

Multi-agent Self-organization and Reorganization to Adapt M2M Infrastructures

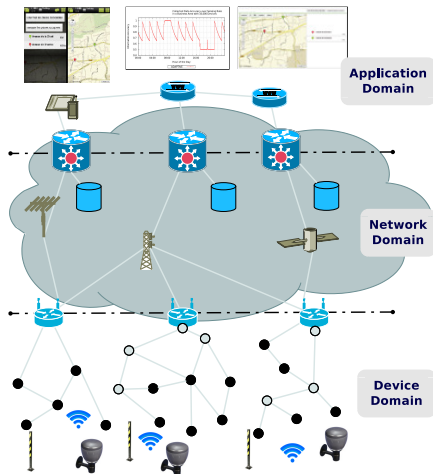
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September 24th, 2015



Machine-to-Machine (M2M)

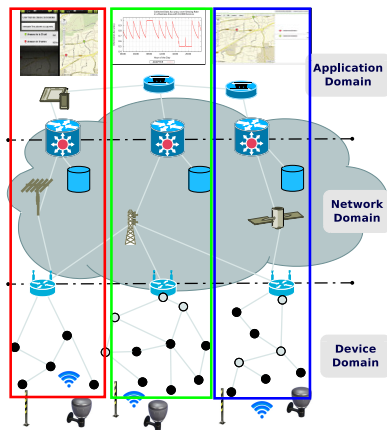


Used by multiple applications

M2M Infrastructures

■ Vertical M2M Infrastructure

- ✓ Control over Devices
- ✗ Expensive Cost
- ✗ Limited reuse between Apps
- ✗ Small Scale Deployment



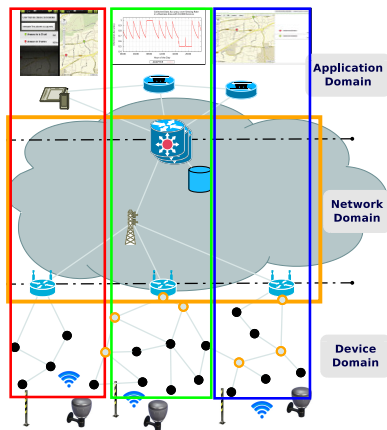
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■ Multi-Vertical M2M Infrastructure

- ✓ Control over Devices
- ✓ Shared Infrastructure Cost
- ✗ Limited reuse between Apps
- ✗ Medium Scale Deployment



M2M Infrastructures

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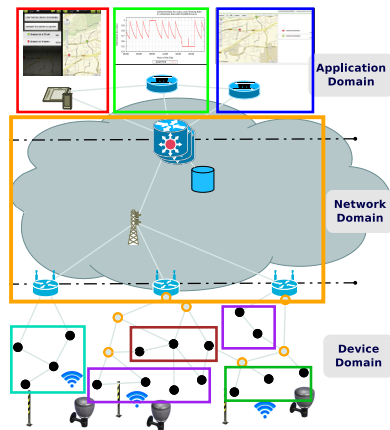
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■ Horizontal M2M Infrastructure

- ✗ Less Control over Devices
- ✓ Shared Infrastructure Cost
- ✓ Reuse of Devices between Apps
- ✓ Large Scale Deployment



M2M Infrastructures

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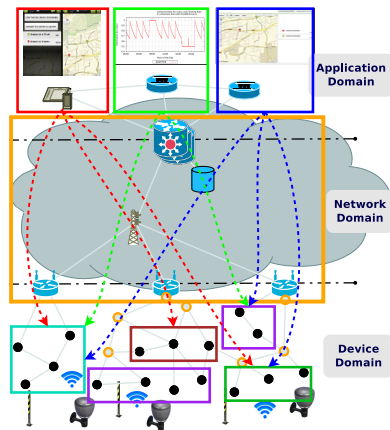
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- ✓ Reuse of Devices between Apps
- ✓ Large Scale Deployment



Problem Statement

- How to balance Vertical and Horizontal Benefits ?
 - ▶ How to **control** the horizontal M2M infrastructure to guarantee **Devices Constraints** and **Application Requirements** ?
 - ▶ How to **adapt** the M2M infrastructure **Dynamics** and **Scale** ?

- **Definition of a Machine-to-Machine specific Governance**
 - ▶ Automated Control and Adaptation Governance processes
 - ▶ Decentralized and Distributed Governance processes

Outline

M2M, Governance and Adaptation

AGAMEMNON : an Adaptive Governance MAS for M2M

Self-reorganization in AGAMEMNON

Implementation and Evaluation

Conclusion

Governance Principles in ICT

COBIT (*HBC⁺ 07*), IBM SOA Governance (*BC06*)

■ 3 Governance Levels

- ▶ **Strategy** : *Functional / Non-Functional Requirements Specification*
e.g. IT Goals, Requirements Planning
- ▶ **Tactic** : *Intermediate Goals Definition*
e.g. Process Goals, Approach Definition
- ▶ **Policy** : *Resource Usage Management*
e.g. Activity Goals, Model Enabling

■ Governance Process

- ▶ **Governance Refinement** : *Performance Analysis and Redefinition*
e.g. Measurement and Realignment, Measurement and Refinement

Governance Principles in M2M

■ 3 Governance Levels

▶ **Strategy** : *Functional / Non-Functional Requirements Specification*

▶ Horizontal : ETSI TC M2M – Functional Architecture

(ETS11)

▶ Vertical : Service Level Agreement (SLA)

(Wef09, SKG⁺ 09)

Ad-hoc Application Requirements

(BMD10)

▶ **Tactic** : *Intermediate Goals Definition*

▶ **Policy** : *Resource Usage Management*

▶ Device Management Recommendations

(MB09)

▶ Device Management Protocols

(ASSC02, LBABV12)

▶ Platform's Device Abstraction

(She10, GGB⁺ 08, BB08)

■ Governance Process

▶ **Governance Adaptation** : *Performance Analysis and Redefinition*



Governance Principles in M2M

■ 3 Governance Levels

▶ **Strategy** : *Functional / Non-Functional Requirements Specification*

- ▶ Horizontal : ETSI TC M2M – Functional Architecture *(ETSI1)*
- ▶ Vertical : Service Level Agreement (SLA) *(Wer09, SKG+ 09)*
Ad-hoc Application Requirements *(BMD10)*

▶ **Tactic** : *Intermediate Goals Definition* ∅

▶ **Policy** : *Resource Usage Management*

- ▶ Device Management Recommendations *(MB09)*
- ▶ Device Management Protocols *(ASSC02, LBABV12)*
- ▶ Platform's Device Abstraction *(She10, GGB+ 08, BB08)*

■ Governance Process

- ▶ **Governance Adaptation** : *Performance Analysis and Redefinition* ∅

Governance Approaches in M2M

Control and Adaptation Systems

Endogenous Control and Adaptation

*Mix the Business Logic processes
and the Governance processes*

■ **Ad-Hoc Adaptive Algorithms**

- ▶ Stochastic/Probabilistic Algorithms
- ▶ Swarm Intelligence
- ▶ Clustering Algorithm

■ Governance Pros/Cons

- ▶ *Requirements Definition* :
Not Explicit, Less Dynamic, Procedural
- ▶ *Control* :
Bottom-Up, No Global State, No Guaranty
- ▶ *Adaptation* :
Fast Reactivity, Locally

Exogenous Control and Adaptation

*Separate the Business Logic processes
and the Governance processes*

■ **Requirement-based Control Loop**

- ▶ Middleware
- ▶ Autonomic Computing
- ▶ Multi-Agent Systems (MAS)

■ Governance Pros/Cons

- ▶ *Requirements Definition* :
Explicit, Dynamic, Declarative
- ▶ *Control* :
Top-Down, Global State, Better Guaranty
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Less Reactive, Globally
- ➔ **Combined with Endogenous**

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Multi-Agent Oriented Programming

Organization

- Collective Behavior : *Role–Social Goals–Norms*
- Functional / Non-Functional Requirements

Agent

- Reactive and Proactive Processes (e.g. BDI)
- Requirement → Control Decisions

Environment

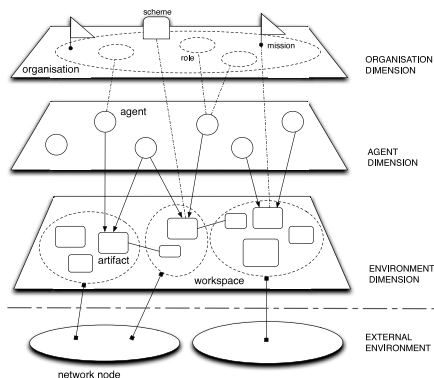
- First-class Abstraction :
Resources, Communication
- External Business Entities Abstraction

Interaction

- Protocols to bind all MAS entities

Reorganization

- Redefine the Organization Specification/Entity
- Top-Down / Bottom-Up



VOWELS dimensions (Dem95)

Multi-Agent Oriented Programming

Organization Strategy

- Collective Behavior : *Role–Social Goals–Norms*
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Environment Policy

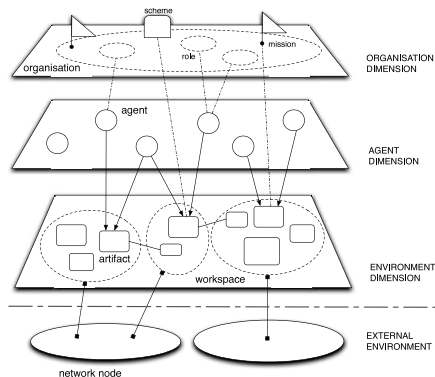
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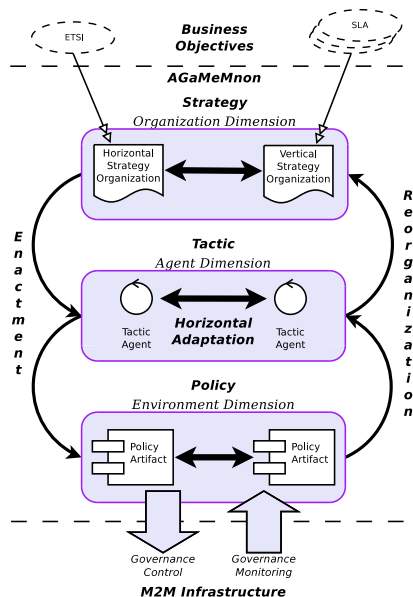
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Overview of the AGaMeMNON Framework

- **Organization-based Governance Strategy**
Normative *MOISE (HB02)*
- **Agent-based Governance Tactic**
Declarative *Jason (BHW08)*
- **Artifact-based Governance Policy**
Resource Abstraction *CARtAgO (ORV08)*
- **Synergistic Integration** *JaCaMo (PBRH10)*
- **MAS Adaptation Governance Refinement cycle**
 - **Top-Down Enactment**
 - **Horizontal Adaptation**
 - **Bottom-Up Reorganization**



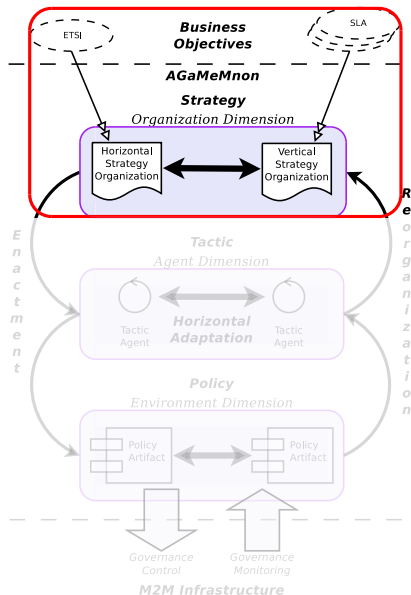
Organization-based M2M Governance Strategy

A Multi-Organizational Specification

- 1 Horizontal Organization
ETSI TC M2M Functional Architecture
- Several Vertical Organizations
M2M Vertical Contract
 - ▶ *End-to-End communication schema*
 - ▶ *Between M2M entities*
 - ▶ *Service Level Agreement (SLA)*

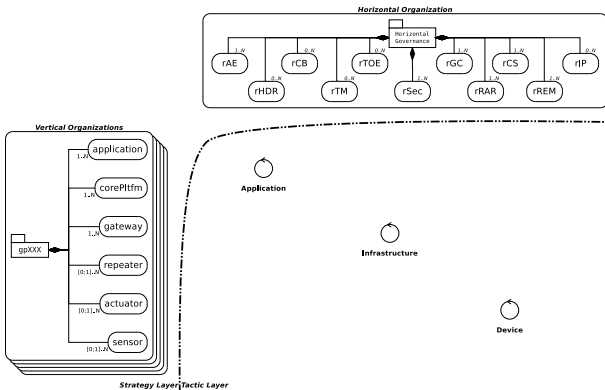
➡ Horizontal Flexibility

➡ Vertical Maintenance



Agent-based Governance Tactic

Agent governs 1 M2M Entity : binds Horizontal and Vertical Strategy



■ Application Agents

Application point of view

- (O1) Maximize utility of contract
- (O2) Minimize subscription cost

■ Infrastructure Agents

Network point of view

- (O1) Ensure end-to-end communication
- (O2) Minimize infrastructure cost

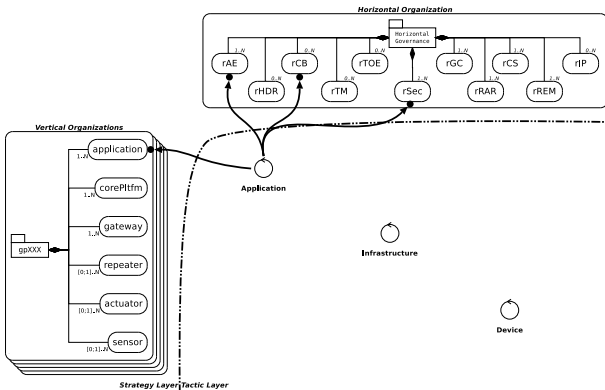
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Device Group point of view

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- (O2) Maximize device lifetime

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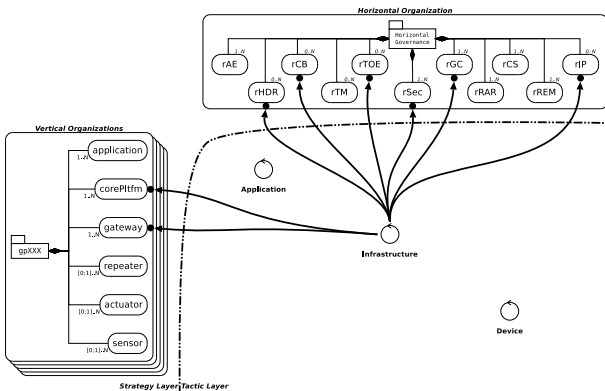
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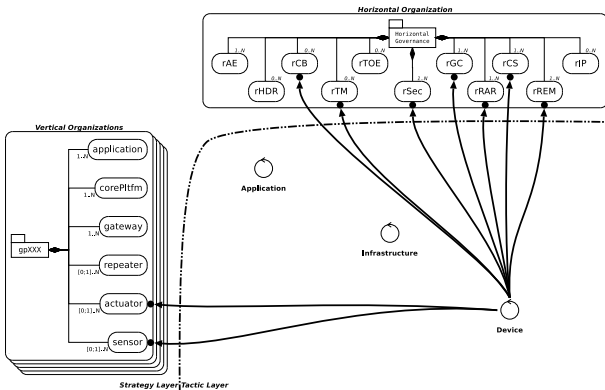
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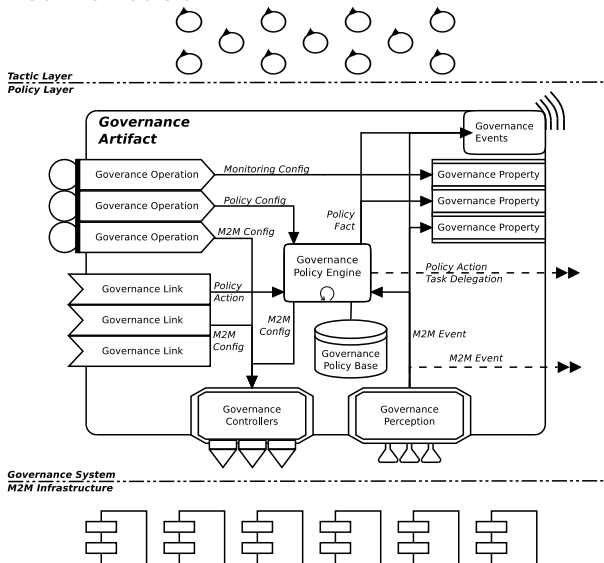
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Artifact-based Governance Policy

Governance Artifact Architecture



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Coupling Bottom-up and Top-down Dynamics



Coupling Bottom-up and Top-down Dynamics



Reorganization =

An organization-centered adaptation process where agents are aware of the state of the organization

Coupling Bottom-up and Top-down Dynamics



Reorganization =

An organization-centered adaptation process where agents are aware of the state of the organization

Self-organization =

An agent-centered process where the implicit state of the organization is the result of their activities in the environment

Coupling Bottom-up and Top-down Dynamics



Reorganization =

An organization-centered adaptation process where agents are aware of the state of the organization

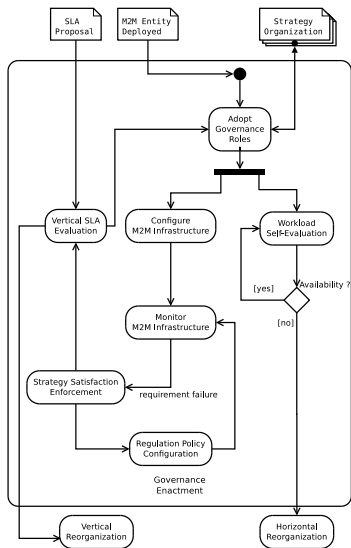
Self-organization =

An agent-centered process where the implicit state of the organization is the result of their activities in the environment

Self-reorganization =

Agents self-organize to define the reorganization process with respect to the organizational and environmental constraints

Agent-based Governance Tactic



■ Governance Tactic : 3 phases

- ▶ Strategy Enactment
- ▶ Horizontal Reorganization
- ▶ Vertical Reorganization

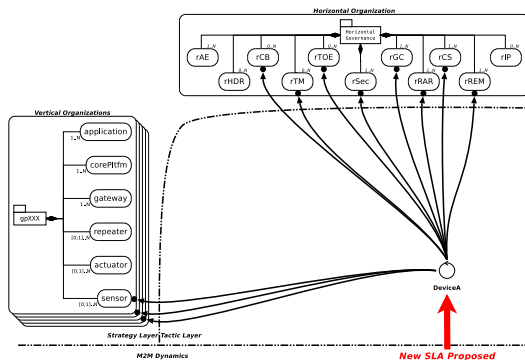
■ Strategy Enactment

- ▶ Realization of *strategy* objectives
- ▶ M2M Infrastructure Configuration
- ▶ Enforce objectives via *policies*
- ▶ Using Governance Artifact

■ Horizontal/Vertical Org. Adaptation

- ▶ Adapt Governance to the M2M Infrastructure Dynamics

Adaptation by Horizontal Self-Organization



■ Adapt number of agents to the governance load

- ▶ 1 Agent for 1 M2M Entity (initially)
- ▶ Overloaded Agent → Delegation

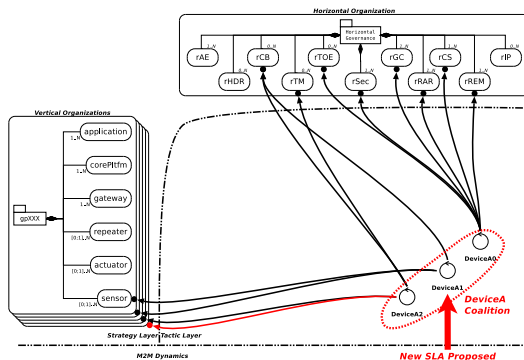
■ Scale-Out : Governance Coalition

- ▶ Informal Organization for 1 M2M Entity
- ▶ Each agent = 1 subset of Governance Tasks
- ▶ Coordination Heuristic before task commitment (new M2M Entity, new SLA, ...)

■ Scale-Down : Agent Self-termination

- ▶ Minimal task threshold
- ▶ Delegates remaining tasks
- ▶ Terminates itself

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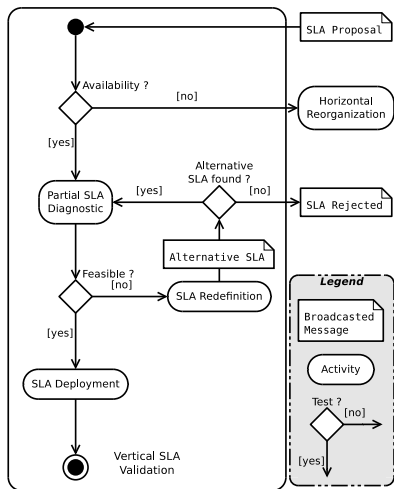
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Adaptation by Vertical Reorganization



1. Handle new Vertical Contracts

- ▶ Before adopting a role in a vertical organization
- ▶ Evaluate feasibility of the SLA
- ▶ Potentially propose an Alternative SLA

2. Refine Vertical SLA to M2M Constraints

- ▶ When failing SLA
- ▶ When critical state (e.g. M2M Devices)

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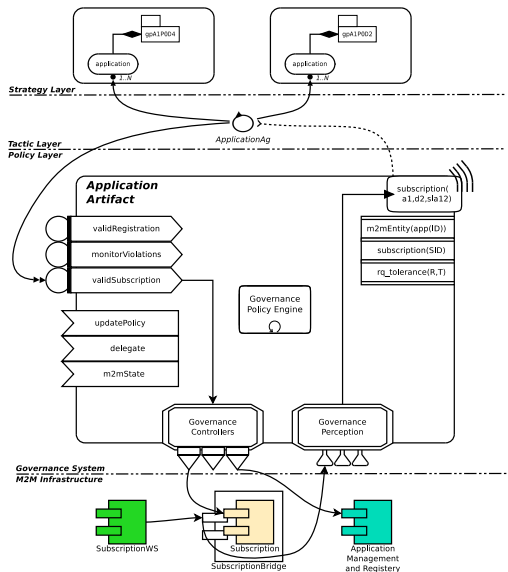
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Governing SensCity with AGAMEMNON



Evaluation with a Simulated M2M Infrastructure

Simulation Scenario : Smart Parking Management

■ Smart Parking Scenario

- ▶ Parking Sensors in different areas
 - Business Area (Peak Hour : 7AM–9AM)
 - Residential Area (Peak Hour : 17PM–20PM)

■ Measure Governance Impact over several (6) years

- ▶ Average **accuracy** of collected data
- ▶ Average devices' battery **lifetime**

■ Different Application Requirement profiles

- ▶ **ON_EVENT** : Notification for each parking state change
- ▶ **NOTIFY(X)** : Notification of parking state each X minutes
- ▶ **ADAPTIVE** : Combines **ON_EVENT** and **NOTIFY(X)** profiles
 - ➡ Adaptation to end-user demand

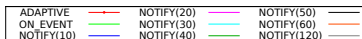
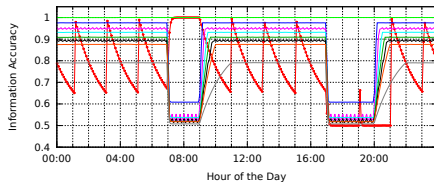
■ Device Battery Constraints

- ▶ Homogeneous and Affine consumption model (Scenario#1)
- ▶ Heterogeneous and Exponential consumption model (Scenario#2)

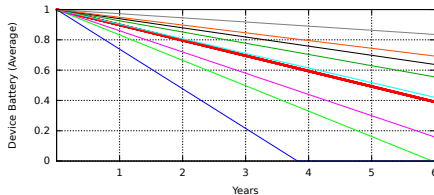
Evaluation with a Simulated M2M Infrastructure

Experiment #1 : Application Vertical Refinement

Collected Data Accuracy over Sensing Rate
in a Business Area with 10,000 Devices



Device Battery over Time



- Benefits of an explicit SLA declaration
 - Enable Governance Management

- Application point of view :
 - #1 – ON_EVENT
 - #2 – ADAPTIVE
 - #3 – NOTIFY(X), $(X \leq 20)$

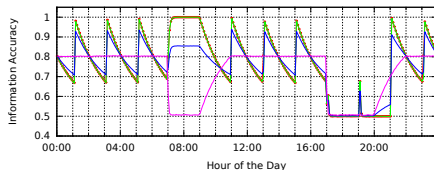
- Device point of view :
 - #1 – NOTIFY(X), $(X \geq 30)$
 - #2 – ADAPTIVE

- ADAPTIVE profile : **best trade-off**
between *application satisfaction*
and *device lifetime*

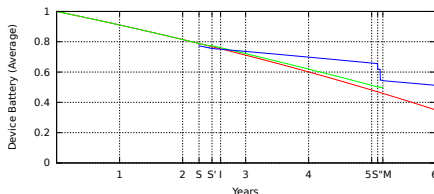
Evaluation with a Simulated M2M Infrastructure

Experiment #2 : Device Regulation and Vertical Refinement

Collected Data Accuracy over Sensing Rate
in a Business Area with 1,000 Devices



Without Device Governance ——— (red)
With Device Governance (Initial Group) ——— (green)
With Device Governance (Generated Group 1/2) ——— (blue)
With Device Governance (Generated Group 2/2) ——— (magenta)



Without Device Governance ——— (red)
With Device Governance (Initial Group) ——— (green)
With Device Governance (Generated Group 1/2) ——— (blue)
With Device Governance (Generated Group 2/2) ——— (magenta)

- Battery consumption improvement by Governance actions :
- ➡ Improve Average Device Lifetime
- ✓ Maintain an acceptable data accuracy during 5 years
- ✗ Improvement to be done after 5 years
- ➡ Finer SLA negotiation tactics

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Synthesis

1. A Machine-to-Machine Governance Model
 - ▶ Horizontal and Vertical concerns
 - ▶ Step to horizontal M2M infrastructure deployment
 - ▶ Dynamic, decentralized and adaptive governance framework
2. A Multi-Agent Oriented Programming approach for M2M Governance Adaptation and Control
 - ▶ Separate governance concerns along MAS dimensions
 - ▶ Multi-organizational specifications
 - ▶ MAS integration within a component-based platform
 - ▶ Couples an agent-centered vision and an organization-centered vision of the adaptation : **self-reorganization**

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What's next ?

- Integrative framework for self-reorganization to design self-adaptive systems



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INTELLIGENCE



<https://connected-intelligence.univ-st-etienne.fr>

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