



Harokopio

Department of Informatics and Telematics

University

Engineering Smart Cyber-Physical Systems

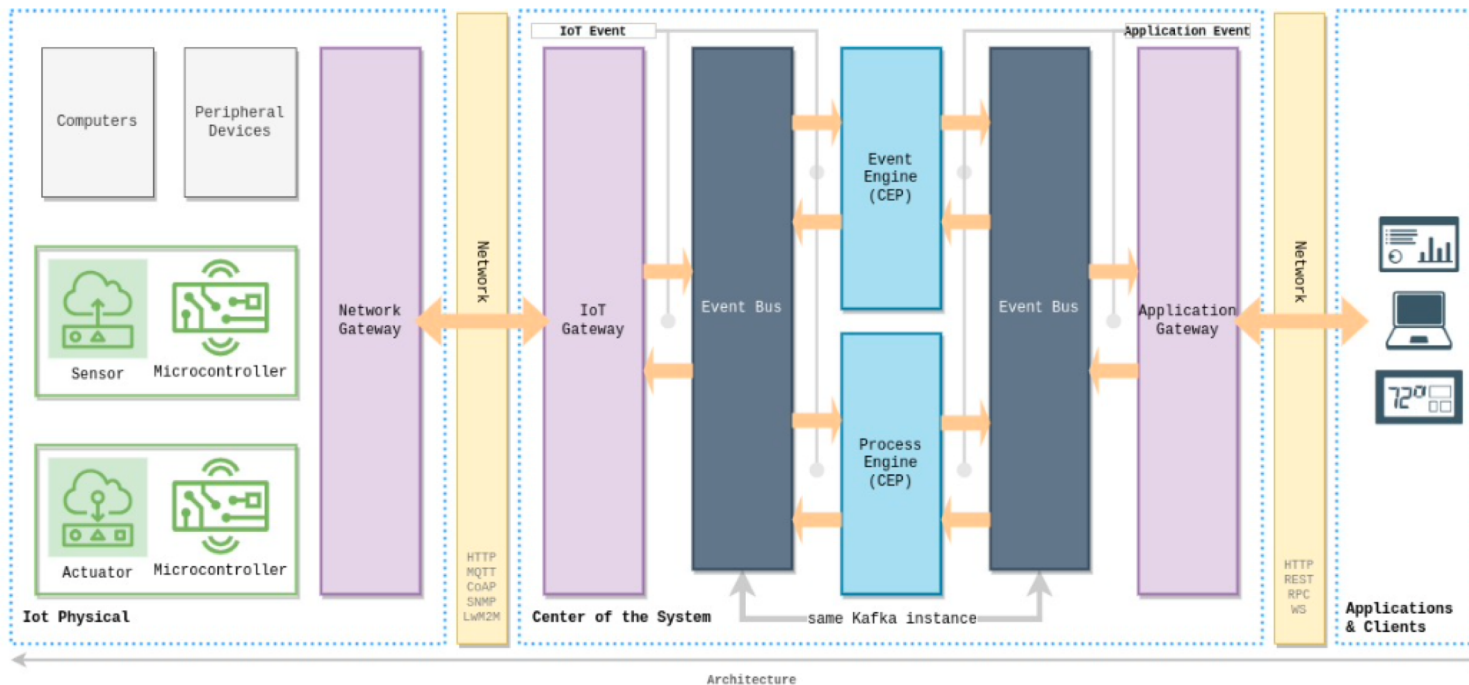
Professor Mara Nikolaidou

- Complex systems – Multiple layers
- **Devices**, aggregators/adapters, edge/fog/cloud, services/applications

Physical World Management

Service composition/ transformation

Service/ application provision



Overview – Research Topics

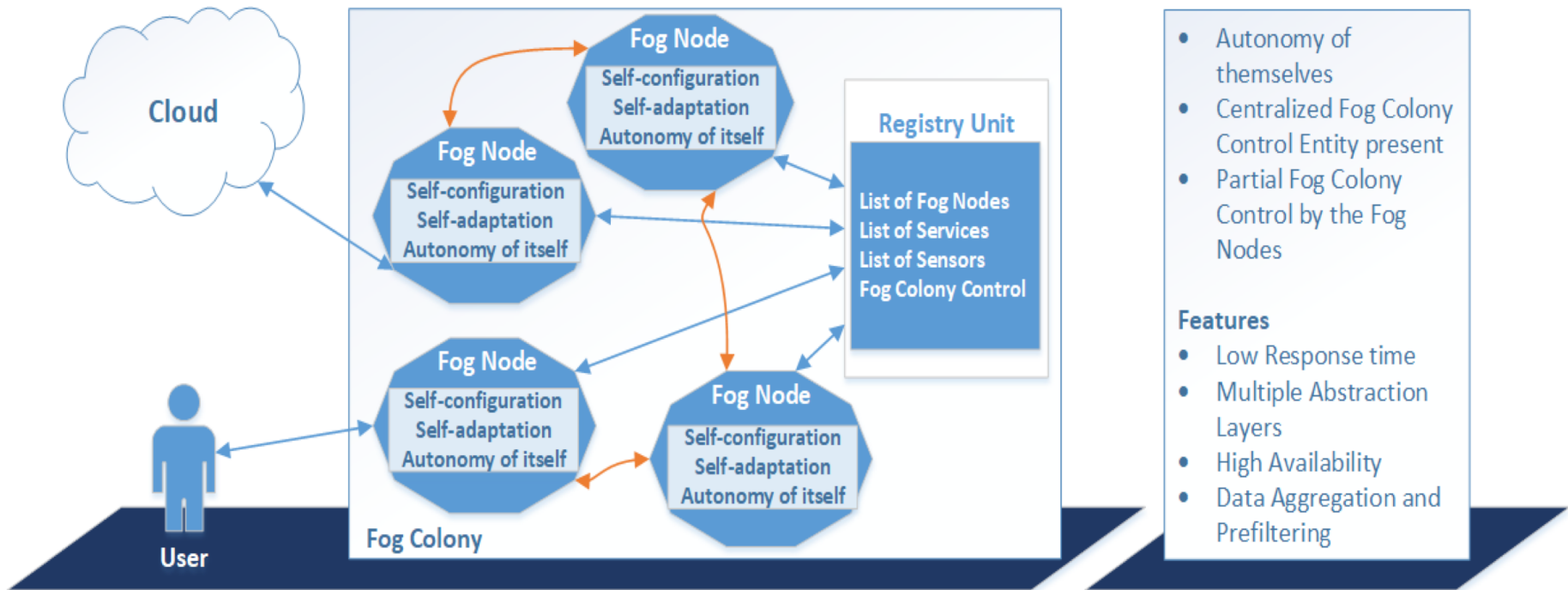
- Smart aggregators in CPS
 - Self-controlled, context-aware aggregators in Fog/Edge Colonies
 - Policies and node management middleware
 - Smart Building Management as a Case Study (EM3, EMC2 project)
- Smart service transformation in CPS
 - Multi-layer composition of IoT events to business events
 - Quality-aware event-based architecture for the composer
 - Enables event fabrication for missing/delayed events
 - Smart Farm management as a Case Study (AfarCloud project)
- Engaging Humans in Cyber-Physical *Human* Systems (CPHS)
 - Human View of CPHS Design
 - Human Concerns and the concept of *Criticality*
 - Remote Elderly Monitoring System as a Case Study (EMBIOT project)

Smart aggregators in CPS

- How "smart" should aggregators become??
 - Manage themselves through self-X properties.
 - Learn from others belonging in the same edge/fog colony
 - Exchange knowledge mechanism: policies
- Aim: Explore "level" of aggregator autonomy
 - Study which approach would work more effectively

Test in a Smart-Managed Building application

Fog Node Autonomy of itself



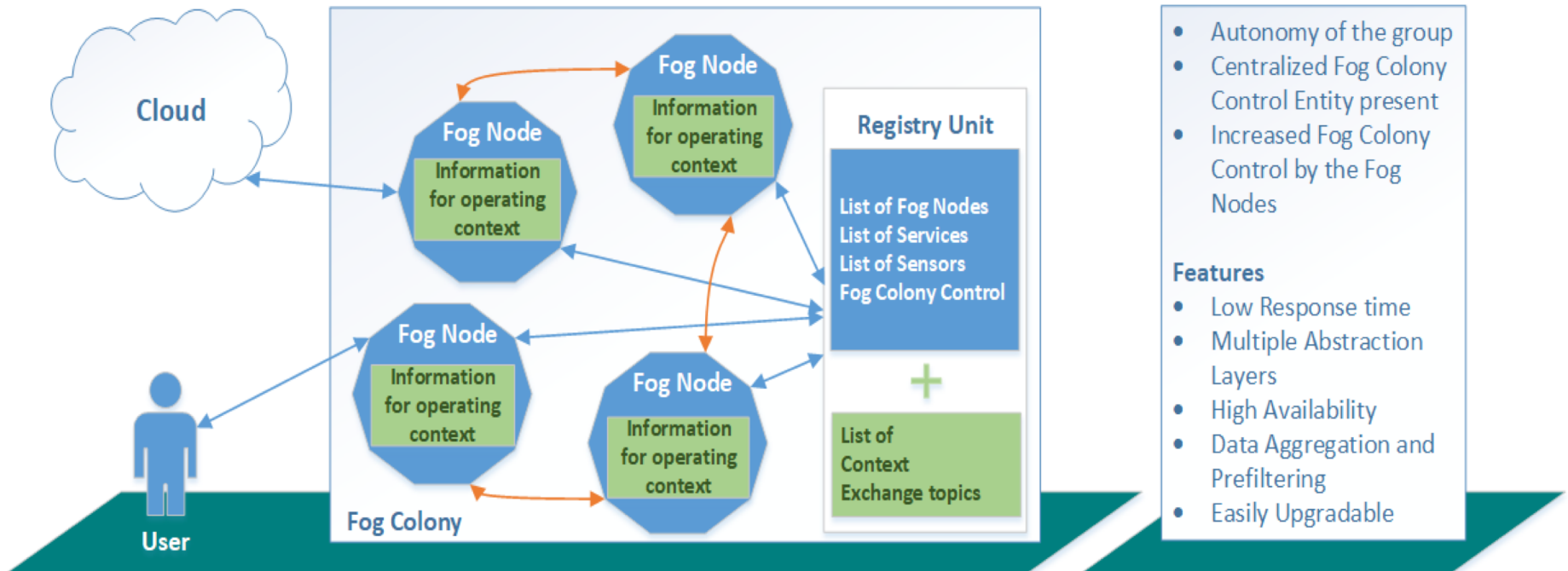
Artifact: Fog Node Self-Monitoring Middleware

Colony Control: Mostly Centralized (Participation control, Service Discovery),

Task/Resource Offloading managed by the nodes

Autonomy: Achieve autonomy of themselves

Fog Node partial Autonomy of the Group

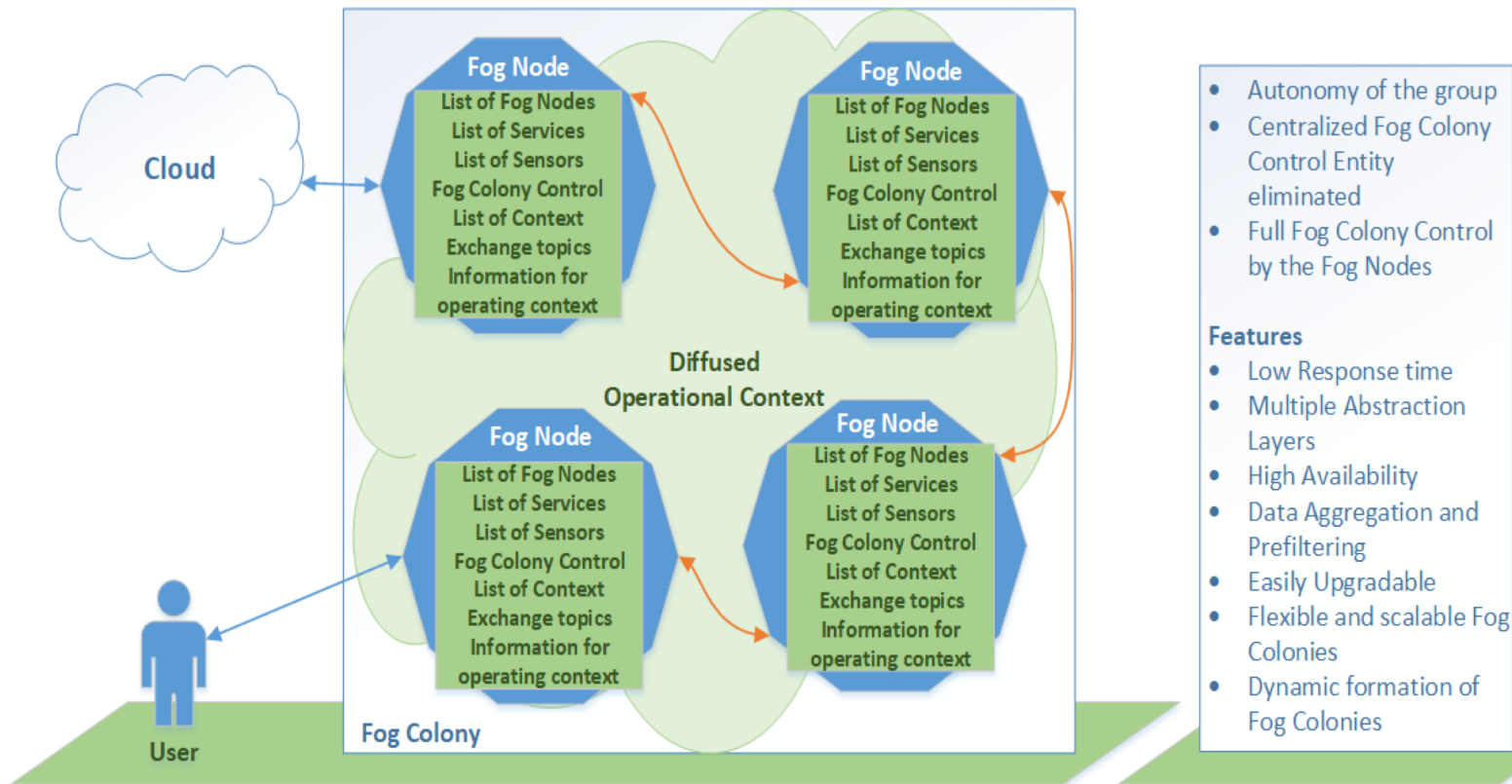


Artifact: Fog Node Self-Control Middleware

Colony Control: Mostly Centralized, (Participation control, Service Discovery), Task/Resource Offloading managed by the nodes, **in a context-aware manner**

Autonomy: Achieve partial autonomy of the Group

Fog Node Full Autonomy of the Group



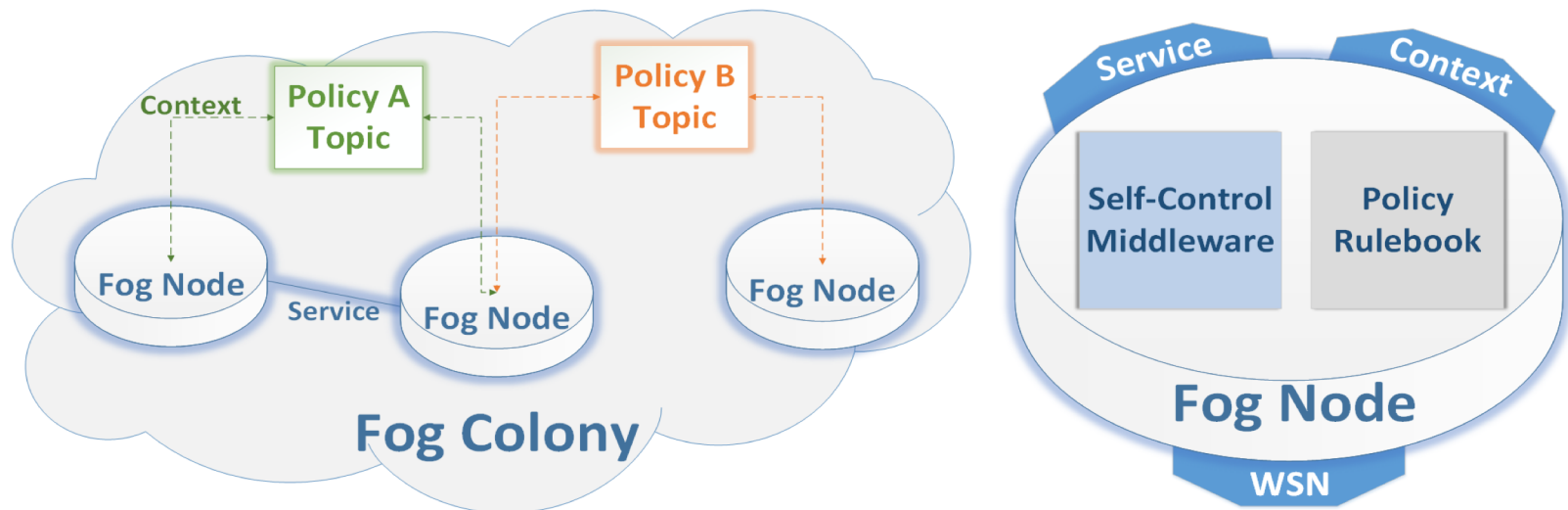
Artifact: ECTORAS protocol

Colony Control: Decentralized, Participation control, Service Discovery, Task Offloading, in a context aware manner

Autonomy: Achieve full autonomy of the Group

The concept of Policies

- Policies prescribe a certain desired behavior for the aggregator.
- The collection of the policies enforced by a node comprise the *Policy Rulebook*
- Just like in the real world people have different rules by which they live by, similarly aggregators of the same group do not need to share the same rules.



Policy Example

Task Offloading

```
information:
  name: "QoS Preservation Policy - Transfer Resources"
  version: "1.0"
monitoring:
  variables:
    - cpu_load: "com.vnikolopoulos.util.functions.Internals cpuLoad"
context:
  variables:
    - node_info: "com.vnikolopoulos.SharedMemory getNodesInfo"
    - accepting_nodes: "node_info->find_all('accepts_new_transfers=
      true')"
    - accepting_nodes_compatible: "accepting_nodes->find_all('
      accepts_sensor_type=micaz')"
decision:
  conditions: "cpu_load > 0.95"
  actions:
    -"for(Node x in accepting_nodes_compatible){
      propose_offload(x);
    }"
resource:
  endpoints:
    - offload: "com.vnikolopoulos.policy.endpoints.
      OffloadingEndpointHandler"
communication
  topic: "qos_transfer_resources"
  message_condition:
    "cpu_load > 0.95 OR
    accept_new_transfers == true OR
    add_or_remove_from(this.status.accepts_sensor_type)"
  message_to_topic:
    - cpu_status: "com.vnikolopoulos.util.functions.Internals
      cpuLoad"
    - sensor_types: "com.vnikolopoulos.util.functions.Status
      servingTypes"
    - accept_new_transfers: "com.vnikolopoulos.util.functions.Status
      accept_new_transfers"
```

Monitoring Section

Decision Section

Resource Section

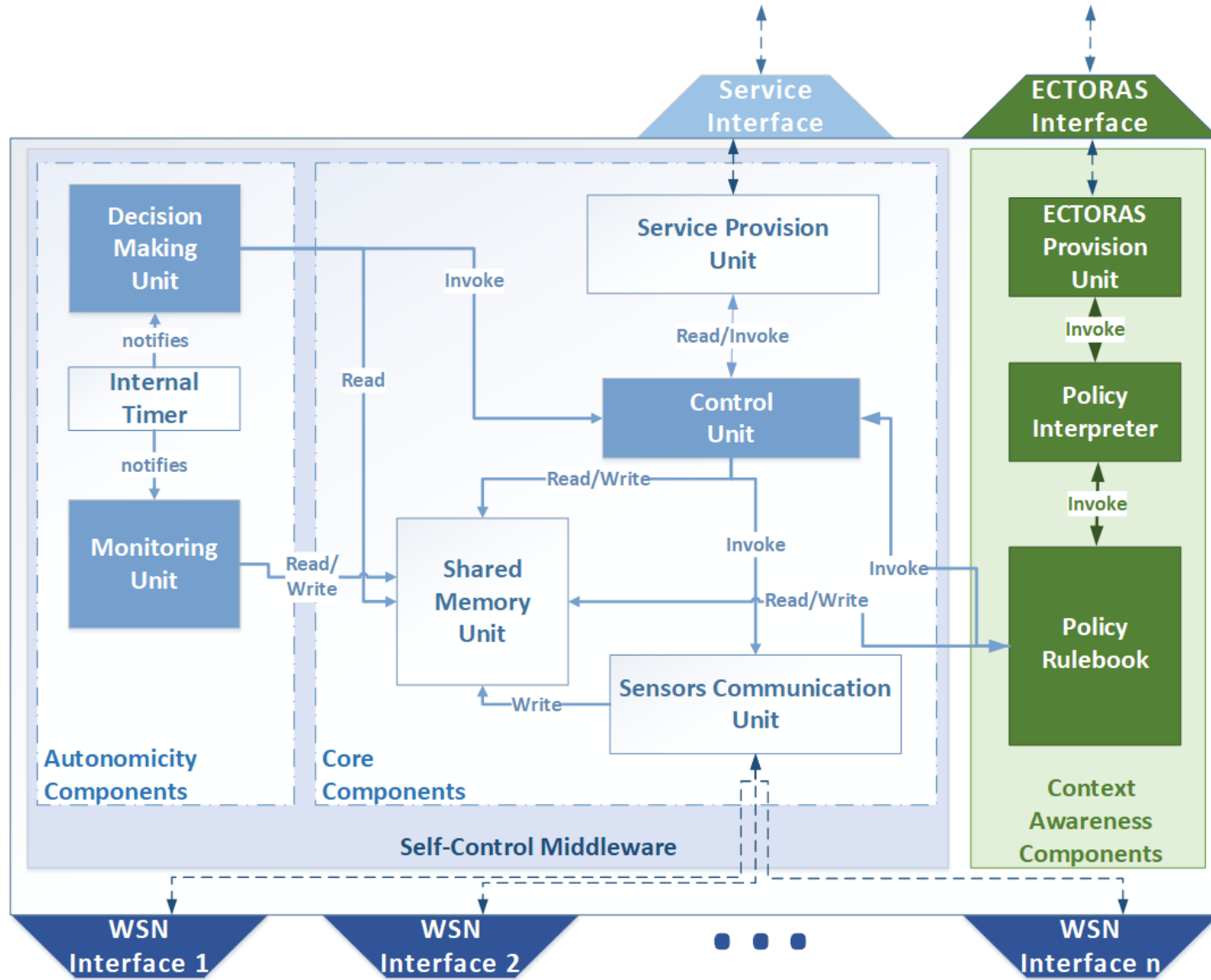
Context Change

- Using a publish-subscribe protocol named *ECTORAS*

Data shared by Task Offloading Policy

```
{  
  "topic": "qos_transfer_resources",  
  "version": 1.00,  
  "identifier": "0x00A5f",  
  "ip": "10.10.3.96",  
  "cpu_status": 0.71,  
  "sensor_types": ["micaz", "ima"],  
  "accept_new_transfers": false  
}
```

Self-control management middleware

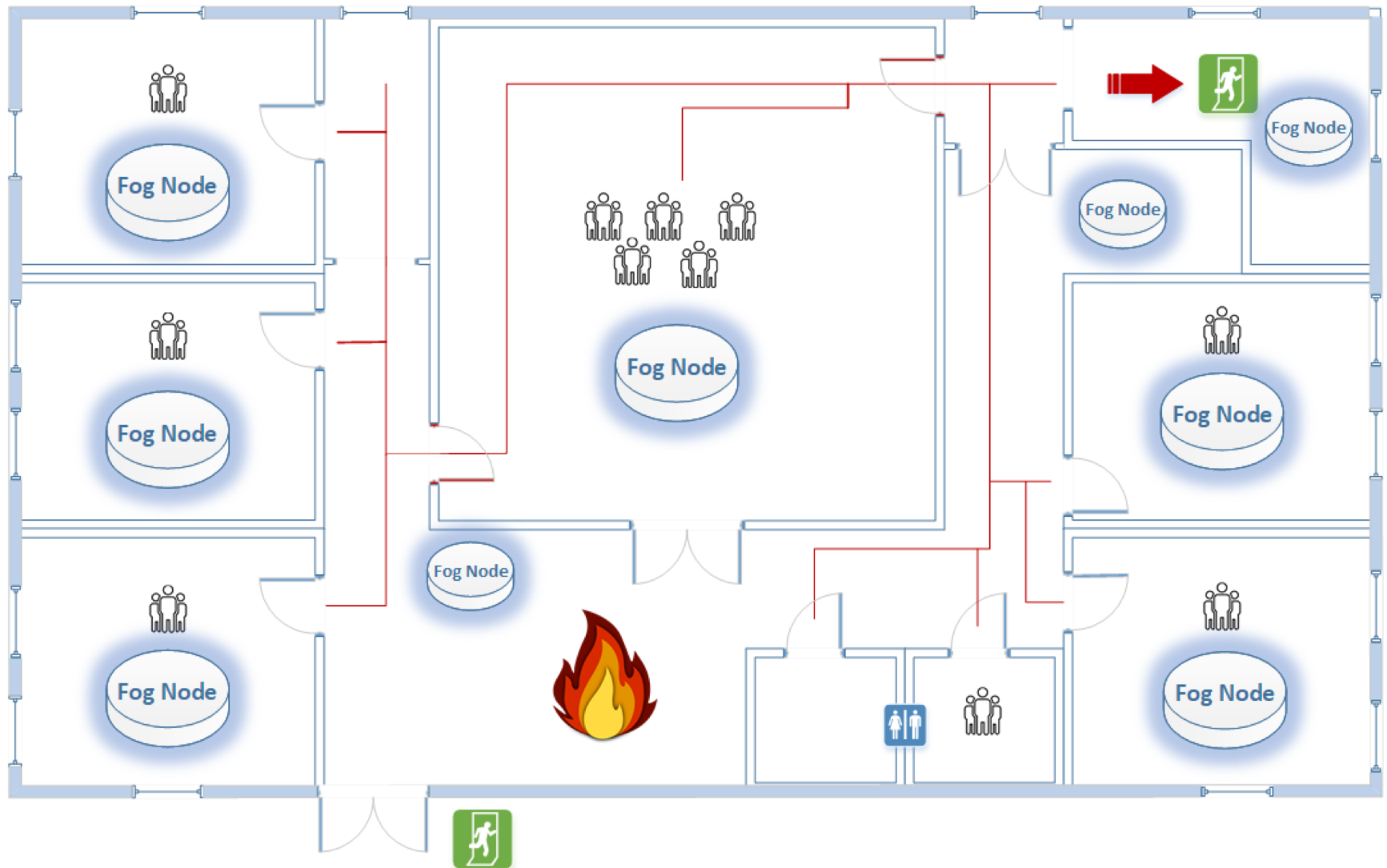


Smart-managed Building: Fire Drills

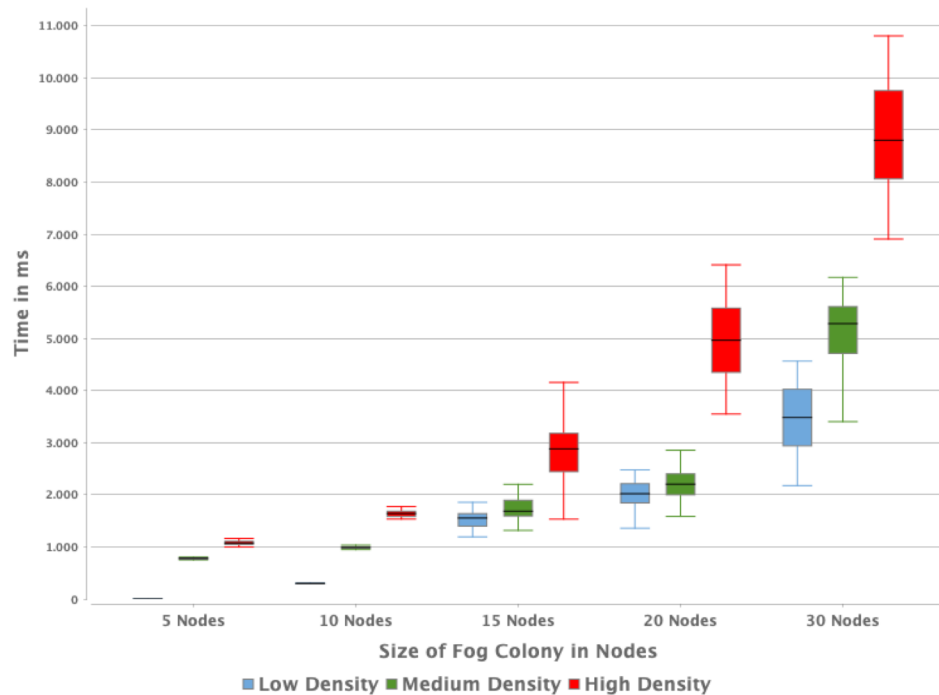
- Target: Explore performance of context-aware vs non context-aware middleware (both developed by our team)
- Testbed consists of 30 Nodes
 - operating on Raspberry Pi 3 revision B units (one node per Raspberry Pi)
 - handled a minimum of 5 sensors and maximum of 50 sensors of different manufactures, whose presence was dynamic
 - Communication performed by a mix of local WiFi and Ethernet networks.
- Experiment conditions
 - A “Walk to the nearest exit with no fire” service is executed by all nodes
 - Nodes handover tasks when too “busy”
 - Different loads, corresponding to people in the building are generated

Part of the scenario (third floor)

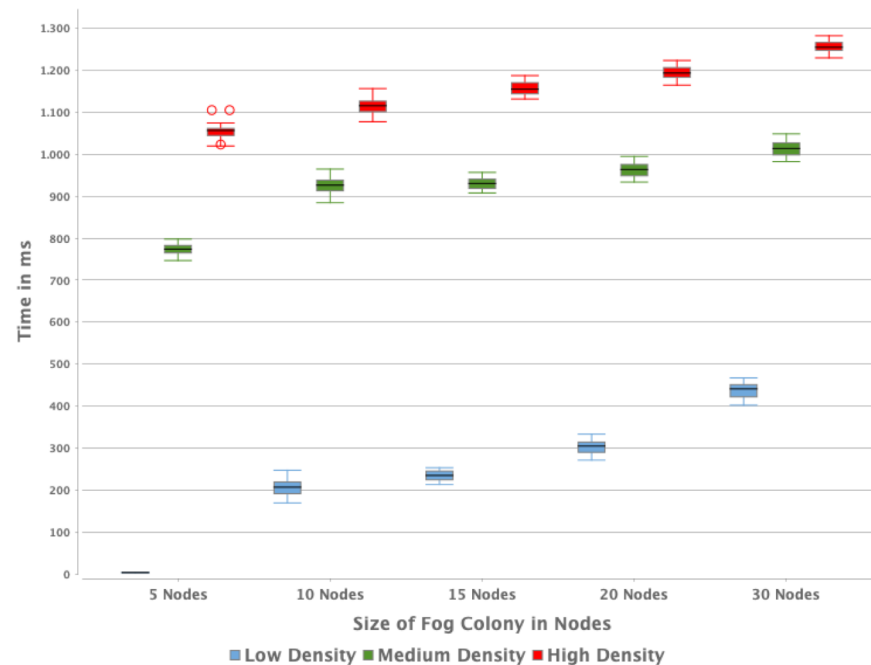
Floor 3



Average Service Request Response Time

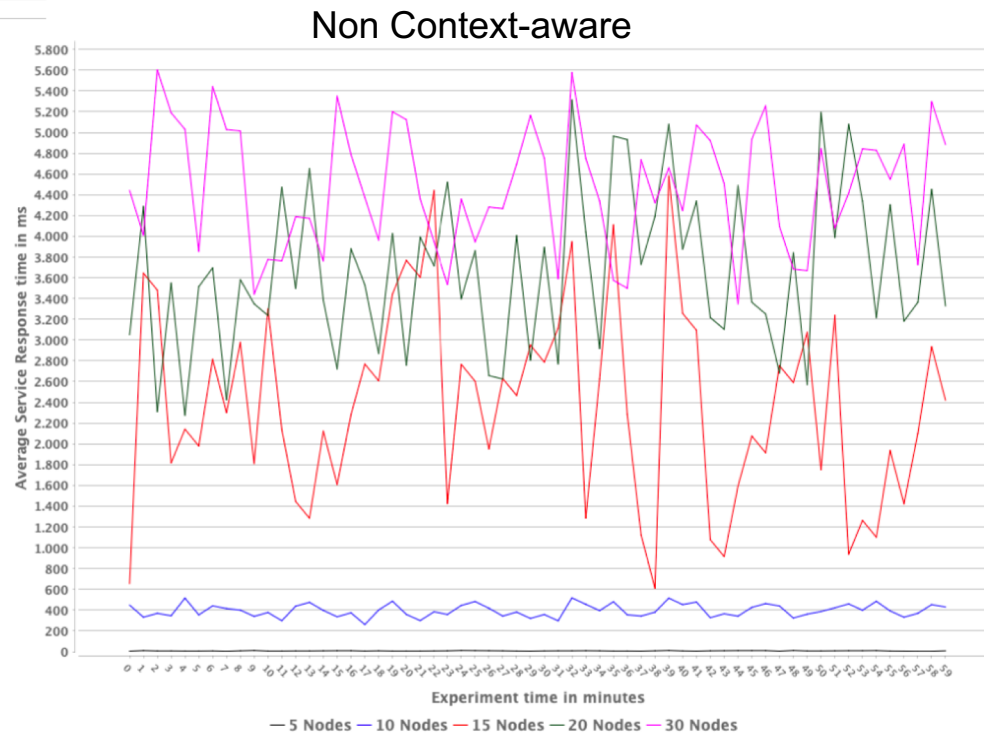
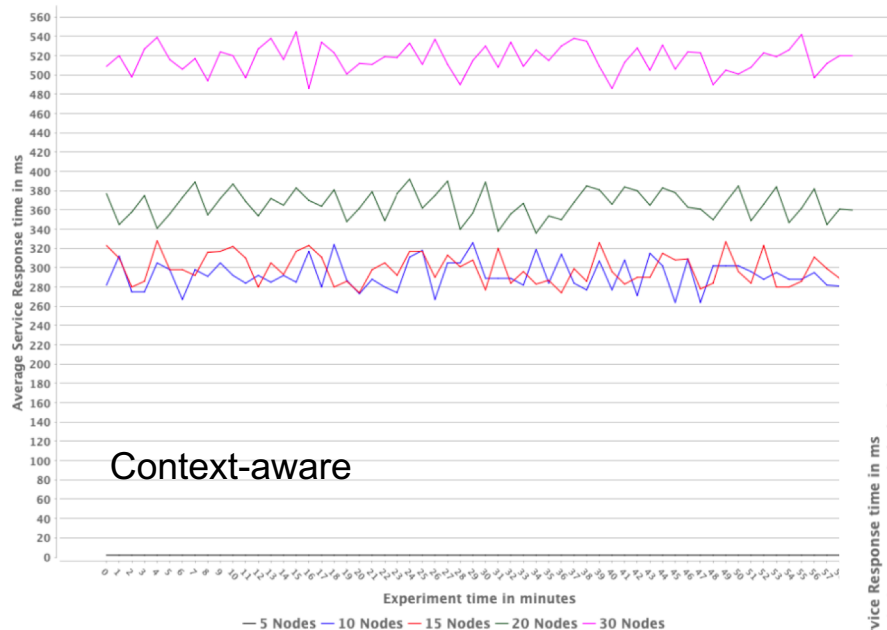


Non-context aware Middleware



Context aware Middleware

- Diversity in Task Offload execution time



- Context-aware self-control middleware supports better performance and stability in response time
- Further test should be performed to cover other KPIs, as energy consumption
- Comparison to other approaches (centralized) is of importance
- Support of heterogeneous node middleware

Nikolopoulos, Vasileios, Mara Nikolaidou, Maria Voreakou, and Dimosthenis Anagnostopoulos. "Fog Node Self-Control Middleware: Enhancing context awareness towards autonomous decision making in Fog Colonies." *Internet of Things* 19 (2022): 100549.

Nikolopoulos, Vasileios, Mara Nikolaidou, Maria Voreakou, and Dimosthenis Anagnostopoulos. "Context Diffusion in Fog Colonies: Exploring Autonomous Fog Node Operation Using ECTORAS." *IoT* 3, no. 1 (2022): 91-108.

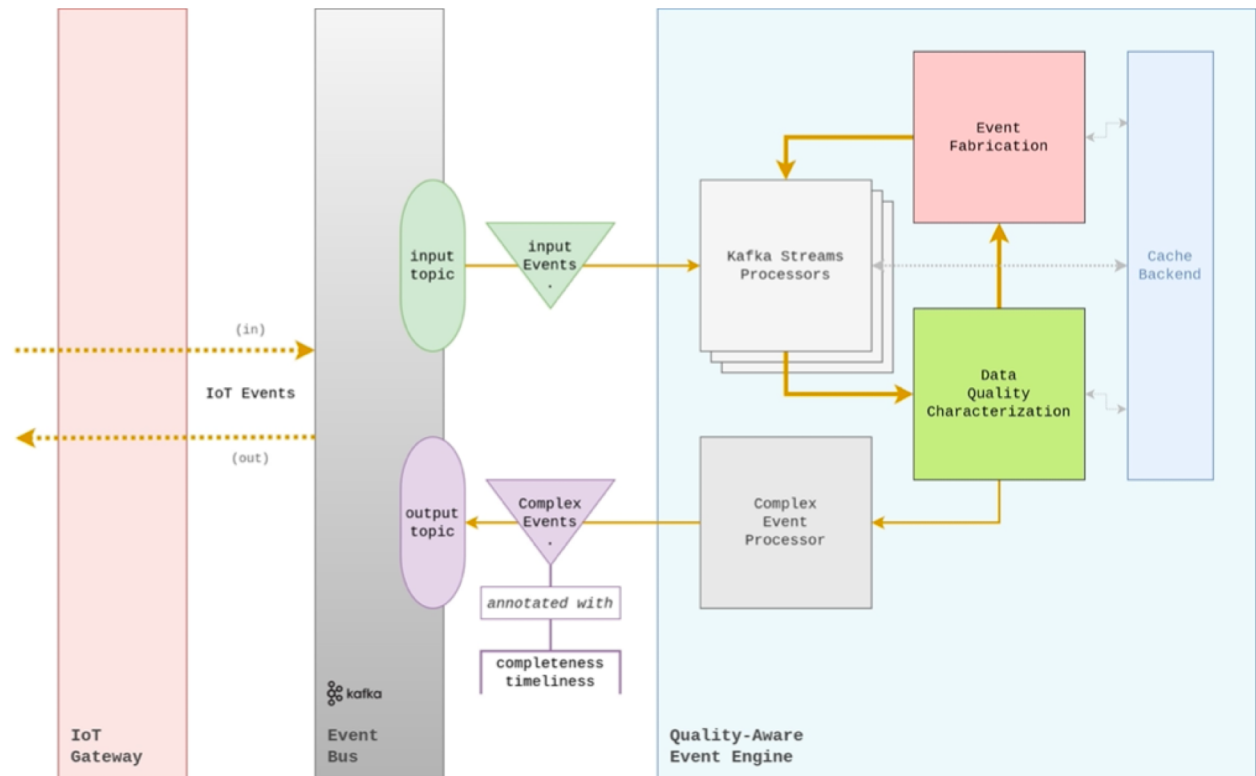
Smart service transformation in CPS

- How "smart" may service composition/transformation middleware be??
 - Multi-layer composition of IoT events to business events
 - Correct the errors of underlying services/devices
 - What about data accuracy?
- Aim: Provide a Quality-aware event-based middleware platform
 - Enables event fabrication for missing/delayed events

Test in Greenhouse management as part of a Smart Farming environment

A Quality-aware Event Engine

- Build upon Kafka platform
 - “Restores” missing events when building composite ones
 - Annotates the composite event “quality”



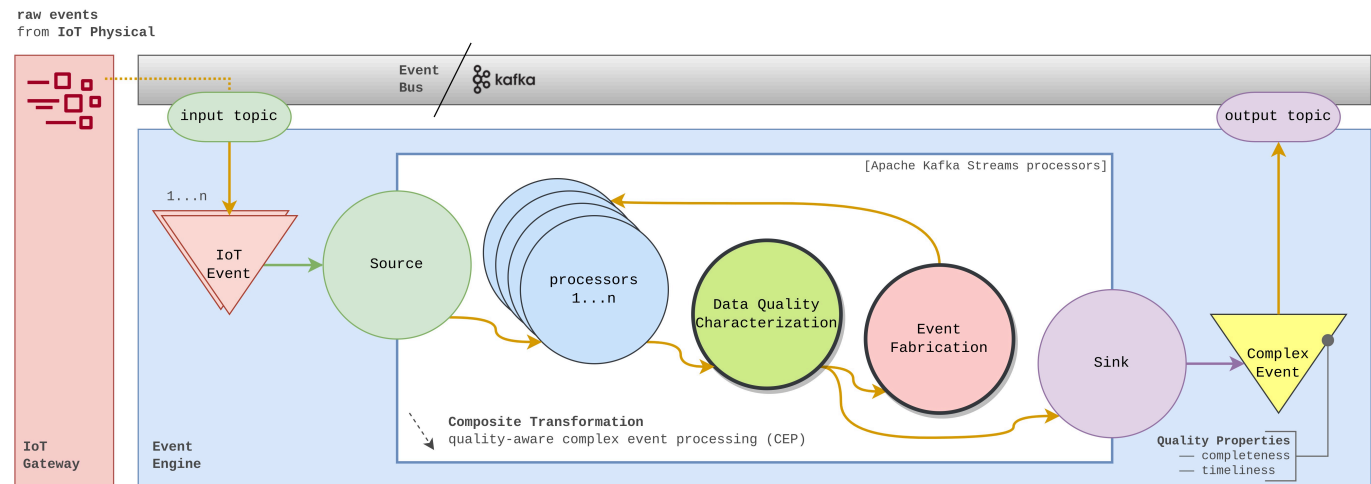
Composite Event Quality Parameters

- Completeness: Is an input event missing?
- Timeliness: Is an input event fabricated?

$$completeness = 1 - \frac{required - obtained}{required}$$

$$timeliness = 1 - \frac{obtained - timely}{obtained}$$

- In erroneous situations both of them decrease.



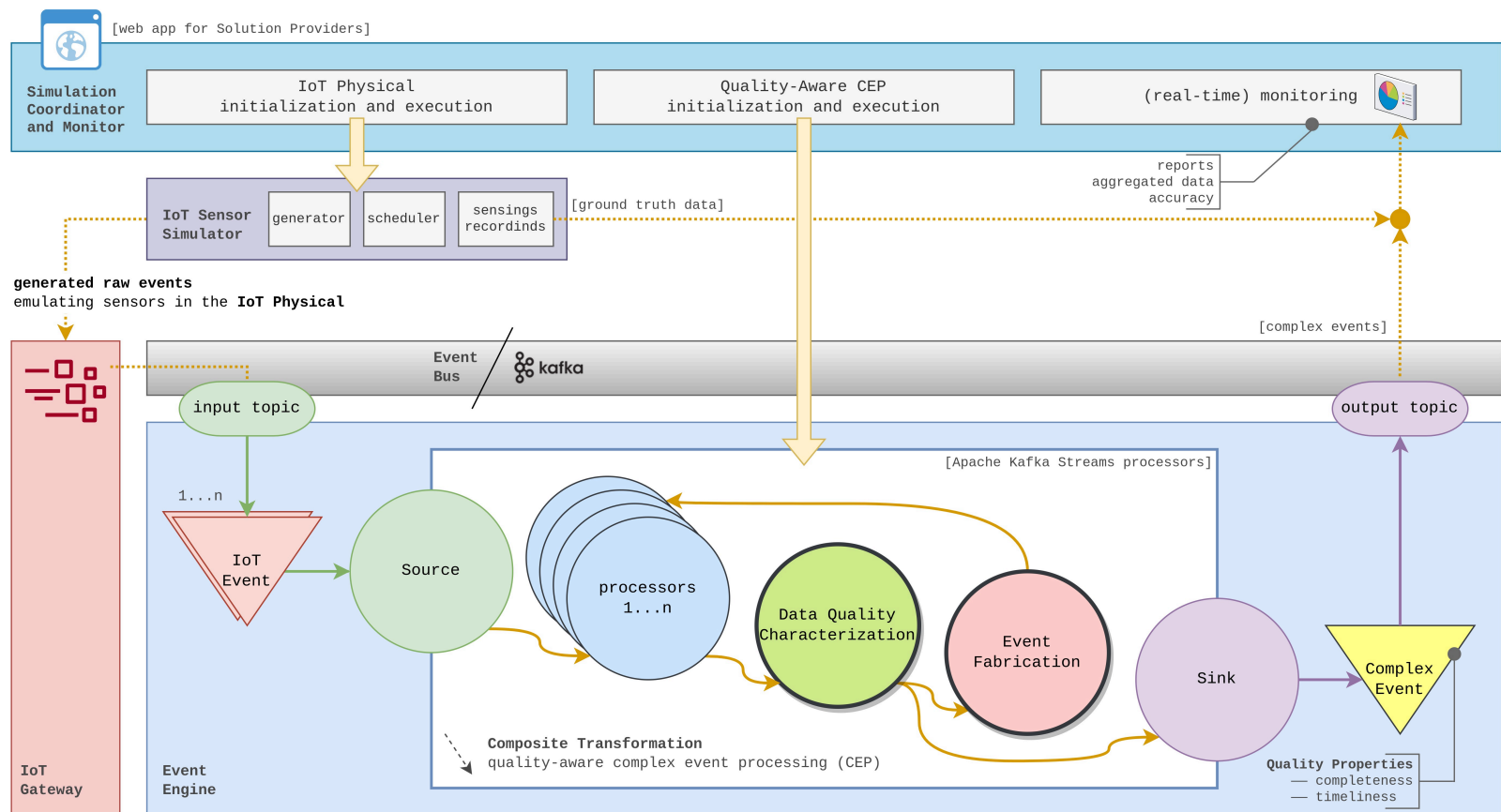
- Target: Maintain completeness at 1
Timeliness decreases
- Our platform explores alternative event fabrication policies
 - Currently
 - Past events (in different time scale)
 - forecasting using Arima or Exponential Smoothing
- Timeliness should become a more sophisticated measurement to reflect the impact of event fabrication to composite event quality

$$timeliness = \frac{1}{n} \sum_{i=1}^n degreeOfTimeliness_i$$

$$degreeOfTimeliness = \begin{cases} 1 - \left(\frac{1}{n} \times |offset|\right) & \text{if } |offset| \leq n \\ 0 & \text{if } |offset| > n \end{cases}$$

Enables

- The exploration of event fabrication policies
- Test and adjust the concept of timeliness as QoS indicator



Greenhouse Management

Compute average temperature
in the Greenhouse

Real world example with 6 sensors

QoS measurement: accuracy

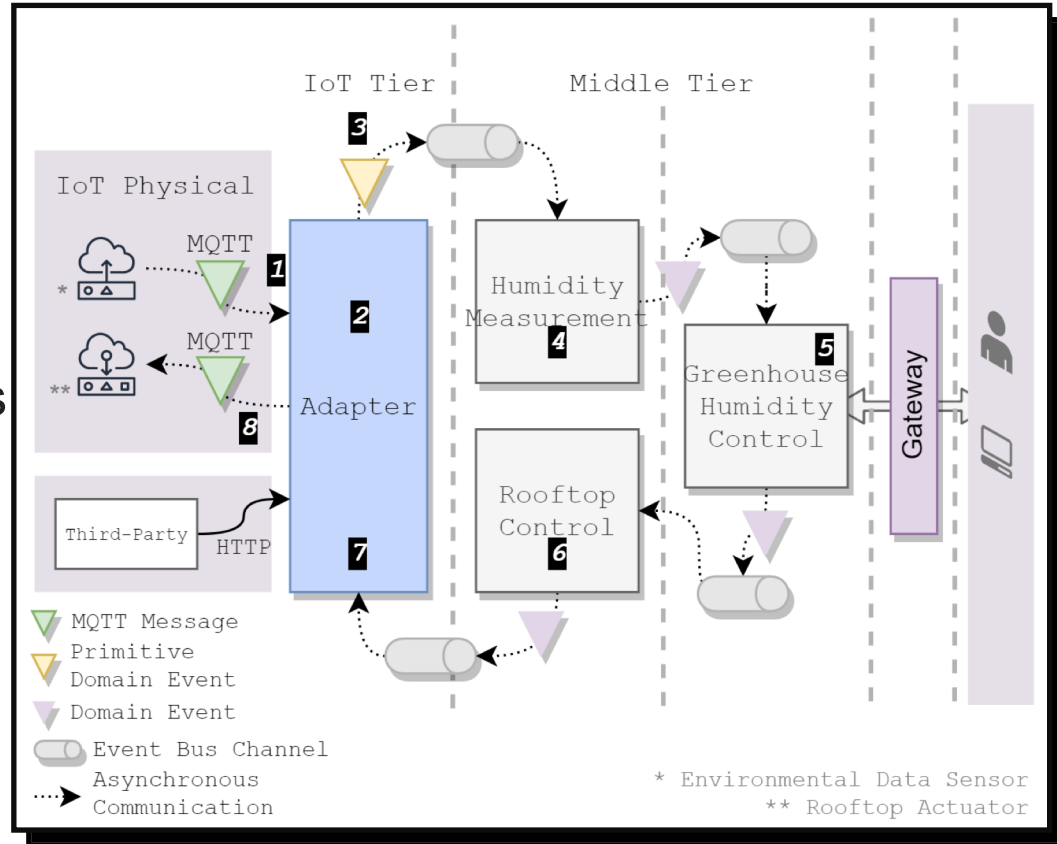
Explore different policies
to treat missing events

✓ Use different number of values
to compute average (2-6)

✓ Fabricate missing events

- use past events

- forecasting using Arima or Exponential Smoothing

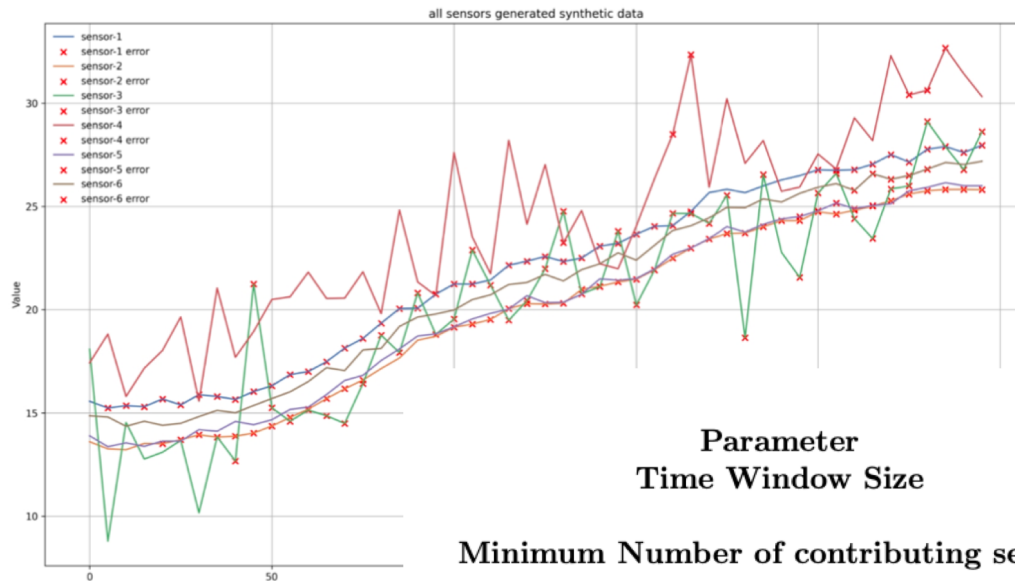


Part of AfarCloud EU project infrastructure

Experimental conditions

Sensor ID	1	2	3	4	5	6
Error Rate	~95%	~90%	~85%	~8%	~8%	~8%

Erroneous conditions



Parameter
Time Window Size

Minimum Number of contributing sensors

Fabrication - past events - steps behind

Fabrication - forecasting - time window size same as time window size

Fabrication - forecasting - steps ahead

Ordinal

small
small
medium
high
disabled
small
medium
high
disabled
small
medium
high

Real

5 seconds
2 sensors
4 sensors
6 sensors
0
2 past time windows
4 past time windows
6 past time windows
-
0
2 future time windows
4 future time windows
6 future time windows

IoT Simulation Coordinator and Monitor

HomeDashboardReal-Time MonitoringIoT Physical EnvironmentInitiatorDebuggerKafkaComposite TransformationsDiagnostics

Real-Time Monitoring / complex events

Displaying 50 complex events created by w_avg_temperature_PT55_null_null_4_false_6_PT55_6 composite transformation

--- select composite transformation ---

download spreadsheets (.zip)

download figures (.zip)

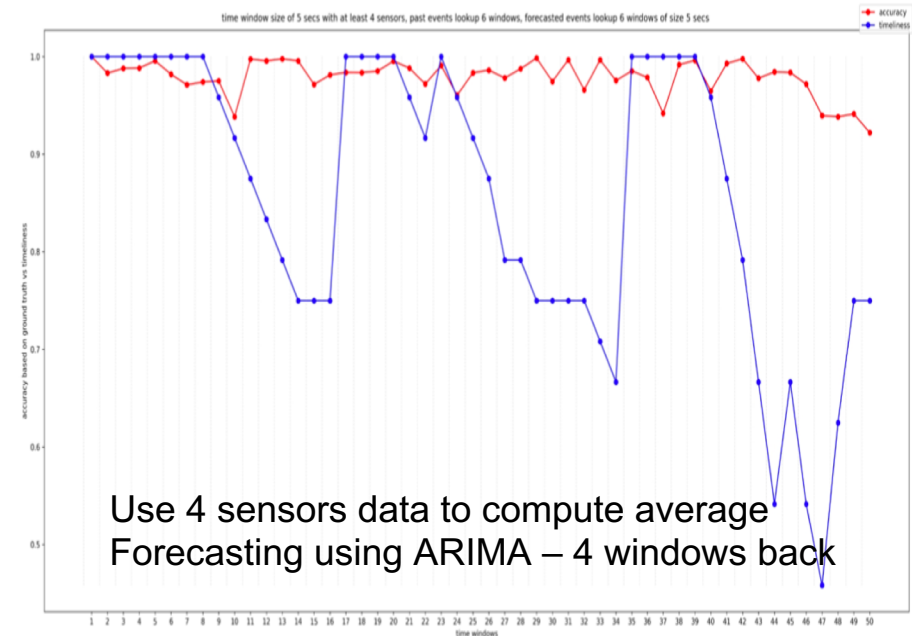
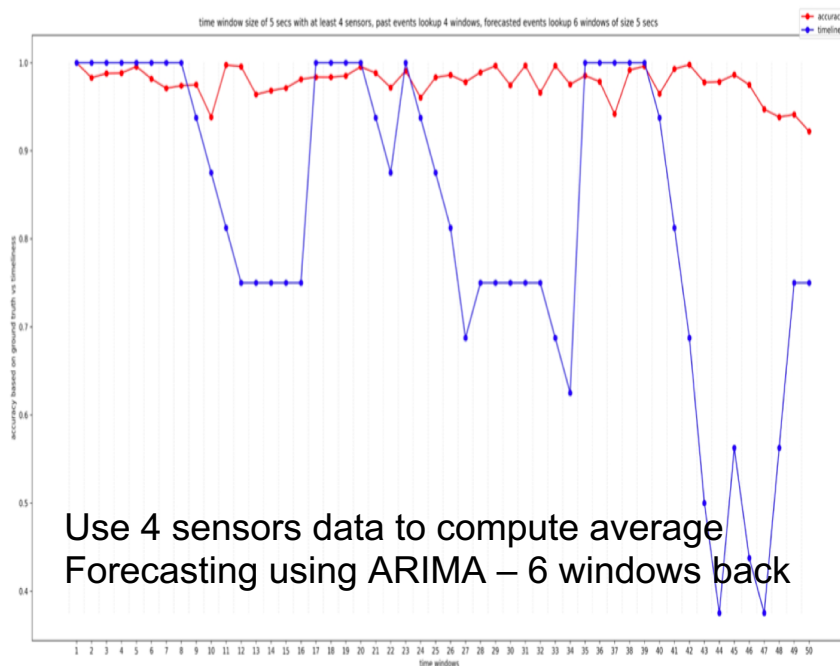
time window size of 5 secs with at least 4 sensors, past events lookup 6 windows, forecasted events lookup 6 windows of size 5 secs

Time Window (simulation)			Air Temperature	Quality Properties				Events		Fabrication: Past Events		Fabrication: Forecasting	
Number	Start	End	Average Value	Completeness		Timeliness (1)	Timeliness (2)	Real	Fabricated	Count	Duration	Count	Duration
16	20:02:15	20:02:20	18.39	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0439	1	0.0129
17	20:02:20	20:02:25	18.16	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
18	20:02:25	20:02:30	19.95	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
19	20:02:30	20:02:35	19.56	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
20	20:02:35	20:02:40	19.50	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
21	20:02:40	20:02:45	21.37	75.00 %	100.00 %	75.00 %	95.83 %	3	1	1	0.0377	0	0.0000
22	20:02:45	20:02:50	20.57	75.00 %	100.00 %	75.00 %	91.67 %	3	1	1	0.0445	0	0.0000
23	20:02:50	20:02:55	20.93	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
24	20:02:55	20:03:00	22.72	75.00 %	100.00 %	75.00 %	95.83 %	3	1	1	0.0425	0	0.0000
25	20:03:00	20:03:05	21.89	75.00 %	100.00 %	75.00 %	91.67 %	3	1	1	0.0451	0	0.0000
26	20:03:05	20:03:10	22.63	75.00 %	100.00 %	75.00 %	87.50 %	3	1	1	0.0421	0	0.0000
27	20:03:10	20:03:15	22.55	50.00 %	100.00 %	50.00 %	79.17 %	2	2	2	0.0514	0	0.0000
28	20:03:15	20:03:20	22.23	75.00 %	100.00 %	75.00 %	79.17 %	3	1	1	0.0387	0	0.0000
29	20:03:20	20:03:25	21.84	75.00 %	100.00 %	75.00 %	75.00 %	3	1	1	0.0365	0	0.0000
30	20:03:25	20:03:30	21.85	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0404	1	0.0143
31	20:03:30	20:03:35	22.29	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0360	1	0.0171
32	20:03:35	20:03:40	24.01	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0414	1	0.0243
33	20:03:40	20:03:45	24.46	50.00 %	100.00 %	50.00 %	70.83 %	2	2	1	0.0558	1	0.0211
34	20:03:45	20:03:50	24.68	50.00 %	100.00 %	50.00 %	66.67 %	2	2	1	0.0709	1	0.0266
35	20:03:50	20:03:55	24.88	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
36	20:03:55	20:04:00	26.26	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
37	20:04:00	20:04:05	25.36	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
38	20:04:05	20:04:10	25.93	100.00 %	100.00 %	100.00 %	100.00 %	4	0	0	0.0000	0	0.0000
39	20:04:10	20:04:15	24.89	100.00 %	100.00 %	100.00 %	100.00 %	5	0	0	0.0000	0	0.0000
40	20:04:15	20:04:20	25.62	75.00 %	100.00 %	75.00 %	95.83 %	3	1	1	0.0395	0	0.0000
41	20:04:20	20:04:25	26.09	50.00 %	100.00 %	50.00 %	87.50 %	2	2	2	0.0691	0	0.0000
42	20:04:25	20:04:30	25.95	50.00 %	100.00 %	50.00 %	79.17 %	2	2	2	0.0538	0	0.0000
43	20:04:30	20:04:35	26.57	25.00 %	100.00 %	25.00 %	66.67 %	1	3	3	0.0710	0	0.0000
44	20:04:35	20:04:40	26.30	25.00 %	100.00 %	25.00 %	54.17 %	1	3	3	0.0737	0	0.0000
45	20:04:40	20:04:45	27.51	50.00 %	100.00 %	50.00 %	66.67 %	2	2	2	0.0735	0	0.0000
46	20:04:45	20:04:50	27.66	25.00 %	100.00 %	25.00 %	54.17 %	1	3	3	0.0760	0	0.0000
47	20:04:50	20:04:55	26.00	25.00 %	100.00 %	25.00 %	45.83 %	1	3	2	0.0734	1	0.0138
48	20:04:55	20:05:00	26.21	50.00 %	100.00 %	50.00 %	62.50 %	2	2	1	0.0566	1	0.0161
49	20:05:00	20:05:05	25.84	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0454	1	0.0152
50	20:05:05	20:05:10	25.50	75.00 %	100.00 %	75.00 %	75.00 %	3	1	0	0.0420	1	0.0157

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Accuracy vs Timeliness

- Are they related?
- Is it effective to fabricate events?

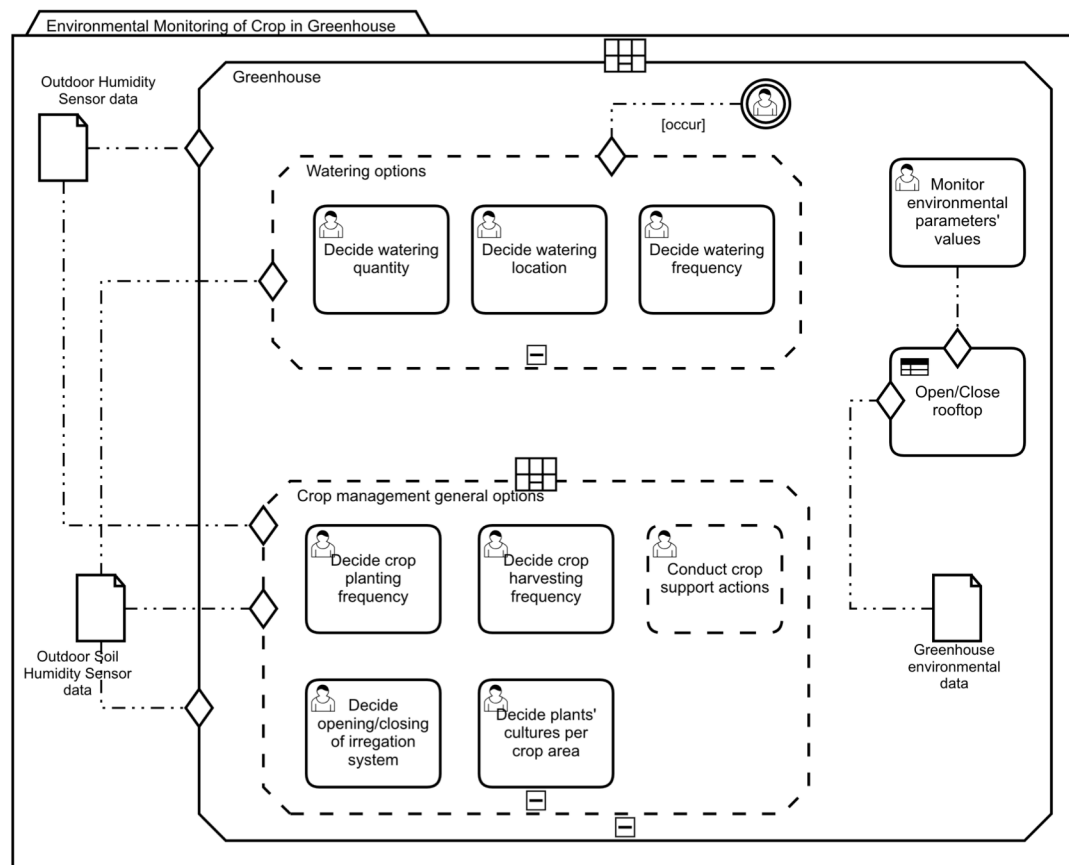


WORK IN PROGRESS

D. Gkoulis, C. Bardaki, M. Nikolaidou, G. Kousiouris, A. Tsadimas (2023). A Hybrid Simulation Platform for quality-aware evaluation of complex events in an IoT environment. *Simulation Practice and Theory*, 27(1)

Exploring User Interface

- Farmers should be provided with alerts, notifications or prompt to initialize specific actions
 - Different options on deciding upon rooftop opening or closing



Process description to be communicated with Farmers in CMMN

- The hybrid simulation platform enables the exploration of event fabrication techniques
 - Practitioners can run our Kafka-based QoS-aware event composition platform and simulate different scenarios to sense their CPS environment.
- When dealing with real-time data streams in most cases the simplest solution is the best
- Timeliness computation and importance needs further exploration
- Make the platform smarter: adjust event fabrication technique to current condition
 - We are building a rule base for this purpose

Engaging Humans in CPHS

- CPHS Design should focus on
 - How to include people in the CPHS loop
 - The fact that they behave differently from computers (for example cognition, unpredictability, motivation)
- Existing CPHSs design efforts¹²:
 - Explore human capabilities to enhance their integration in the system
 - Neglect their incentives, motivating them to act as prescribed
 - Keep human participant out of the design process, restricting their willingness to participate

1 – S.K. Sowe, E. Simmon, K. Zettsu, F. de Vaulx, I. Bojanova, “Cyber-Physical-Human Systems: Putting People in the Loop”, IEEE IT Pro, Jan-Feb 2016.

2 - S. F. Ochoa, G. Fortino, and G. Di Fatta, “Cyber-physical systems, internet of things and big data,” Future Generat. Comput. Syst., vol. 75, pp. 82–84, 2017

Our Proposal

- A CPHSs Design Approach:
 - Consider human motivation factors and their *concerns*
 - Include human participants in the design process
- Human concerns
 - Relate to human willingness to actively participate in CPHSs
 - Might restrict system functionality in practice
 - Should be transformed into system design requirements
- The proposed approach:
 - facilitates model-based design
 - integrates the human perspective in a discrete view
 - supported by standard UML tools (Magic Draw)

CPHS design views

⇒ Human view

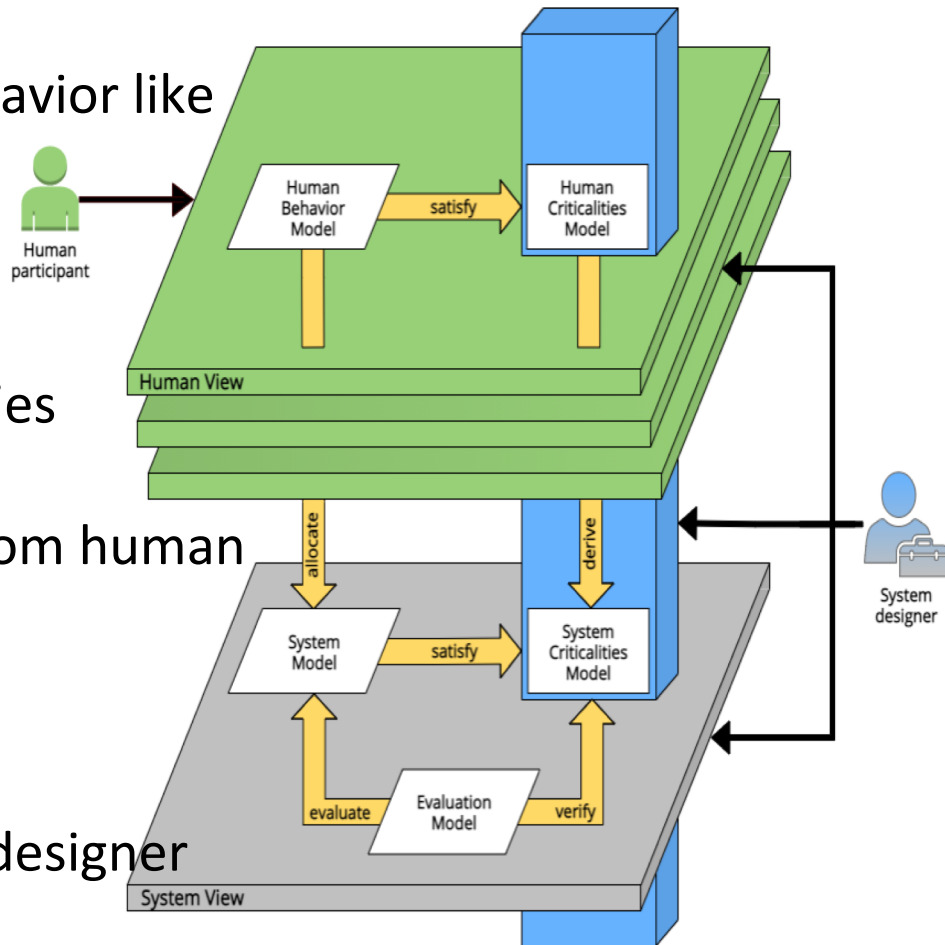
- Human Behavior Model
 - entities related to human behavior like activities

⇒ Criticalities view

- Human Criticalities Model
 - human concerns and criticalities
- System Criticalities Model
 - system criticalities, derived from human ones

⇒ System view

- System Model
 - system structure, defined by designer
- Evaluation Model
 - verify system criticalities

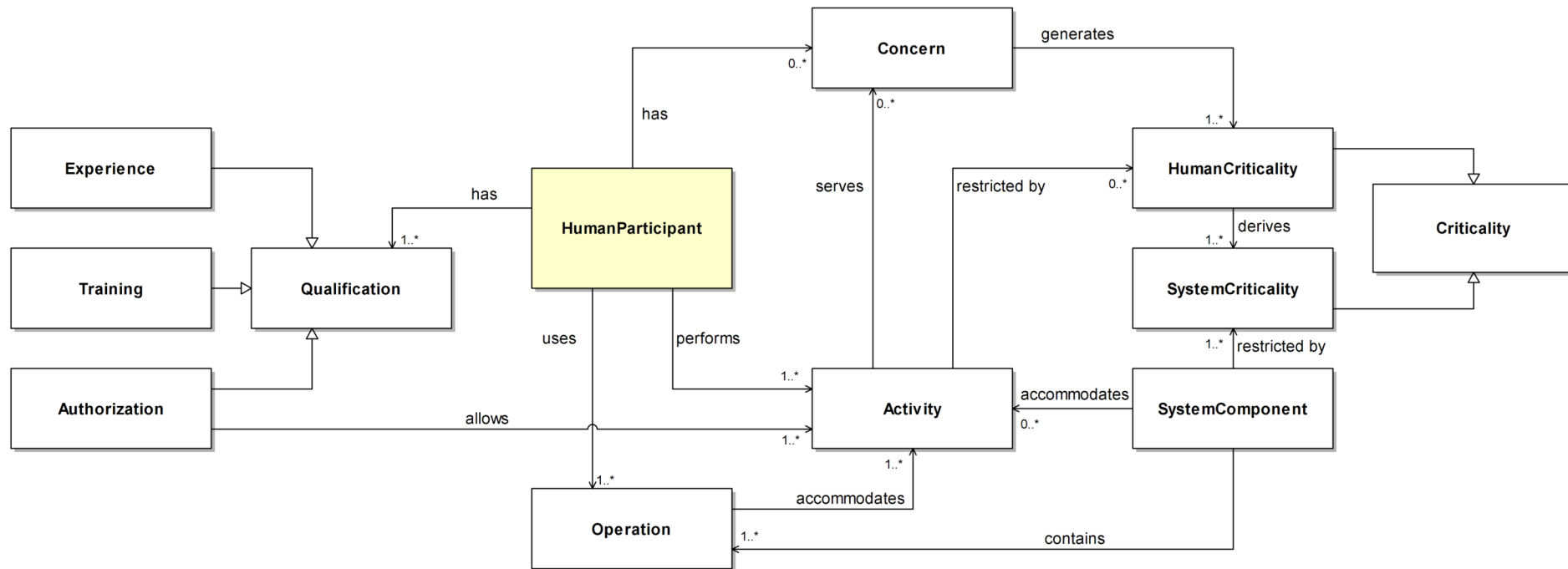


The Concept of *Criticality*

Aim

- indicate the severity for the human participant if the system does not accommodate his/her concern
- transform human concerns into CPHS design requirements
- enable the verification of these requirements

Definition: Extend SysML profile functionality



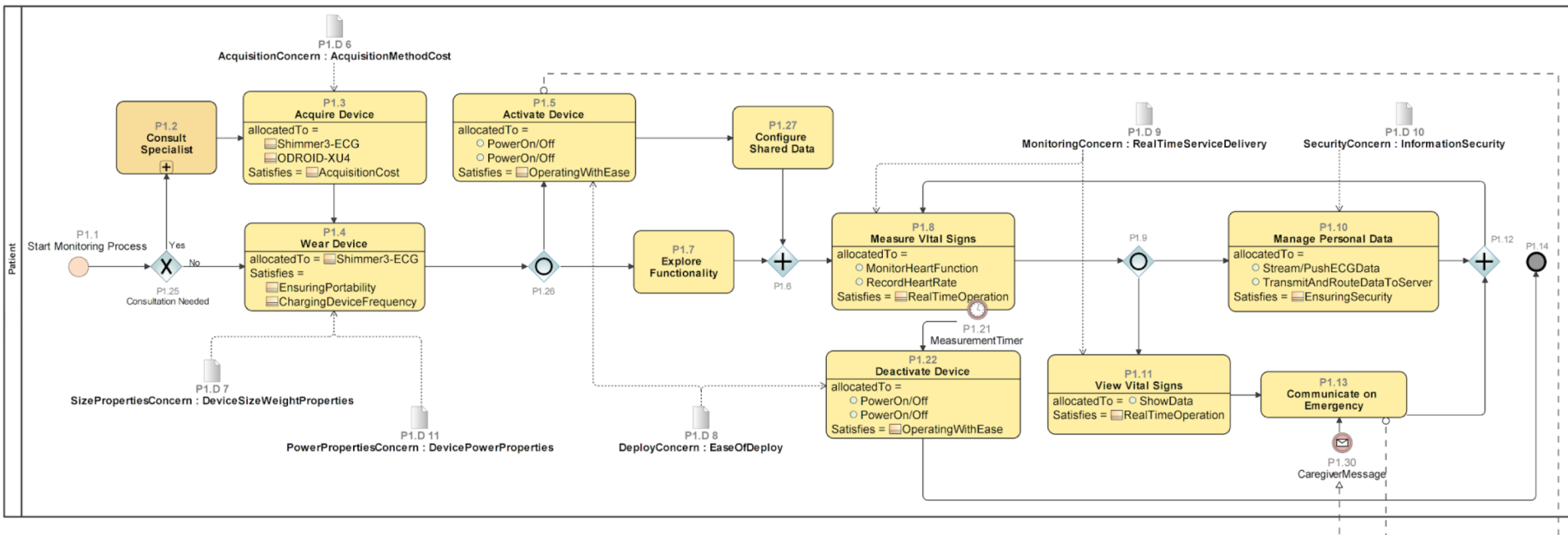
Remote Elderly Monitoring System (REMS)

- Enables real-time remote monitoring of vital signs while patients are at home
 - Signs are monitored by wearable devices (ECGs)
 - Success relies on the willingness of patient to wear the devices and become part of the CHPS
 - Basic Home components:
 - Medical device(s), e.g., sensor → measures vital signs
 - IoT gateway/Aggregator → collects sensor-generated data
- Target
- Engage patients in REMS service
 - Help patients choose a REMS configuration for their Home

Testbed: Embiot project in Qatar

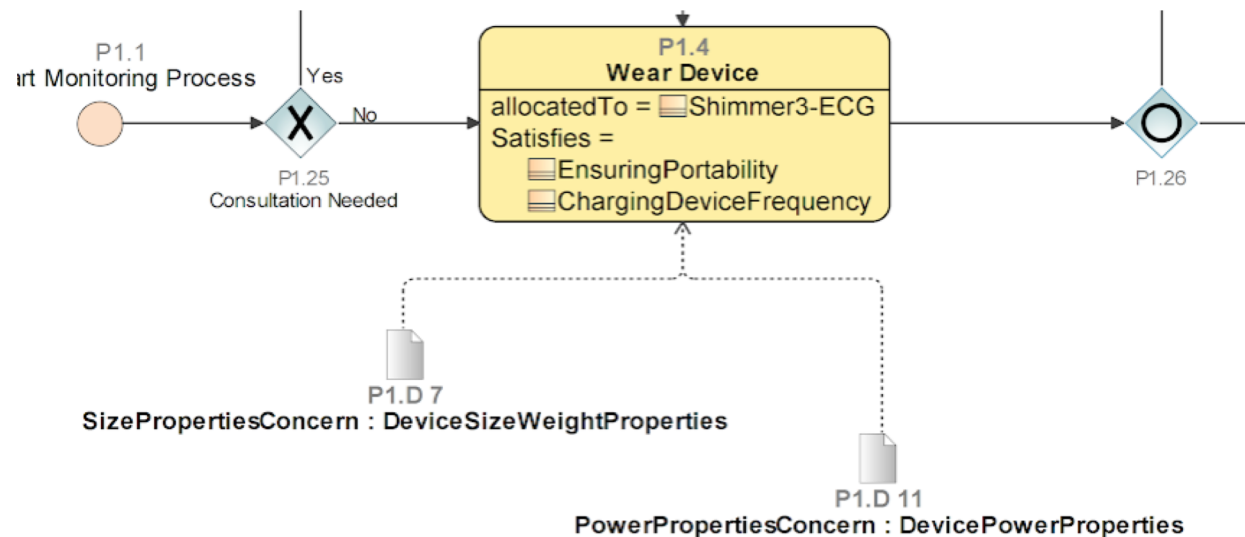
REMS: Identifying Tasks and Patient Concerns

- Use of BPMN
- Human tasks
 - relate to different concerns
 - satisfy specific criticalities

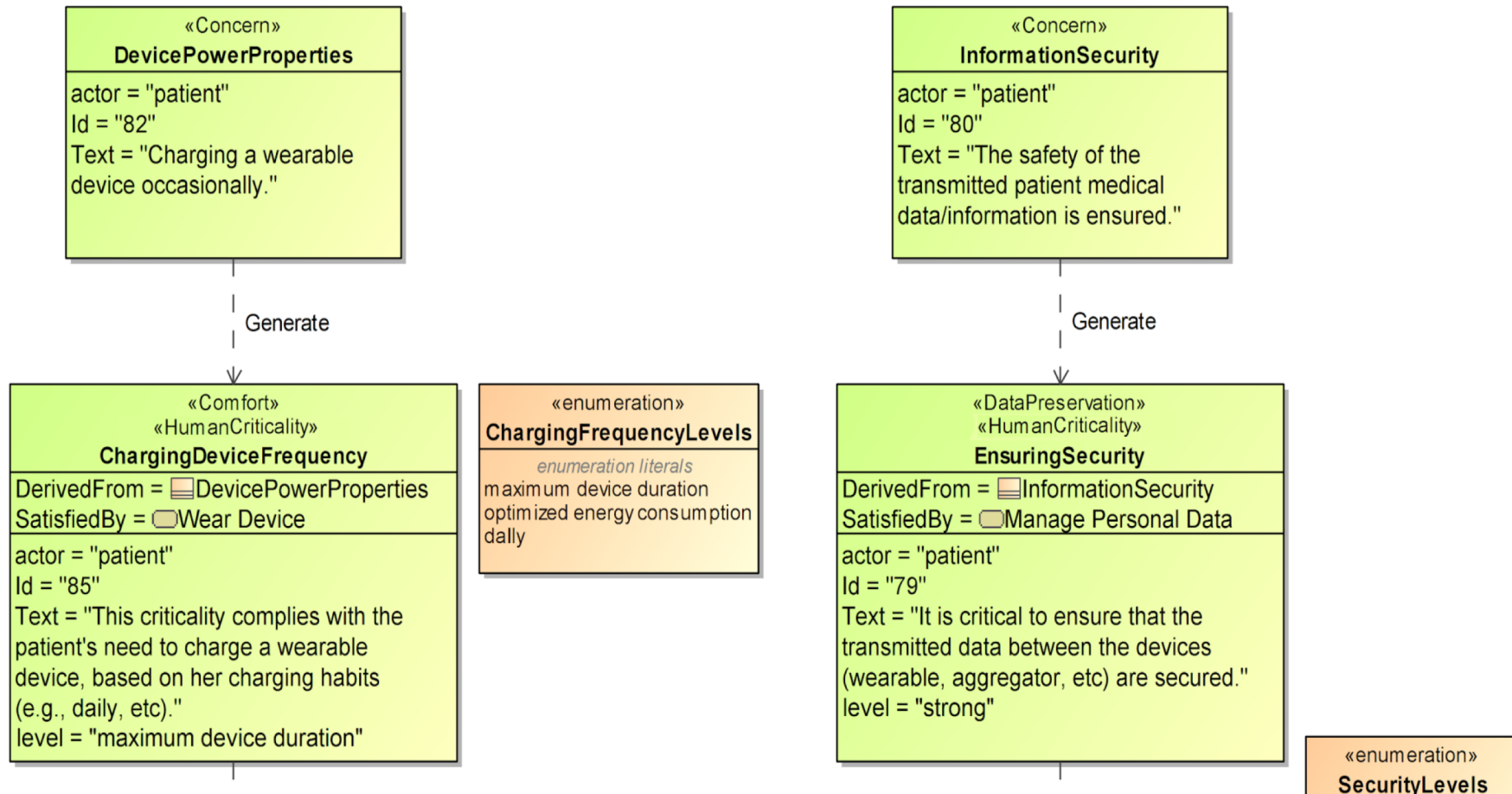


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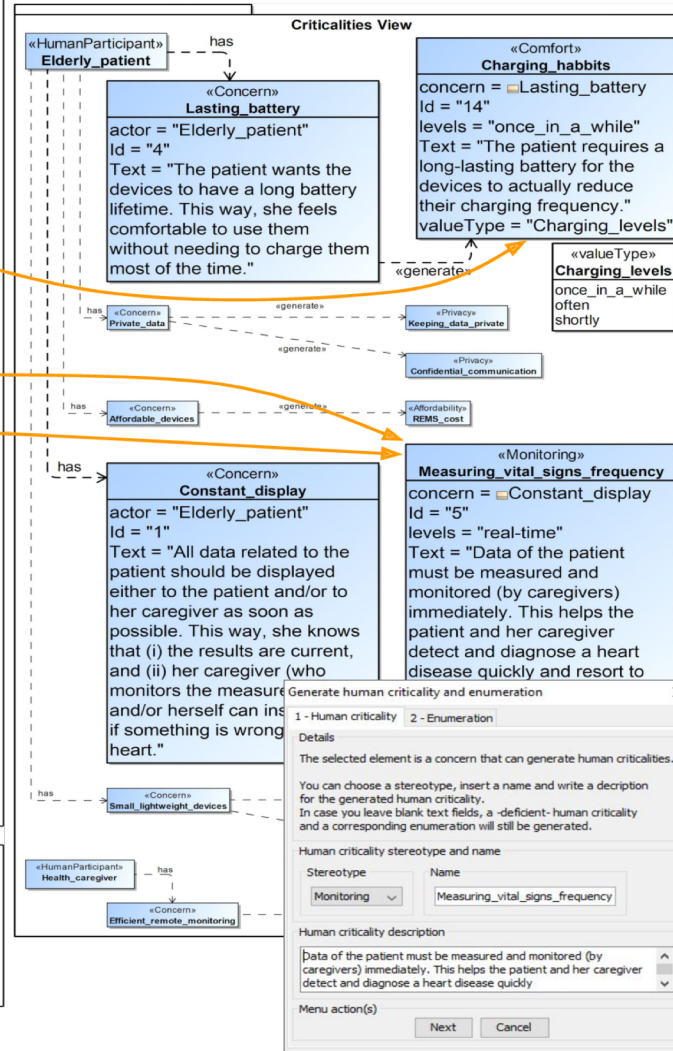
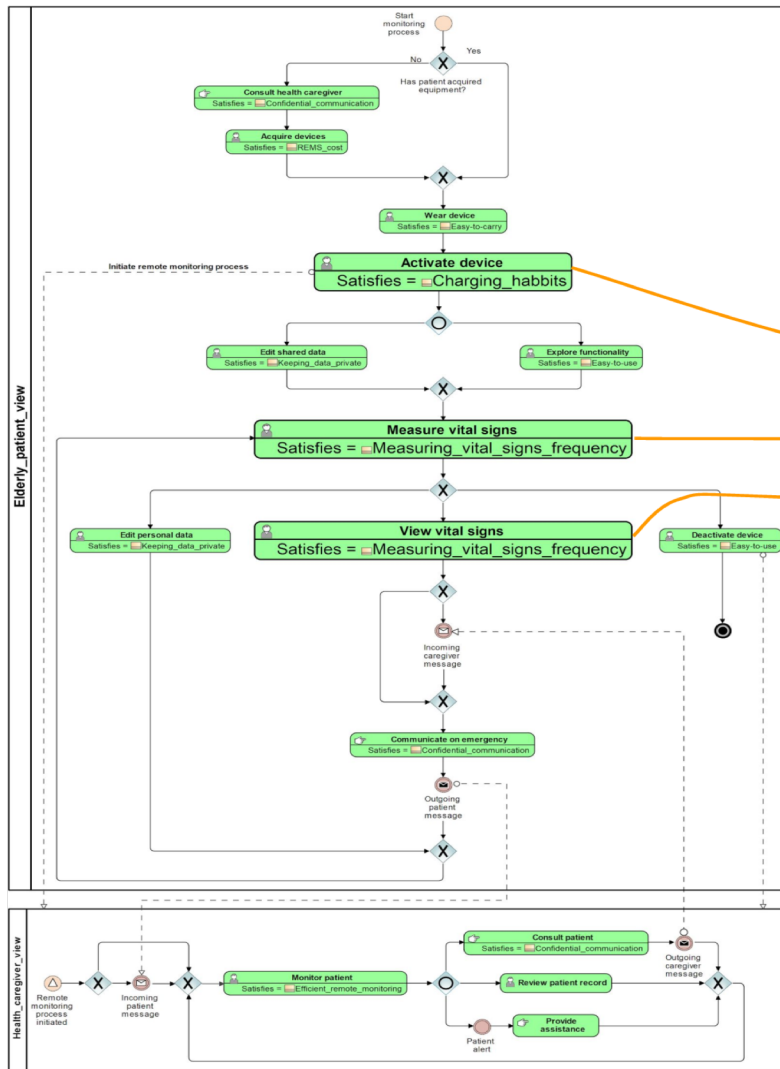


REMS: Define Human Criticalities

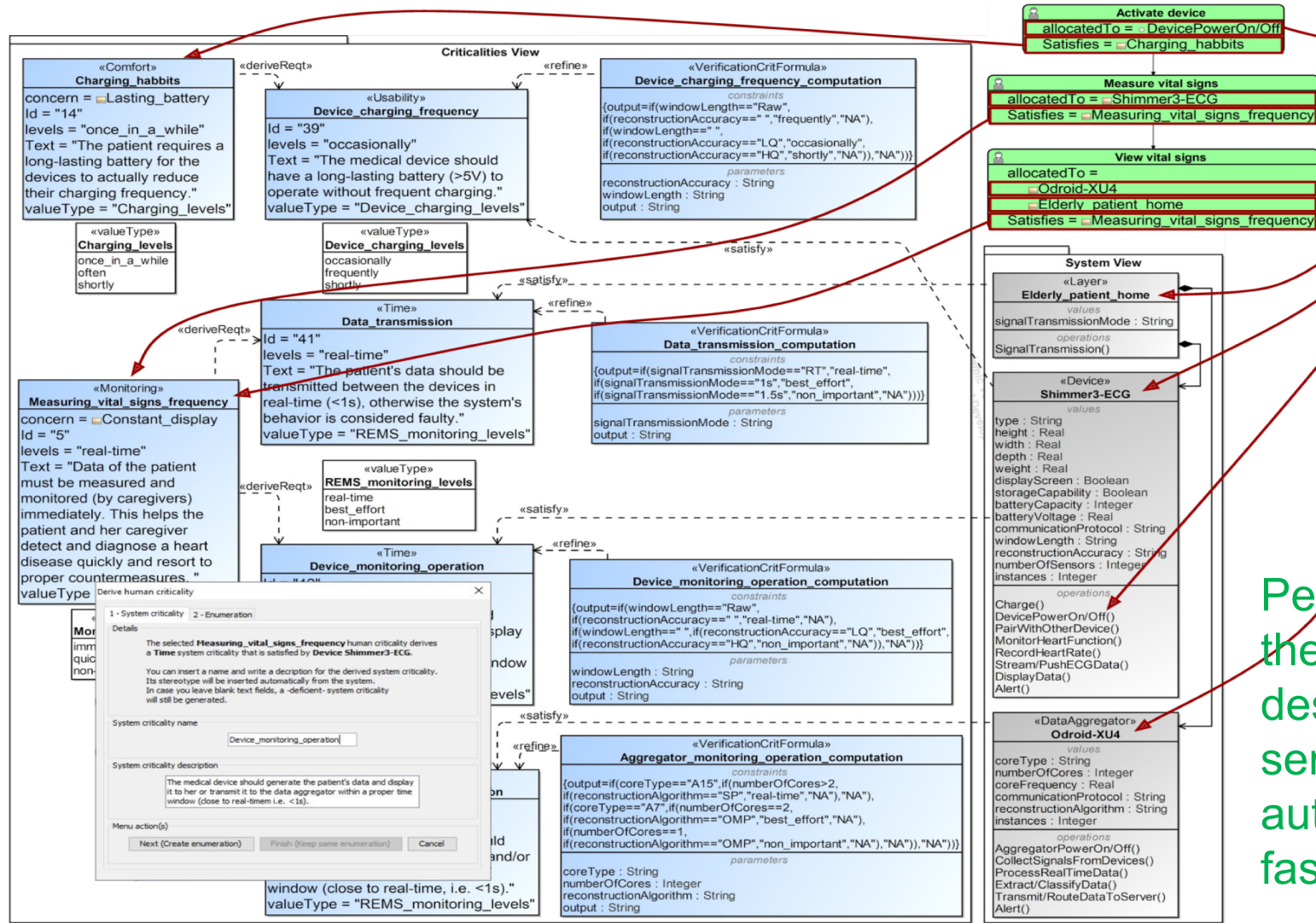


Mapping patient activities to patient concerns

Performed by patient with the assistance of the solution designer



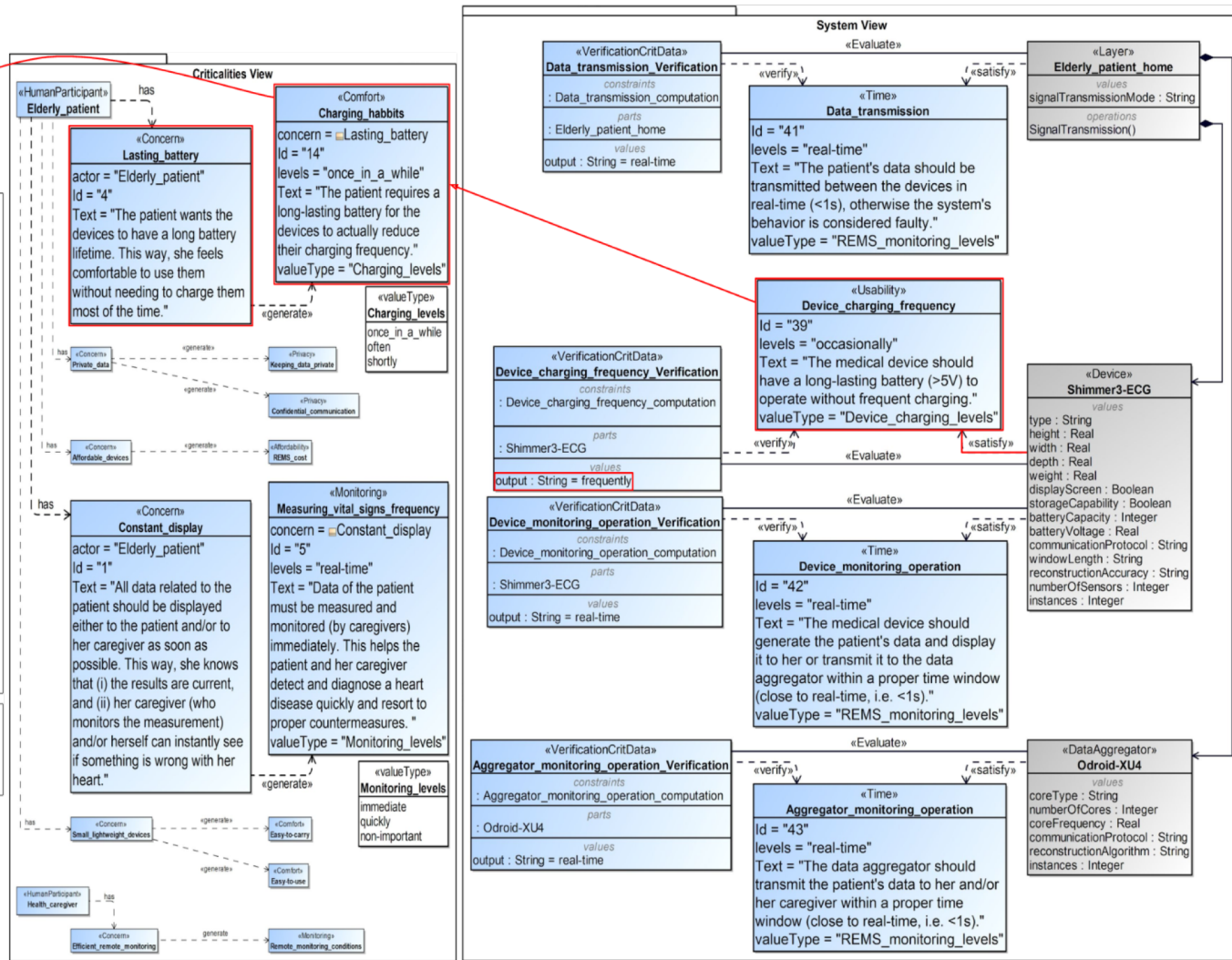
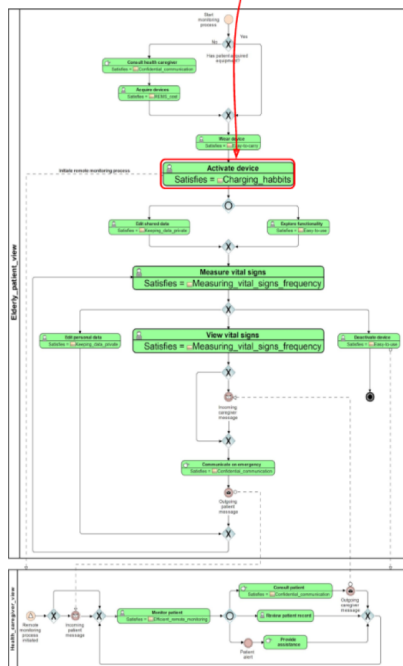
Derivation of system criticalities



Performed by the solution designer in a semi-automated fashion

Verifying criticalities across views

Performed
automatically

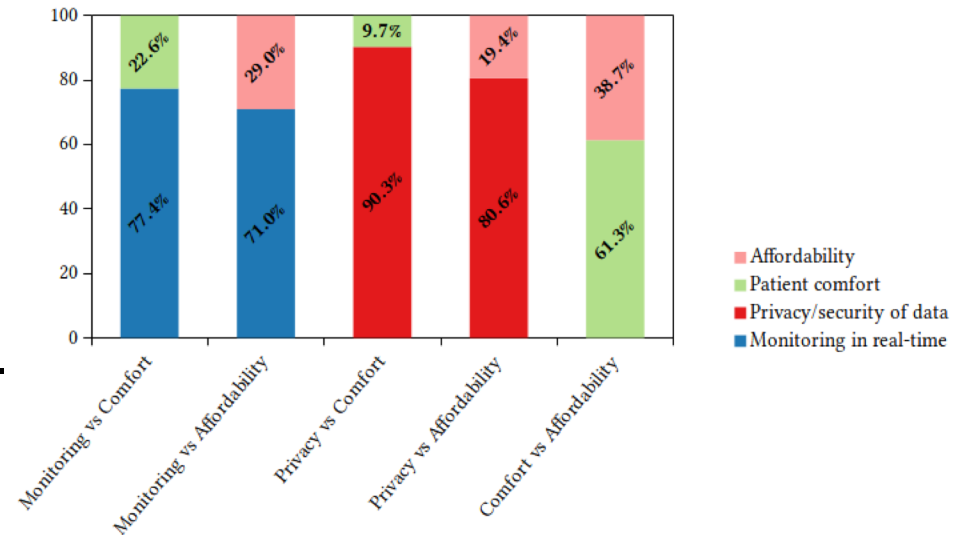


Patient Experience

- Patients participating in EMBioT trial evaluated criticalities
- Four criticality categories were identified

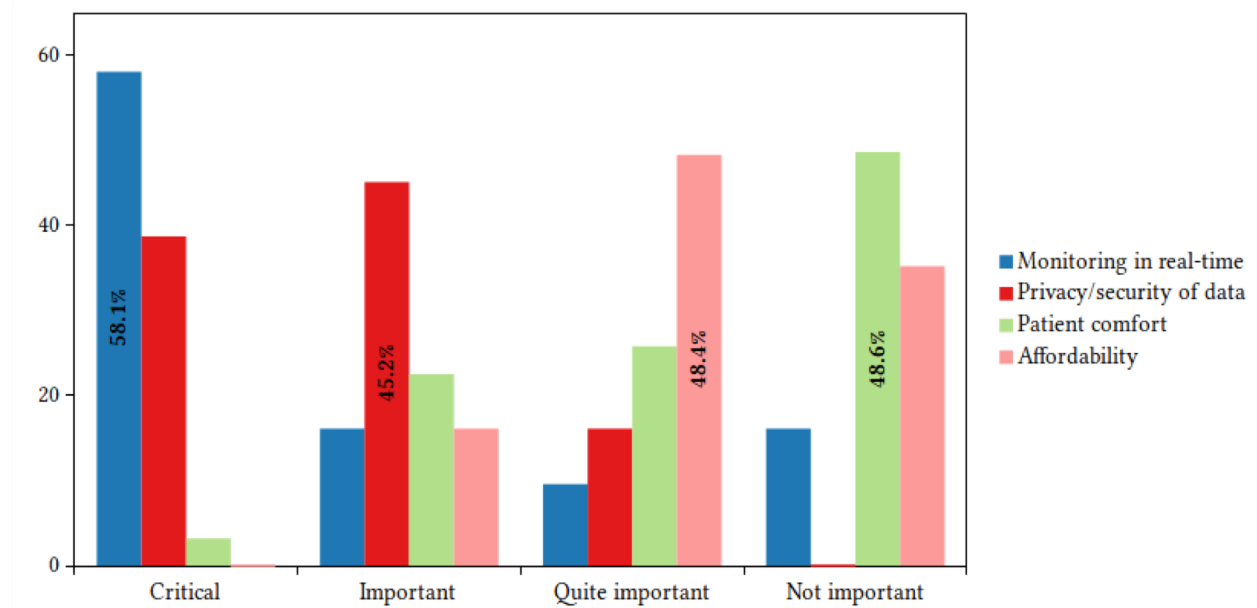
Right balance between them is not trivial

- Patients have the change to decide what is more important for them by “co-designing” the system
- Solution designers may help them to model their concerns



Patient Experience

- 77,6% of them stated that participating in the design process convince them to use REMS, others would it anyway.
- Sometimes what they choose in practice is different than what they believe in an abstract fashion
- Age and condition may affect their concerns.



- Model-based CPHS design
 - Utilizing features of standardized languages (BPMN, SysML)
 - introduction & management of criticalities
 - derivation of system criticalities from human concerns
- Empowering CPHS human participants to
 - Document their concerns and incentives
 - Participate in the design process
- Further exploration is needed in more complex case studies
- Ethical Design of CPHS (IEEE 7000:2021 Standard)

Nikolaidou, M., Kotronis, C., Routis, I., Politi, E., Dimitrakopoulos, G., Anagnostopoulos, D., ... & Bensaali, F. (2021). Incorporating patient concerns into design requirements for IoMT-based systems: The fall detection case study. *Health informatics journal*, 27(1)

Kotronis, C., Routis, I., Politi, E., Nikolaidou, M., Dimitrakopoulos, G., Anagnostopoulos, D., ... & Djelouat, H. (2019). Evaluating internet of medical things (IoMT)-based systems from a human-centric perspective. *Internet of Things*, 8

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Funding mainly from
EU Projects, QRF (Qatar Research Fund), ELLIDEK (National Greek Research Funding Institute)

Comments & Discussion

