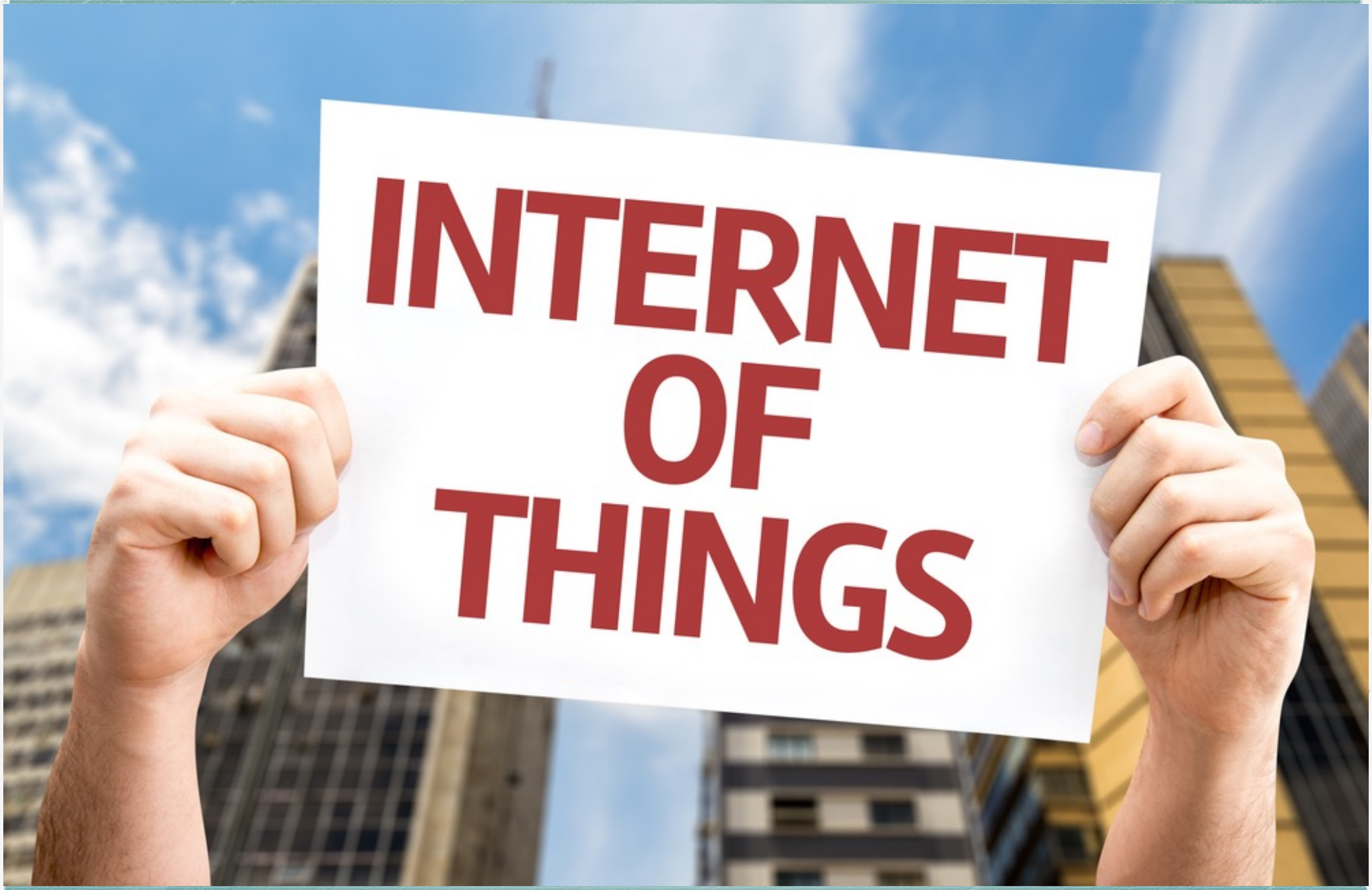
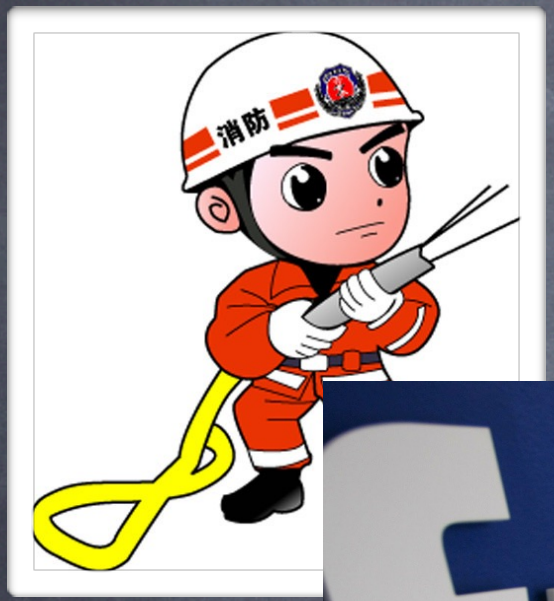
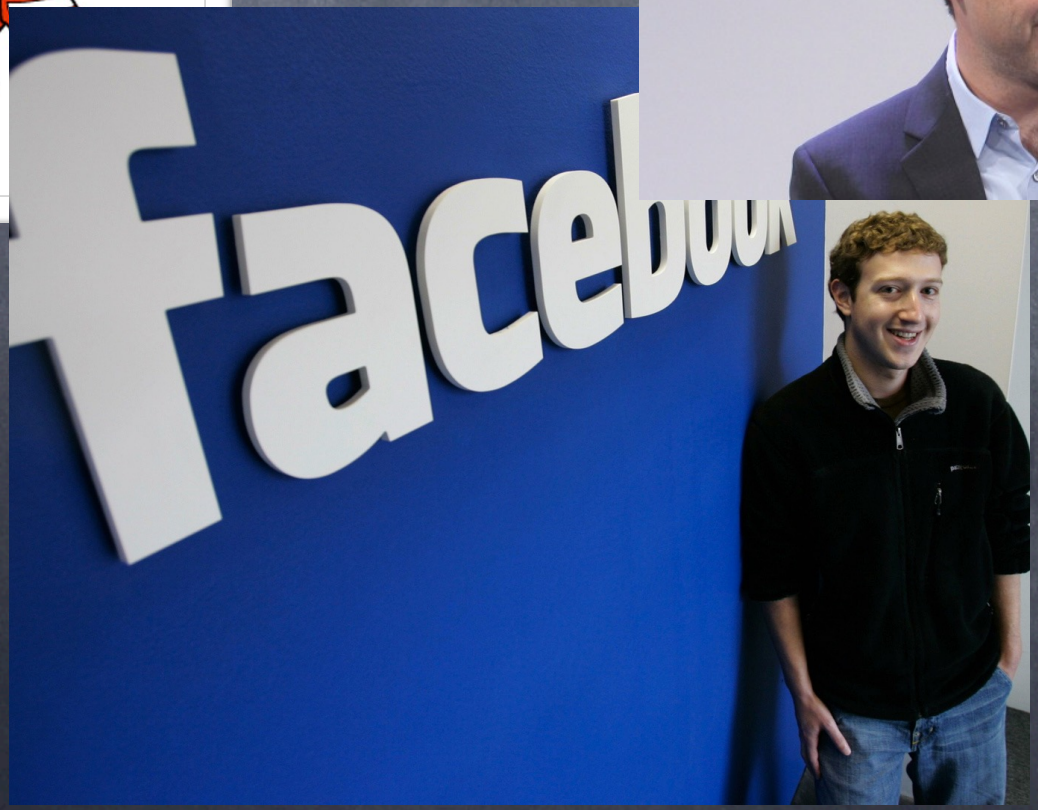
Internet-of-Things and Middleware

Chi-Sheng Shih
Spring 2017

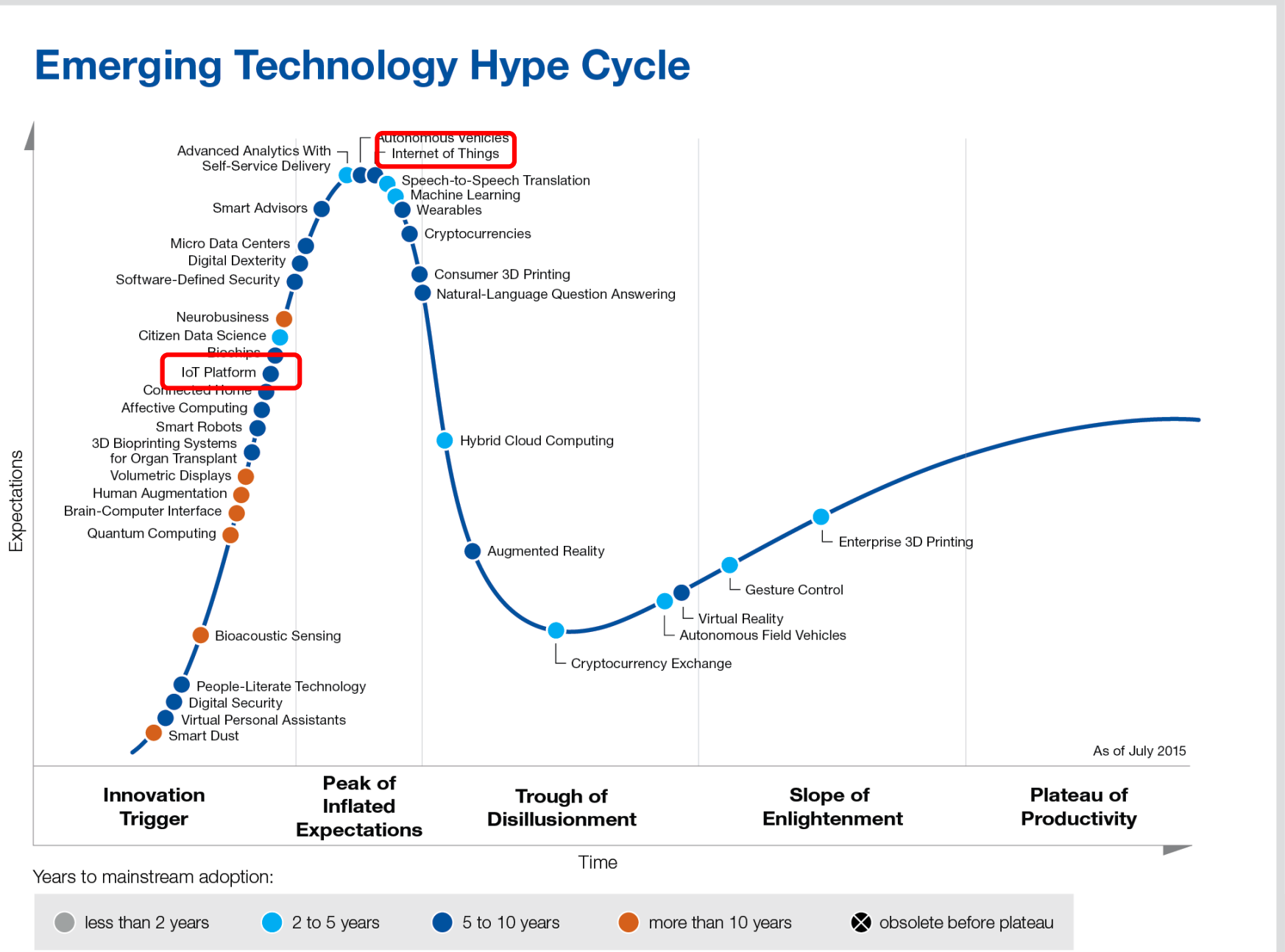

INTERNET
OF
THINGS

Who do you think the first one knowing your apartment is on fire?





Gartner Hype Cycle and IoT, July 2015



http://www.gartner.com/newsroom/id/3114217

Smart Applications using IoT

Making Things Smart

- Internet of Things (IoT) can be used to build many smart applications
  - Smart Wearable
  - Smart Living
  - Smart Home
  - Smart Building
  - Smart Factory
  - **Smart Transportation**
  - **Smart Cities**

Traffic Control for Smart City

Smart City ≠ Smart Cars

Cities are of the people, by the people, for the people

Intersection without flow control

Causes of traffic congestion in the city

- Congestion is one of major complains in metropolitans. In particular, congestion on intersection.
- Traffic lights are widely used to control traffic flow.
  - Unfortunately, *efficiency* is not the purpose of deploying traffic lights.
- Phased switching process periodically gives non-conflicting flows right to access the intersection.
  - Delay is part of setup phase to clear the intersection, which is estimated based on the travel time for a vehicle in *free flow* condition.
  - Frequently phase change can reduce average delay for vehicles but setup phase reduces intersection throughput.
  - One-by-one/First-come-first-serve policy leads to congestion on intersection when the flow is slower than expectation.

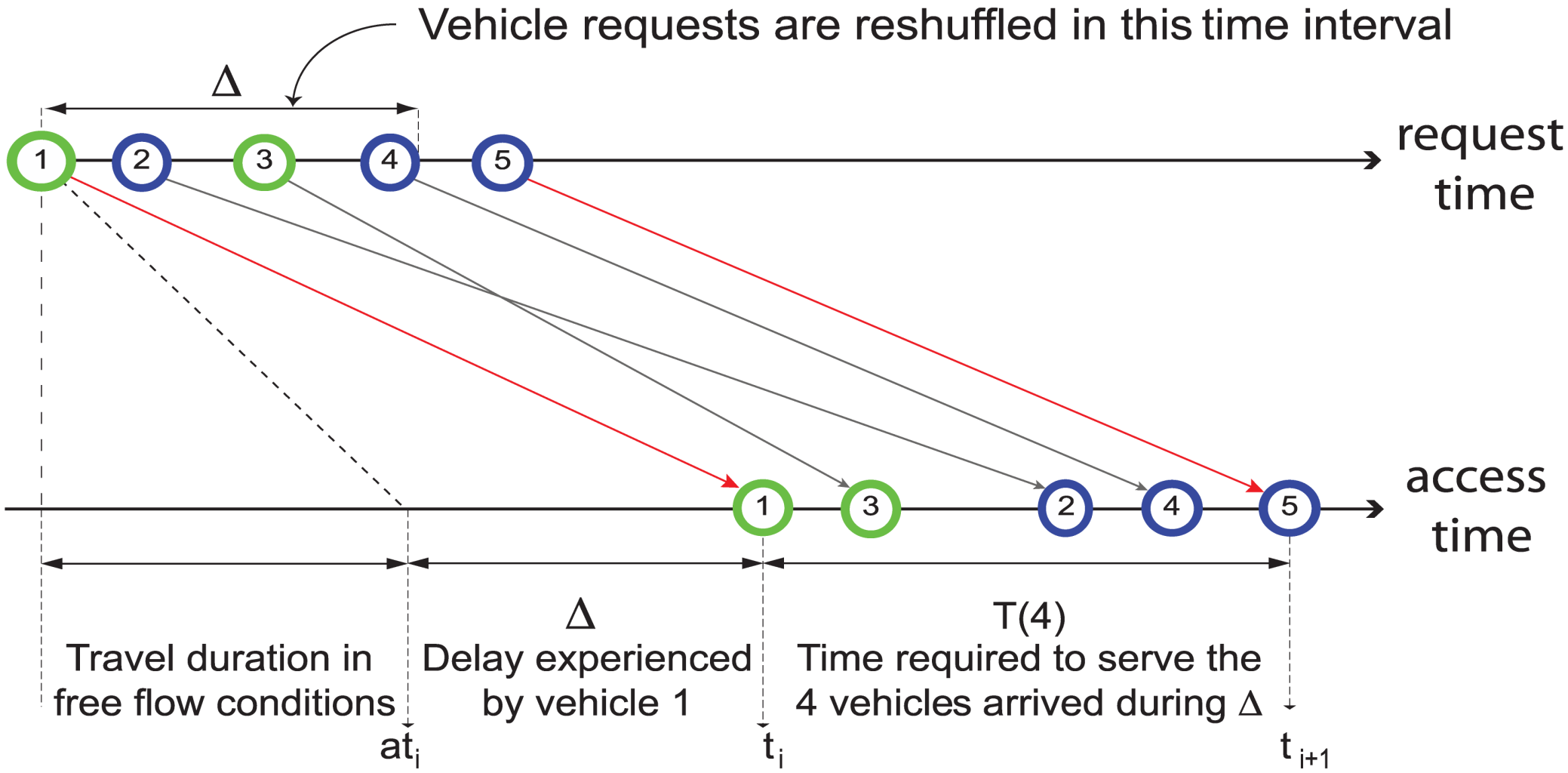
Is traffic light right for traffic control?

Intersection without traffic light

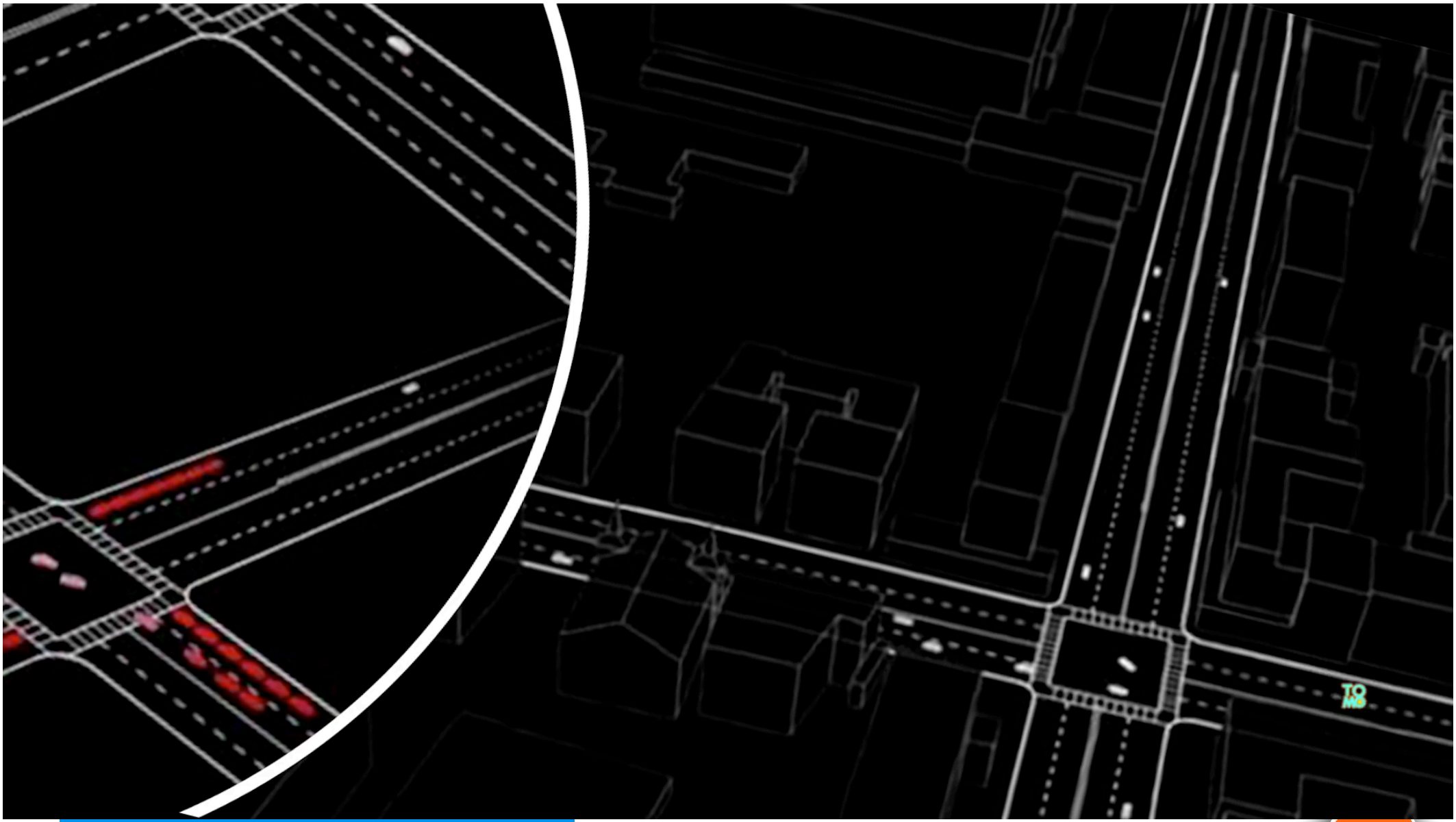
Slot-based Intersection (SI) Management

- Slot-based intersection management can double intersection capacity for twice.
- Each vehicle approaching the intersection will be assigned a time slot to access the intersection, drives at expected speed, and crosses the intersection at expected/slower speed.
  - Vehicles belong to the same flow will be grouped together to access the intersection.
  - The vehicles slow down or speed up to the expected speed before intersection, and do not stop at intersection.

Tachet R, Santi P, Sobolevsky S, Reyes-Castro LI, Frazzoli E, Helbing D, et al. (2016) Revisiting Street Intersections Usi
Slot-Based Systems. PLoS ONE 11(3): e0149607. doi:10.1371/journal.pone.0149607



- The number of vehicles in one group are limited to ensure each vehicle reaches the intersection at the beginning of the assigned time slot.



Challenges of Slot-based Intersection Management

- Vehicles have to make requests to traffic controller and follow the control.
  - Communication infrastructure
- Follow the control commands
  - Driverless cars are more willing to follow the commands.
- Infrastructure to detect vehicles
- Exception handling

No Traffic light vs. traffic light

WHO'S WHO?

Who's Who?

Networked Embedded Real-time Systems

智慧整合控制系統

Cloud Computing

Wireless Sensor Networks

聯網型嵌入式系統

物聯網

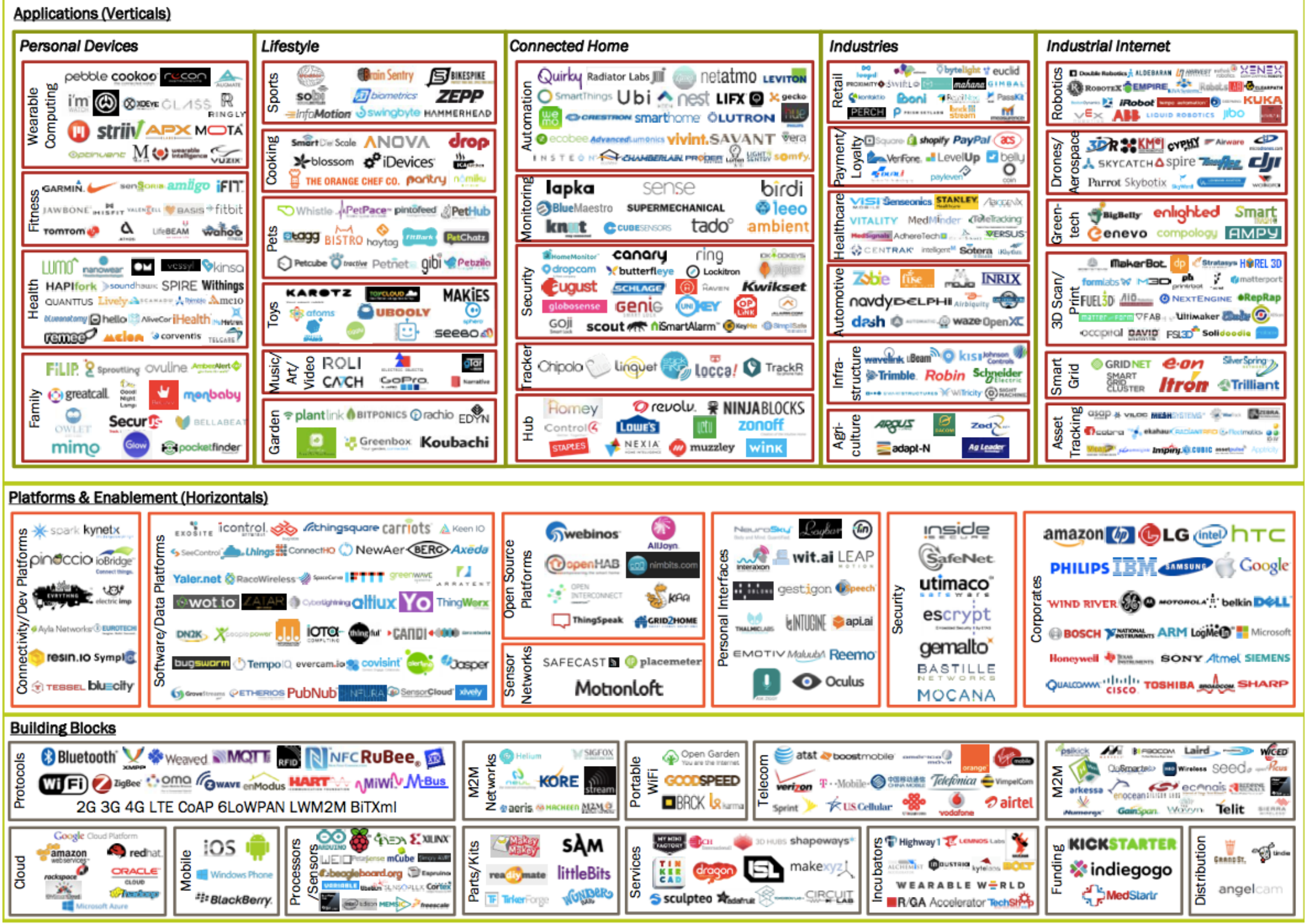
Cyber-physical Systems

Machine-to-Machine

網宇實體系統

Internet of Things

物聯網，聯網物，還是聯物網



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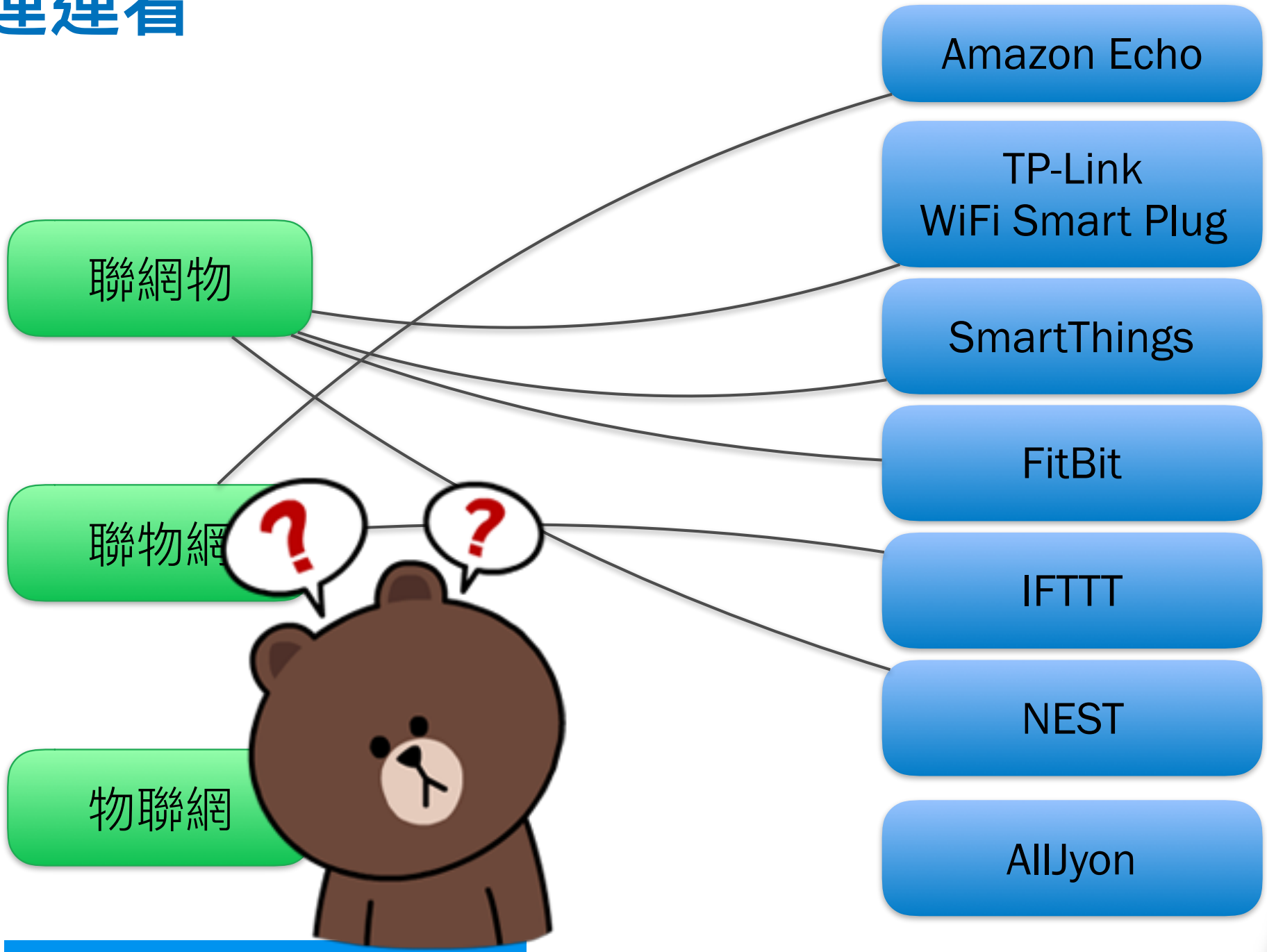
物聯網，聯網物還是聯物網?

- 聯網物:物能上網，卻只聯到服務商，物物不相連。
- 聯物網:物聯成網，卻網網不相連。
- 物聯網:物物相聯成網。

連連看


Amazon Echo
TP-Link
WiFi Smart Plug
SmartThings
FitBit
IFTTT
NEST
AllJyon
聯網物
聯物網
物聯網

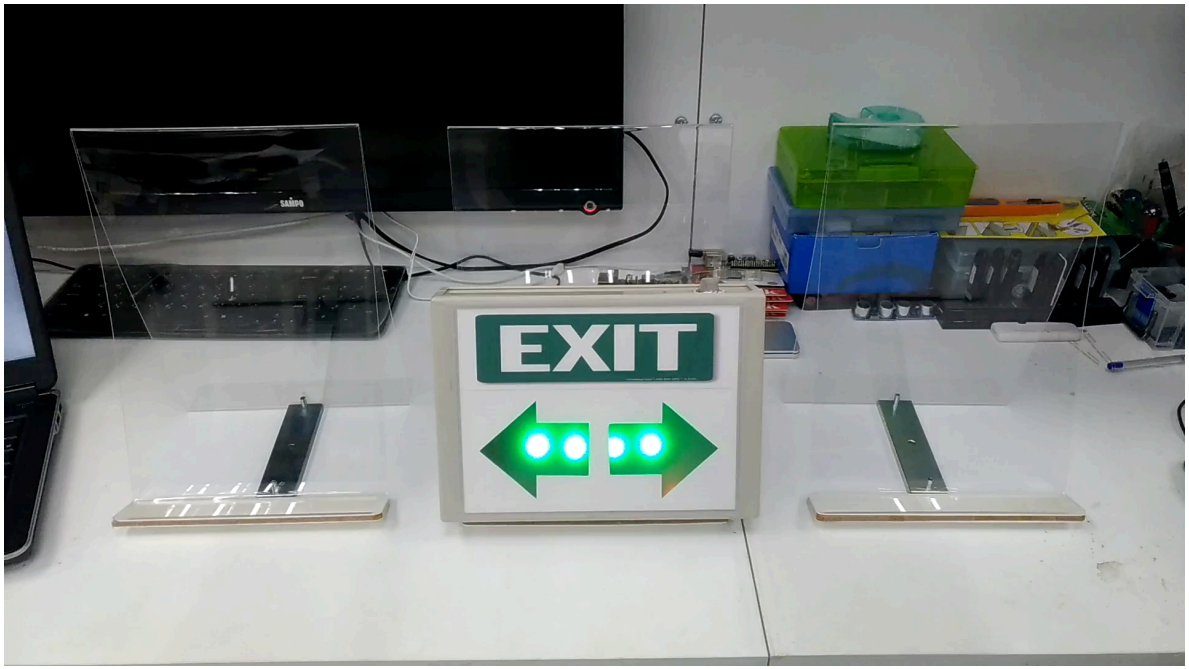
物聯網與你我的生活

- 早起要出門運動，才發現洗好的運動服還沒乾？
- 30分鐘後要出門了，才發現電鍋的時間錯誤，稀飯還沒煮？

- 這些都與日常生活相關，但是卻可有可無。
  - 不能慢跑，改做核心肌肉訓練。
  - 沒煮稀飯，巷口有早餐店。

攸關性命/商業的應用

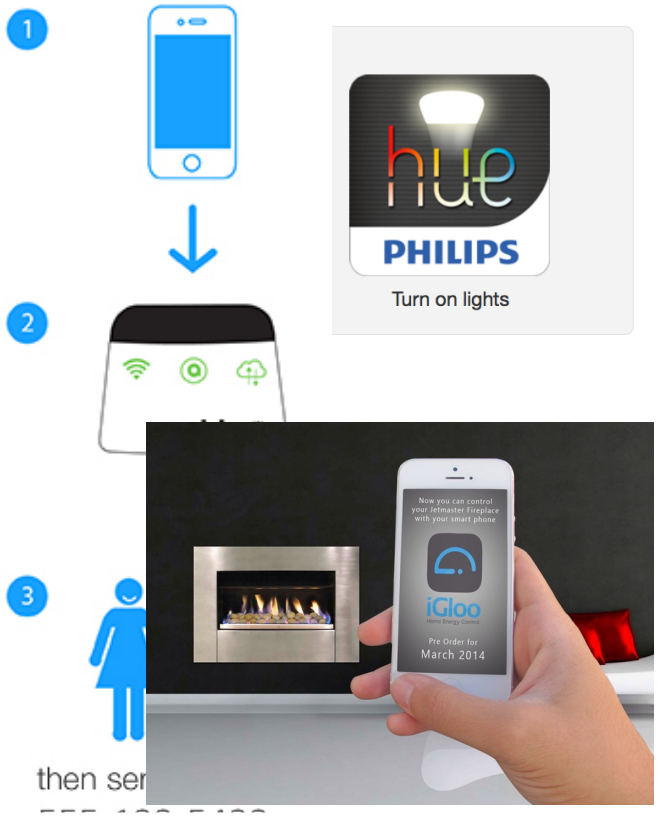
- 車子要出門，發現昨晚充電現沒接好？
- 火車要發車了，才發現 50 公里外的軌道有障礙物需要排除？
- 電網要送電了，才發現 150 公里外電塔上的電線曲線夾角過大？
- 火災警報響了，往哪裡逃生？

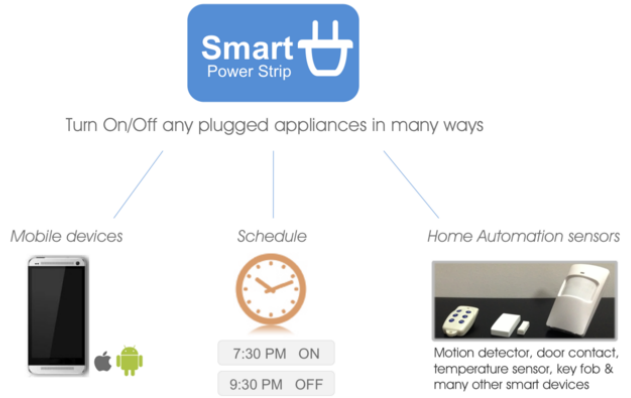


Challenges of IoT Development

Challenges

- IoT application is still hard to develop.
  - Look at many kickstart projects
- Hardware platforms are not well-supported.
- Programming IoT needs both HW and SW expertise on sensing, embedded, distributed computing, and cloud computing.
- Distributed device management is a nightmare.





Challenges of IoT systems

- Diverse Hardware Environment

  In future M2M systems, there will be many devices and platforms for hardware and software components.

- Evolving System Architecture

  M2M systems are deployed to serve for many years; the hardware and software components will evolve over time.

- Dynamic User Needs

  During the lifetime of machine-to-machine systems, users served by a system may change their needs, due to context, preference, lifestyle, etc.

- Service Composition Capability

  New services may be flexibly composed by the system components to add new capabilities integrating existing and new system components to create a new architecture.

- Multiple Objective Optimization

  The system middleware is to provide the best solution for multiple objectives such as comfort, energy consumption, reliability, and responsibility.

Current M2M development

- Many current M2M systems are developed
  - in a low-level language
  - from the node's perspective
  - "Current designs favor architectures where the WSN stack is highly application- or even deployment-specific, rather than application-agnostic as usual."*
- Reasons:
  - Resource constrained nodes (MSP430, ATmega)
  - Lack of OS support (Tiny OS)
  - Often developed by "WSN geeks"*
- Results:
  - Labour intensive, long development cycles
  - Error prone, developers need to consider error handling well
  - Static networks, difficult to adapt to changing conditions, or changing requirements

Intel-NTU Center

WuKong: Intelligent Platform for Machine-to-Machine

INC NSC

Wu-Kong : Project Goals

Intel-NTU Center

- The project is to build an *Intelligent Virtual Middleware* that can
  1. recognize and adapt to user context and needs;
  2. configure or transform devices into service components;
  3. deploy the most effective yet least expensive solutions;
  4. conduct all of the above capabilities dynamically and remotely.
- Wu-Kong promotes a new M2M programming paradigm:

  *developers should concentrate on high-level functional **flows**, instead of low-level sensor coding.*

(The name Wu-Kong comes from a heroic character, also known as the *Monkey King*, in the Chinese epic novel *Journey to the West*,

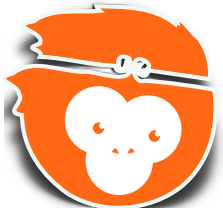
– born from a stone, acquired super powers through teachings of many masters.

– was a trouble maker, but was captured and condemned under a mountain.

– became a loyal guard of a monk travelling to the western heaven.)

Roles in a WuKong System

- Human Entities
  - Application developer: builds programs using a flow editor
  - Device installer: builds *NanoKong* (tiny firmware+JVM), sets up device configuration, and deploys it on the network
  - M2M user: informs Master the user requirement and policy
- System Entities
  - Flow-based program (FBP) Editor: used by developer to create an M2M application
  - Network Base Station: used by installer for enabling device node connection to the network
  - WuKong Master: contacted by user before running an application, will discover devices on network, map FBP components to devices, and deploy the code (for functionality and communication link) to node



Wu-Kong : User's Perspective

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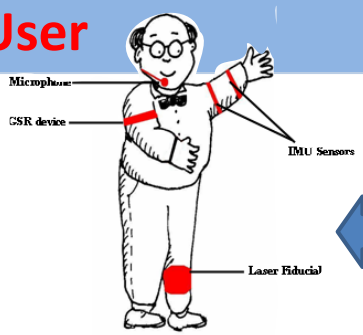
User



Application

Master

Communication Media

- Human
- Broadband
- Wireless

Gateway

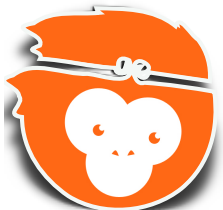
Sensor Nodes

Infrastructure Provider

User (naïve and demanding)
- Sends the request (via some user interface) to apps
- Defines context and high-level policy

Apps (running on user device and/or cloud)
- Interact with user
- Have access to unlimited computing power and intelligence

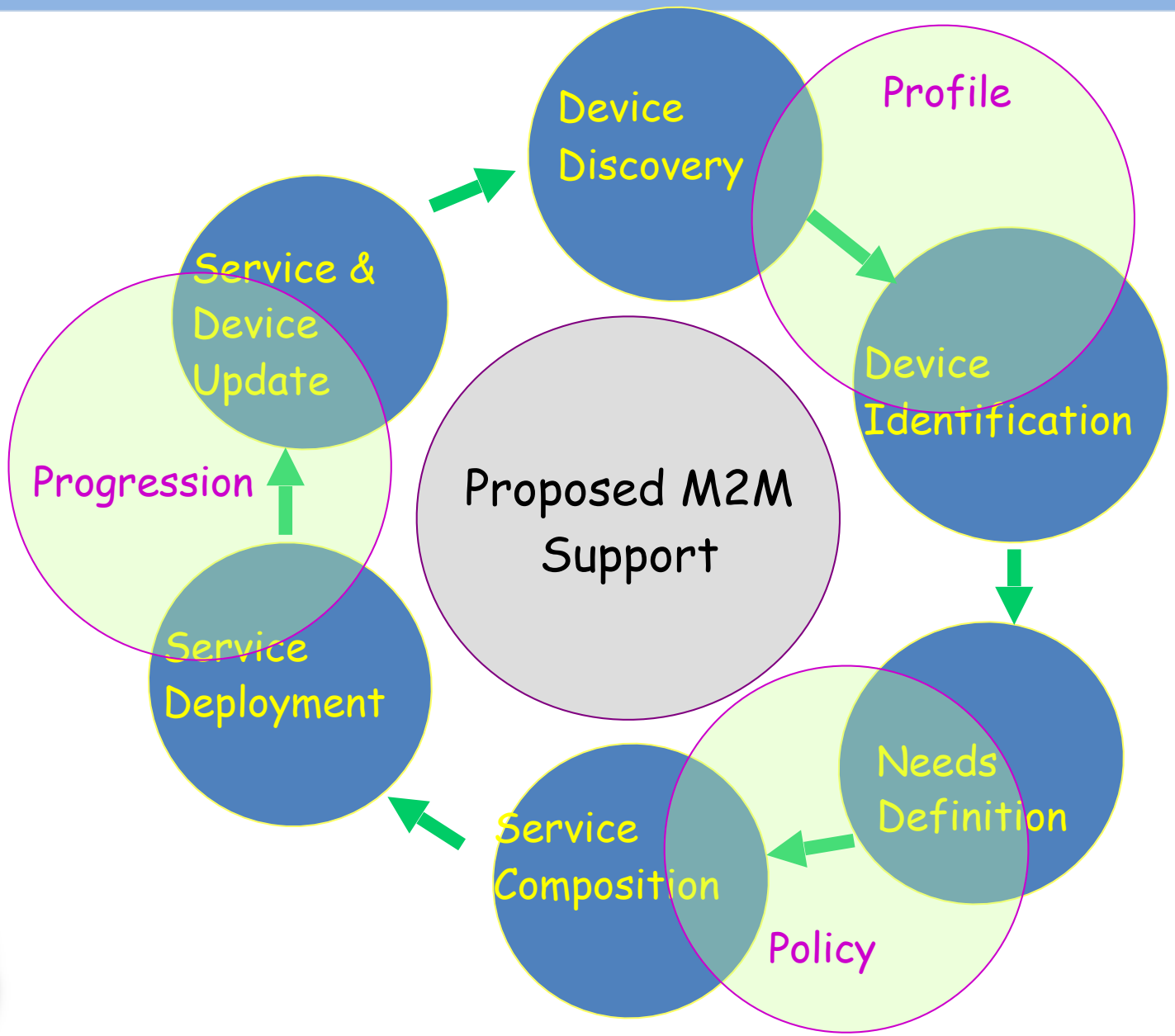
Master (coordinator for WSN)
- Has computing power to make coordination decisions
- Connects WSN to outside (as one of the *Gateways*)



Gateway (Cohort for Master)
- provides extra computing/connection
- provides backup coordination

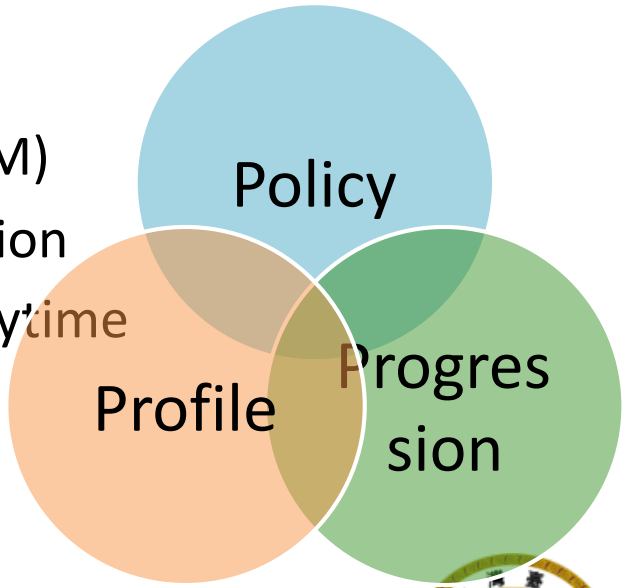
Nodes (sensor devices)
- Physical world sensing and actuating
- Need only limited computing power to sense/ send data

A New Paradigm: Tri-Framework on M2M development cycles



Wu-Kong : Software Perspective

- Tri-Framework approach
- Profile Framework (abstraction for heterogeneous nodes)
  - Device classes (capabilities): discover, share and control
  - Heterogeneous and virtual sensor sharing
- Policy Framework (adaption for M2M context)
  - Configuration decision and constraint optimization
  - Configuration <-> fault tolerance, security, trust
- Progression Framework (embedding intelligence in M2M)
  - Sensor to Master to cloud distribution and coordination
  - Tools for application access and control anywhere, anytime



Wu-Kong : Master's Perspective

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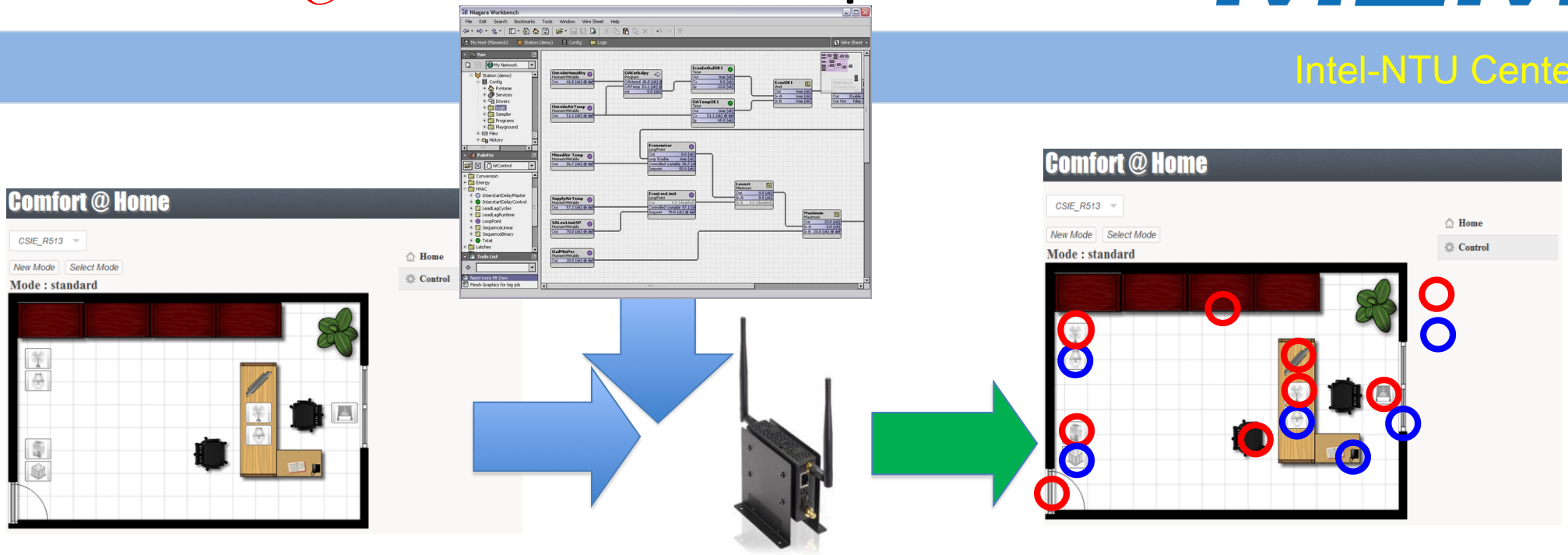


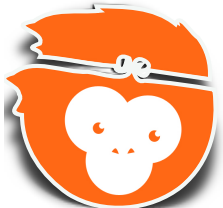
Flow-Based Programming allows domain experts to easily put together M2M data and control flows by connecting functional components to produce results & actions.

Given a **user context**, Wu-Kong is to discover the sensors and devices in the target environment, select the most desirable sensors to use, and automatically decide mapping from components to devices,

From the flow-based program (FBP), **Intelligent Compiler** generates the actual (Java) code to be loaded on selected sensors and networks to provide networked services, and deploy codes as required in FBP.

WuKong : Profile Framework

- To configure an M2M network, Master needs to determine what resources are available on a sensor device.
- Master-device protocol has three phases:
  1. Determine what devices are on the network
  2. Determine what those devices can do (*profile*)
  3. Determine what those devices should do
- After Master has "discovered" devices and queried them, the profile framework on each device provides:
  - *What resources are available on the device*
  - *A way to access and configure those resources*



Wu-Kong : Master's Perspective

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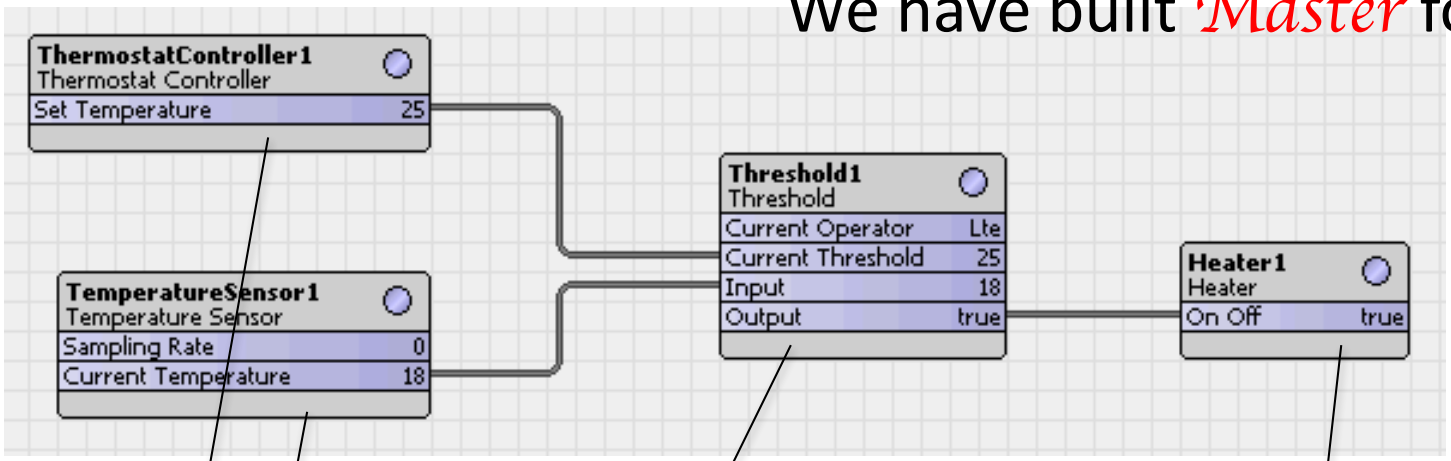
Given logical flows that have been defined, they must be mapped to some physical networks of nodes/sensors for execution.

We have built *Master* for that.



logical

Physical

Candidate1,2

Candidate1,1

WuClass 1

WuClass 2

WuClass 3

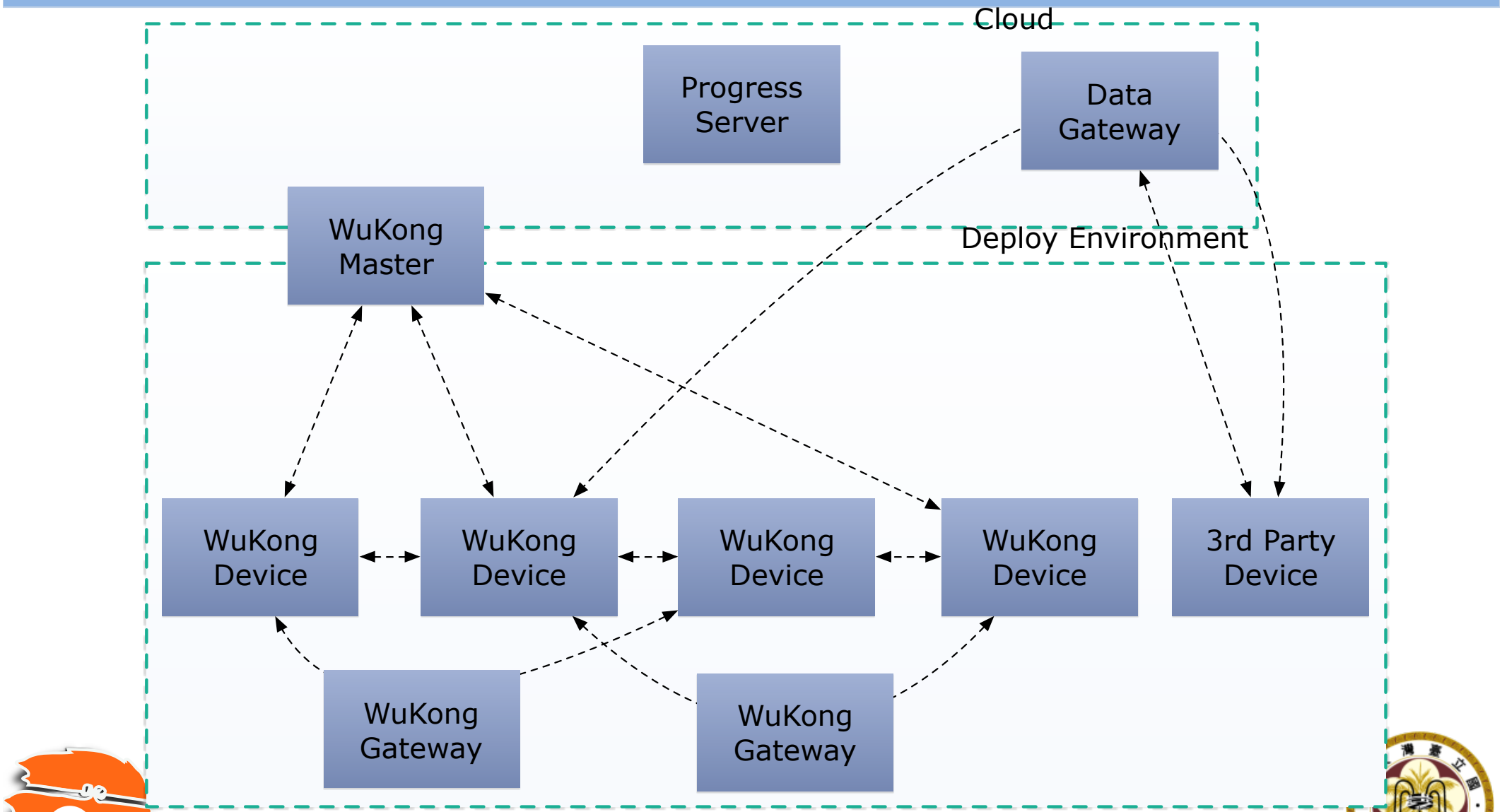
WuClass 4

Cost: $C_{31,41}$

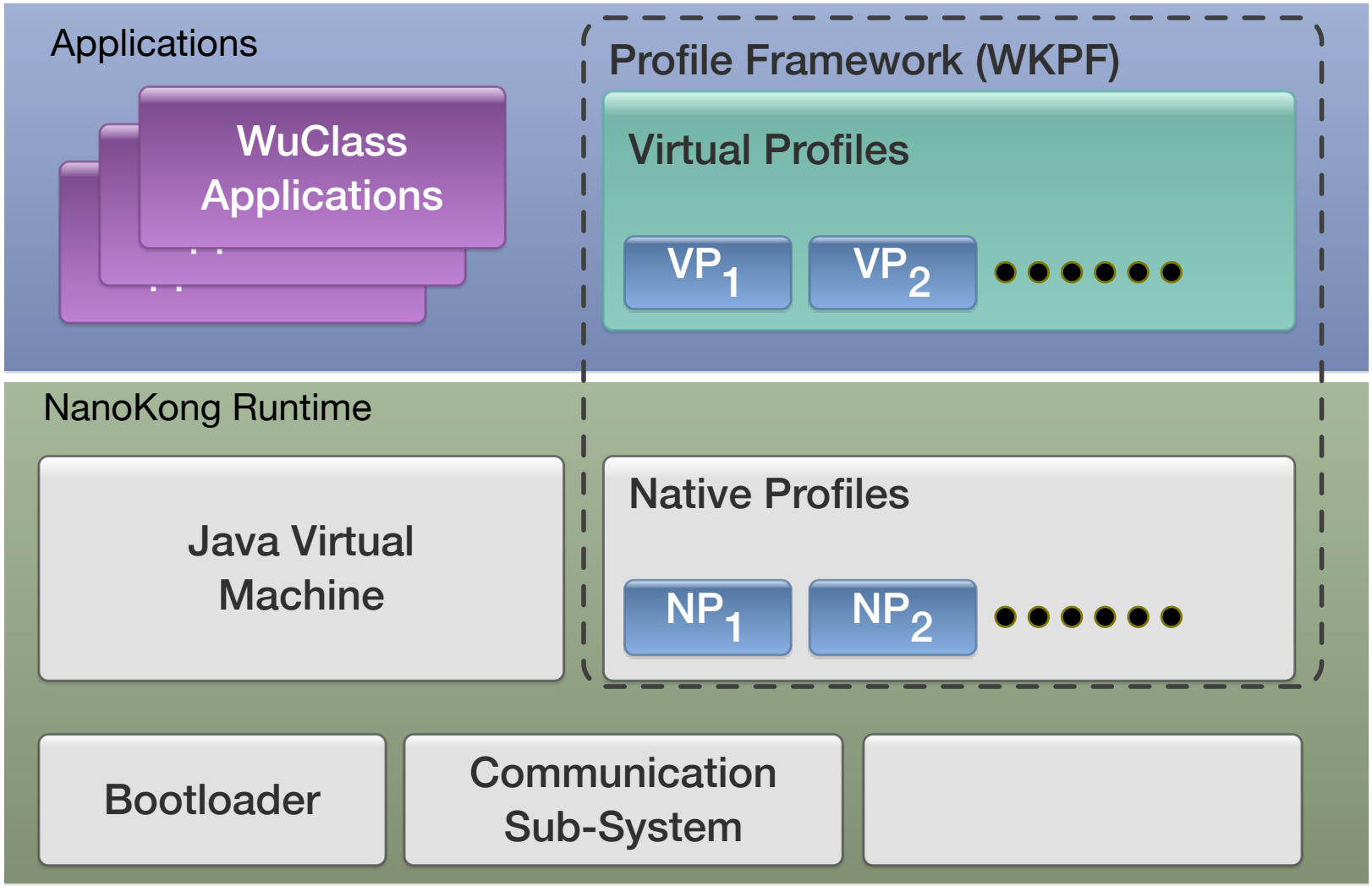
Constraints:

$Q^1_{31,41}$, $Q^2_{31,41}$

Wu-Kong System Architecture



On Devices


Applications
WuClass Applications
Profile Framework (WKPF)
Virtual Profiles
VP1
VP2
NanoKong Runtime
Java Virtual Machine
Native Profiles
NP1
NP2
Bootloader
Communication Sub-System

Wu-Kong System Building Steps

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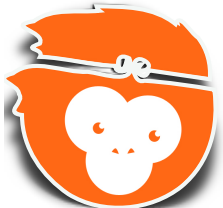
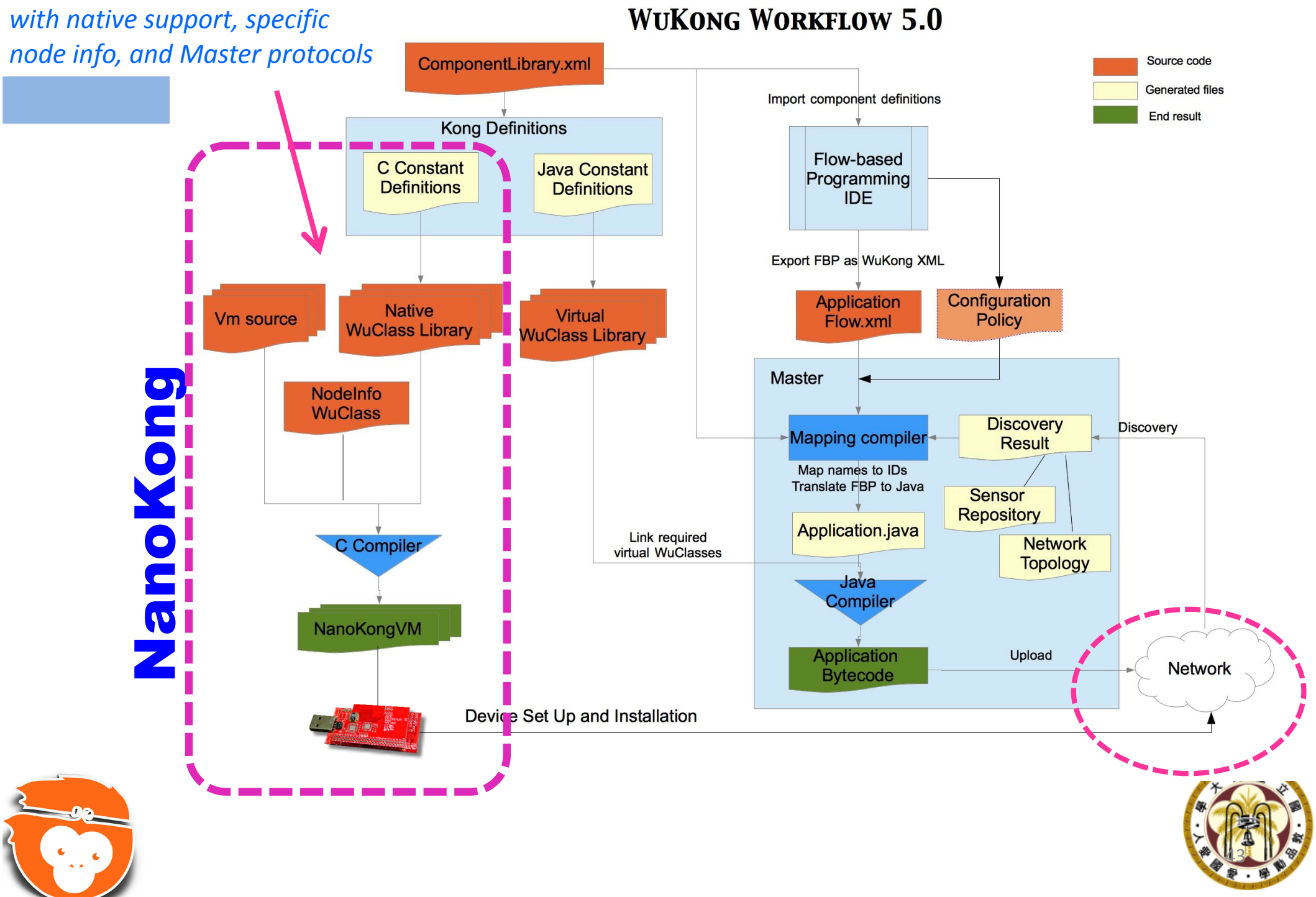
1. Build intelligent sensor devices using NanoKong
    1. Sensor classes (capabilities) are defined and selected for NanoKong
    2. JVM and device networking support are also included
2. Build flow-based programs using IDE
    1. Program components are selected from a component library and linked together
    2. IDE is used to build an application flow structure and export in XML
3. Build a working M2M using WuKong Master
    1. User sends the flow XML to Master to define the application flow
    2. Master discovers sensors remotely, maps them to flow components, and deploys the codes to all sensor nodes

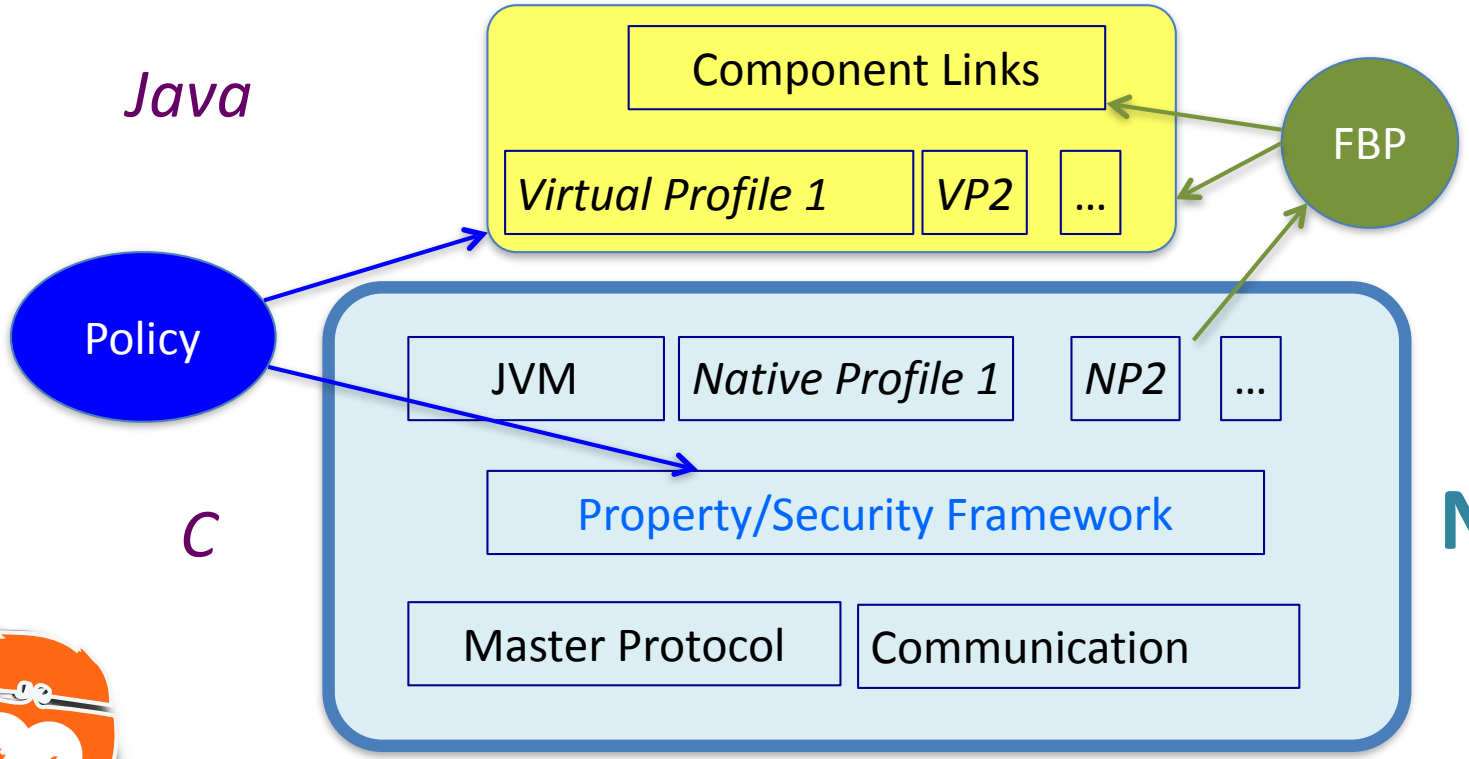


Each sensor device is loaded with native support, specific node info, and Master protocols



Building NanoKong Platforms

- Every node must be statically pre-loaded with native profiles for sensor device drivers, communication support, as well as JVM.
- Functionality beyond the device's native hardware design can be added by uploading software function code on a device. Such a functionality is referred as an virtual profile (in Java code)



NanoKong VM code size (NanoVM)

Memory requirement: 25K Flash, 2K RAM

Type	Component	Size (bytes)
VM	*Core JVM*	*5604*
VM	*Communication (ZWave+Zigbee)*	*7564*
VM	*Profile Framework*	*4244*
VM	*Native Profiles*	*632*
VM	*AVR Specific IO*	*3630*
VM	*String operations/user IO*	*950*
VM	*Total*	*22624*
VM	*Total compiled*	*20824*
Application	*Home automation application (native)*	*413*
Application	*Native Threshold WuClass (C)*	*199*
Application	*Virtual Threshold WuClass(Java)*	*330*

NanoKong VM code size (Darjeeling)

Memory requirement: 75K Flash, 2K RAM

Type	Component	Size (bytes)
VM	*Core JVM*	*27770*
VM	*Communication (ZWave)*	*2965*
VM	*Profile Framework*	*8032*
VM	*Native Profiles*	*1379*
VM	*AVR Specific IO*	*3445*
VM	*String operations/user IO*	*14698*
VM	*Total C code*	*47736*
VM	*Total*	*74856*
Application	*Home automation application (native)*	*576*
Application	*Native Threshold WuClass (C)*	*199*
Application	*Virtual Threshold WuClass(Java)*	*330*

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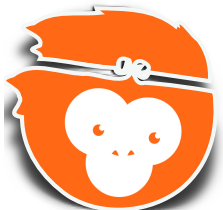
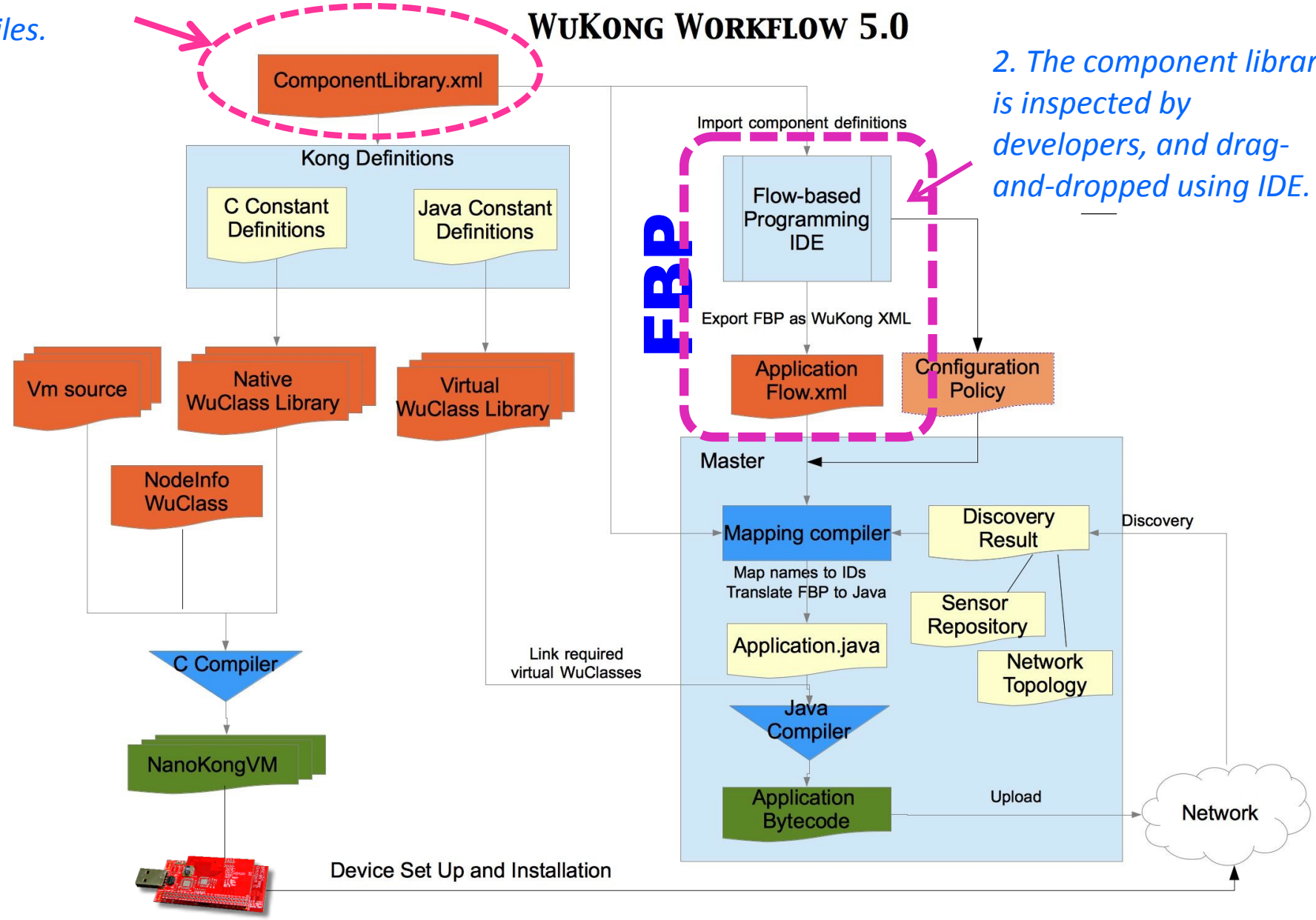


1. We have created a component library that includes all native and virtual profiles.

2. The component library is inspected by developers, and drag-and-dropped using IDE.



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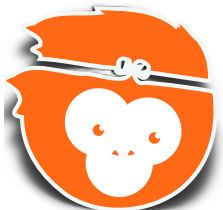
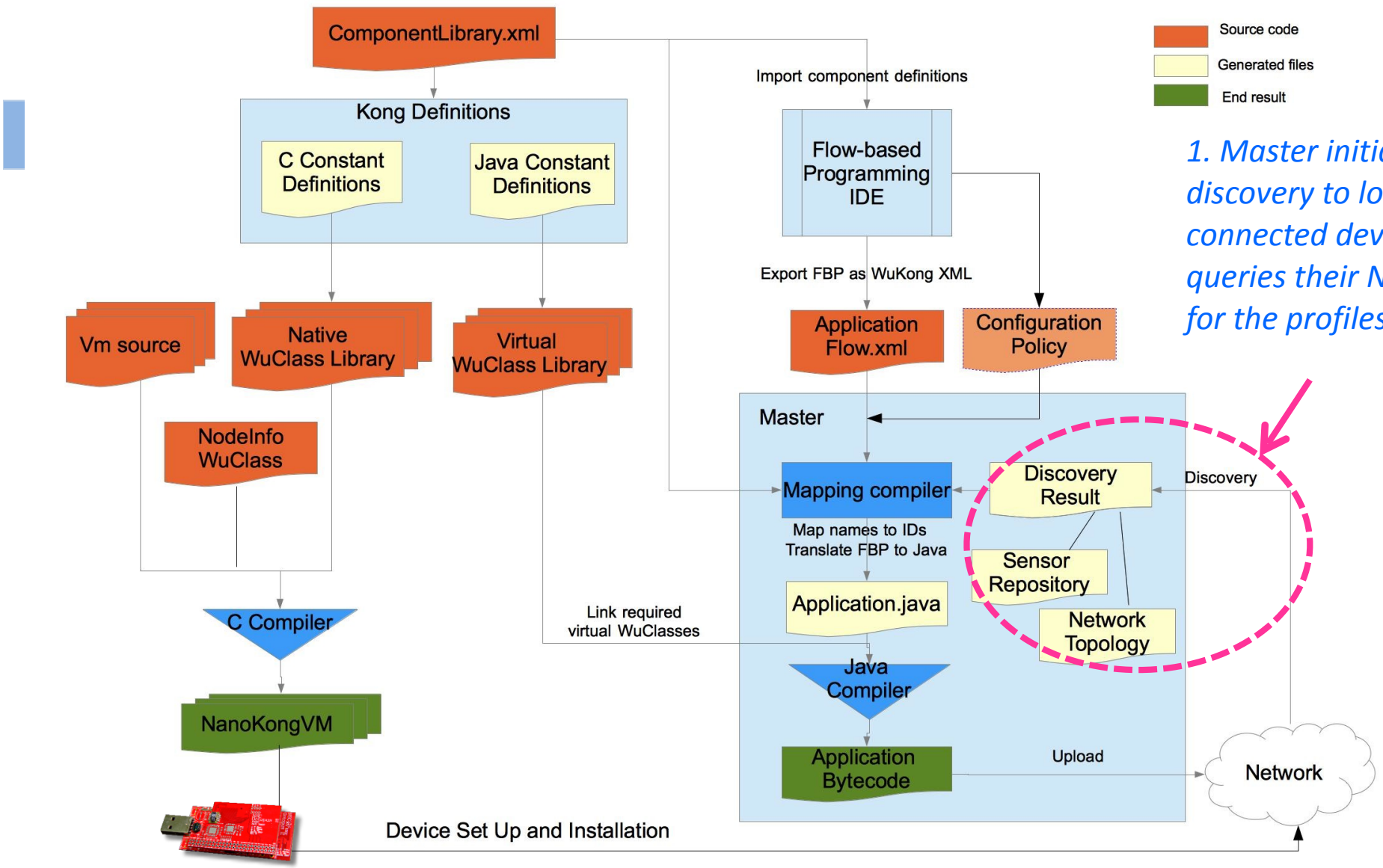


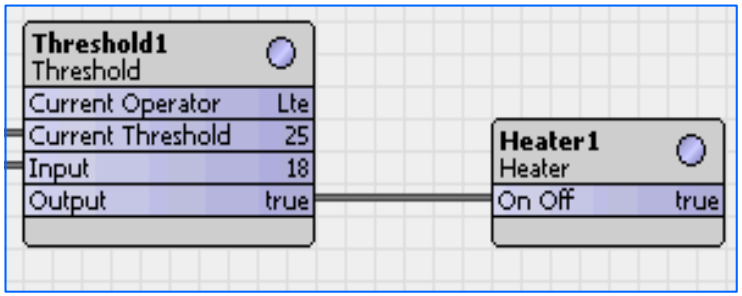
WuKong Workflow 5.0



1. Master initiates the discovery to look for all connected devices and queries their NanoKong for the profiles supported.

WuKong : Profile Framework

- A standard component library defines the components we use to create the FBP
  - Represents some kind of functionality
  - Either hardware or software
  - Defines
    - an interface as a set of properties
    - a method to run, either periodically, or when the input changes
  - FBP links connect component properties

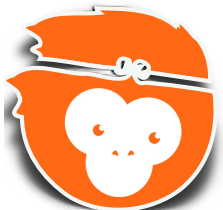


- The profile framework takes care of
  - telling the master what components are available on a node
  - creating new instances of components and links between them
  - propagating changes between linked properties
  - invoking the component's method

WuKong : Profile Framework

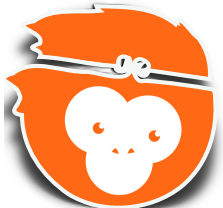
- Some examples
  - A light sensor (hardware)
  - A threshold (software)

```
<WuClass name="Light_Sensor" id="5" type="hard">
        <property name="current_value" datatype="short" access="readonly" />
        <property name="refresh_rate" datatype="refresh_rate" access="readwrite" default="10" />
</WuClass>

<WuClass name="Threshold" id="1" type="soft">
        <property name="operator" datatype="ThresholdOperator" access="readwrite" default="lt" />
        <property name="threshold" datatype="short" access="readwrite" default="30" />
        <property name="value" datatype="short" access="readwrite" default="20" />
        <property name="output" datatype="boolean" access="readonly" />
</WuClass>

<WuTypedef name="ThresholdOperator" type="enum">
        <enum value="LT"/>
        <enum value="GT"/>
        <enum value="LTE"/>
        <enum value="GTE"/>
</WuTypedef>
```

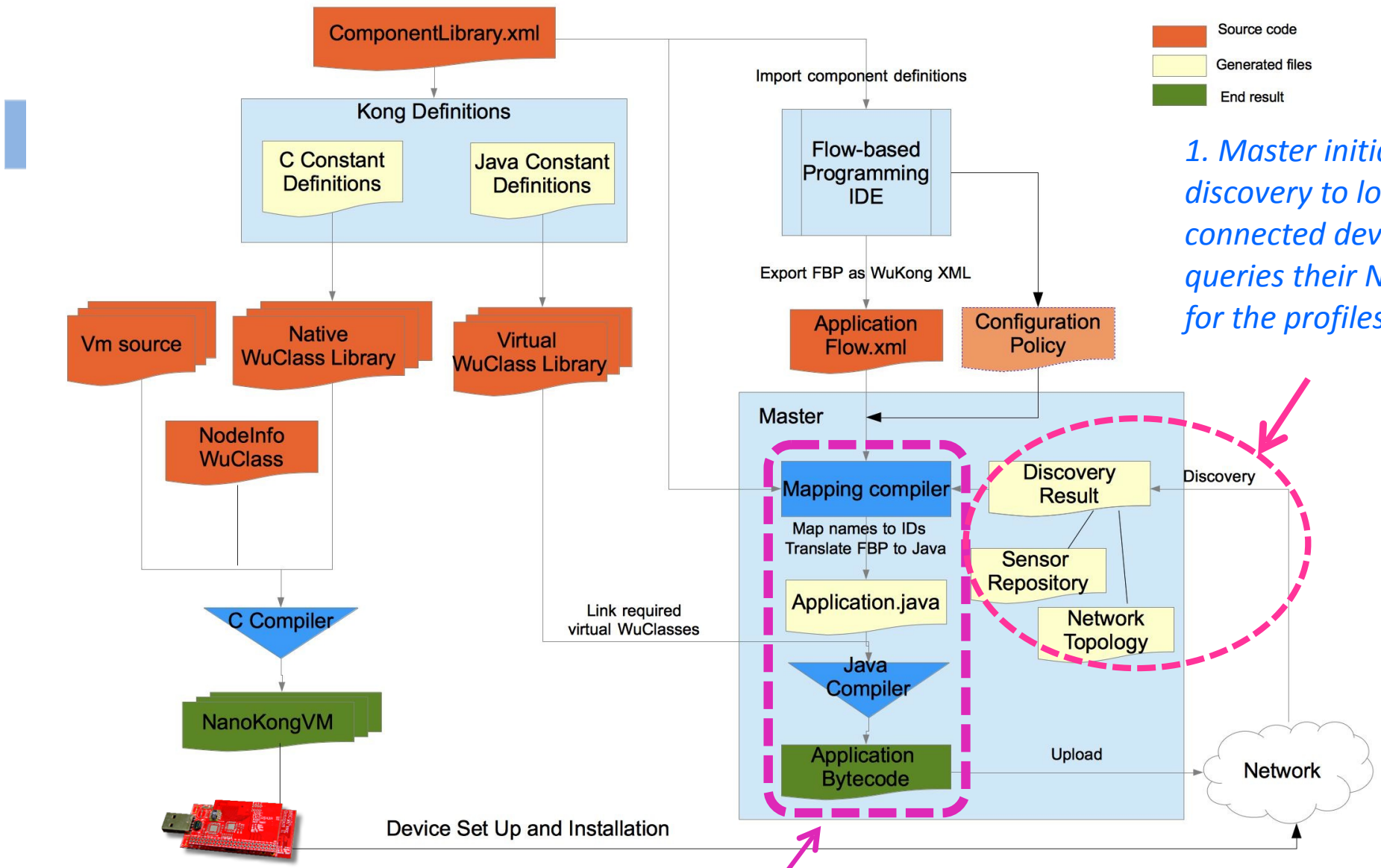


Native vs. Virtual Components

- Most device profiles are defined and pre-loaded to access a device's fixed native hardware
- Functionality beyond the device's native hardware design can be added by uploading software function code on a device.
- Such a functionality is referred as an “virtual” profile
  - This profile isn't (directly) tied to the node's hardware
  - It is implemented in software (Java bytecode)
- In this way virtual sensors can be implemented, e.g. combining data from different sensor sources into a new 'sensor'.

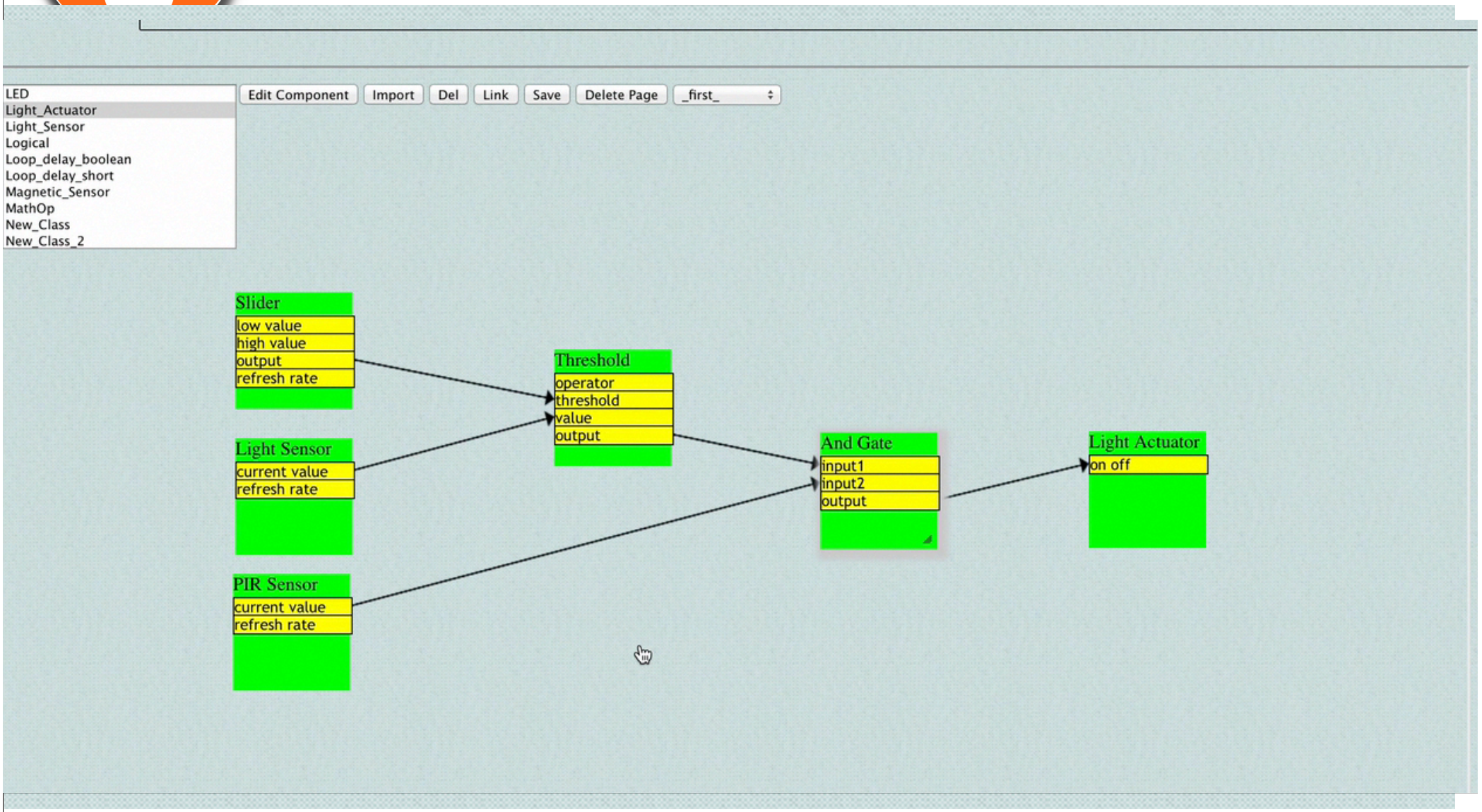


WuKong Workflow 5.0

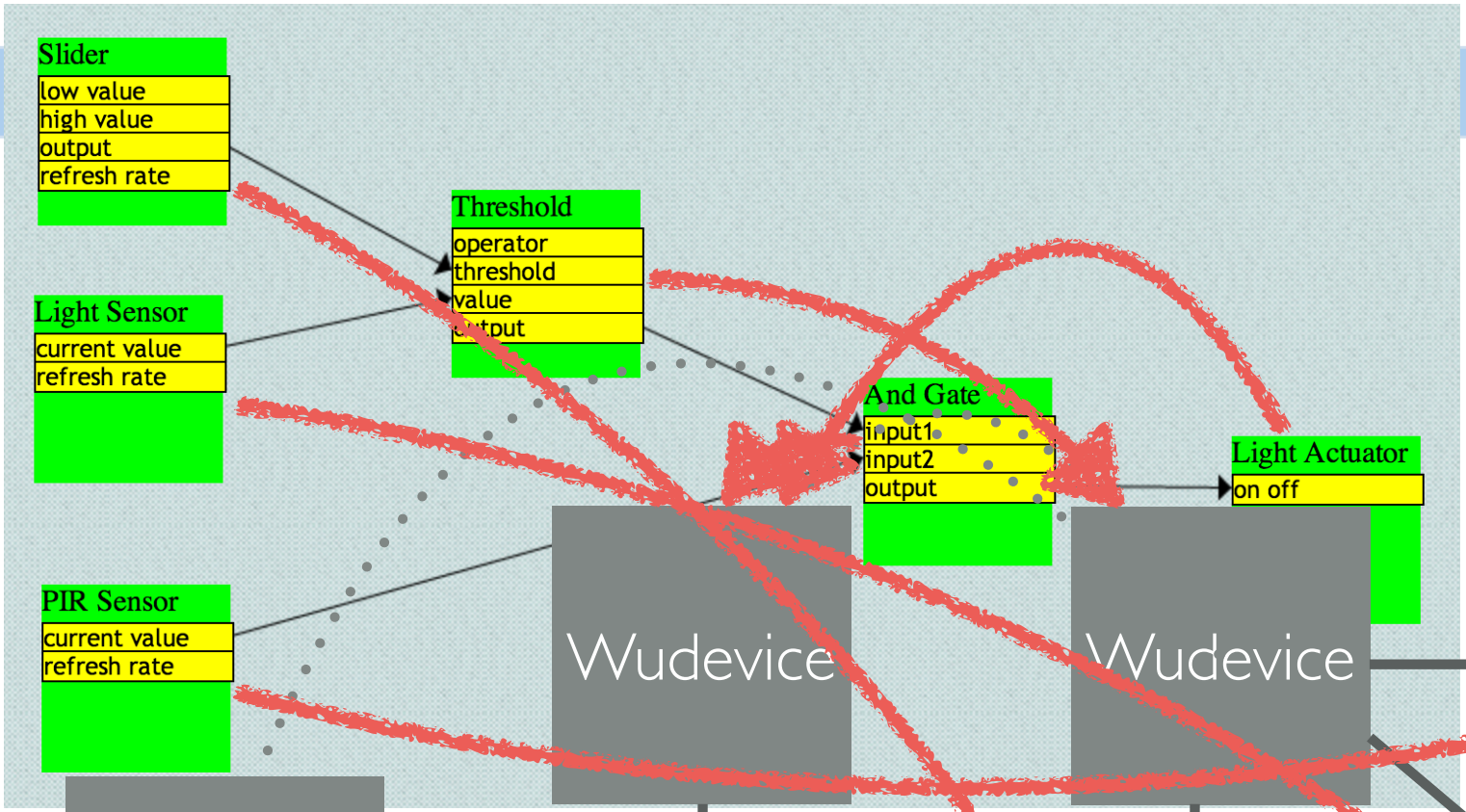


1. Master initiates the discovery to look for all connected devices and queries their NanoKong for the profiles supported.

2. Master uses mapping algorithms to selects different devices for a FBP, and upload the codes


LED
Light_Actuator
Light_Sensor
Logical
Loop_delay_boolean
Loop_delay_short
Magnetic_Sensor
MathOp
New_Class
New_Class_2
Edit Component
Import
Del
Link
Save
Delete Page
first
Slider
low value
high value
output
refresh rate
Threshold
operator
threshold
value
output
Light Sensor
current value
refresh rate
And Gate
input1
input2
output
Light Actuator
on off
PIR Sensor
current value
refresh rate

Sensors, Actuators and WuDevices



Wudevice

Wudevice

Wudevice

PIR Sensor

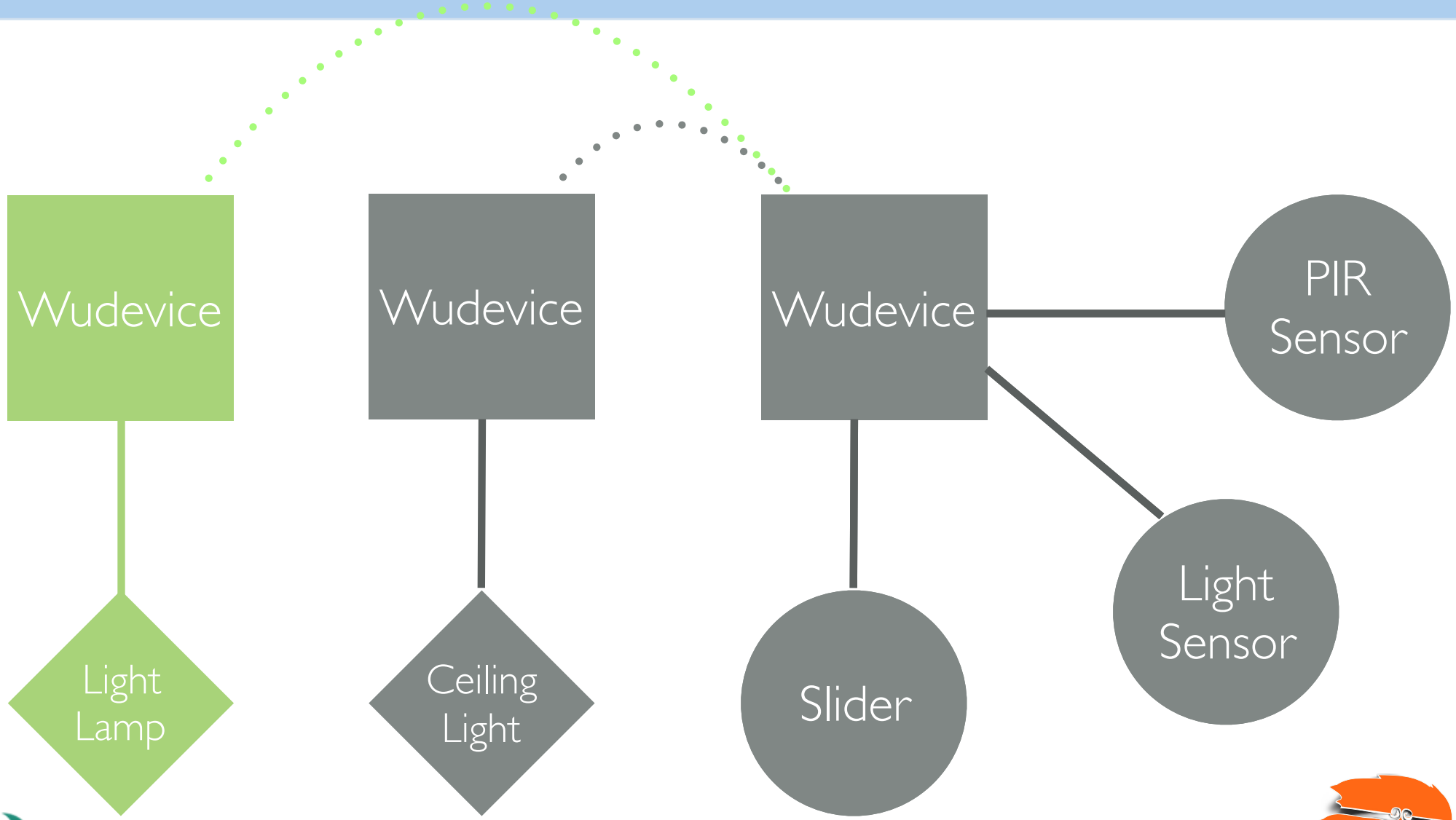
Light Lamp

Ceiling Light

Slider

Light Sensor

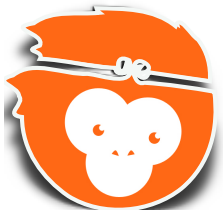
Sensors, Actuators and WuDevices



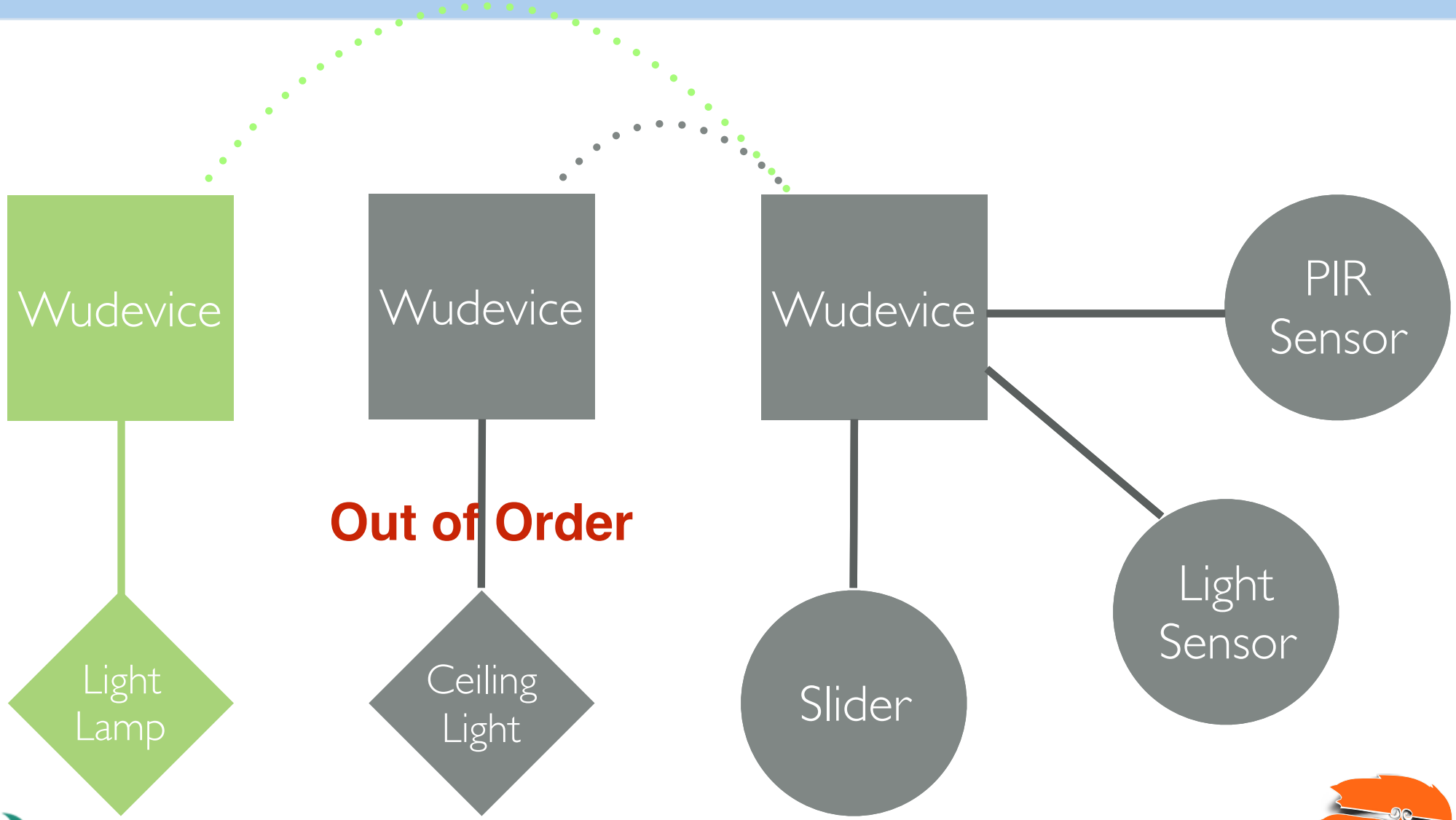
Health and idle

Self-reconfiguration to handle fault

- Self-reconfiguration is a must-have feature for managing large-scale M2M systems.
- Fault Tolerance Policy defines how WuKong master handles the faults:
  - When the system is deployed, the Master checks if fault tolerance requirement can be fulfilled.
    - Example: to provide services and allow at most *n* simultaneous failures, the system should have at least *n+1* candidate nodes to deploy the services.
  - During the run-time, the master handles the faults according to the given policy.
    - Example:
      - Policy: there should be at least one temperature sensor within the study room
      - Remapping temperature service from a failure node to a health node.

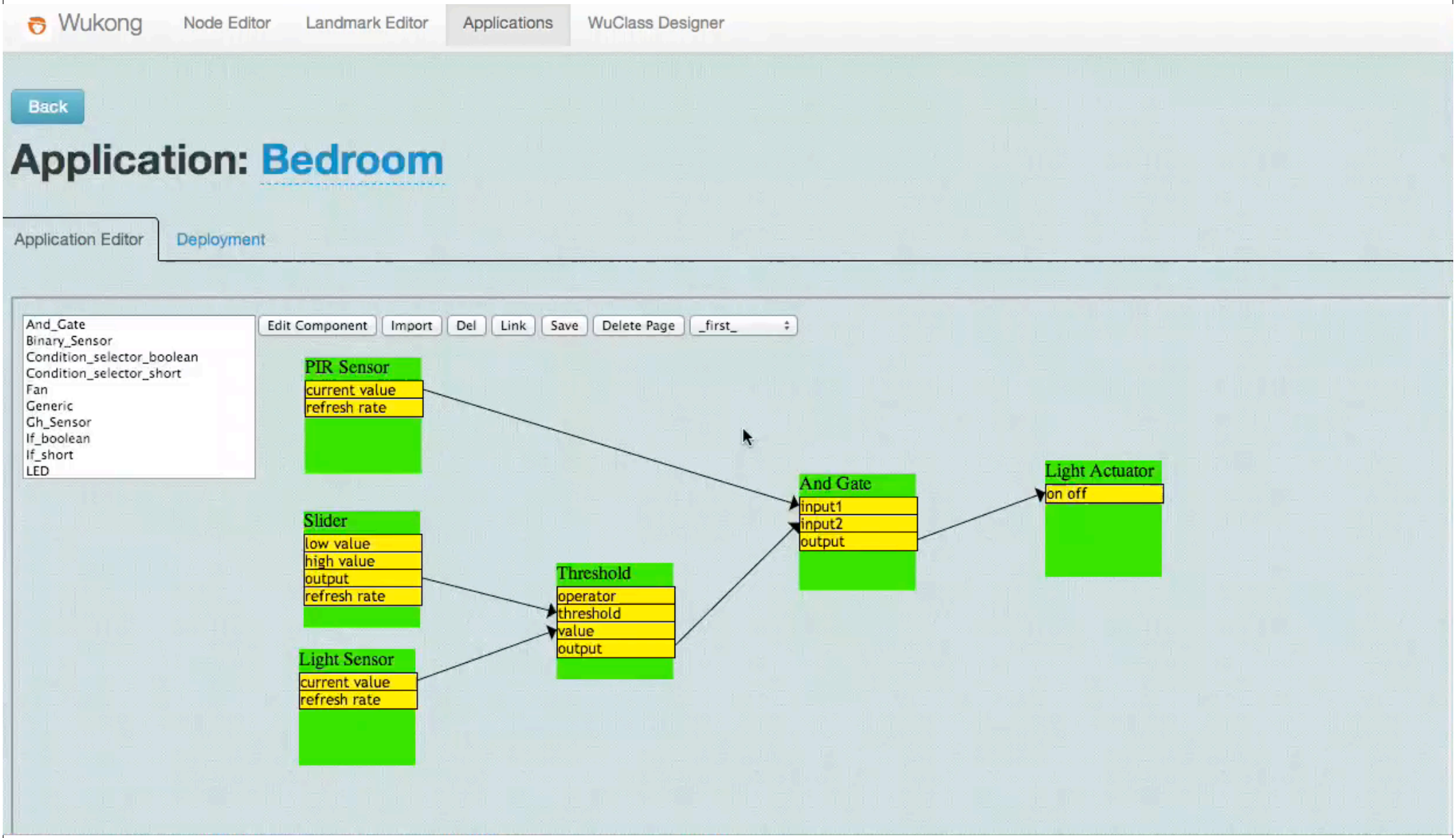


Sensors, Actuators and WuDevices

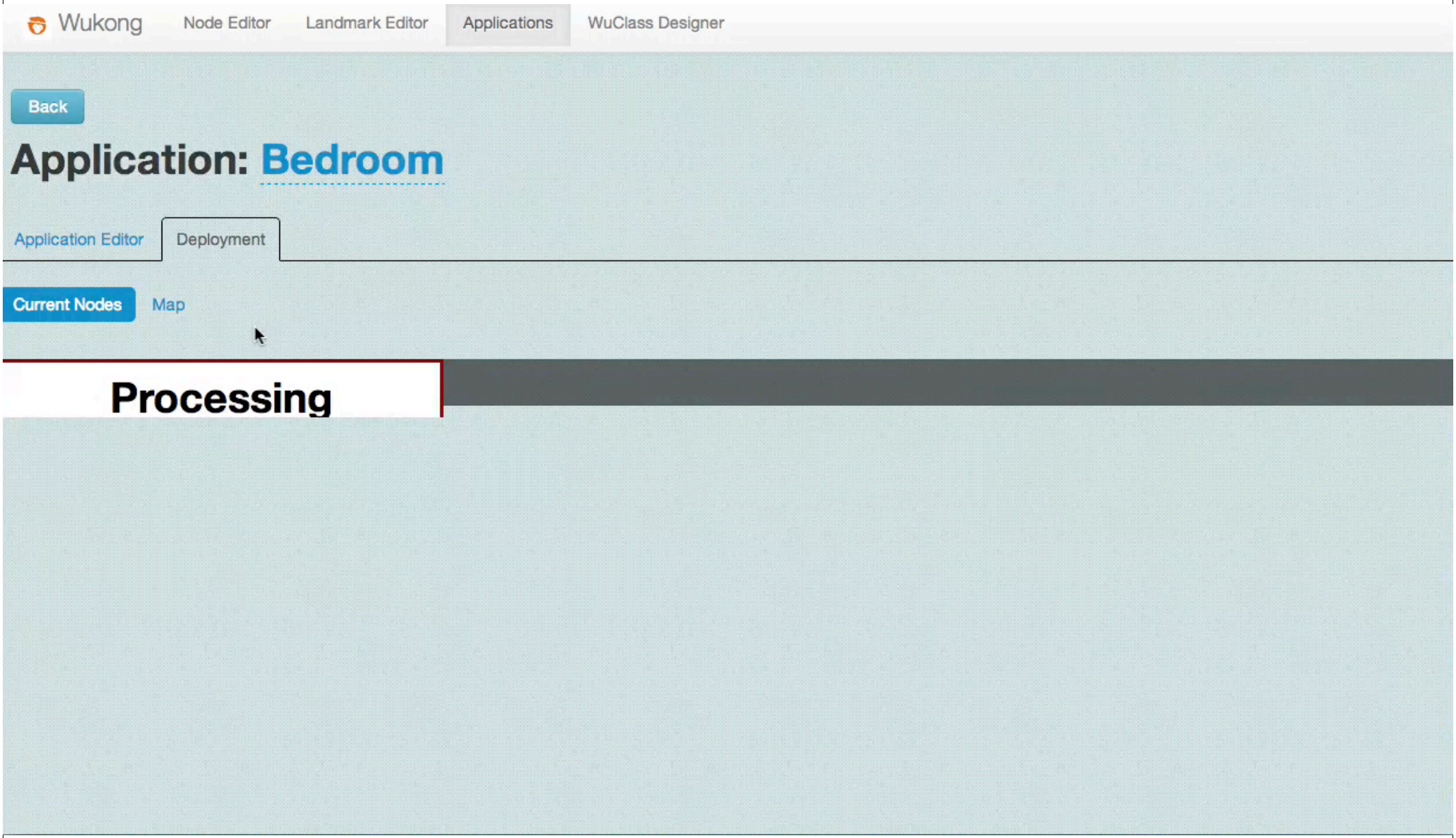


Health and idle

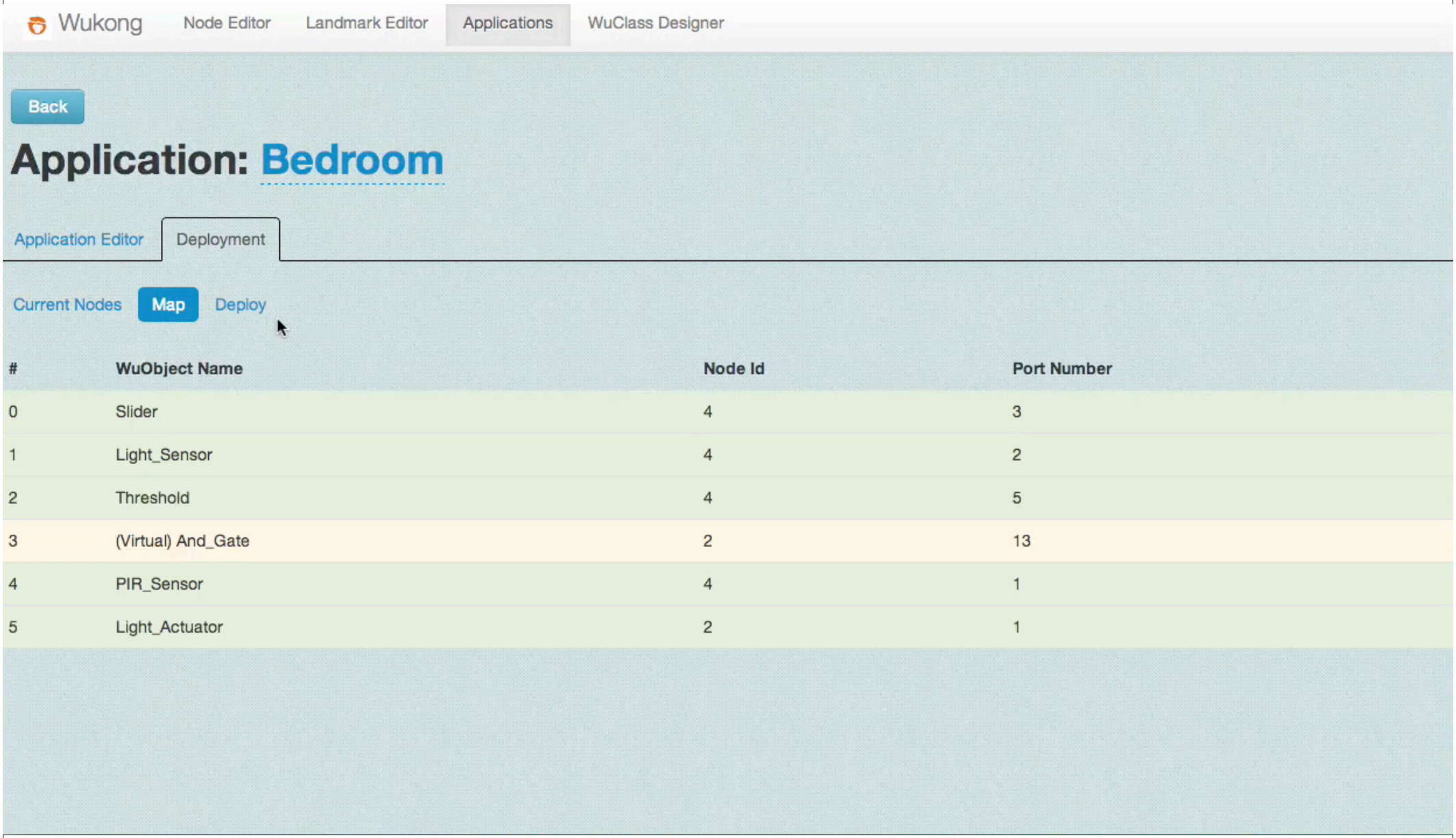
Reconfiguration without Reprogramming



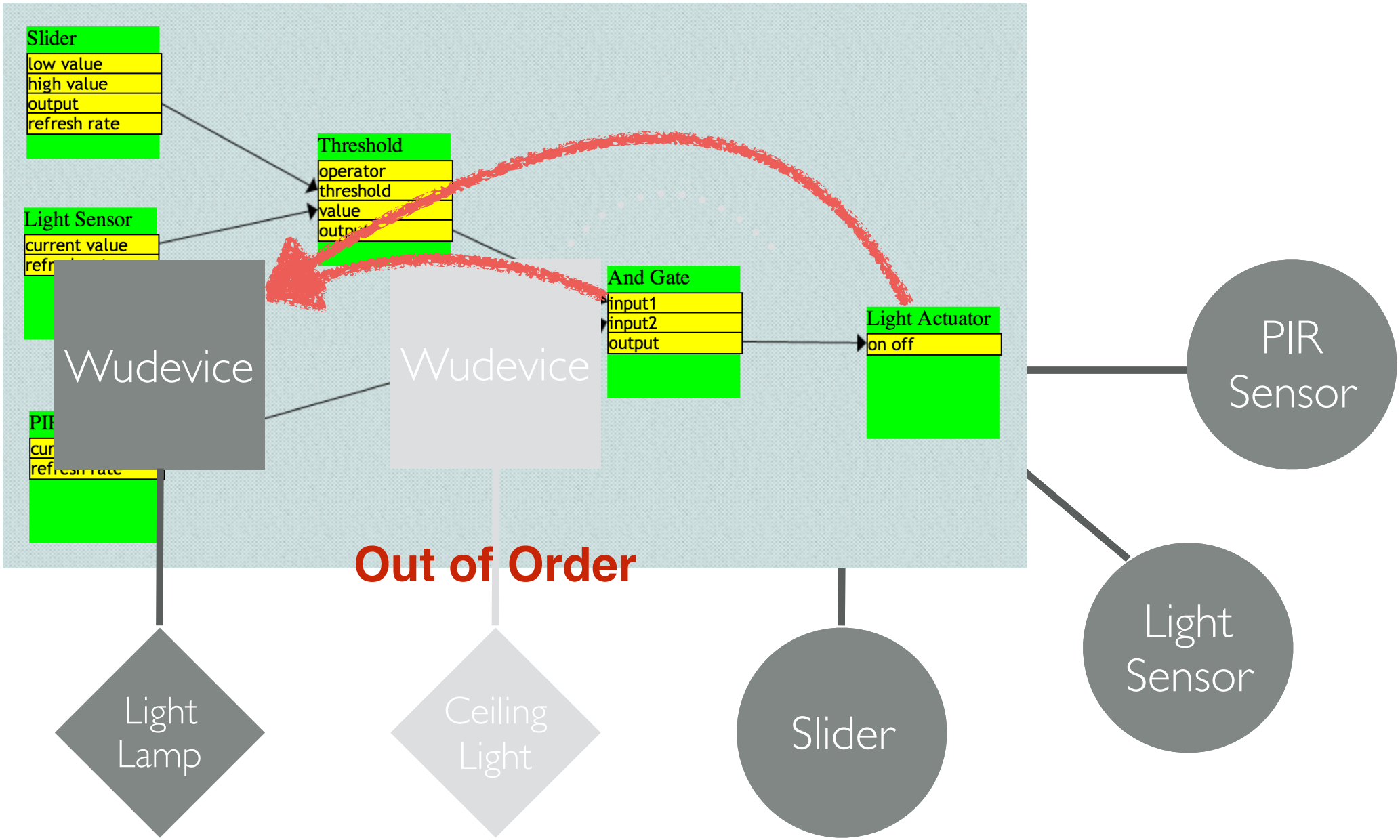
Reconfiguration without Reprogramming



Reconfiguration without Reprogramming



Sensors, Actuators and WuDevices



Up and running

Think Logical; Let Master Get Physical

- M2M Paradigm Shift: *Think Logical; Let Master Get Physical*
  - Sensor applications should be re-usable by different sensor devices and users
  - Users should have the freedom to choose the devices they want to use.
- WuKong provides an open system for developers to build and users to adopt new sensor applications.
- We want to make both user's and service provider's lives easier.
  - For users, we want to allow different types of applications, under various context and policies, to be easily configured and deployed on a set of sensors
  - For service providers, we want to make M2M operations simple and flexible to improve industry's operational cost