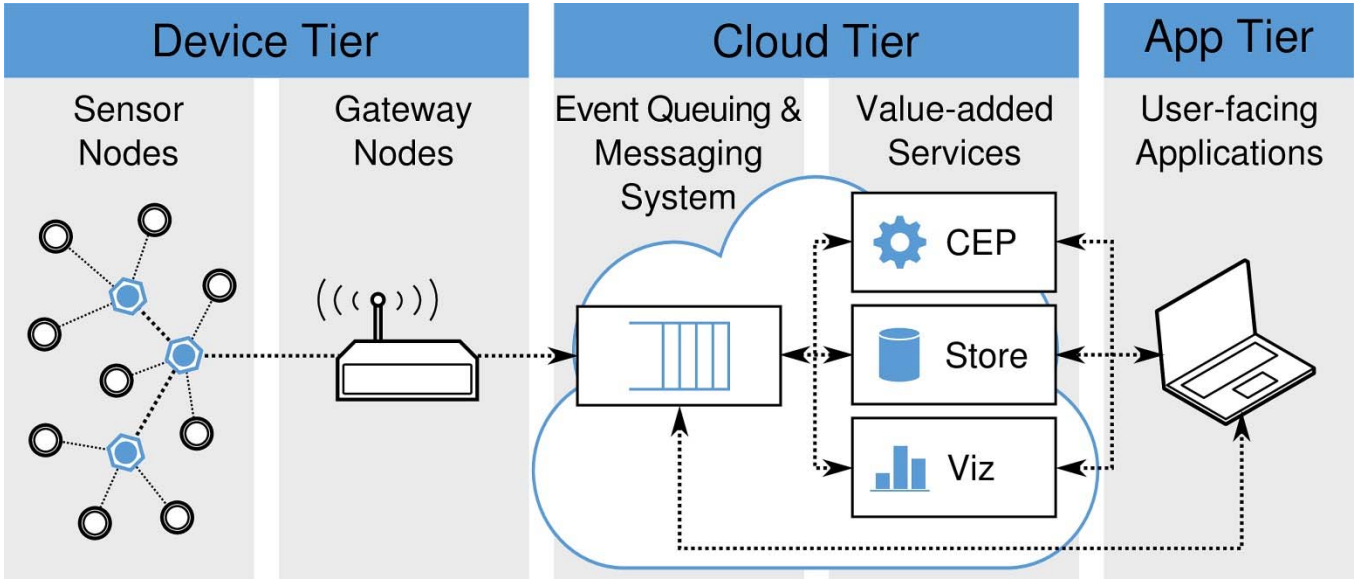
Cloud centric Internet of Things

- Internet of Things:
  - Connect everything and everyone everywhere to everything and everyone else
  - Abstracting services of trillions of interconnected (sensor) devices
  - Providing interoperability in face of heterogeneity
- Sharing economy of heterogeneous sensors:
  - Sensor devices used for many applications over Internet
  - Middleware for efficiently distribution, storage and processing of sensor data
- Cloud for storage, processing, distribution
  - Flexibility
  - Reliability
  - Pay-as-you-go

Cloud centric IoT reference Architecture



- Producers, services, consumers loosely coupled by event queuing system
- Pub/sub well established data dissemination pattern for IoT

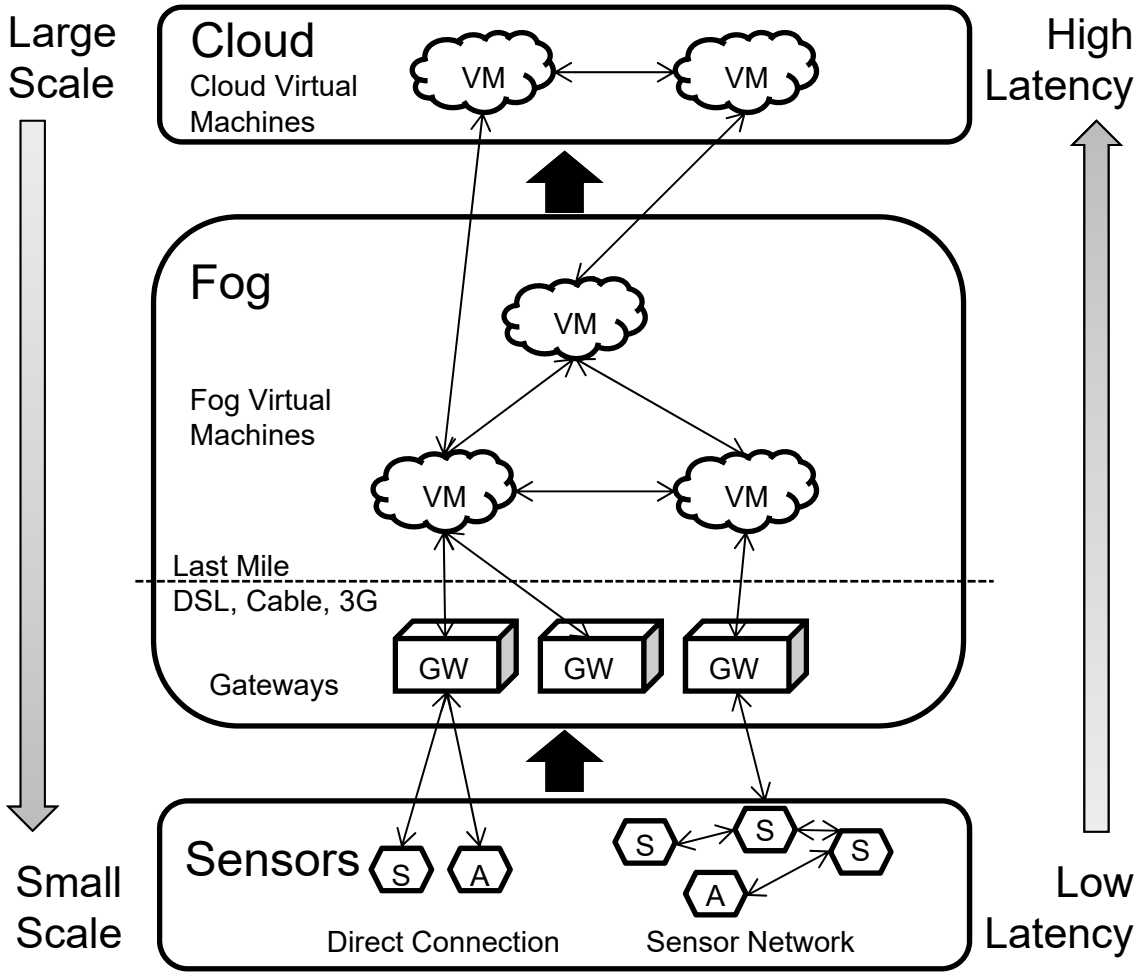
Advantages of Pub/Sub for IoT

- Publish/subscribe properties making it suitable for IoT:
  - Efficient monitoring: "Sense once, notify many"
- Decoupling:
  - Time decoupling
    - do not have to be online at the same time
  - Synchronization decoupling
    - asynchronous communication
  - Space decoupling
    - do not have to explicitly address messages (topic based in this work)

Limitations of Cloud centric IoT

- Placement on "other" edge of the network:
  - Usually not near the customer, but where economically feasible
  - Considerable (unnecessary) delay
  - Usually limited uplink throughput available
- Limited control over data:
  - Unknown or ambiguous privacy policies
  - Privacy protection laws
- Possible solution:
  - Leverage local processing on existing **gateways**
  - Offload processing on demand to Cloud

Fog-based IoT System Model

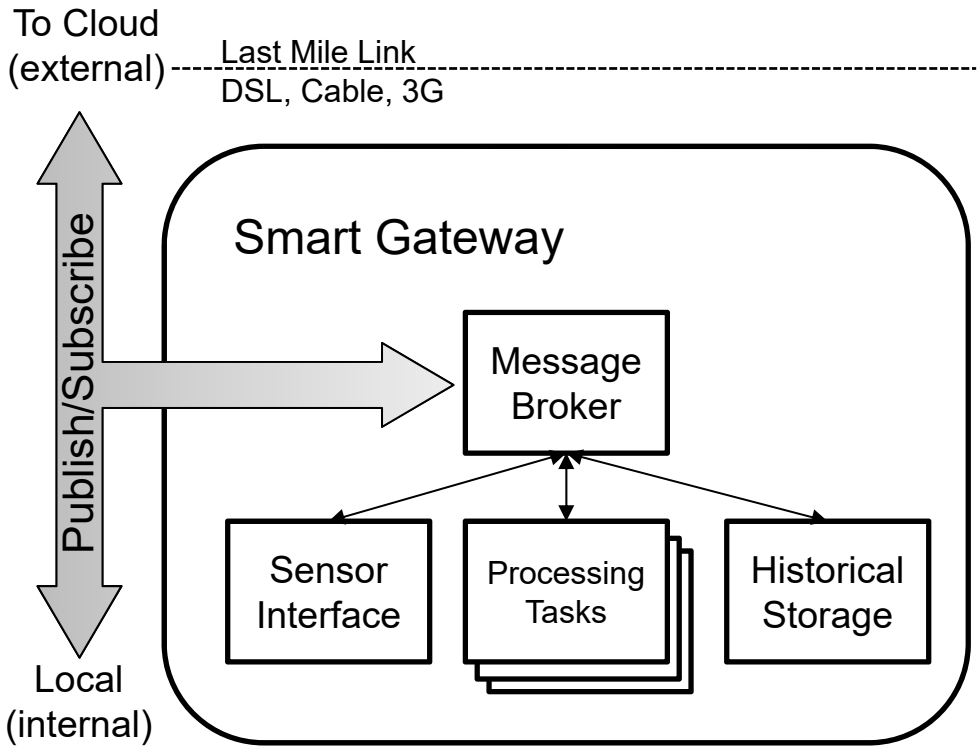


Examples of Gateway Hardware

Device	CPU Clock	Memory	Storage	Price
Intel NUC	1.3 GHz	16 GB	SATA	~$300
BeagleBone Black	1 GHz	512 MB	4GB EMMC, SD	$55
Raspberry Pi 3	1.2 GHz	1 GB	SD	~$35
TP-Link TL-WR841N	650 MHz	32 MB	4 MB	~$20

- Existing gateways potentially have unused processing and storage capabilities right at the edge
- Gateways still severely constrained:
  - Limited CPU power
  - Limited memory
  - Limited Storage
  - Limited Uplink Bandwidth
  - But: Usually no power constraints

Proposed Gateway Model



- Application view: Pub/sub is virtual bus
- Local broker enables local dissemination, processing, storage of messages

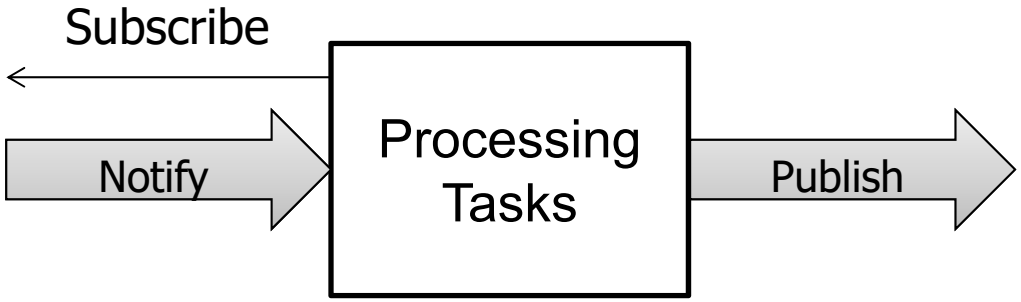
Problem Statement

- On demand offloading of processing tasks to Cloud necessary

- How can publish/subscribe help moving processing to fog gateways?
  - Task Migration
  - (Profiling)

- In this work:
  - (Architecture outline for offloading of IoT processing tasks)
  - Processing task offloading scheme on top of pub/sub
  - Proof-of-concept implementation and evaluation of offloading on top of MQTT

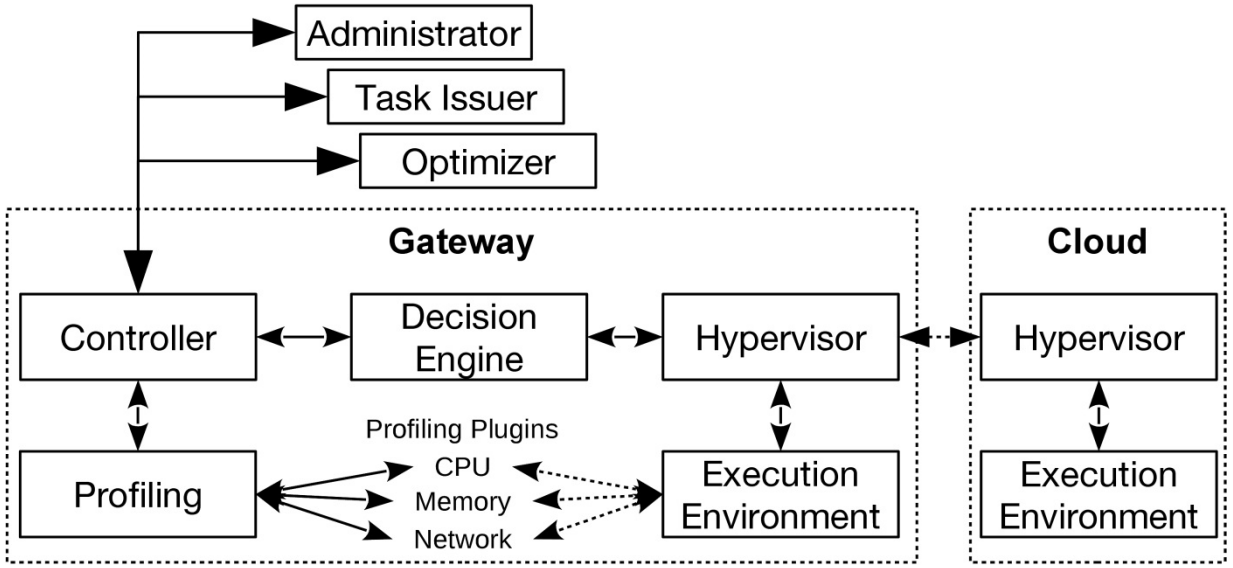
Sensor Data Processing Task



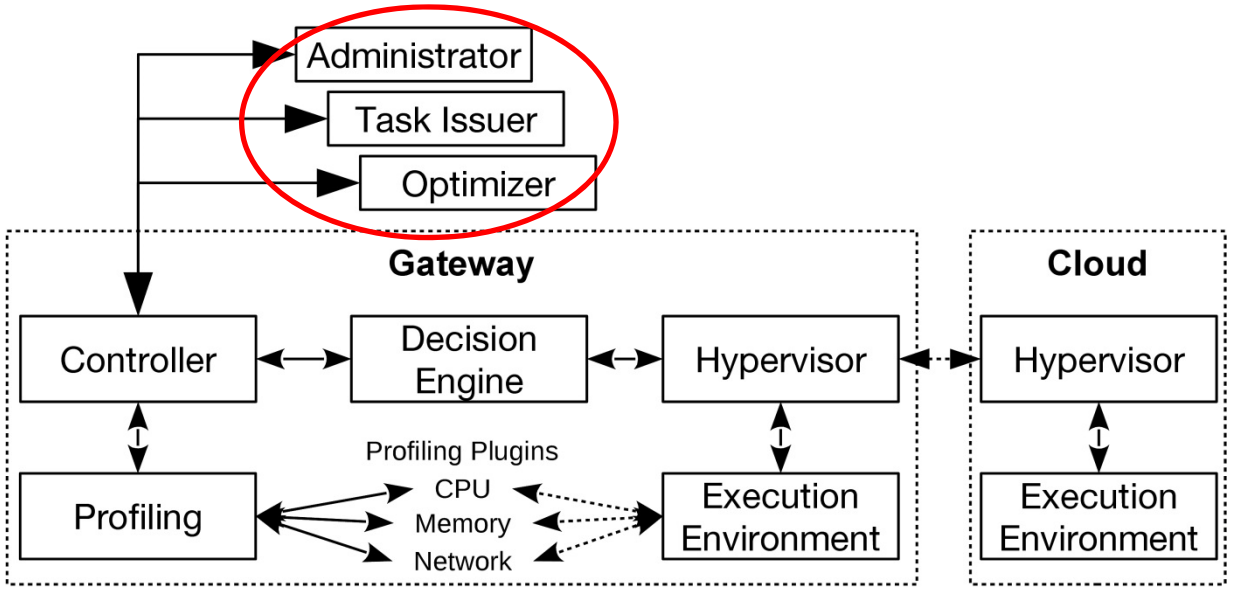
- Continuously running
- Input: Subscription on a set of input topics
- Computation: Arbitrary
- Output: Publication(s) on set of output topics

- Default place of processing: **Gateway**
- Offloaded to Cloud when resources not available
- Issuer defines additional constraints and requirements

Offloading Architecture

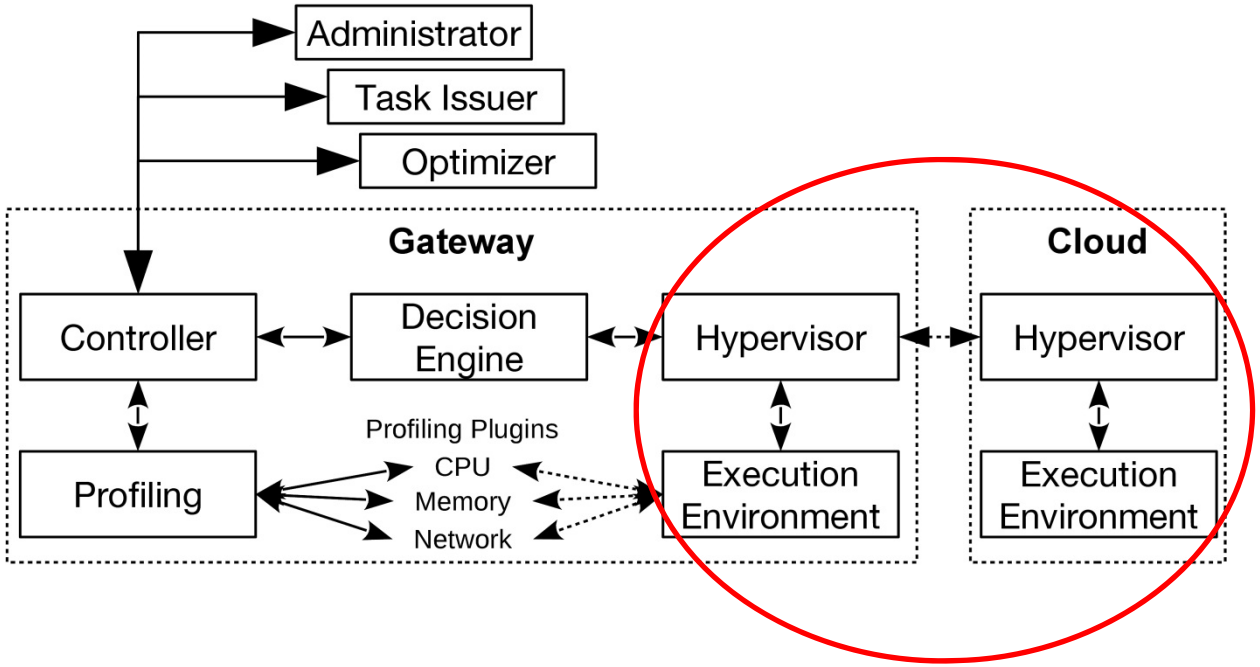


Offloading Architecture



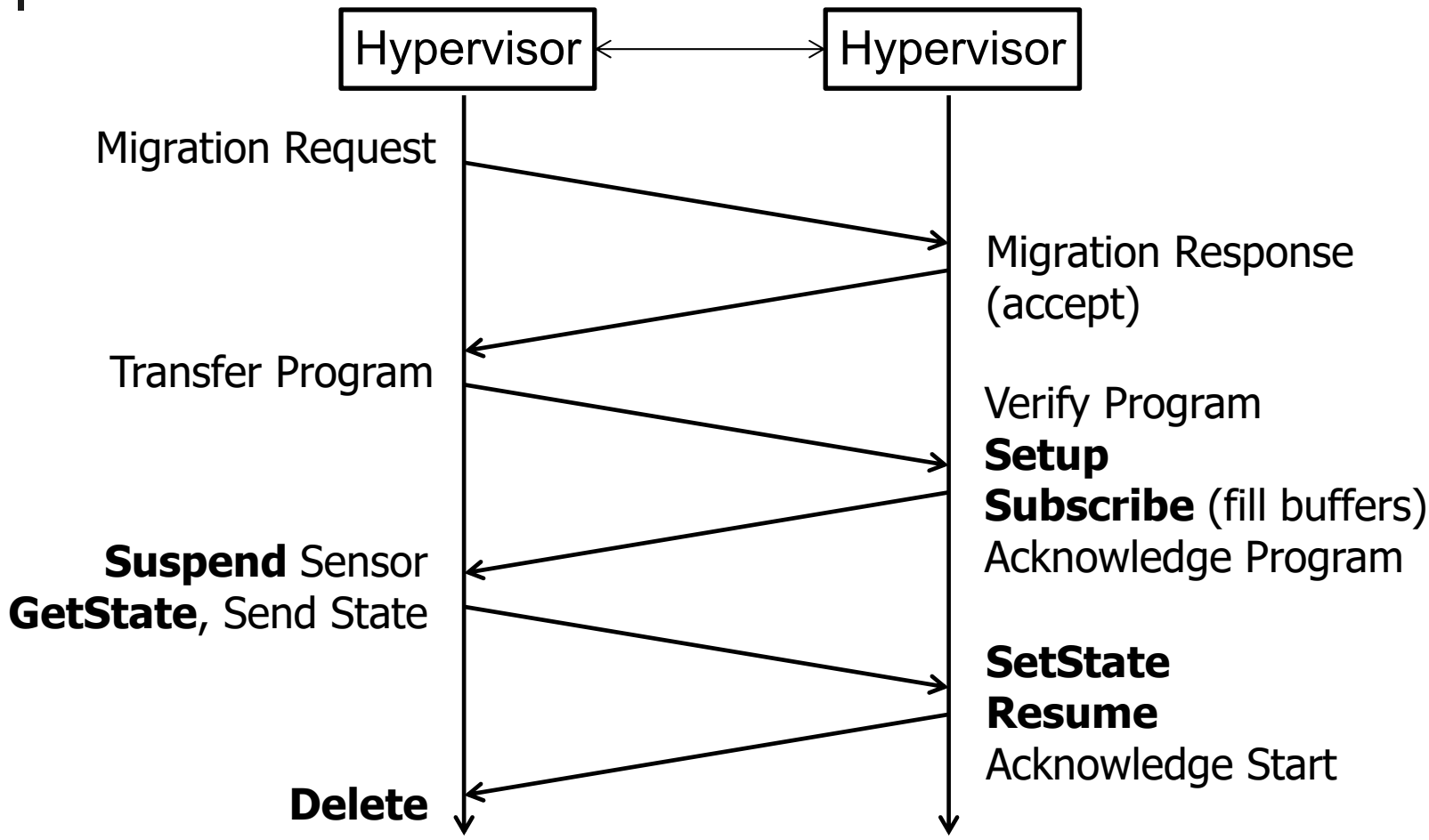
- 3 distinct roles that interact with the system:
  - Administrator defines computational constraints
  - Issuer defines task and privacy and computation requirements
  - Optimizer defines the optimization goal

Offloading Architecture



- Migration Framework executes decision to transfer

Virtual Sensor Migration Sequence



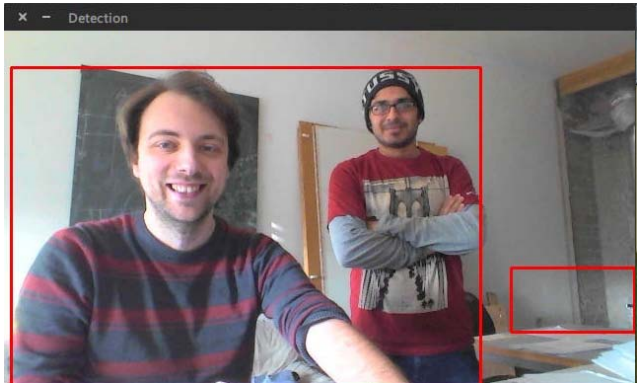
Virtual Sensor Migration Interface

Interface provided by processing task:

- **setup** (called before launch to initialize task)
- **subscribe** (subscribe to input topics and fill buffers)
- **setState** (set initial state to representation given)
- **resume** (resume processing)
- **suspend** (stop processing)
- **getState** (get representation of the process state)
- **delete** (terminate the processing task)

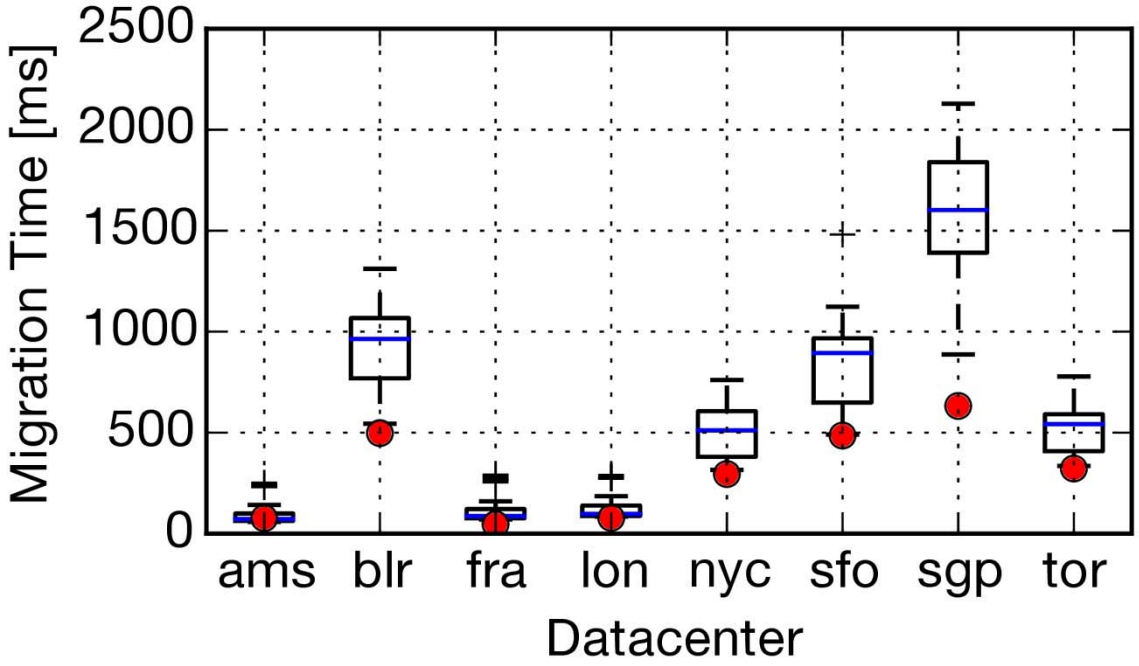
Migration Prototype & Evaluation

- Sample Application:
  - Motion detection App
  - Using python, cv2, MQTT
  - Code: 3kb
  - State (Background image): 21kb
  - Resolution: 640x360, 2fps



- Setup:
  - Beaglebone Black (TU Berlin) + Cloud (Digital Ocean)
  - Series of 30s with camera pictures repeated
  - Process is running on gateway and migrated back and forth 64 times to and from Cloud (8 locations)

Evaluation of Migration Time



- Estimated time using throughput and RTT (red)
- Takeaway:
  - With current technologies: migration in few seconds
  - Estimate lower bound for migration time

Conclusion

- Full potential of IoT only fully utilized through increased edge processing
- Presented offloading scheme on top of pub/sub
- Prototypical implementation for MQTT
- Migration time in the order of seconds

- Future work
  - Policy (Placement Problem)
  - Mapping of virtual bus to heterogeneous implementations (MQTT, Kafka, RabbitMQ, etc.)
  - Broker Placement, Routing

Q&A

Questions?

Optimization Problem Formulation (1)

- Optimizing for (monetary) cost:

$$\min_{x_i \in 0,1} (c_{transfer} \cdot \omega_{tr} + c_{memory} \cdot \omega_{mem} + c_{cpu} \cdot \omega_{cpu}) \quad (1)$$

where

$$c_{transfer} = \sum_{i=1}^{n} x_i \quad (rx_{i,loc} + tx_{i,loc}) + (1 - x_i)(rx_{i,rem} + tx_{i,rem}) \quad (2)$$

$$c_{memory} = \sum_{i=1}^{n} mem_i \cdot x_i \quad (3)$$

$$c_{cpu} = \sum_{i=1}^{n} cpu_i \cdot x_i \quad (4)$$

Optimization Problem Formulation (2)

- Constraints of Gateway Hardware:

$$\sum_{i=1}^{n} cpu_i \cdot (1 - x_i) \leq avail_{cpu} \cdot f_{cpu} \quad (5)$$

$$\sum_{i=1}^{n} mem_i \cdot (1 - x_i) \leq avail_{mem} \cdot f_{mem} \quad (6)$$

$$\sum_{i=1}^{n} rx_{i,rem} \cdot (1 - x_i) + tx_{i,loc} \cdot x_i \leq avail_{bw\downarrow} * f_{rx} \quad (7)$$

$$\sum_{i=1}^{n} tx_{i,rem} \cdot (1 - x_i) + rx_{i,loc} \cdot x_i \leq avail_{bw\uparrow} * f_{tx} \quad (8)$$