Design and implementation of an ITS station to bridge automotive and IoT systems

Master Thesis in Computer Science and Networking

Supervisors: Prof. Piero Castoldi, Dr. Paolo Pagano
Candidate: Michele Carignani

OUTLINE

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- **Internet of Things** and Wireless Sensor Networks technologies

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- Connected cars and **Cooperative Intelligent Transport Systems**

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- **Integration** of automotive and IoT

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IMPLEMENTATION AND RESULTS

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IMPLEMENTATION AND RESULTS

- **Facilities** implementation

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IMPLEMENTATION AND RESULTS

- **Facilities** implementation
- **Results** achieved for the **URBELOG** project

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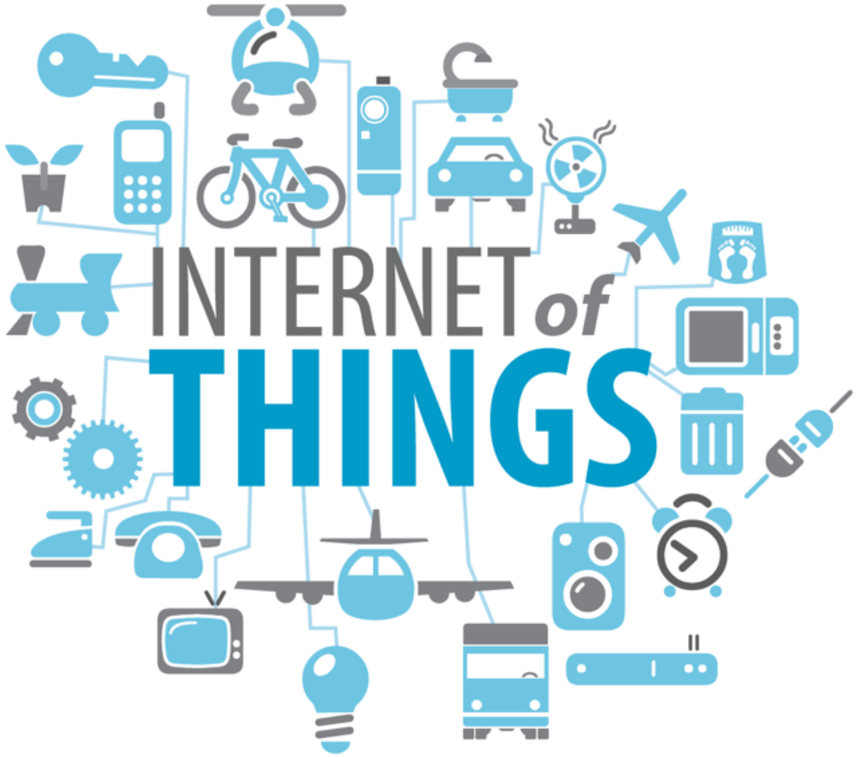
Internet of Things



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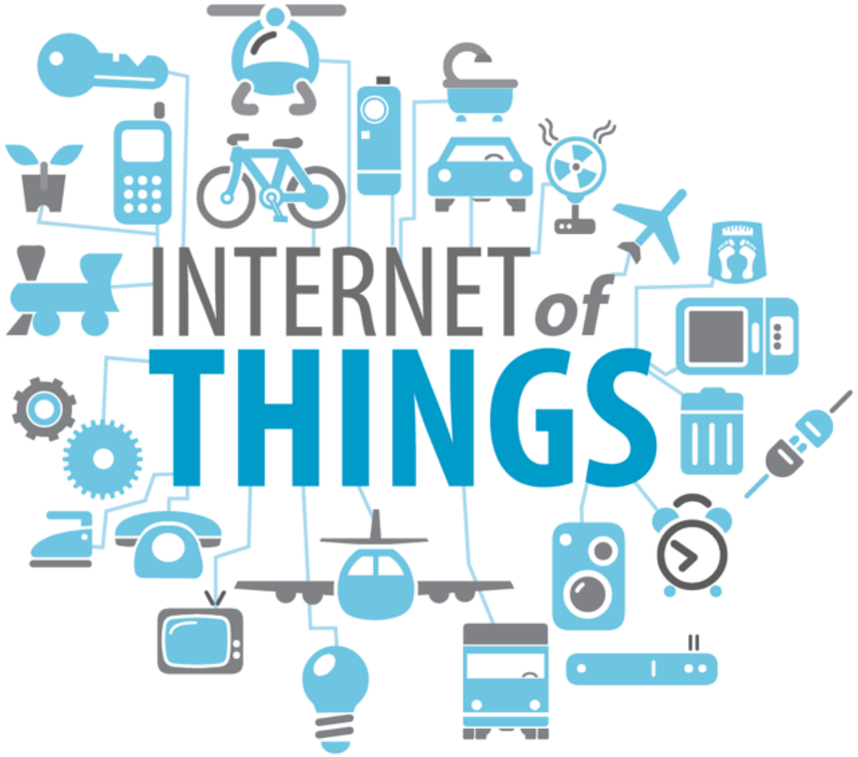
Internet of Things



“A global infrastructure […] interconnecting physical and virtual things […]” (ITU-T)

- 2014: 10 billion new processors
  - 2% for GP, 98% embedded
- Worldwide market
  - 158.6 billion $ by 2015
  - steady growth of 7% in 5 years

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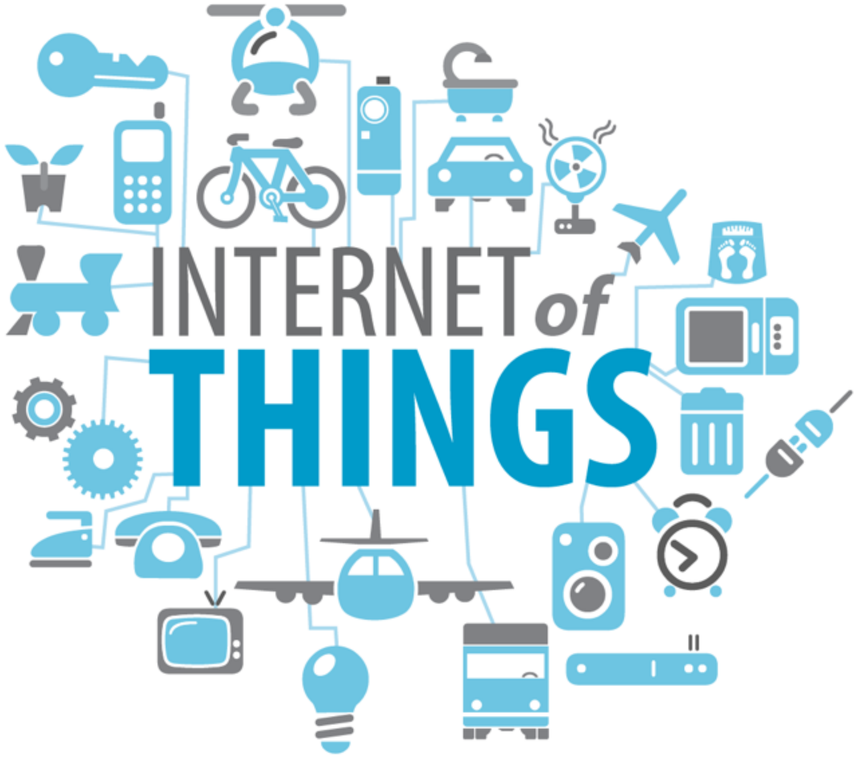

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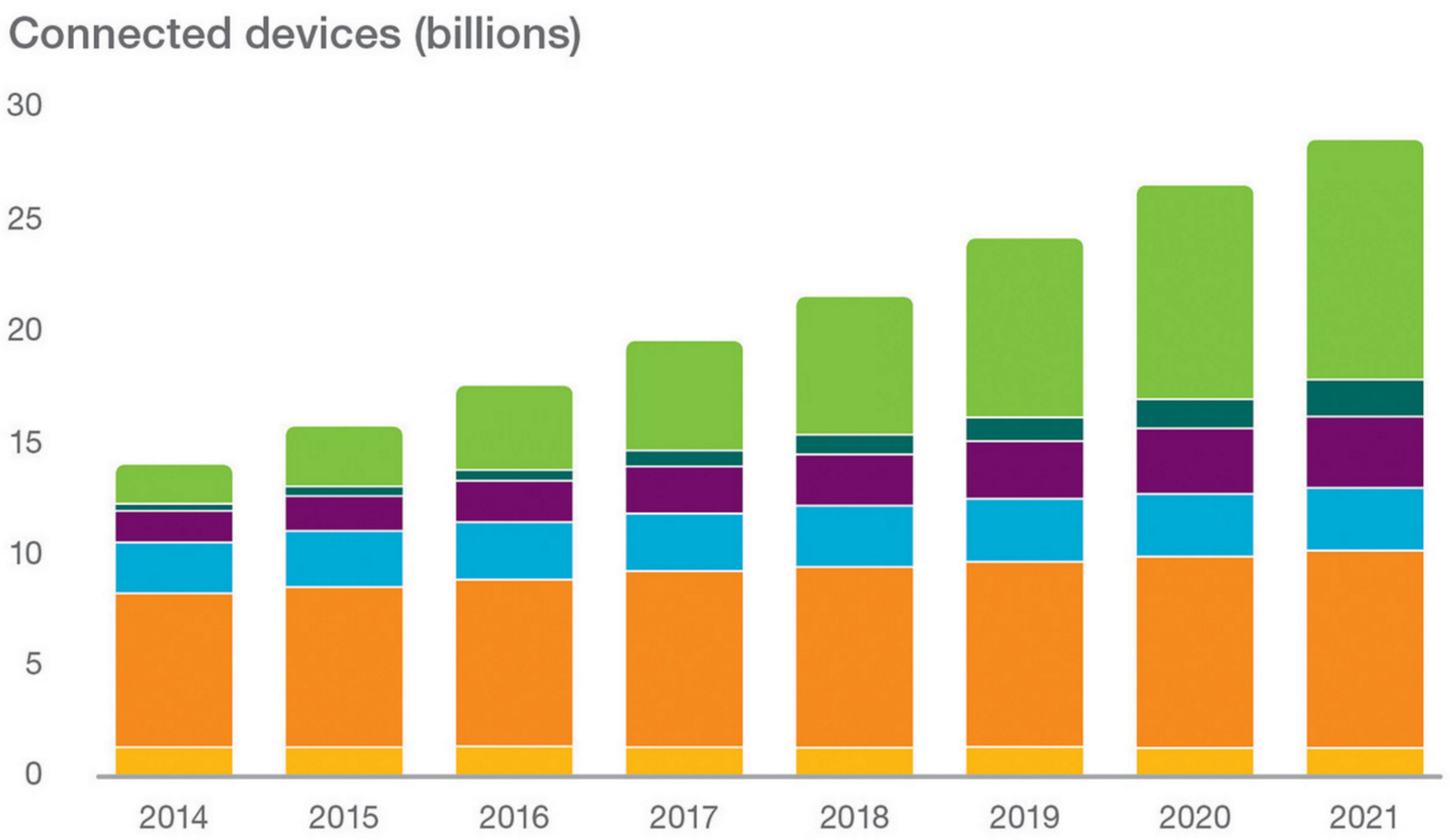
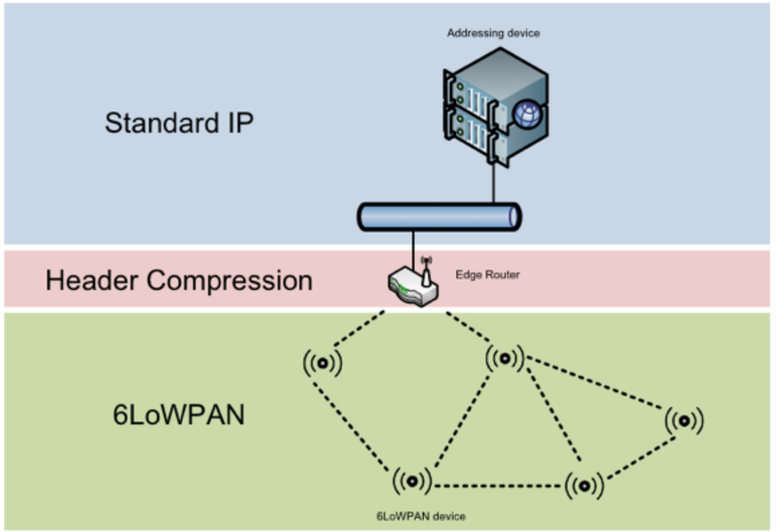
Machine to Machine (M2M)



	15 billion	28 billion
M2M: non-cellular	2.6	10.7
M2M and consumer electronics; cellular	0.4	1.5
Consumer electronics; non-cellular	1.6	3.1
PC/laptop/tablet	2.4	2.8
Mobile phones	7.1	8.7
Fixed phones	1.3	1.4
	2015	2021

Source: http://www.ericsson.com/mobility-report

IoT Standard open stack

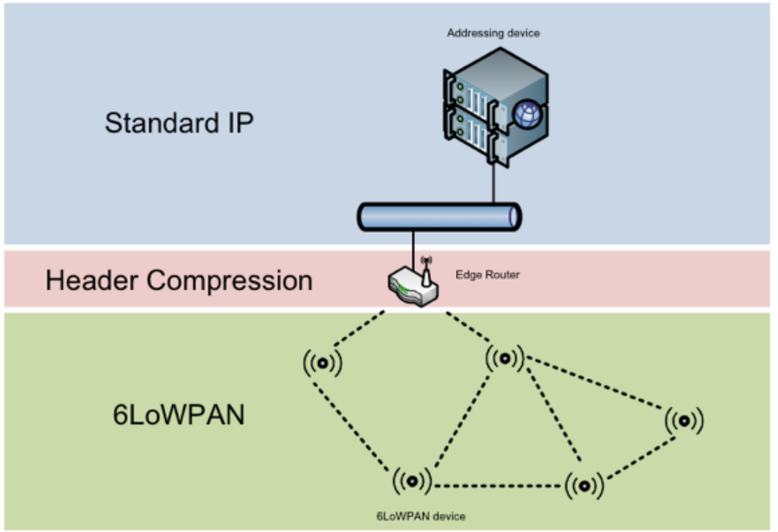


IoT Standard open stack

- **IEEE 802.15.4**
  - LR-WPAN
  - short-range,
  - low-data-rate,
  - efficiency (cost, power)

- **6LoWPAN**
  - IPv6 over Low Power
  - Minimal (code, memory)
  - End-to-end with Internet

- **CoAP**:
  - REST-ful model
  - Lightweight HTTP-like



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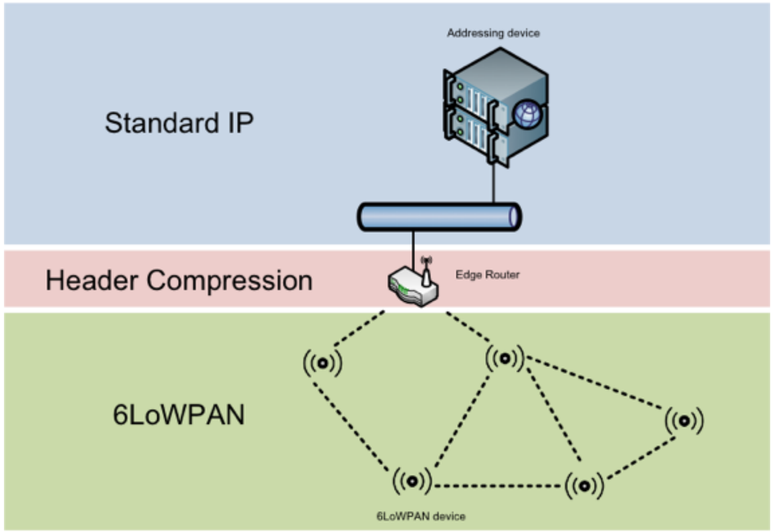
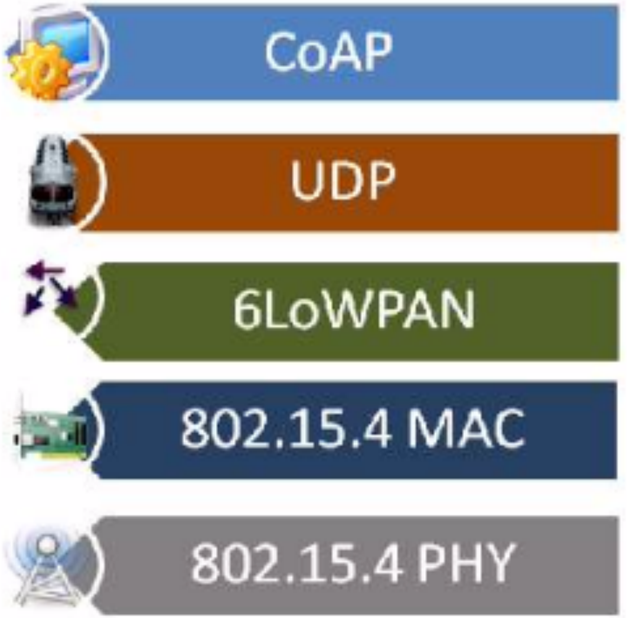
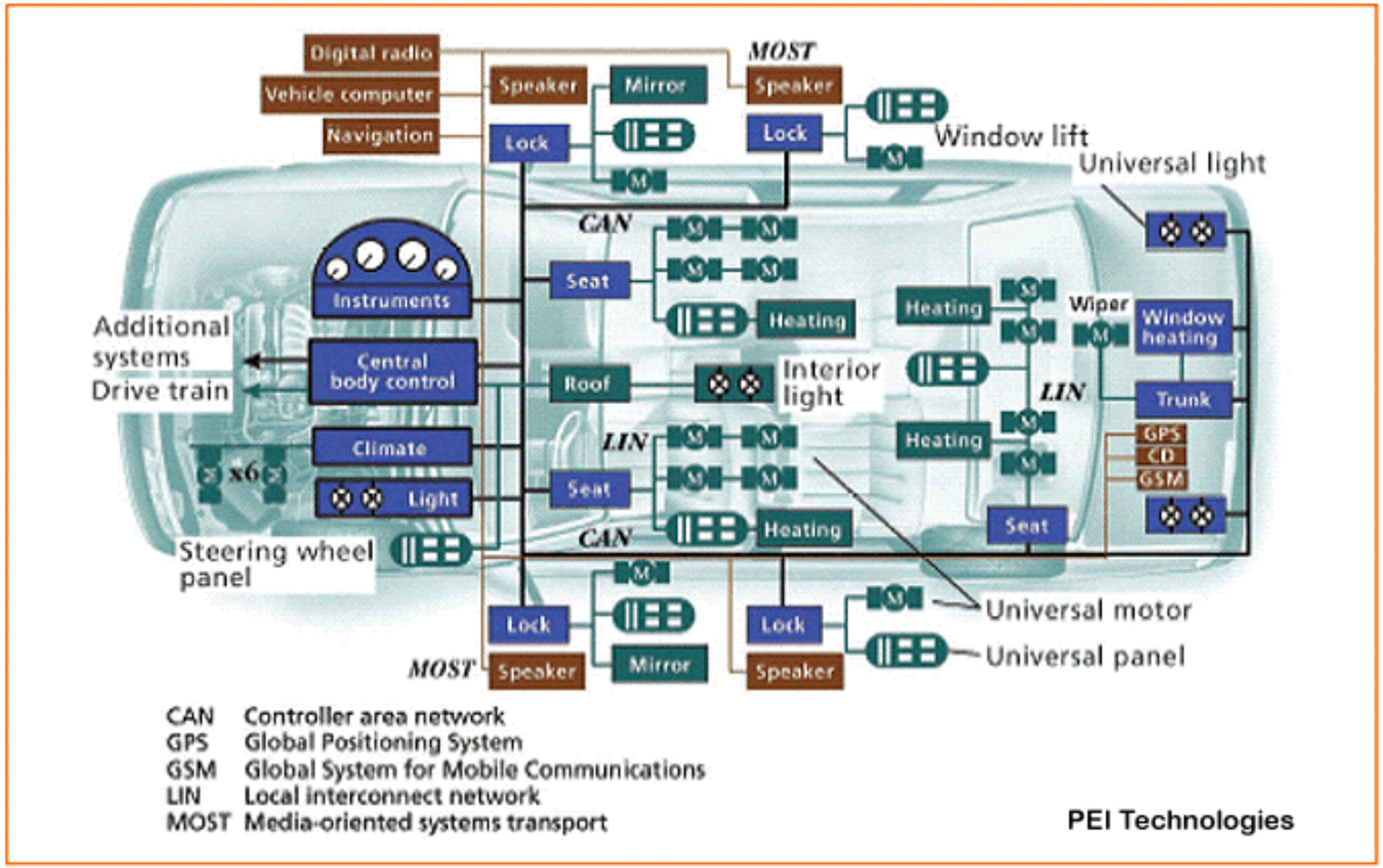




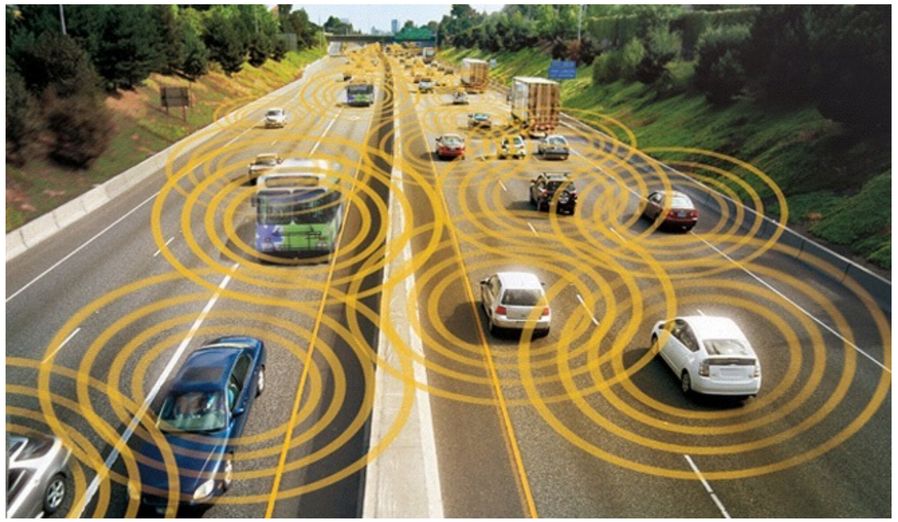
From the fully connected car…

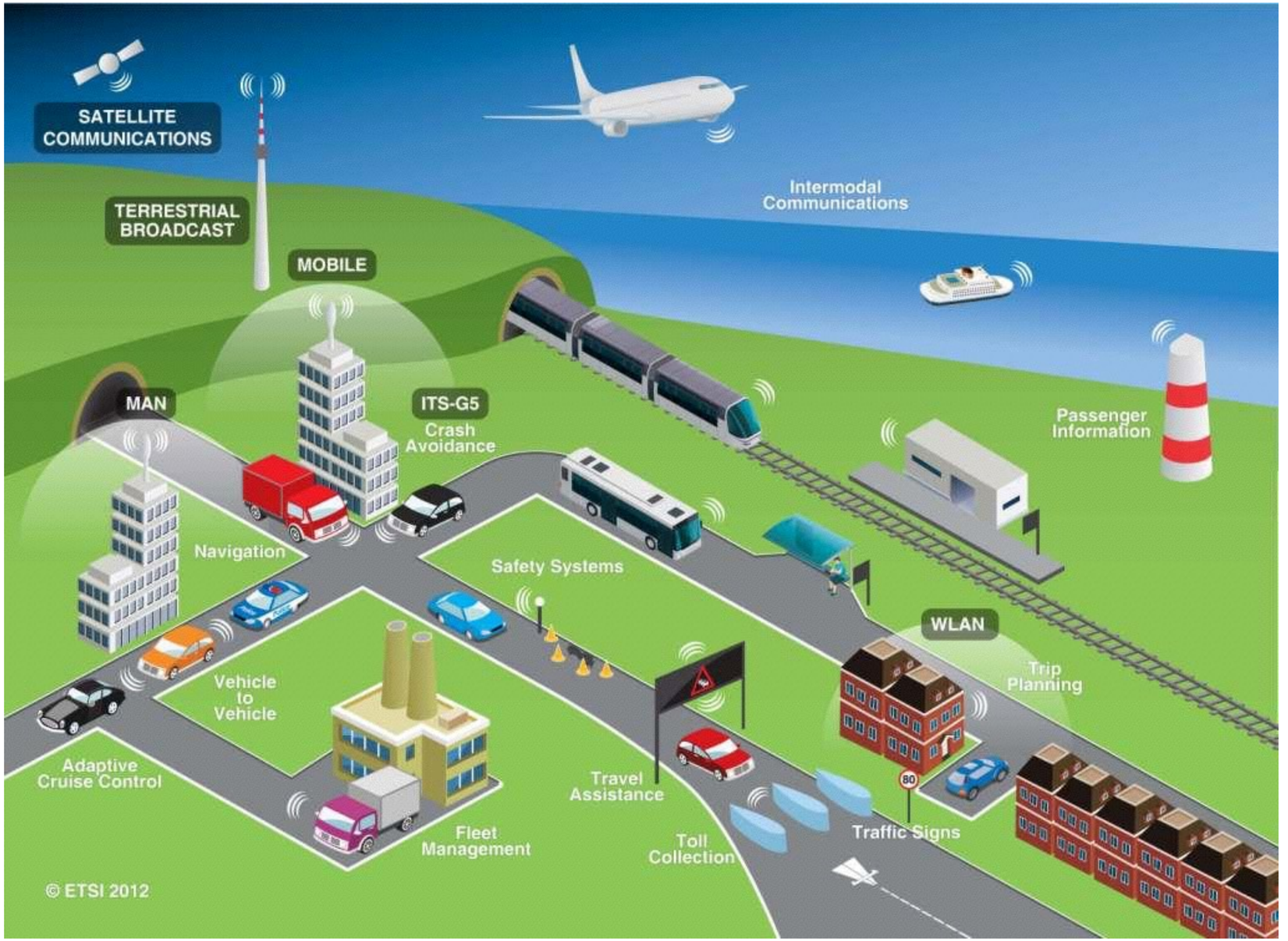
- Connected car is a reality
- Hundreds of ECUs in the on-board networks
- Monitoring, diagnostics, infotainment (apps, music…)
- Mostly closed and proprietary



… to Cooperative ITS

systems "to support transportation of goods and humans with information and communication technologies in order to efficiently and safely use the transport infrastructure and transport means (cars, trains, planes, ships)"





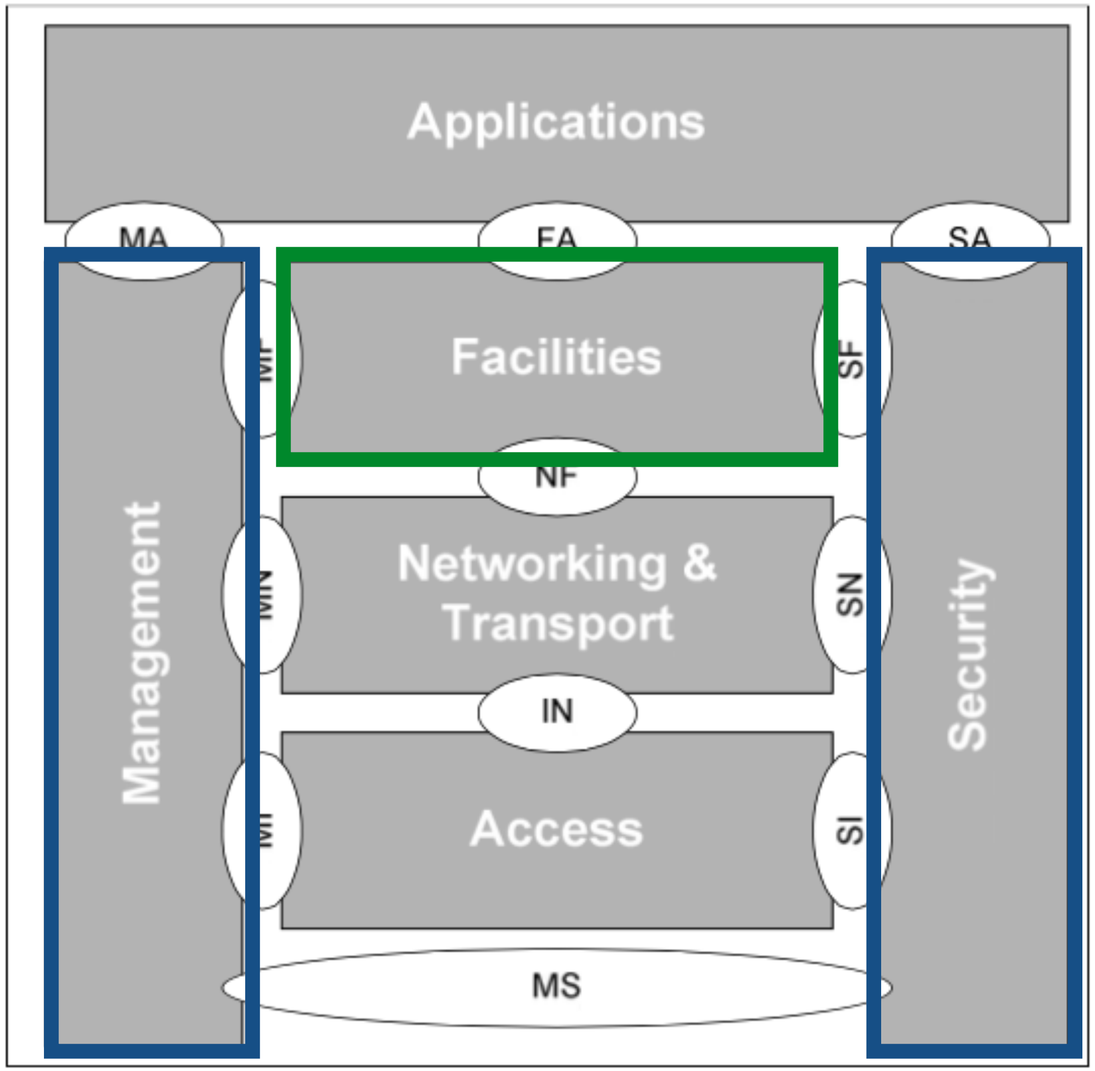
Standardization

Release1 of the standards jointly announced by ETSI and CEN on Feb 2014

Operational deployment started based on published standards

Release2 features being discussed

ITS: EU Standards in force (1)



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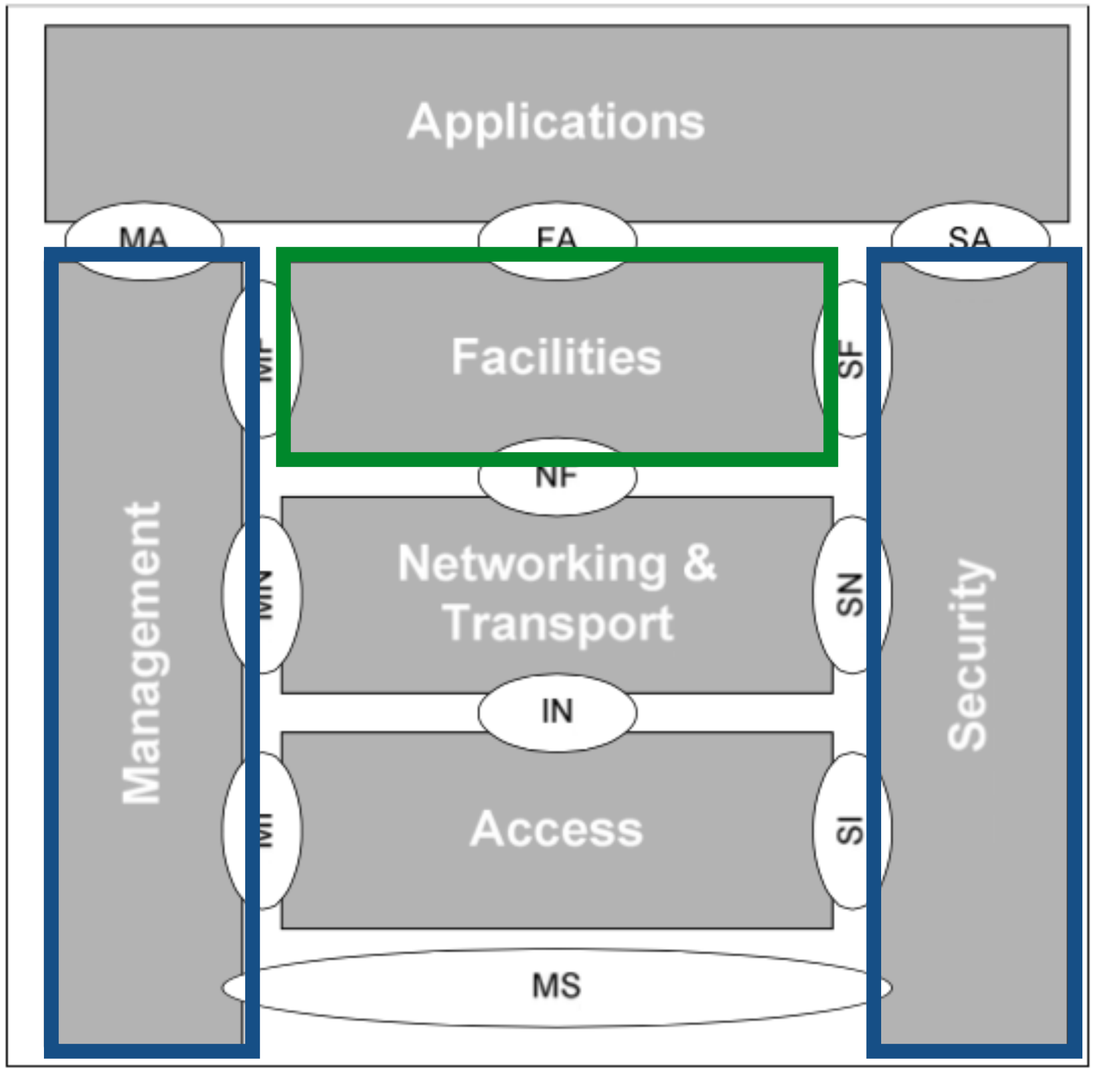

- **ITS Station** (vehicular, road-side, central, personal)

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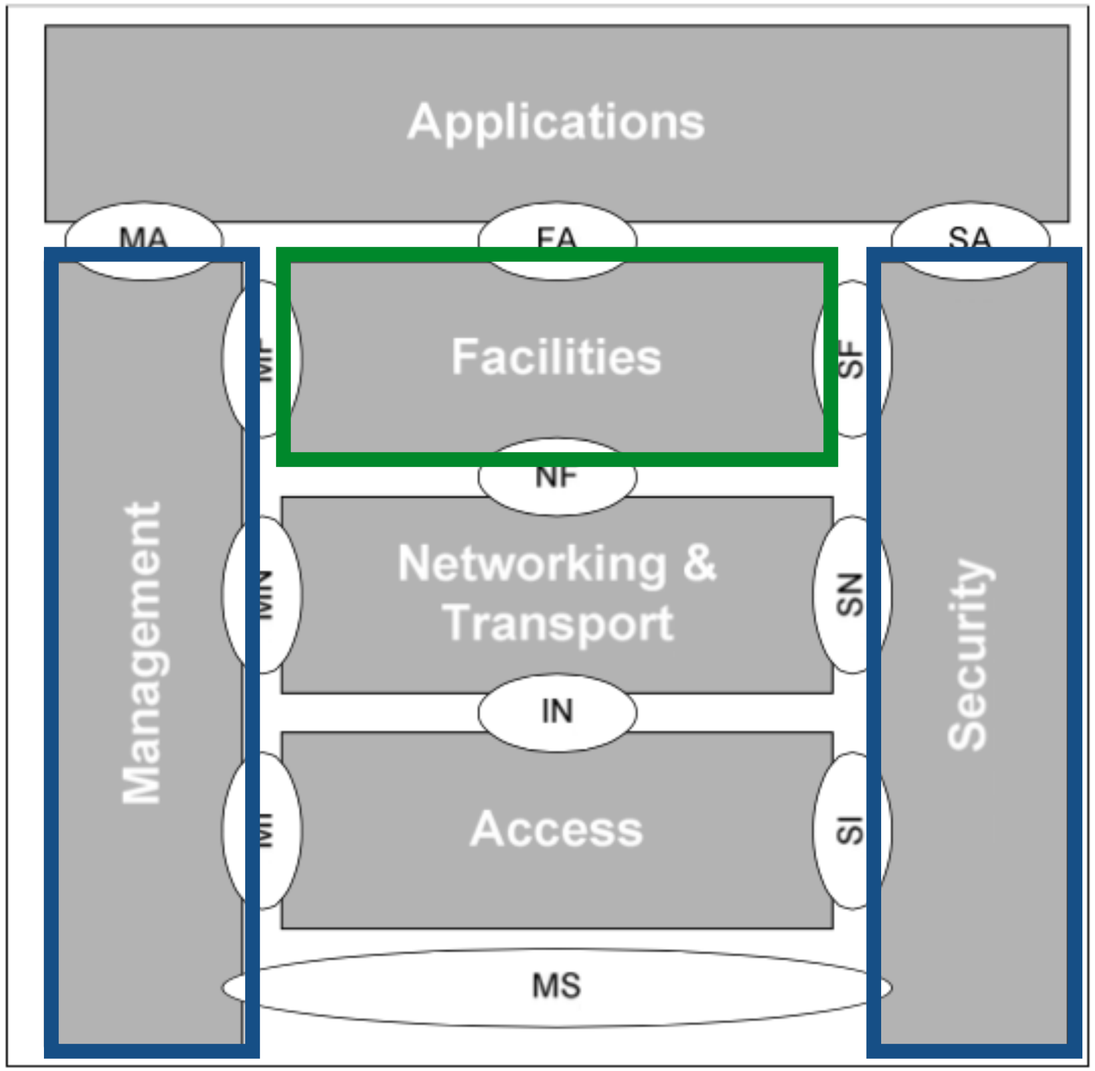

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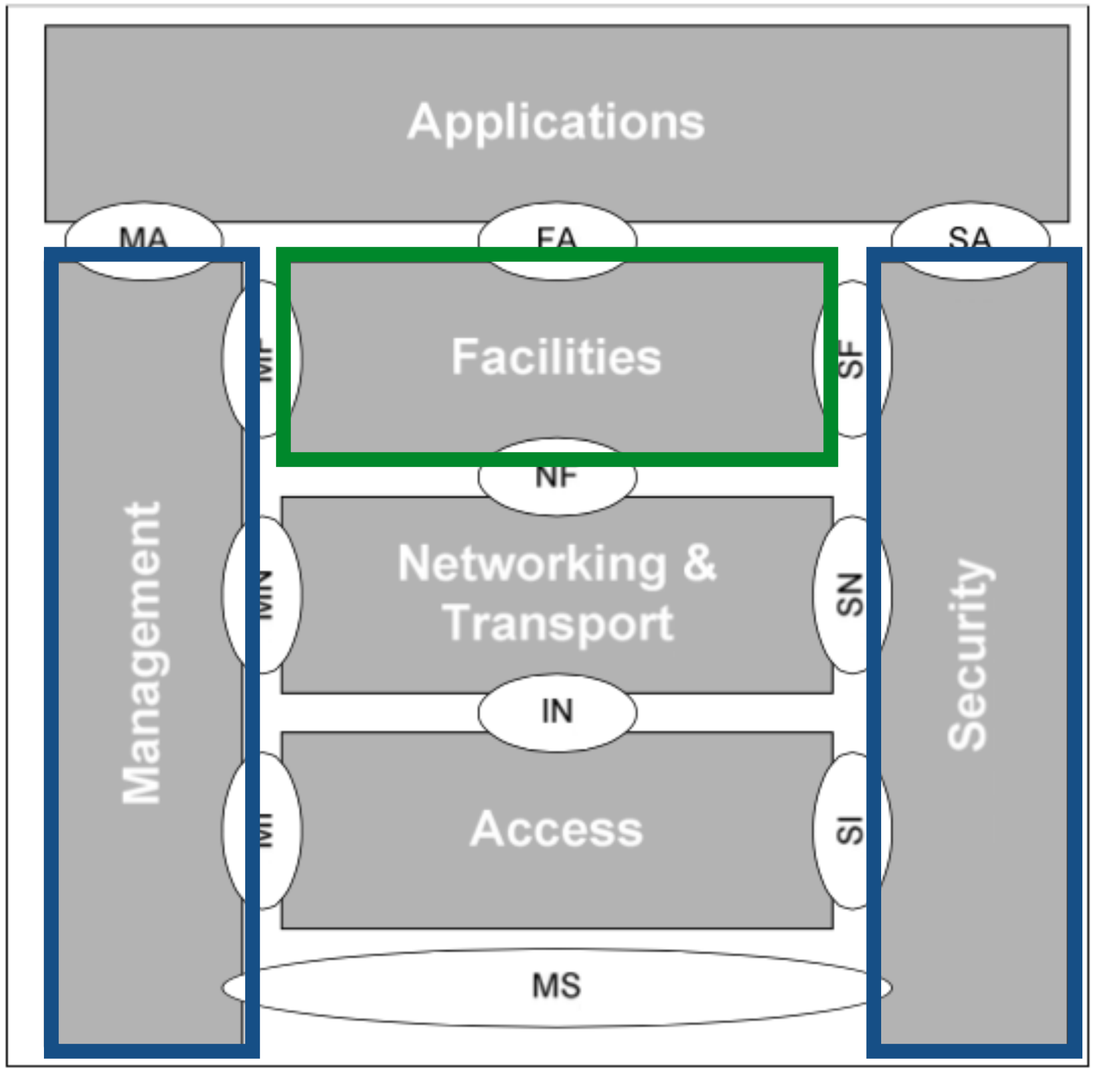

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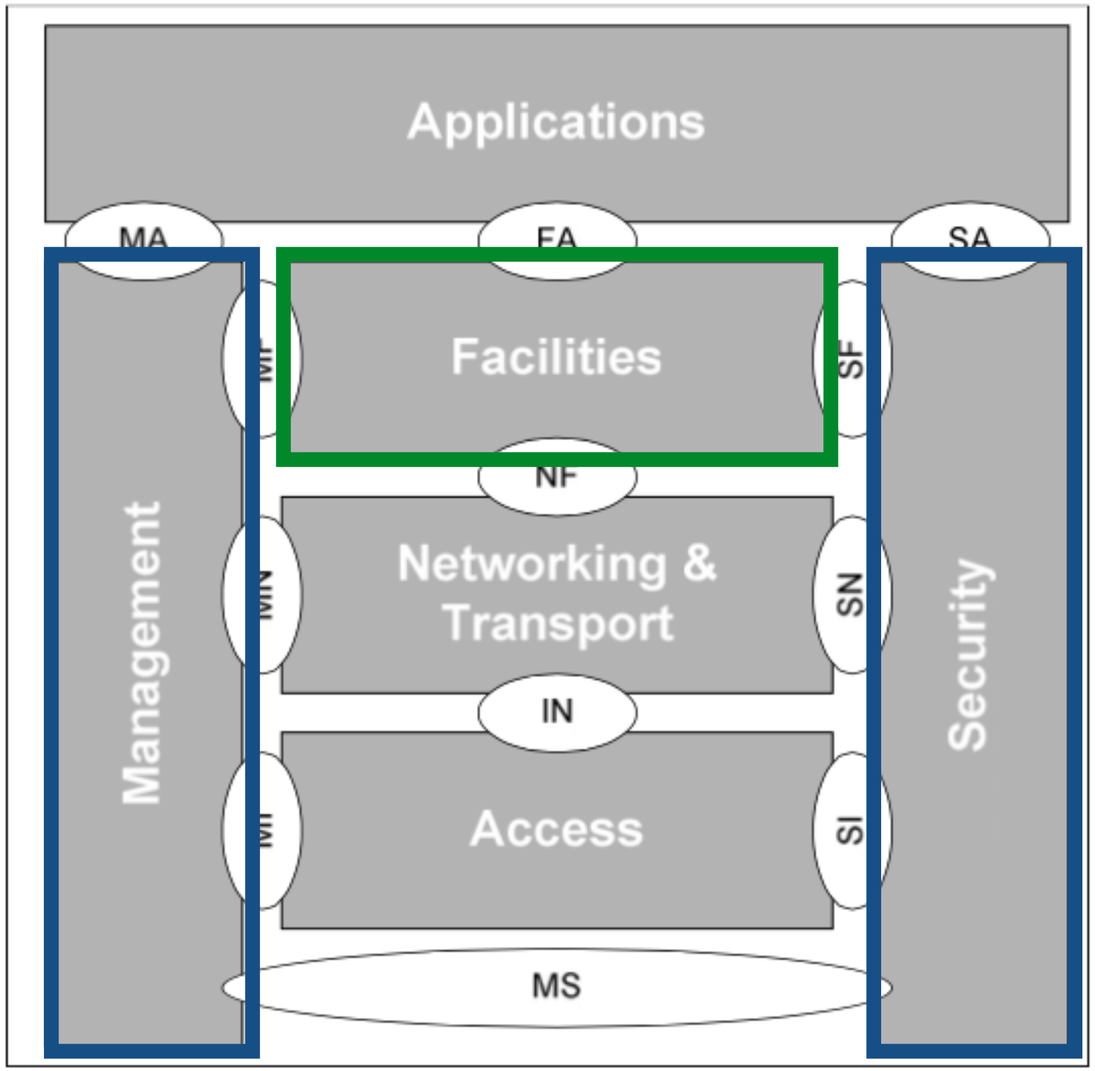

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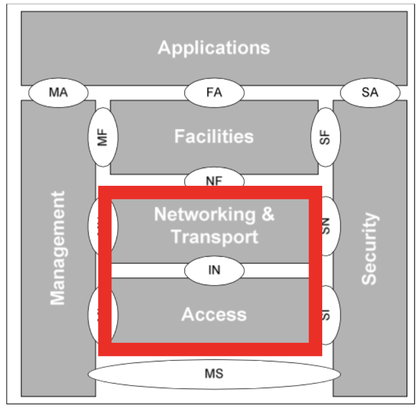
- ~ ISO/OSI layered structure but:
  - Full stack Management and Security
  - Novel layer of Facilities

ITS-S:Access and Networking



IEEE 802.11p

- Access for fast moving objects (notably vehicles)

GeoNetworking

- Provides addressing based on geographical position (geobroadcast, geomulticast, unicast)

Basic Transport Procotol

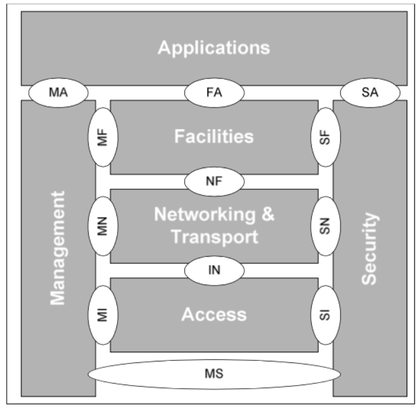
- Simple multiplexing and demultiplexing
- Best effort

Basic Transport Protocol (BTP)

GeoNetworking (GN)

IEEE 802.11p

ITS: Facilities



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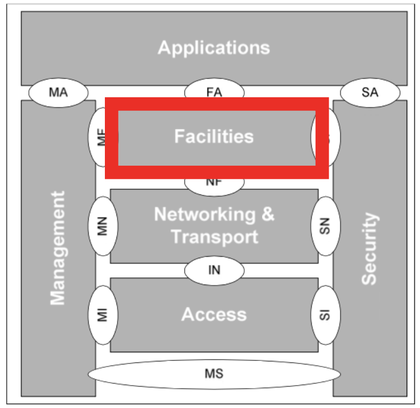

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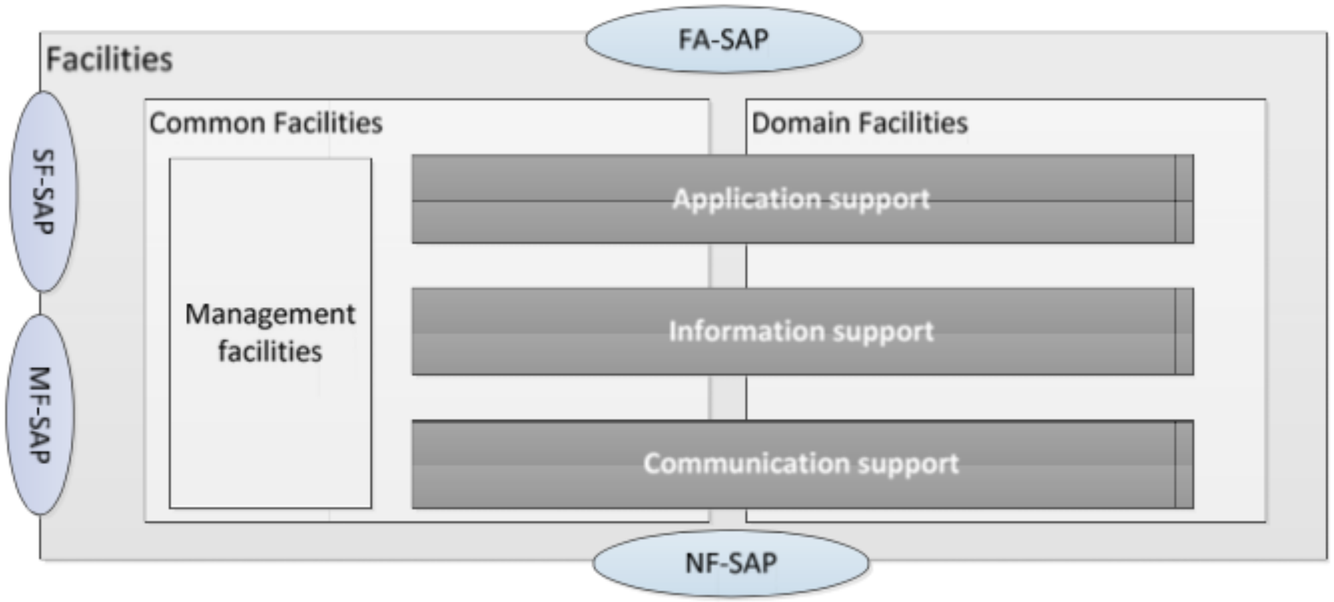

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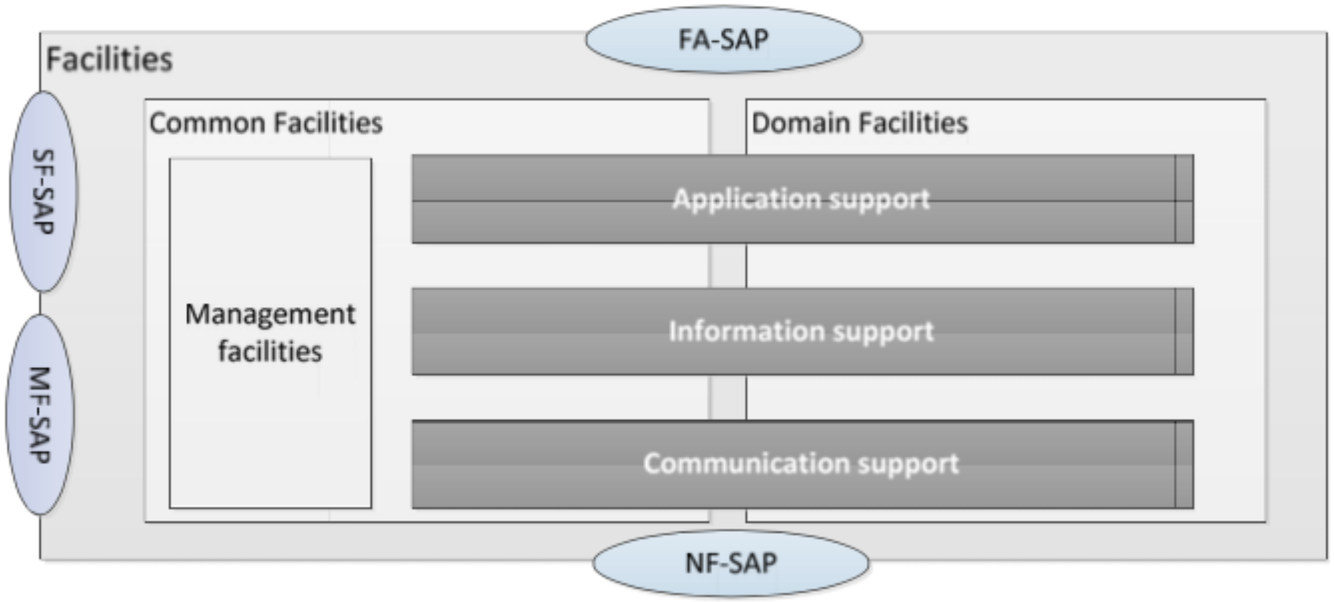

Provide (among others):

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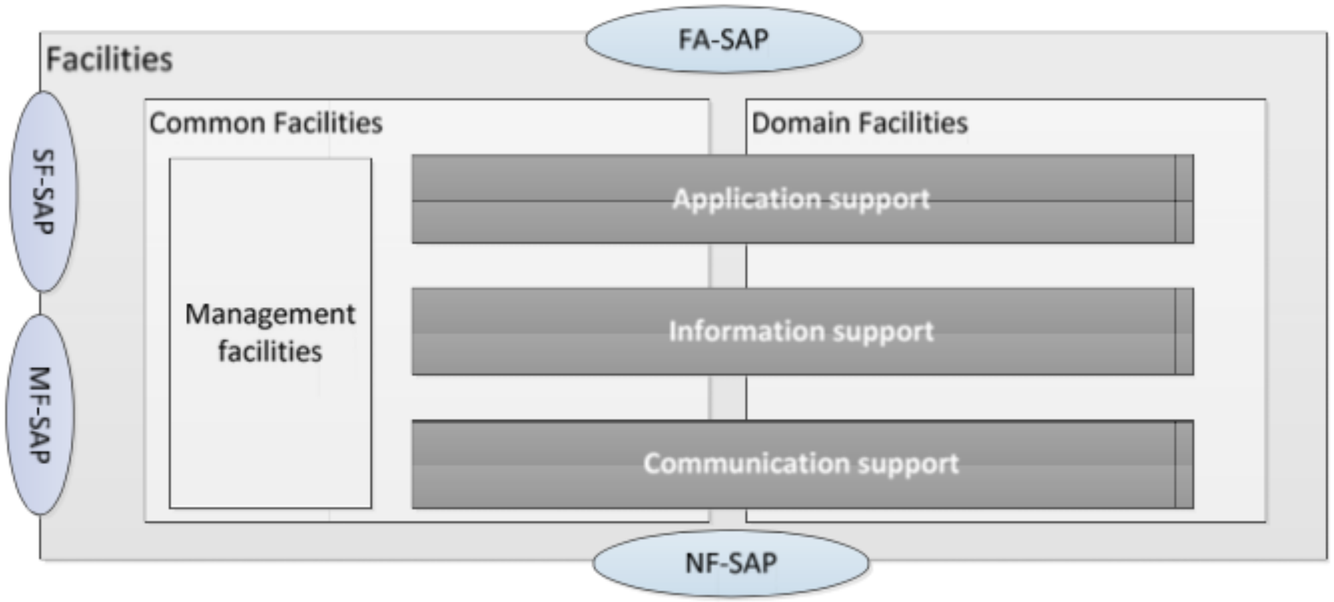

Provide (among others):

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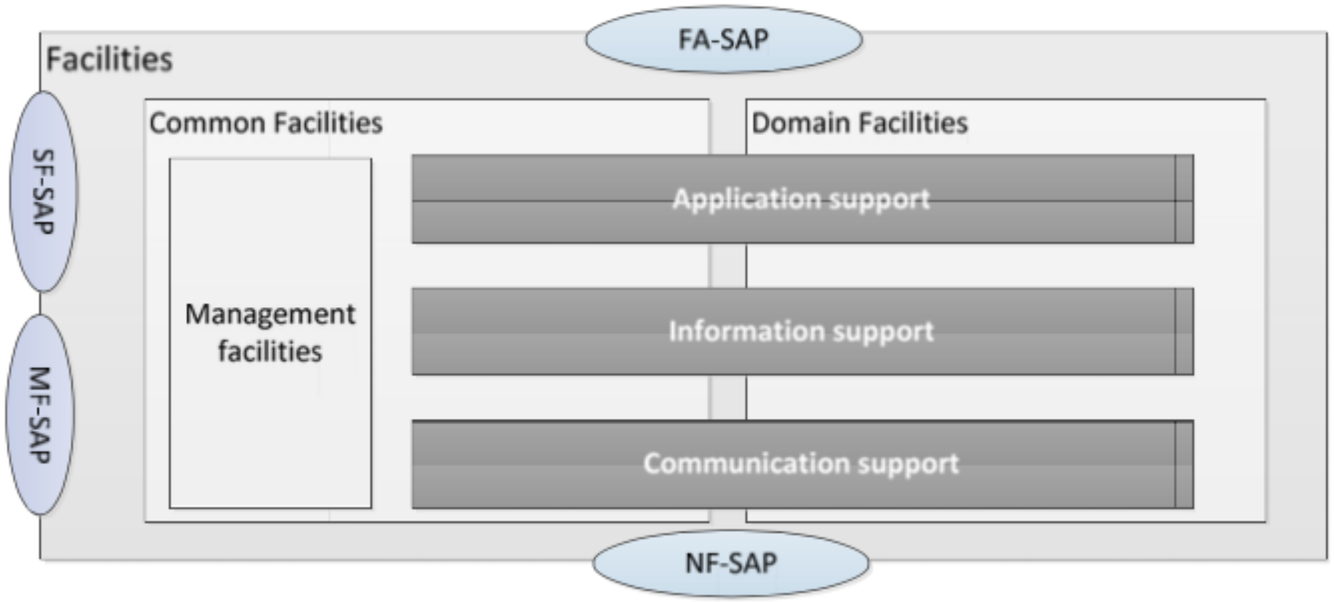

Provide (among others):

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- Billing and payement

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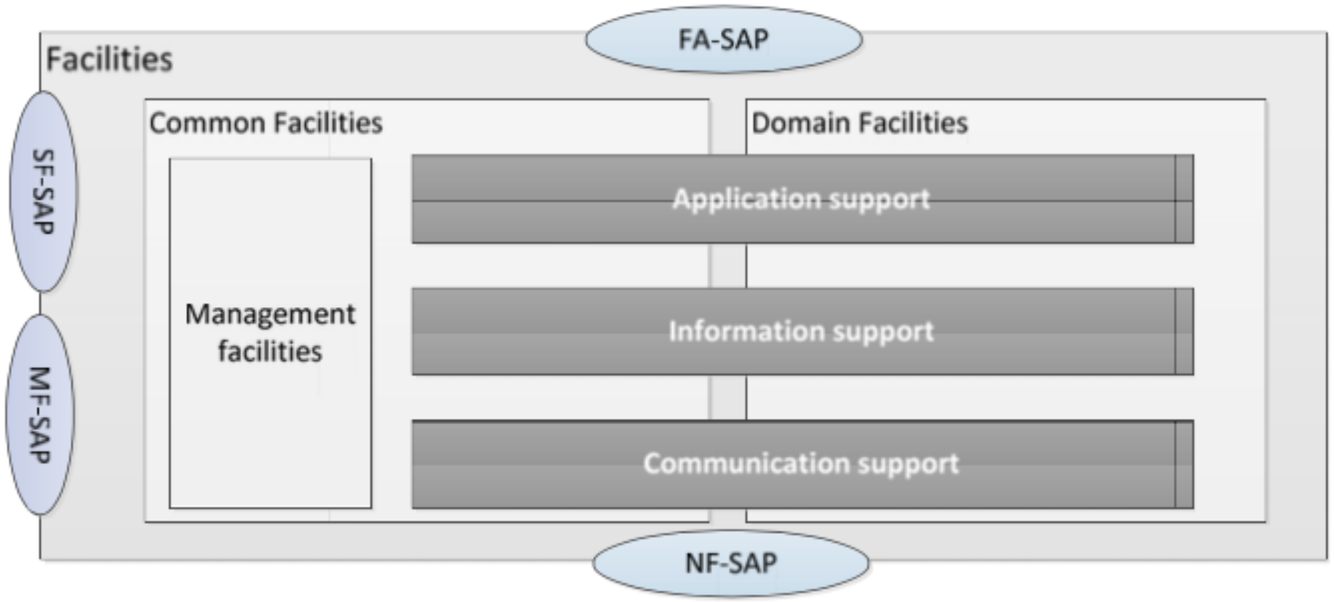

Provide (among others):

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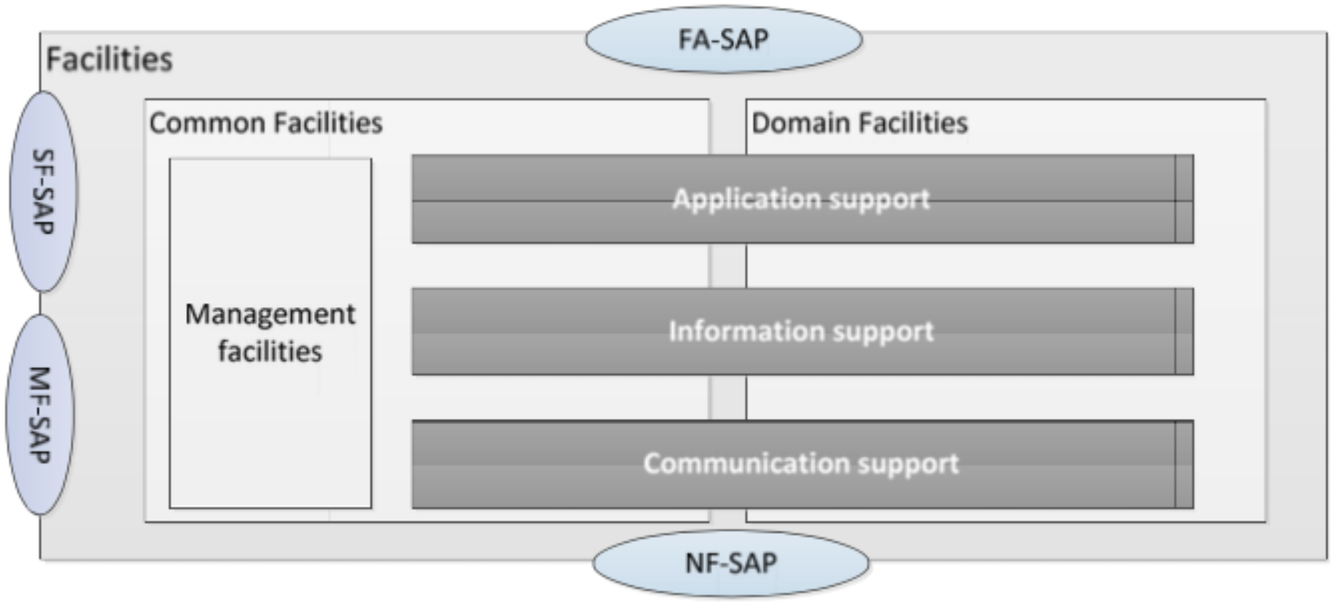

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- Local Dynamic Map

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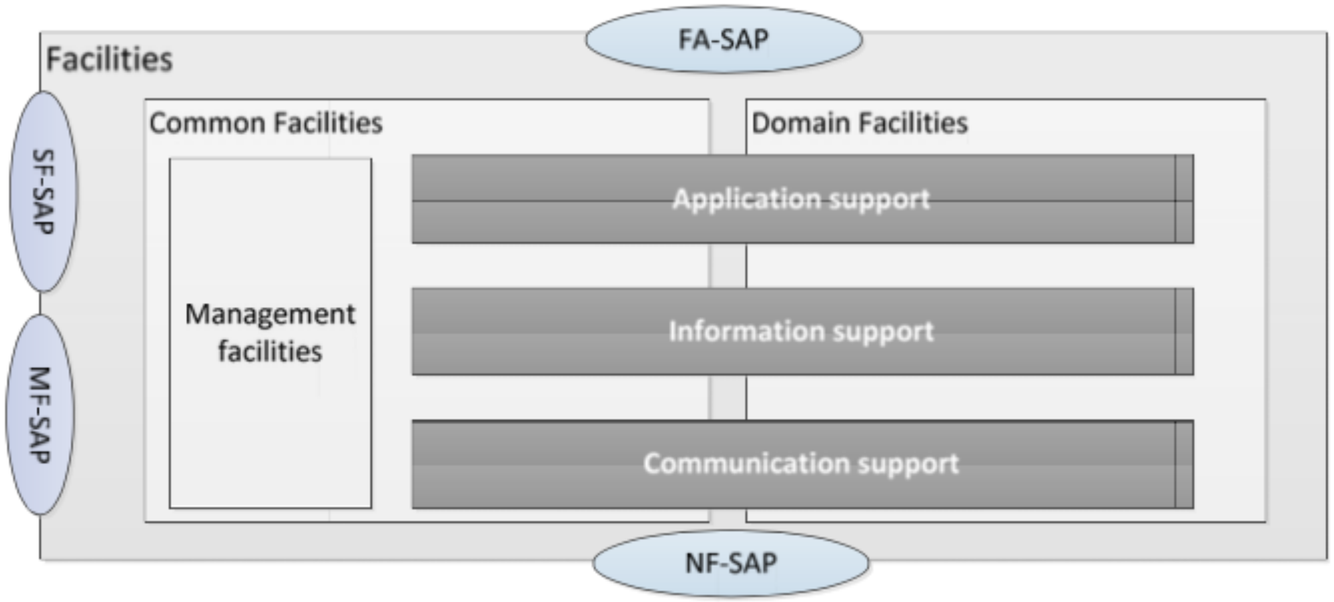

Provide (among others):

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- Decentralized Environmental Notifications

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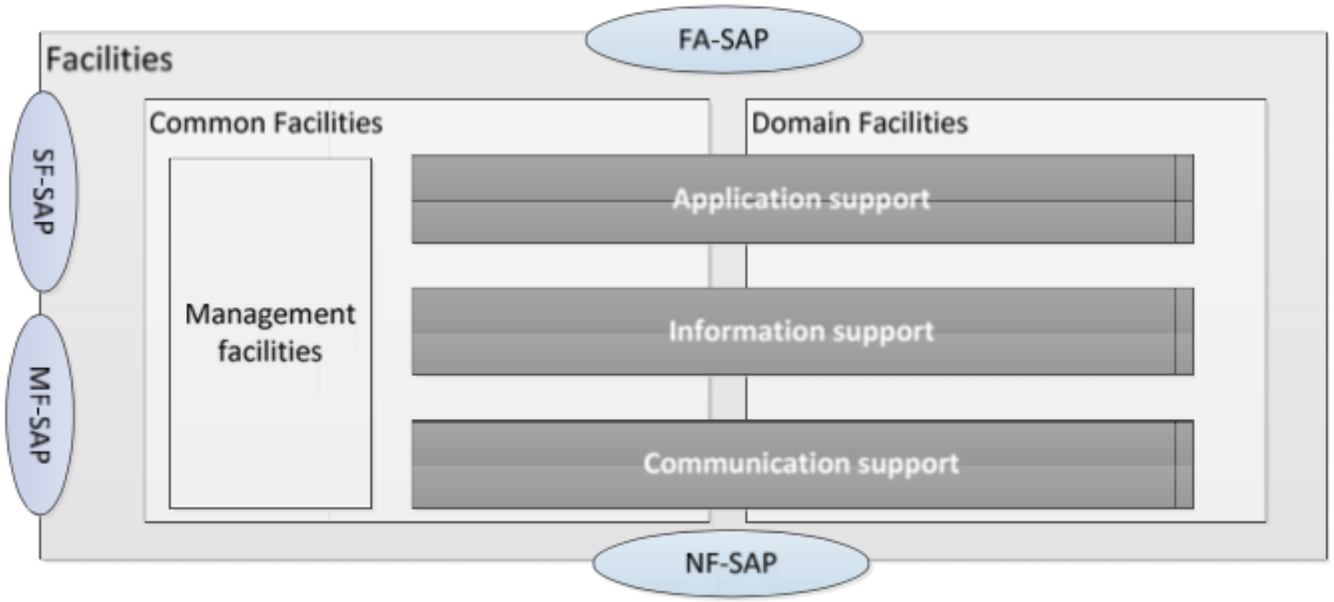

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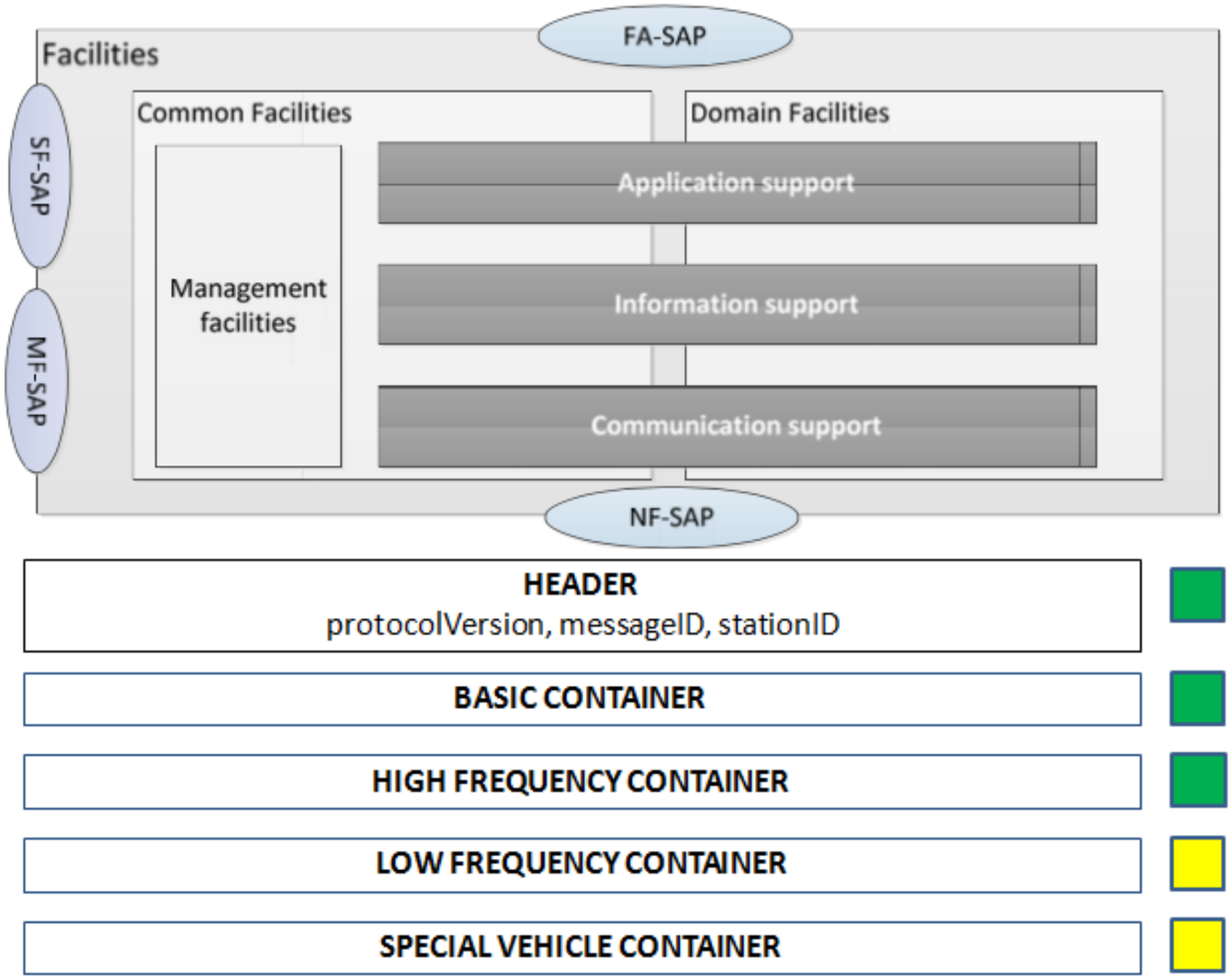

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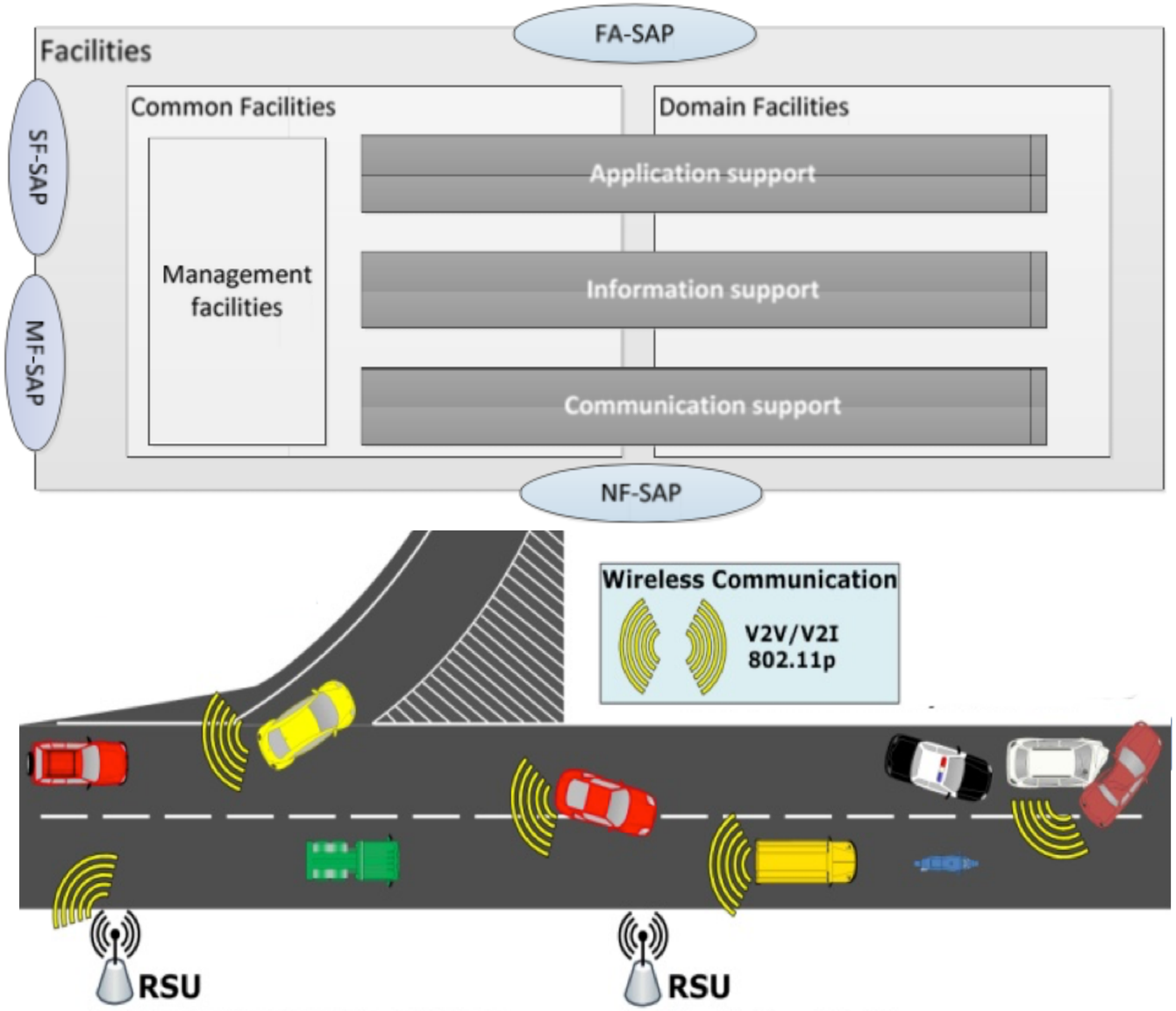

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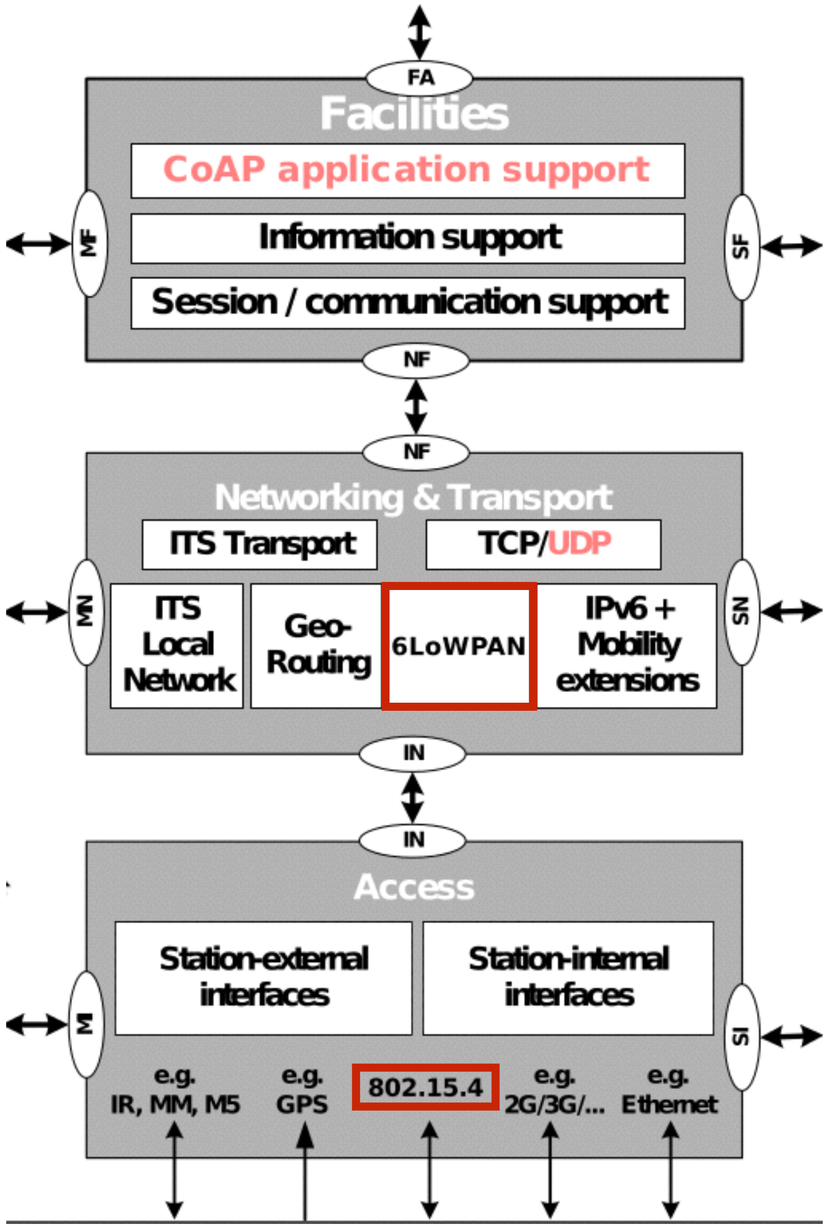
DESIGN

ITS and IoT integration: motivations

- **No current inclusion** of IoT into ITS-S
- The vehicle as a **smart environment** and **smart objects for ITS**
- Enabling **Smart Cities**
- Applications
  - Verified **QoS** in goods logistics
  - Optimized **routing** and management
  - … among others

ITS and IoT integration: how

- Both **on-board** or **road-side** IoT
- Access: **IEEE 802.15.4**
- Network and Transport: UDP supported, **6LoWPAN**, **RPL** needed
- Facility: smart objects resources integrated within **CA messages**, ….



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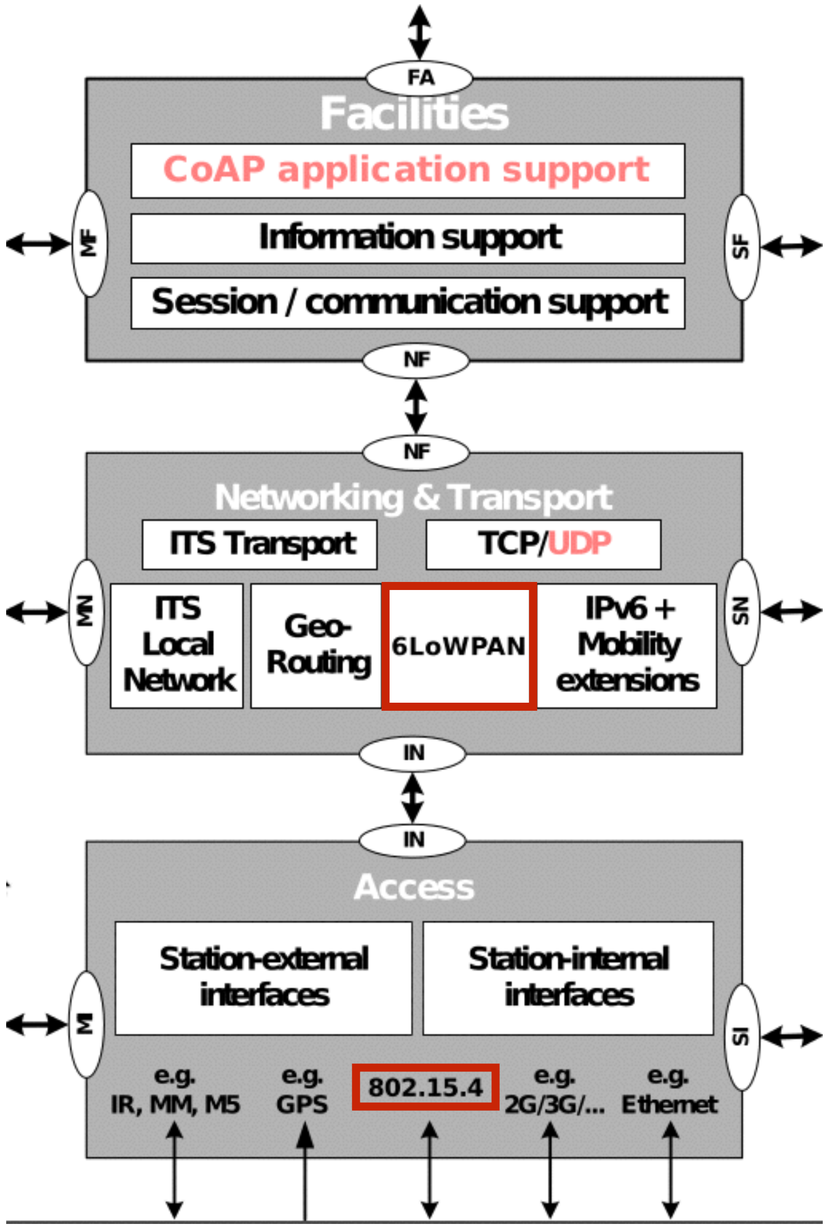
Currently new standard being edited by

cnit



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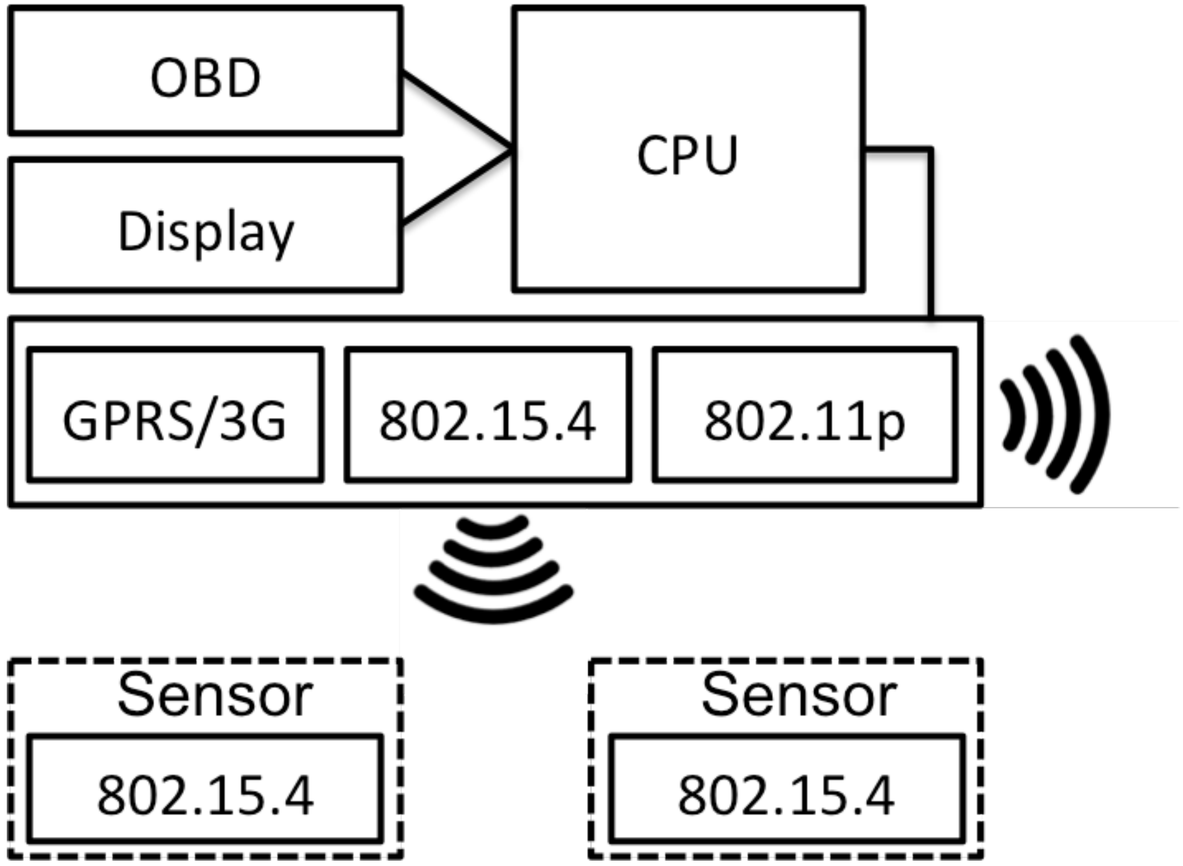

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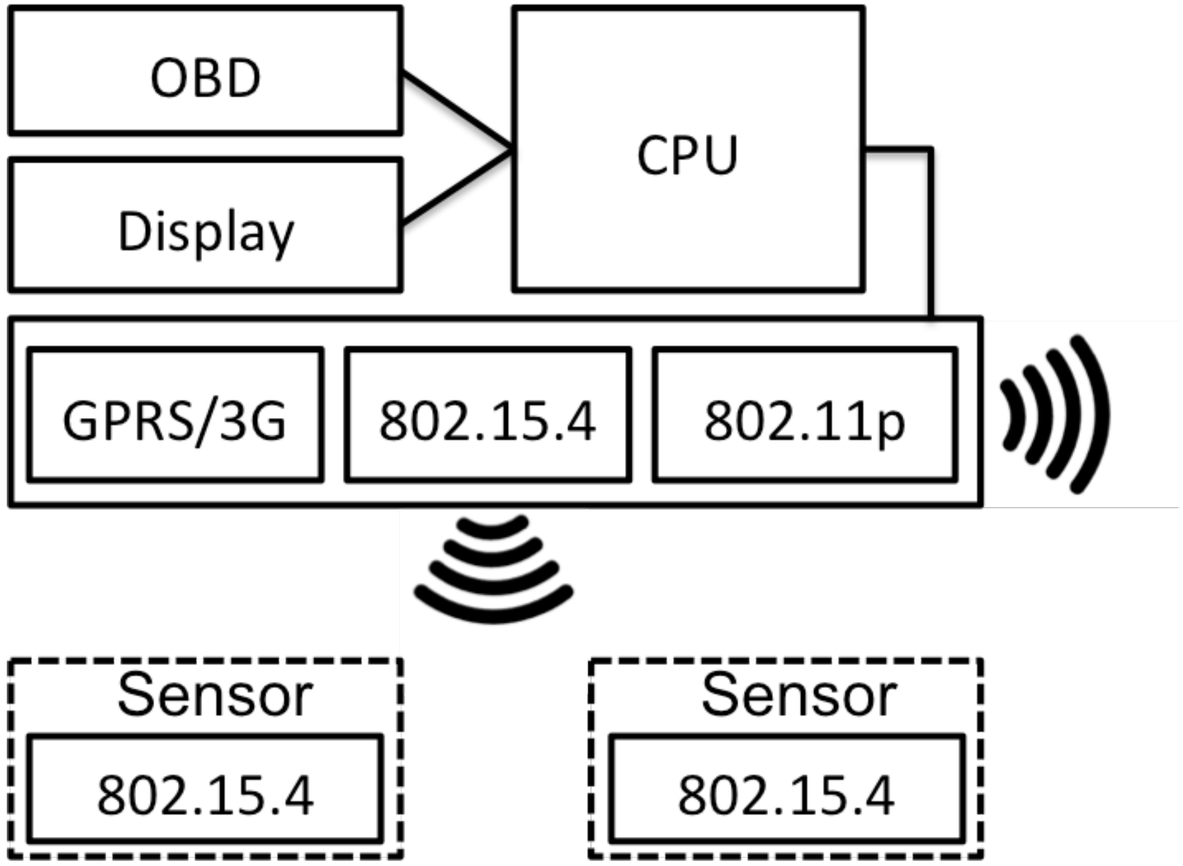
- Constrained resources, need for performance, real time requirements



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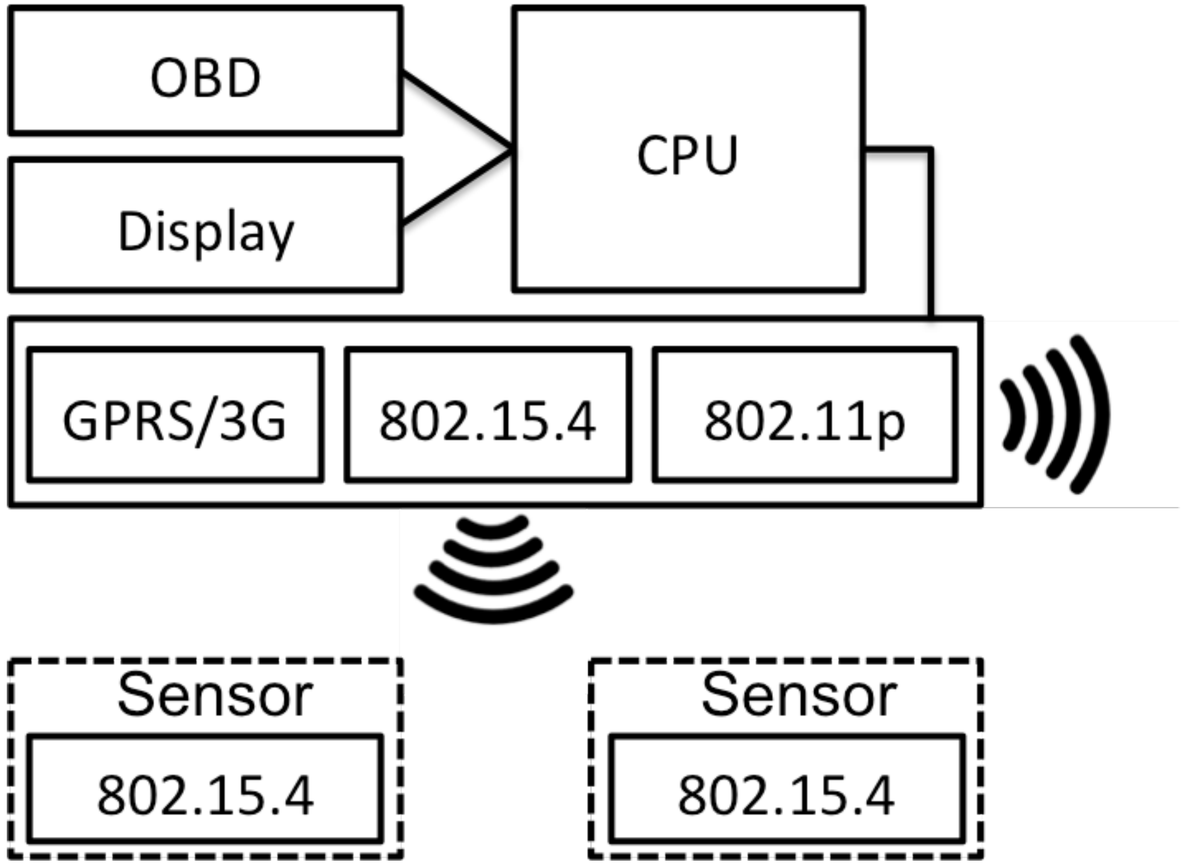

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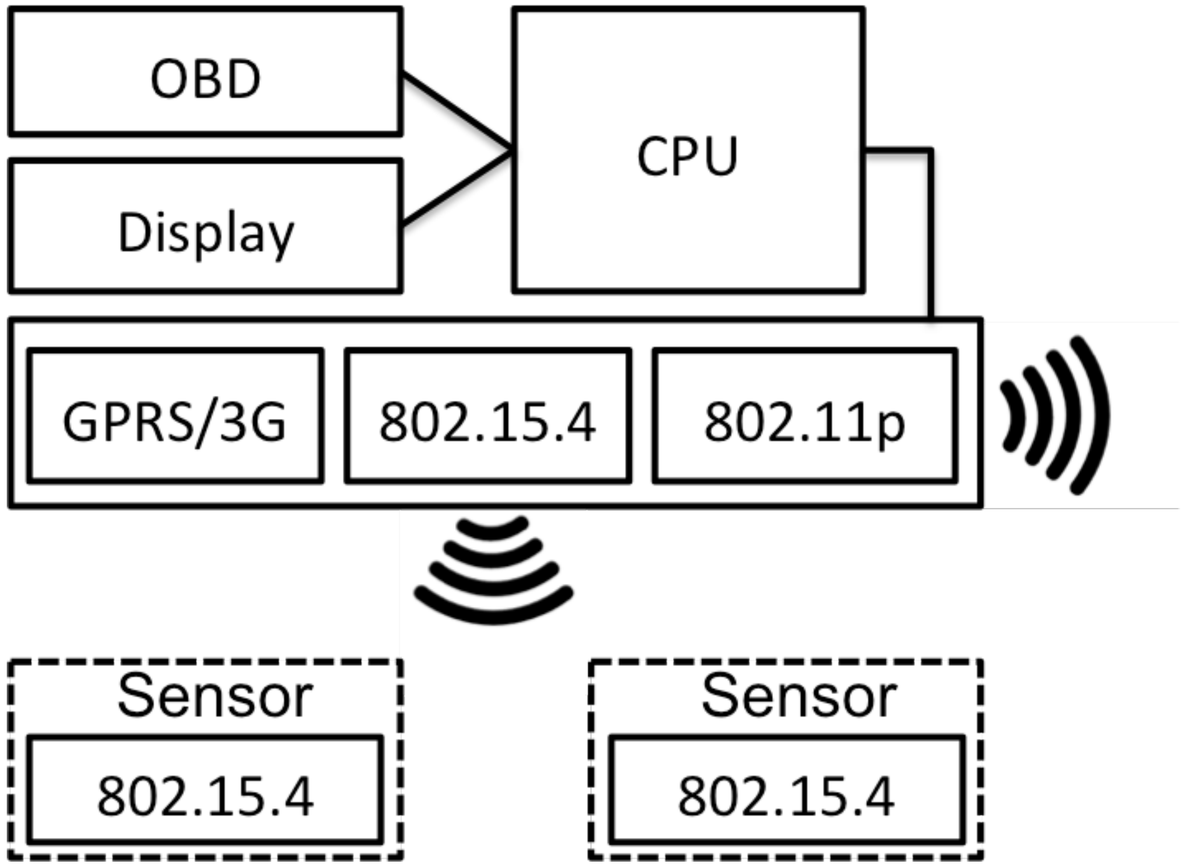

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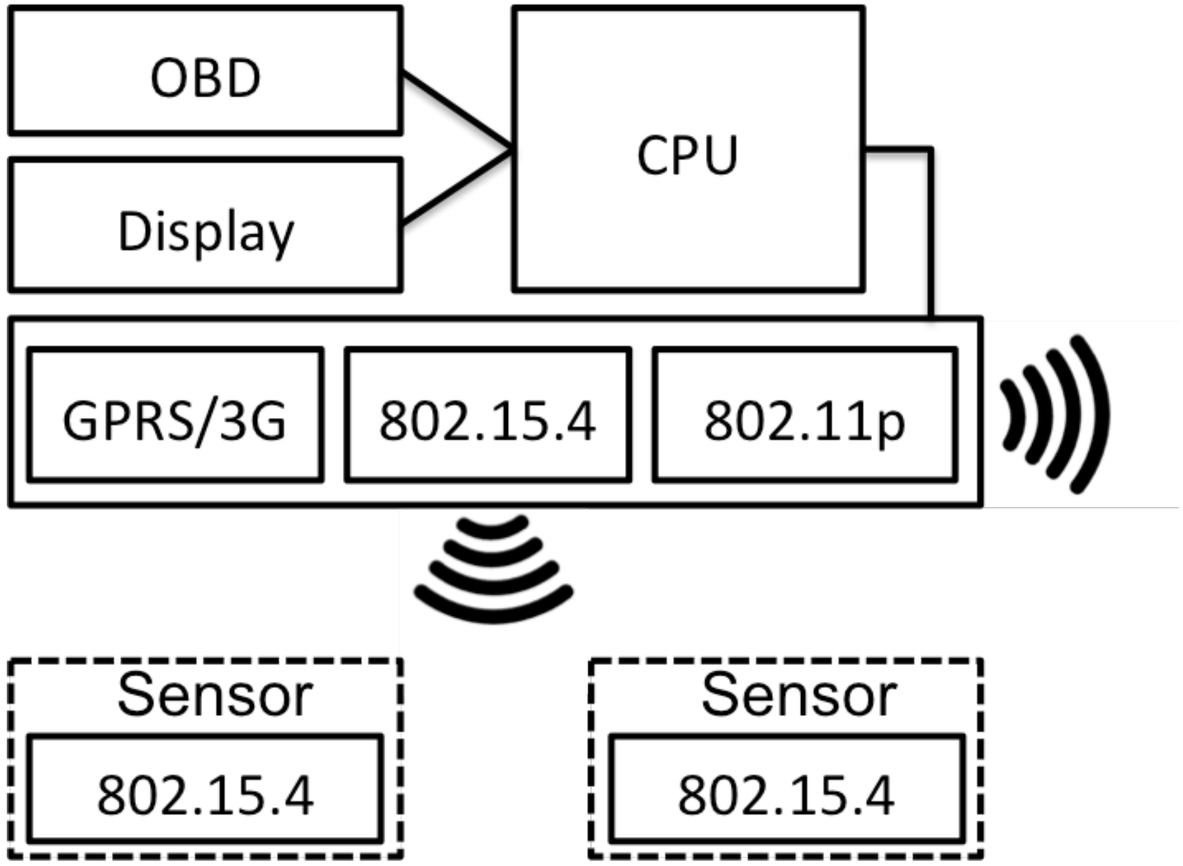
- Following the concepts and naming of ETSI standards
- Implementing standard communication protocols at any layer



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SELECTED HARDWARE

- Beagle Bone Black
  - IEEE 802.15.4 tranceiver
  - GPS/GPRS
  - IEEE 802.11n
  - CAN / OBDII
- IEEE 802.11p gateway (ITRI IWCUv5)

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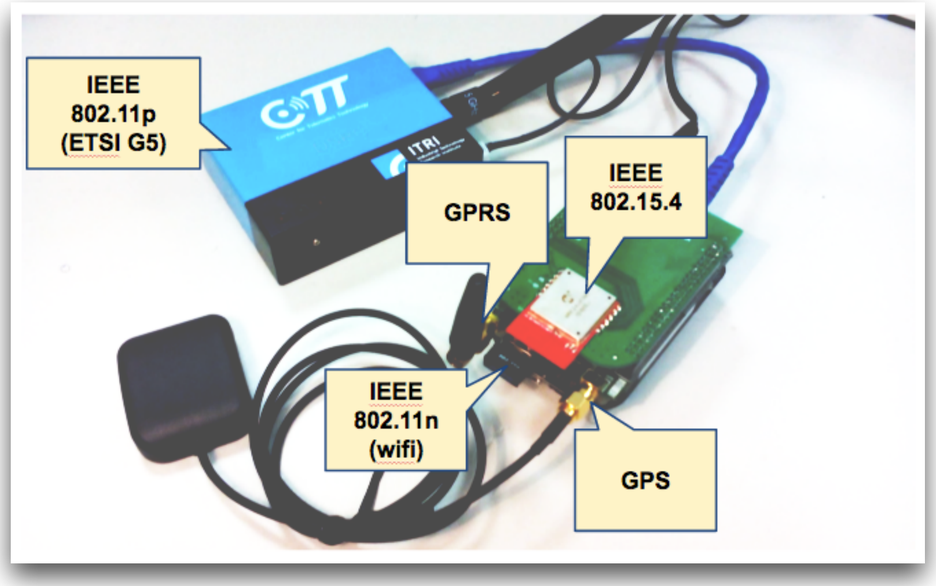

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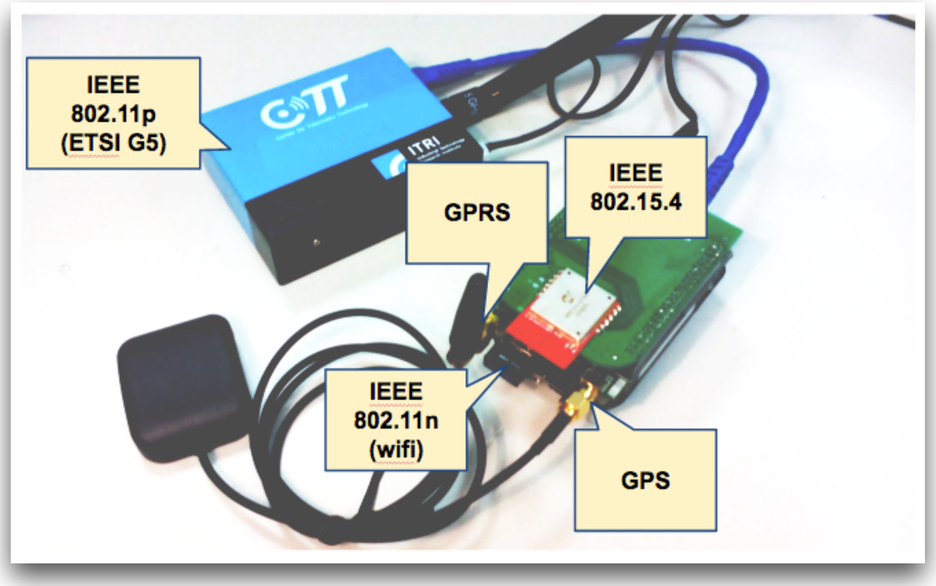

DESIGNED AND DEVELOPED SOFTWARE (Thesis contribution)

- A **framework** for applications and services
- An event and I/O **orchestrator** (Implemented on embedded Linux)
- **Gateways** and **Facilities** implementation

Framework design

- Component based design
- Abstracting **events** management
- Introducing **Services**
- **ItsStation**
  - Wrap event loop
  - Refer service and application registries

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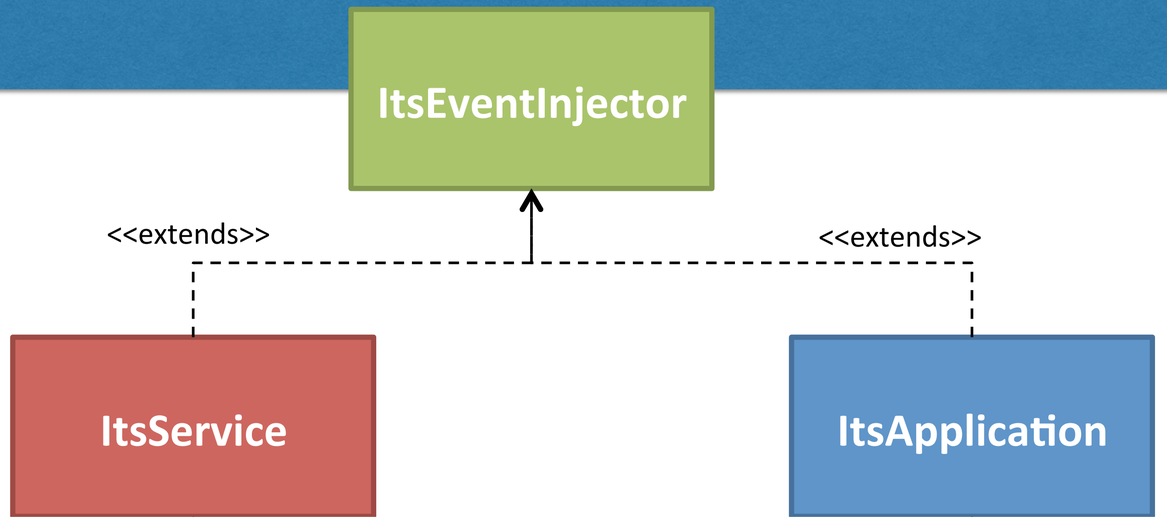

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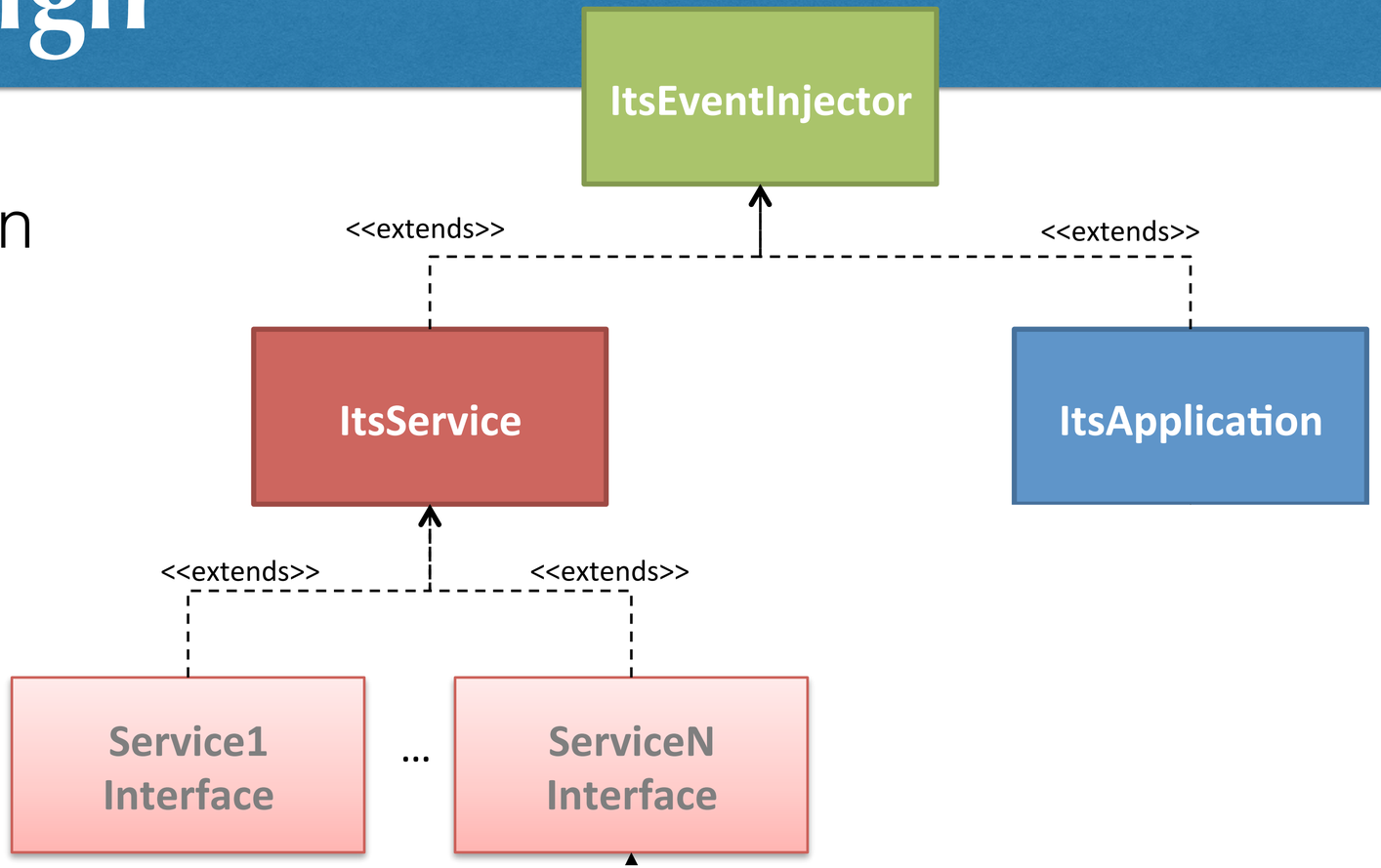

Framework design

- Component based design
- Abstracting **events** management
- Introducing **Services**
- **ItsStation**
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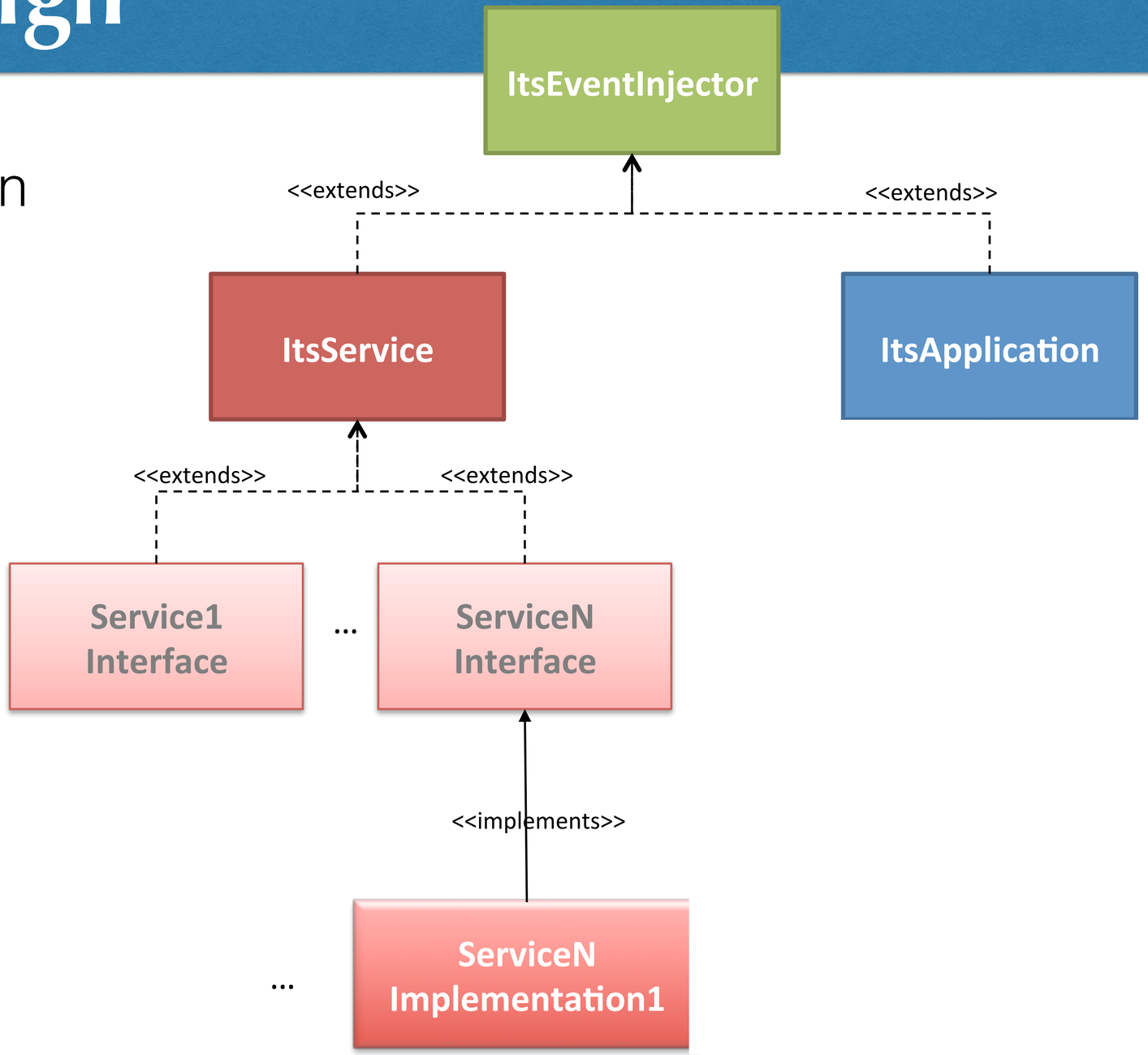

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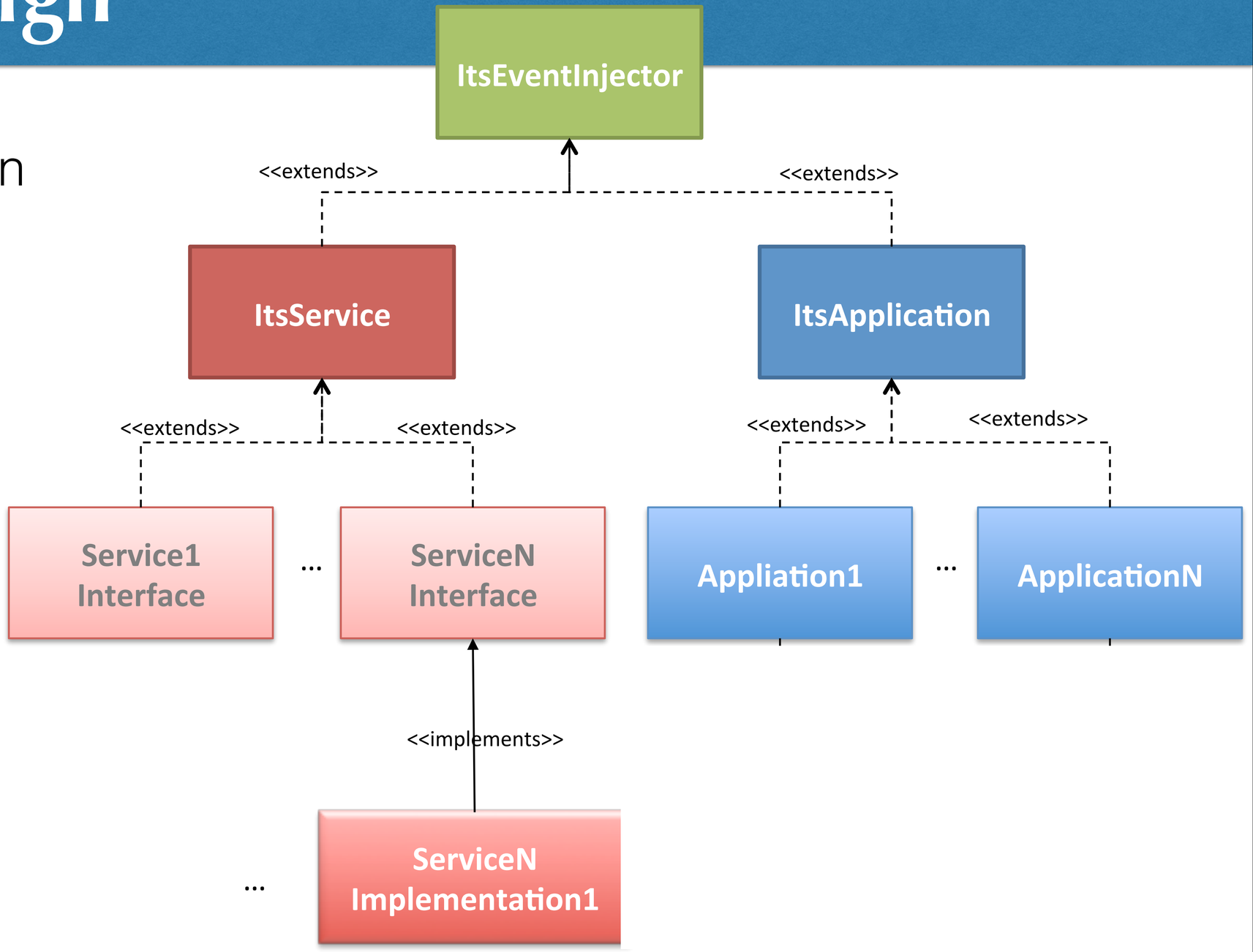

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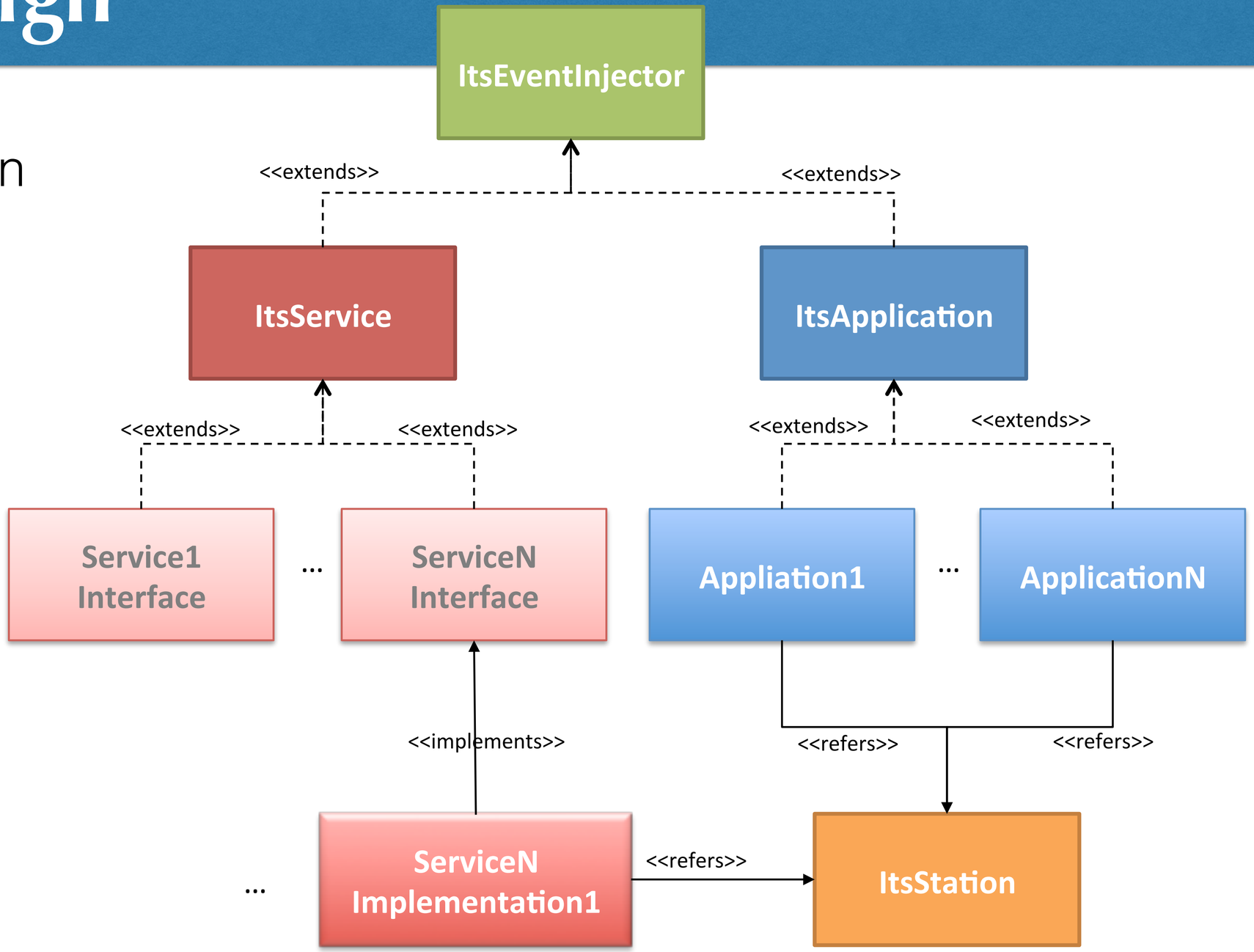
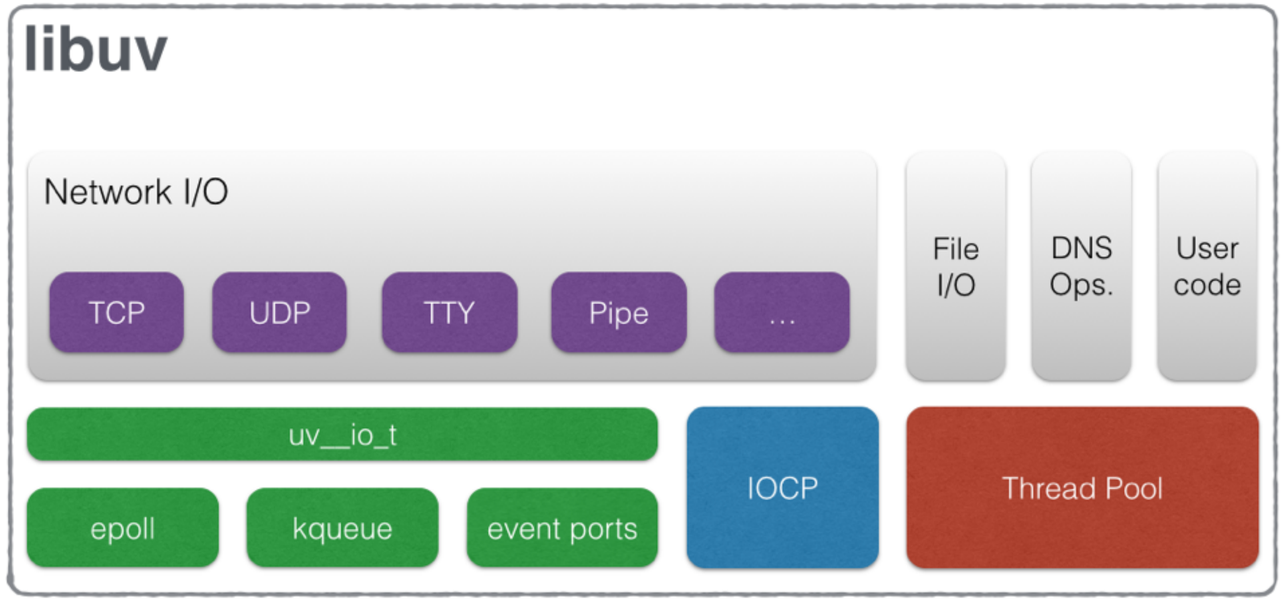


IMPLEMENTATION

Framework implementation

- The core library of **nodejs,** “non-blocking I/O” in C language
- Portable wrapping over **epoll**, asynchronous model (asynchronous handling of file descriptors, timers)
- Thread pool, work dispatch, threading and sync primitives



Events management

- By means of the **ItsStation** (I/O) and **ItsEventInjector** (event engine)
- Abstracts using of `std::Function`
- Different events handled asynchronously

EVENTS API

- `timer()`
- `periodically()`
- `asynchronously()`
- `shutdown()`
- `on()`
- `trigger()`

Example: CAN Service Interface

- Controlled Area Network: manufacturer in-vehicle network
- A service to retrieve information from the car such as RPM, speed, odometer

```
class CanServiceInterface :
  public noes::StationService
{
  public:
    CanServiceInterface();
    CanServiceInterface(noes::ItsStation* s);
    virtual can_data_t get() = 0;
    virtual void print(can_data_t d) = 0;
};
```

Example: CAN Service implementation

- HW: Implemented via OBDII adapter over serial (i.e. `/dev/ttyS1`)
- SF: **Query periodically** and **cache data** structure

```
OBDIIServiceImpl::OBDIIServiceImpl(noes::ItsStation *s):
    CanServiceInterface(s)
{
    try {
        update();
        this->periodically(1000, [this](int k){
            this->update();
        });
    } catch (SerialException &e) {
        // …
    }
}
```

CA facility implementation

API

- `generate()`: collection and encapsulation
- `encode()`: serialization in ASN.1 Unaligned-PackedEncodingRules
- `decode()`: deserialization from bytes
- `start_dissemination()`: manage CAMs dissemination
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Implementation details

- Extension of CAM PDU

```
LoadingZoneContainer ::= SEQUENCE {
 vin UTF8String SIZE ((18)),
 engineStatus EngineStatus,
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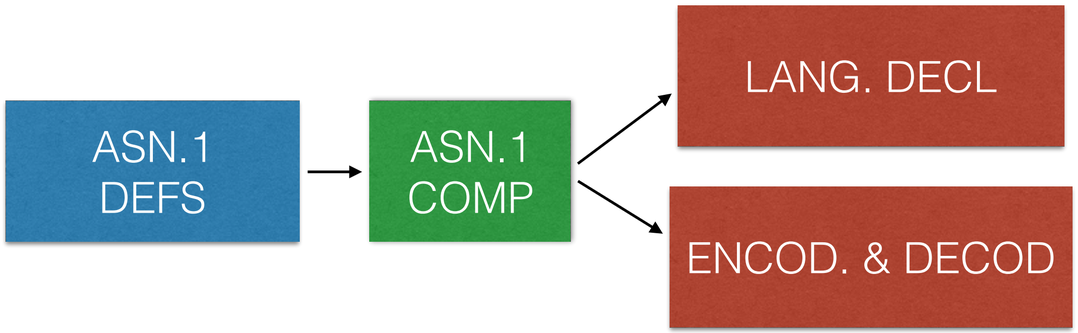
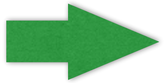
- ASN.1, `asn1c`, `CAM_t` type



BTP Gateway implementation

- Using 802.11p board in bridge mode
- Implemented ETSI Protocol Control Information (PCI)
- PCI serialization
- Gateway module on the IWCUv5



```
typedef struct btp_pci_s {
  int btp_type;
  int packet_type;
  int store_and_forward;
  int latitude;
  int longitude;
  int macAddr_i[6];
  int dport;
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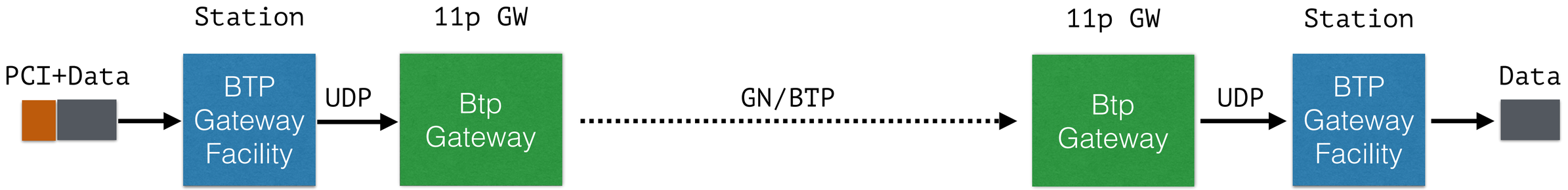

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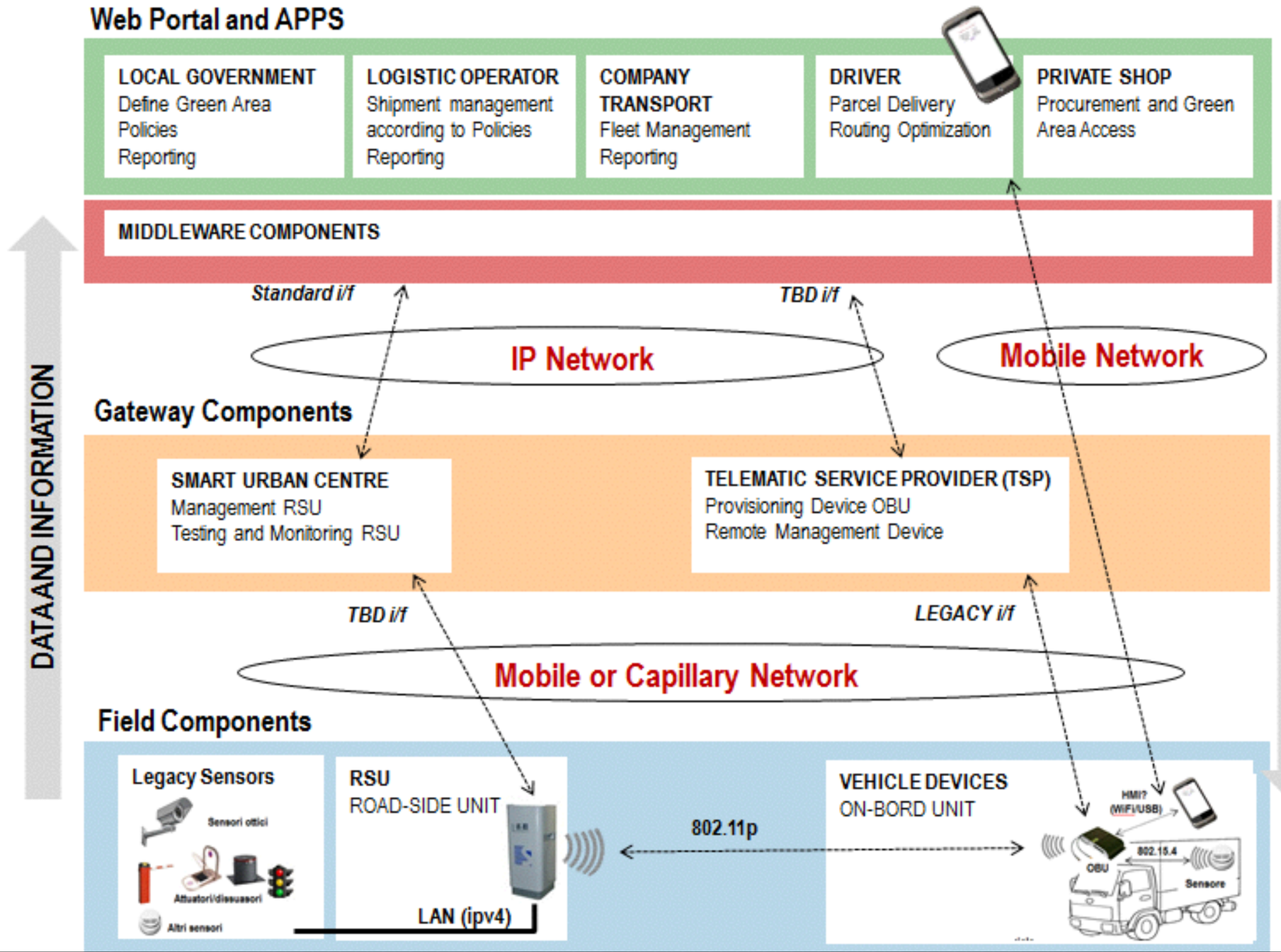
- Therefore IoT is available usual **sockets** API (via `libuv` wrapper)

RESULTS

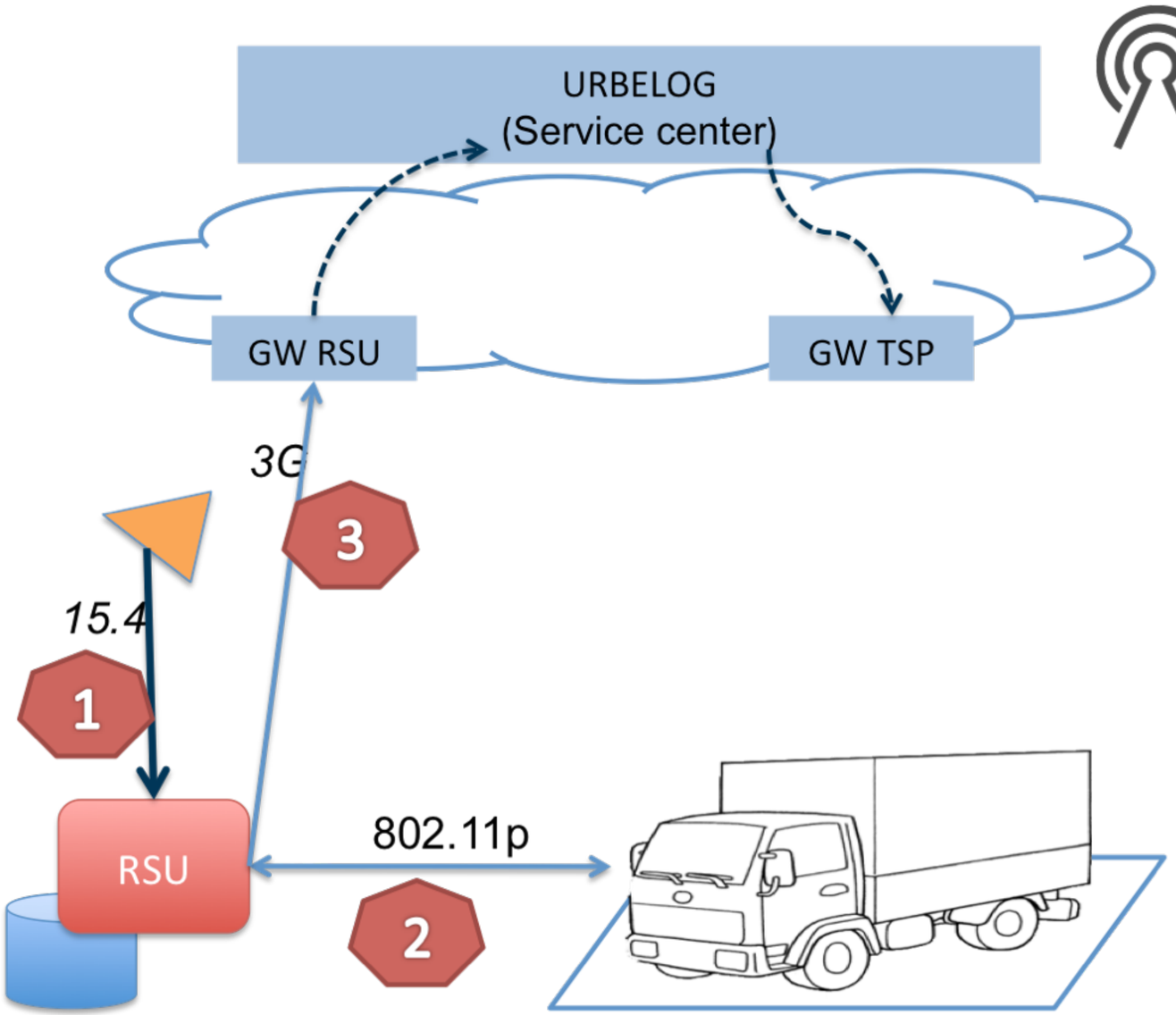
URBELOG Project

- Last mile logistic optimization:
  - real time tracking of goods to enforce good practices
  - reduce emissions
- Loading zone application
  - Parking slots real time discovery, booking
  - Parking slot status monitored and advertised



Parking slot use case

- URBELOG use case: real time tracking of parking lot status with vehicle authentication
- Smart cameras network (IoT segment)
- Vehicle acknowledgment and free spots advertisement via CAMs (802.11p + GeoNet)
- Notification of change status to Service Center (also notifies infringements)



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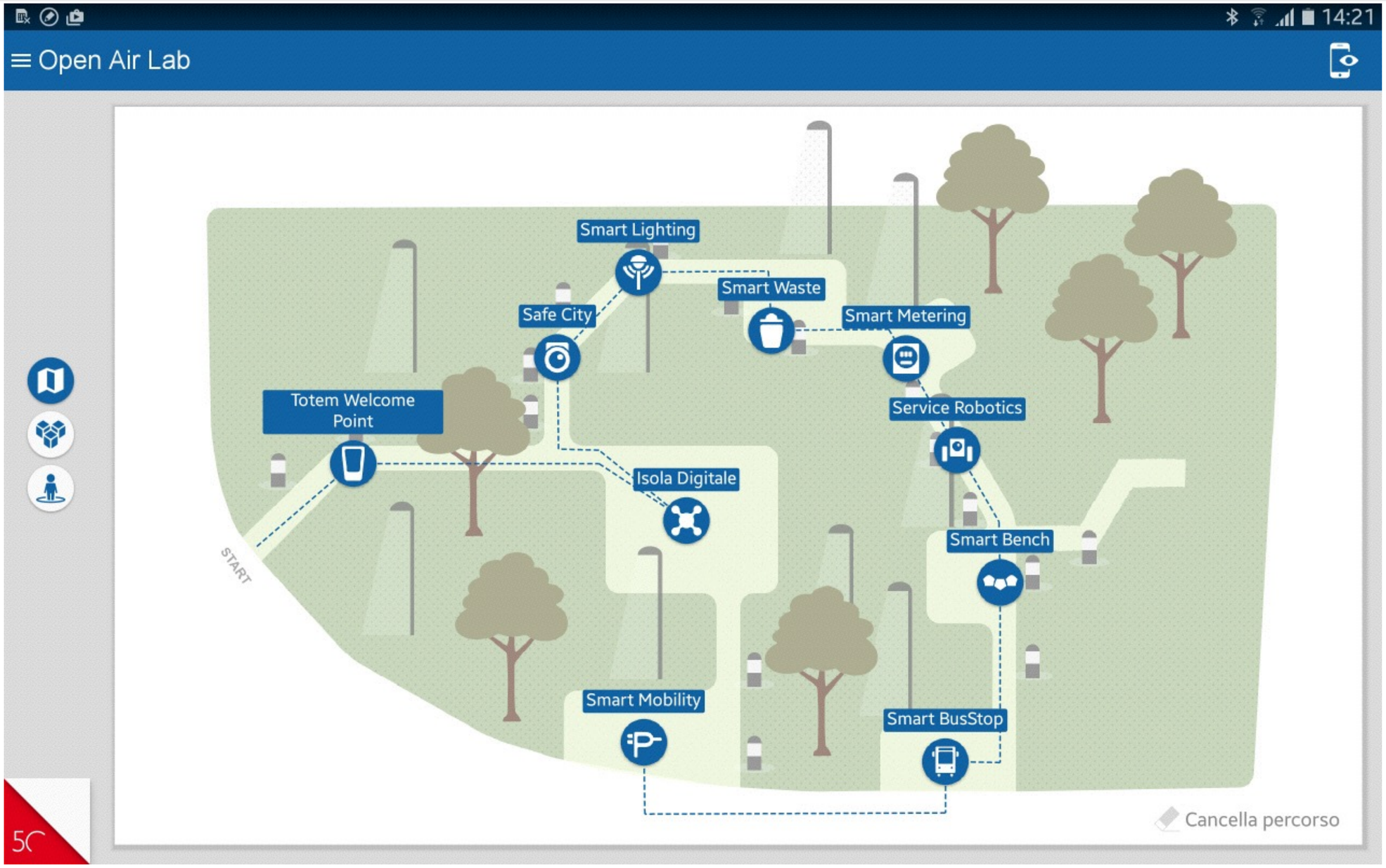
Vehicular ITS Station, **UrbelogOBU**:

- Disseminates CAM (BTP Gateway)
- Reads vehicle data (rpm) to include in CAM (OBDII Service)

"A prototype bridge between automotive and IoT"

by *Carignani et al.* will be presented at
IEEE World Forum on Internet of Things,
Automotive workshop on Dec 14th 2015

On field demo on Nov. 13th



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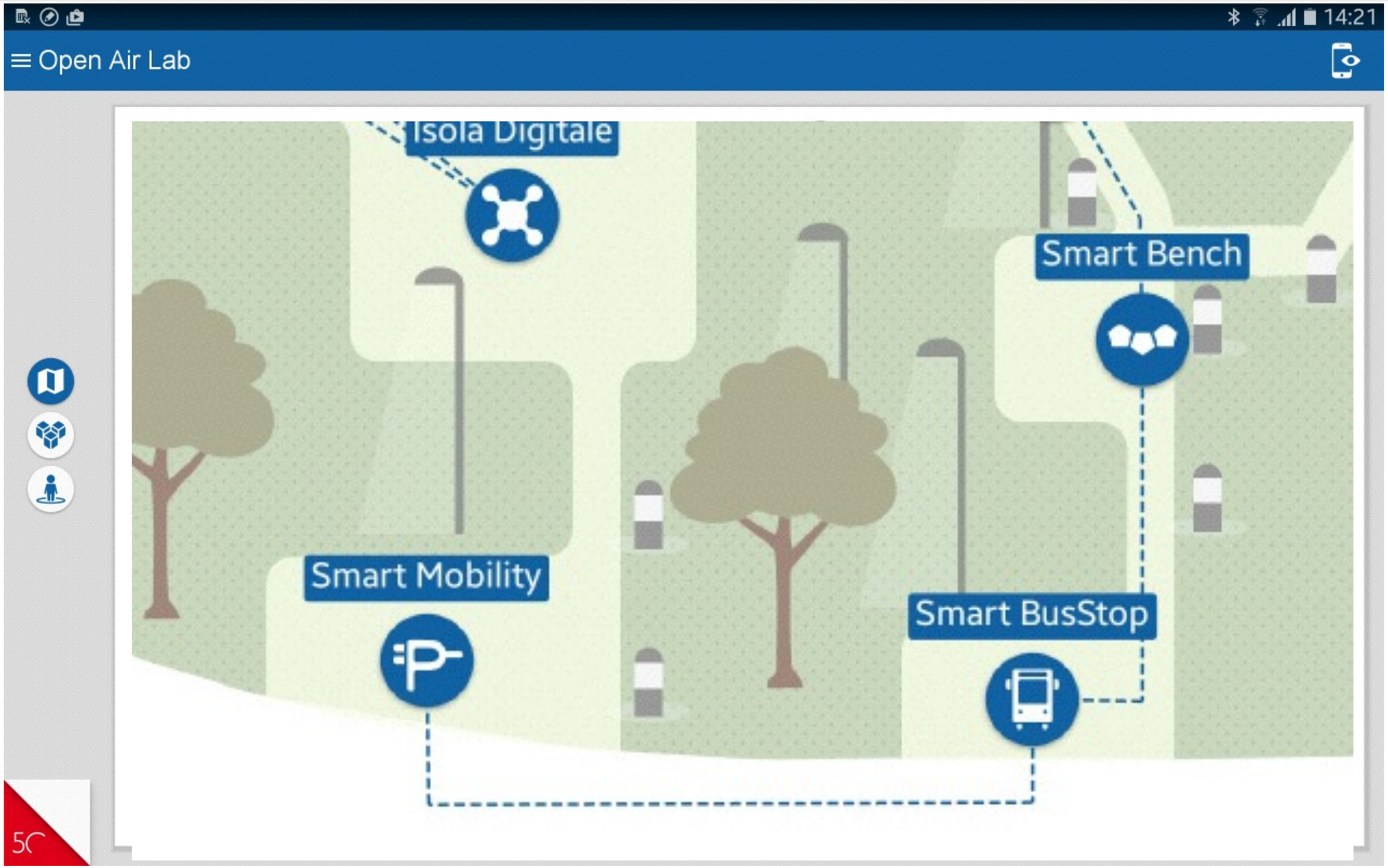

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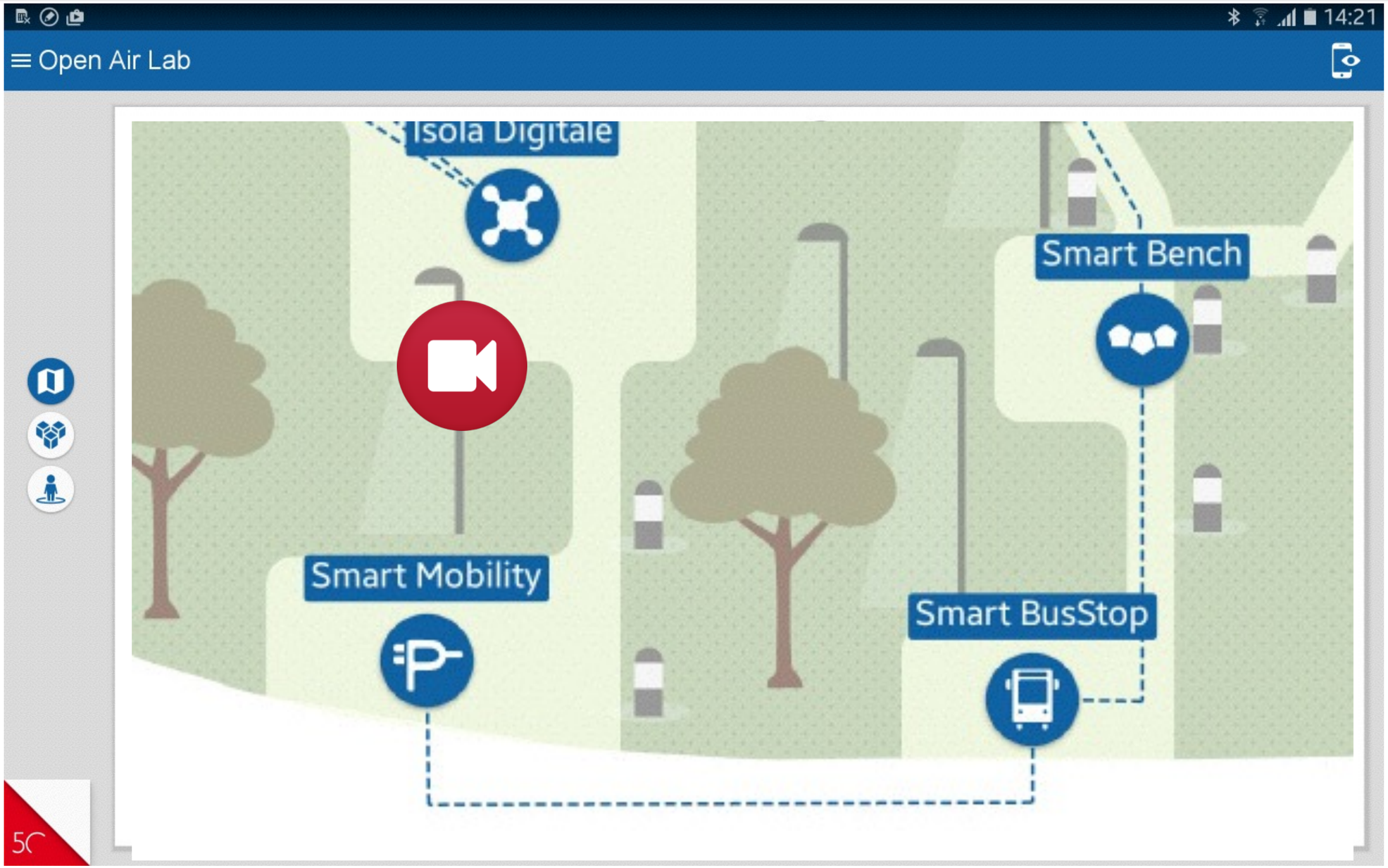

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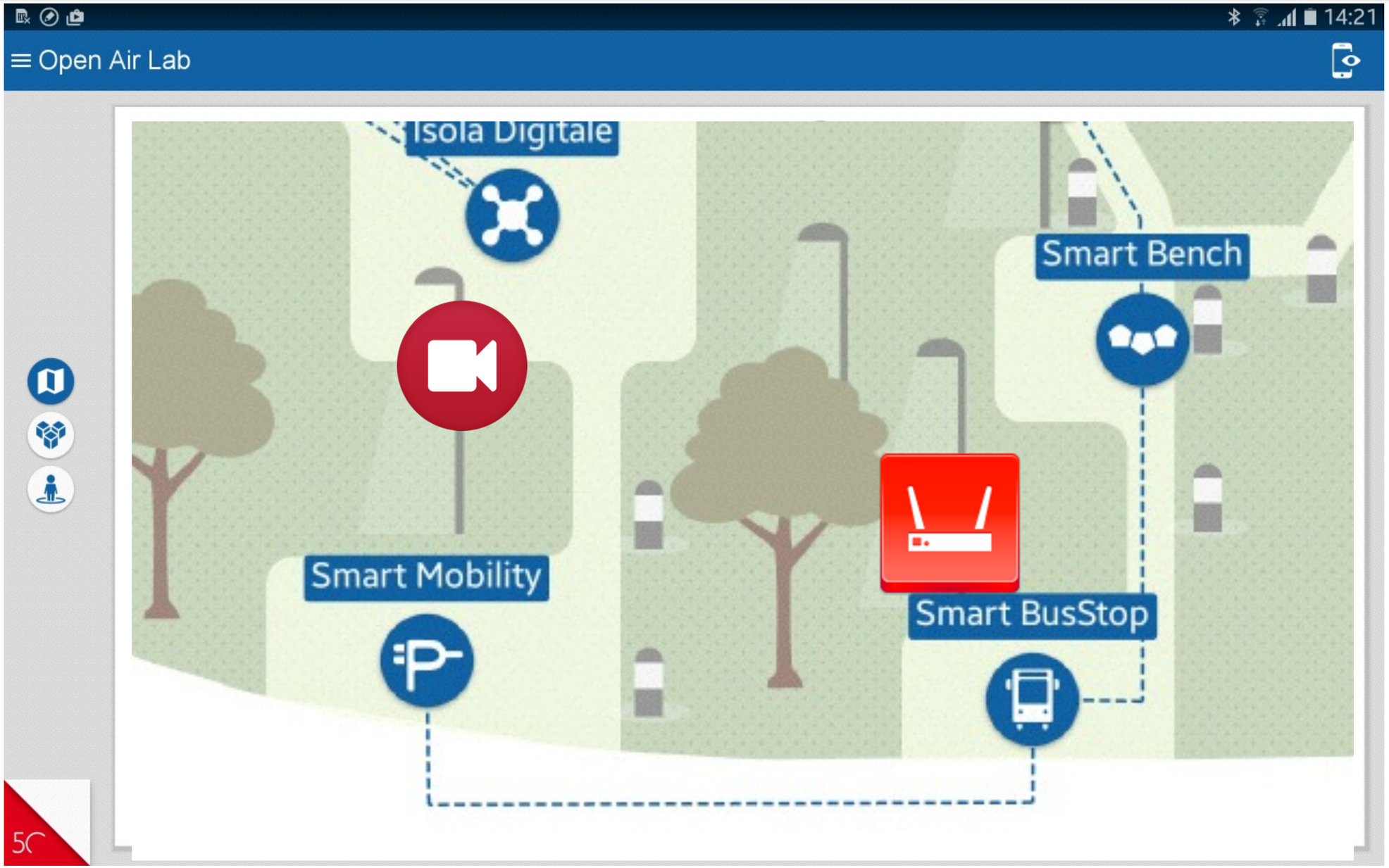

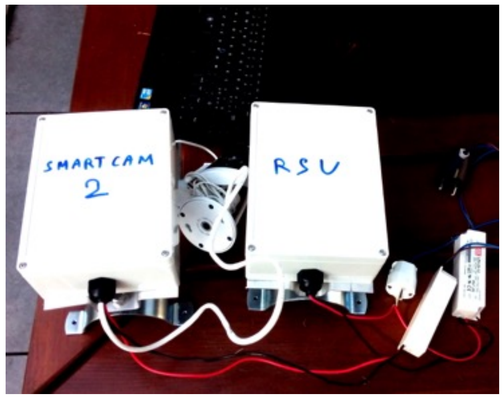

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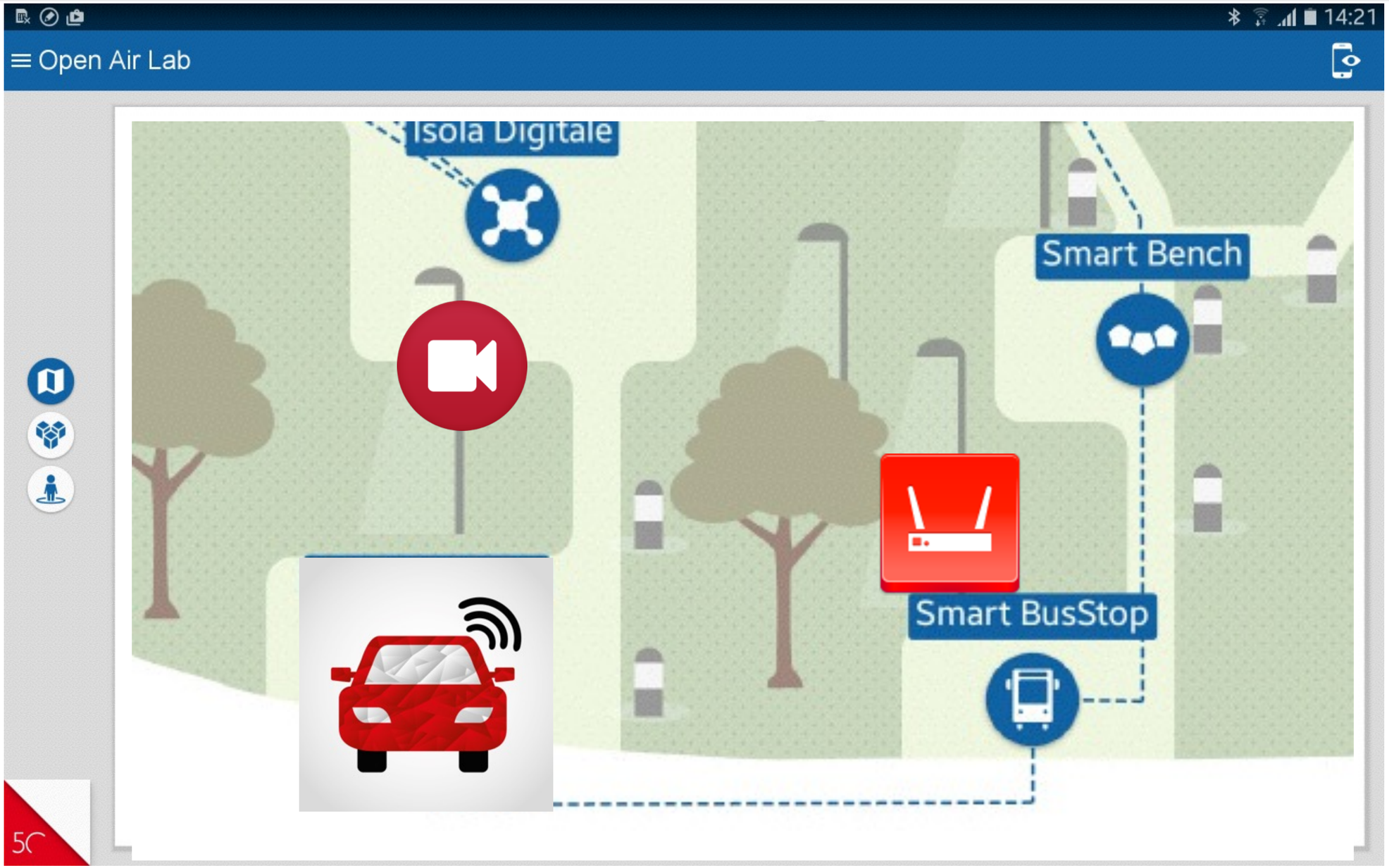

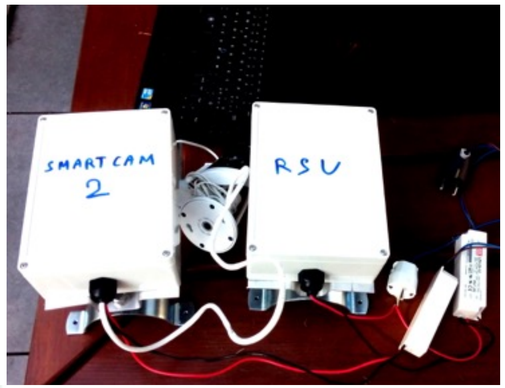

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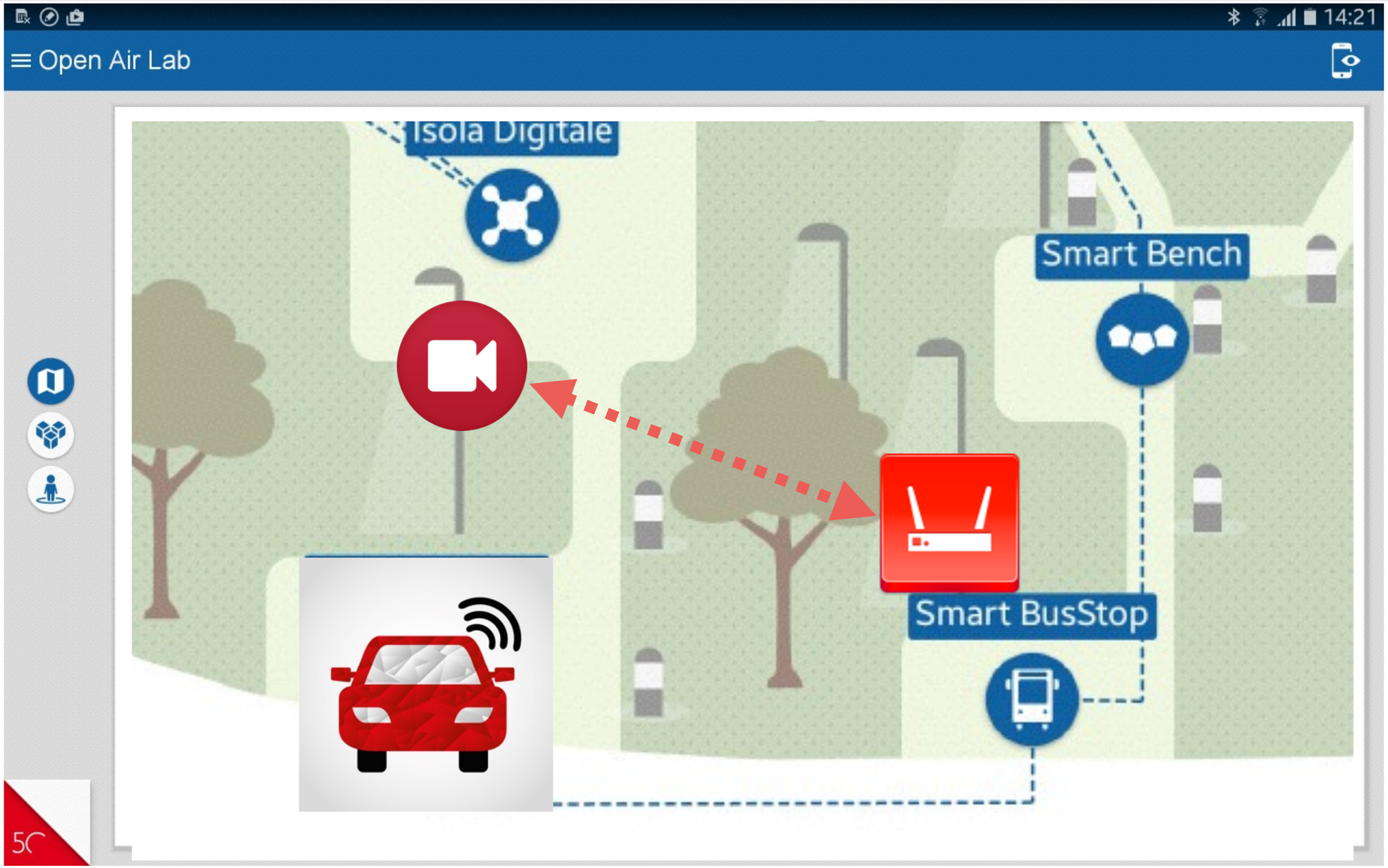

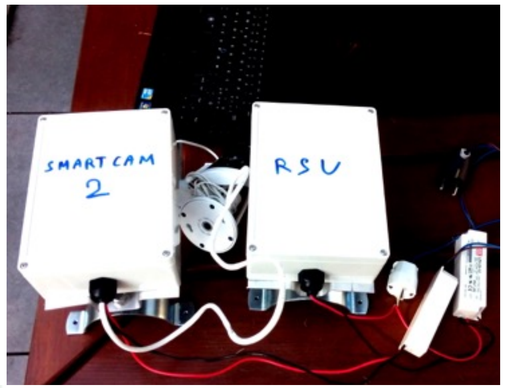

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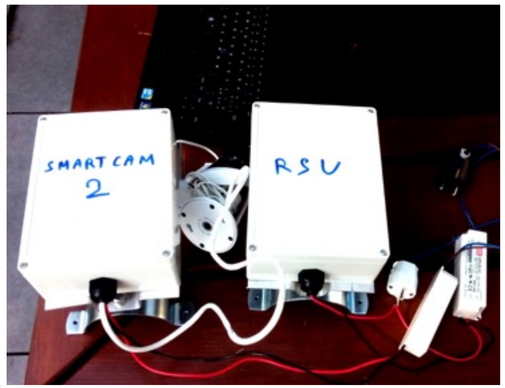

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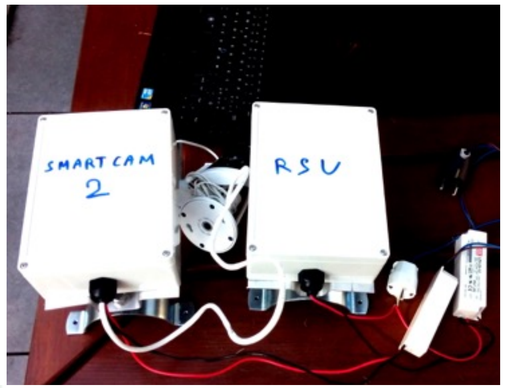

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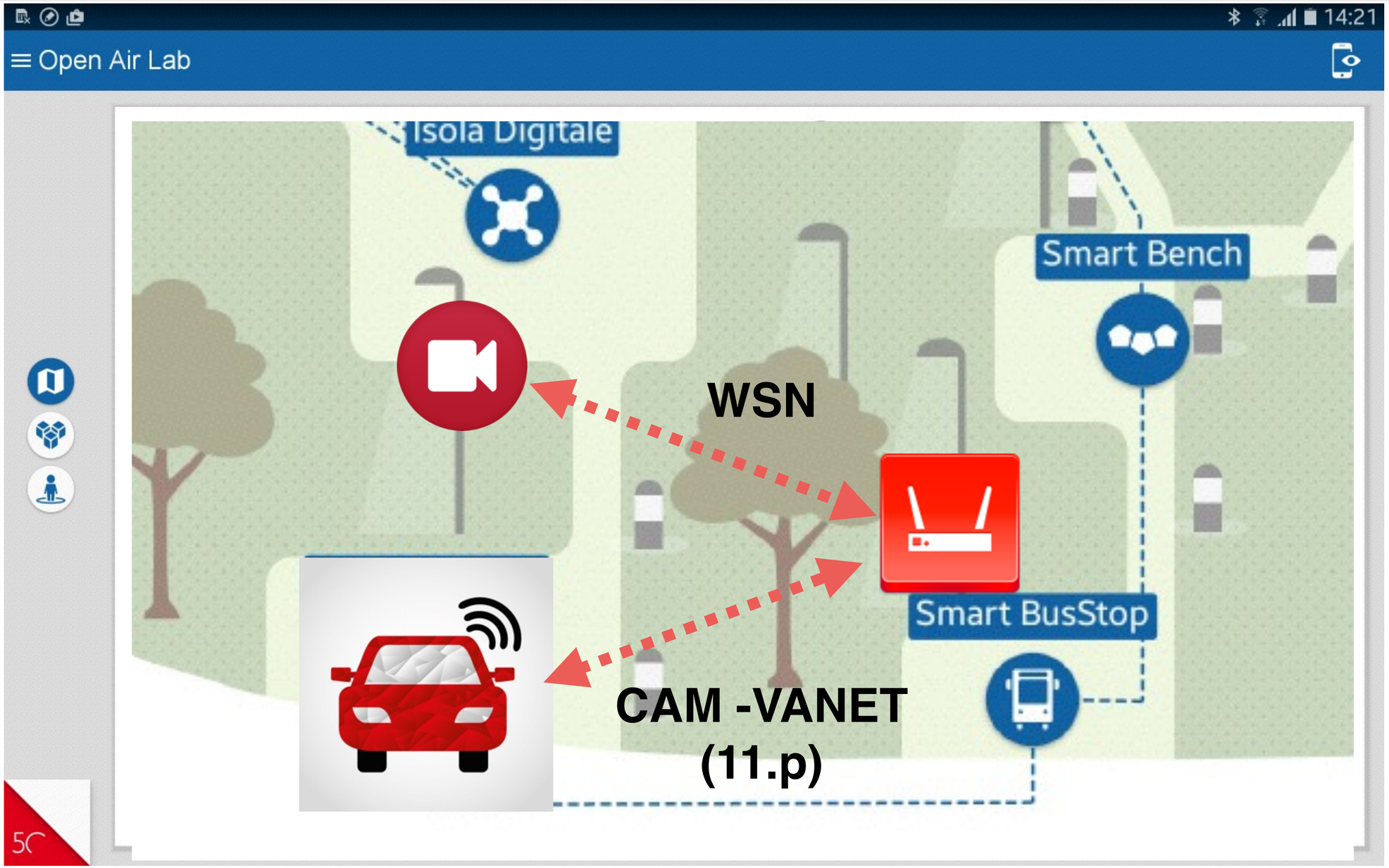

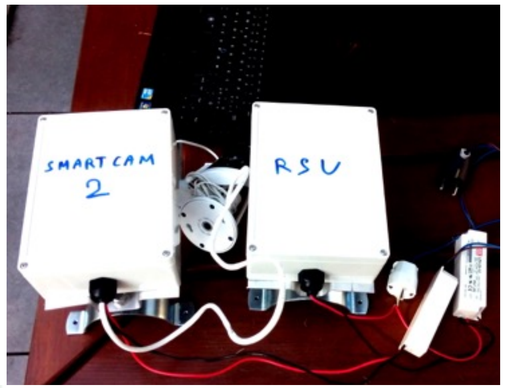

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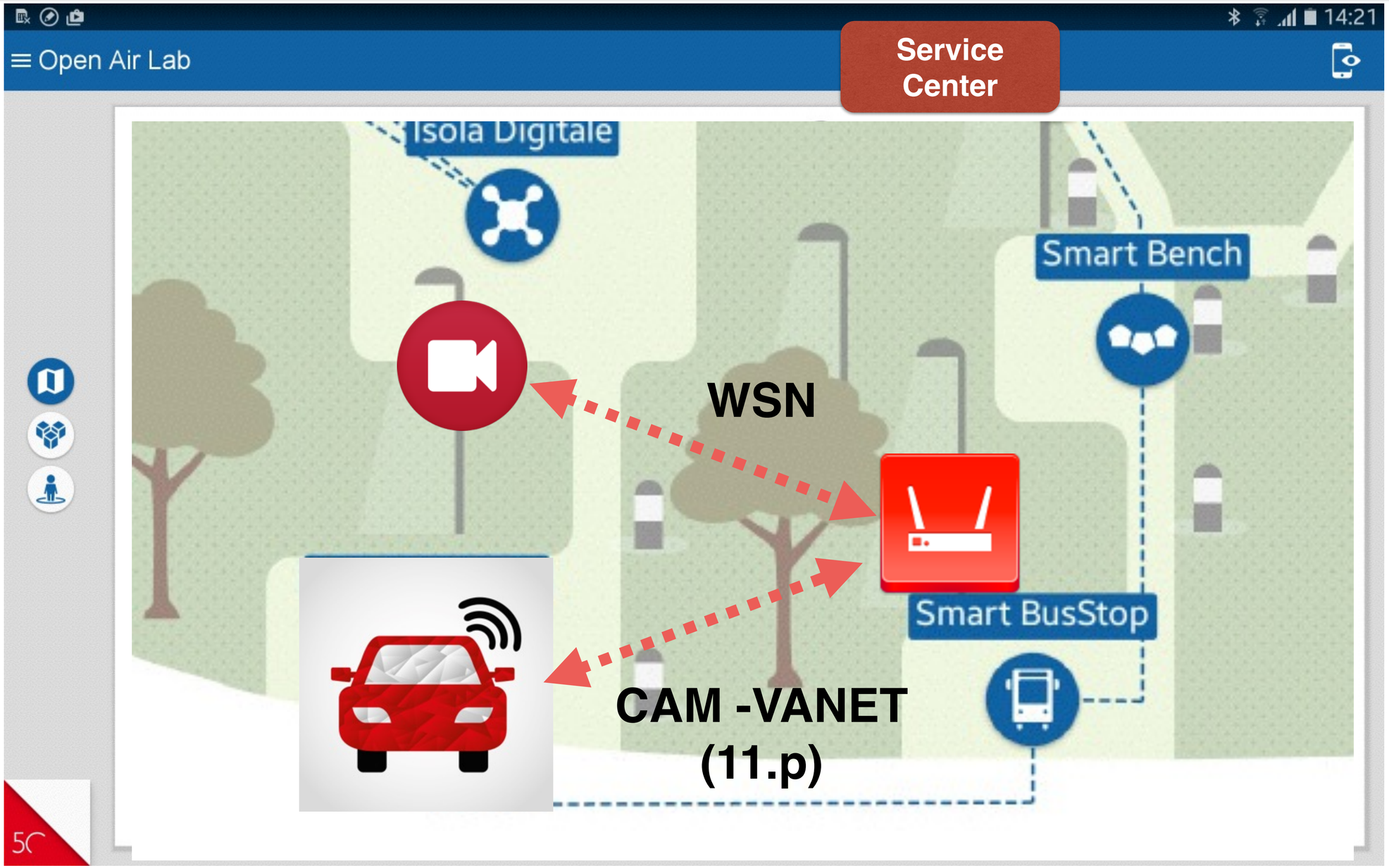

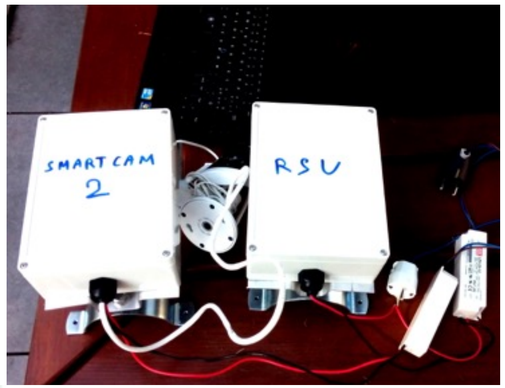

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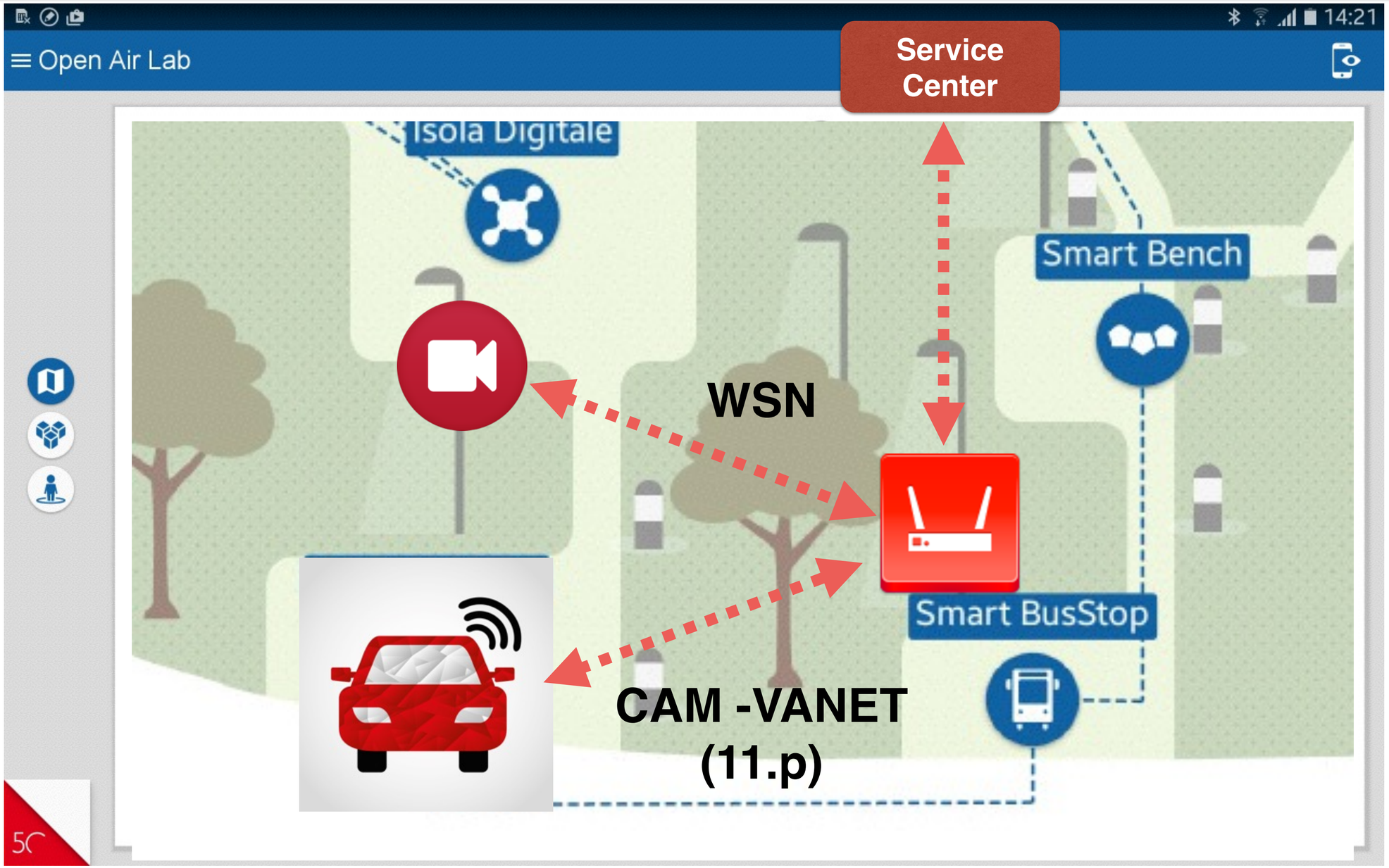

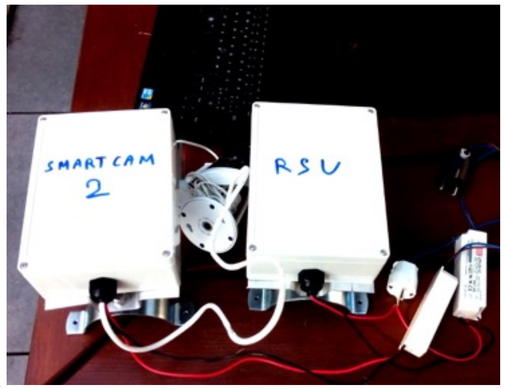

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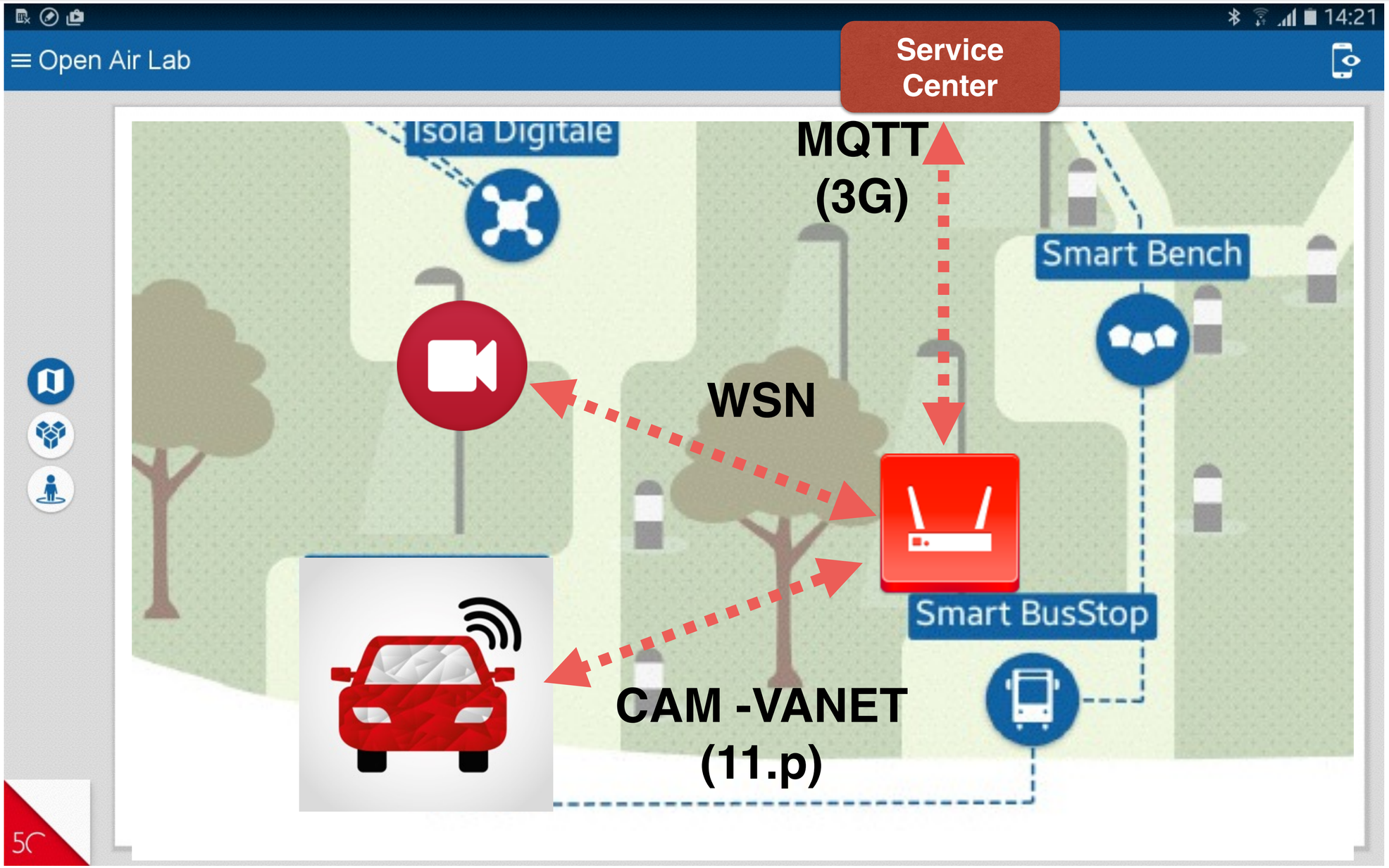

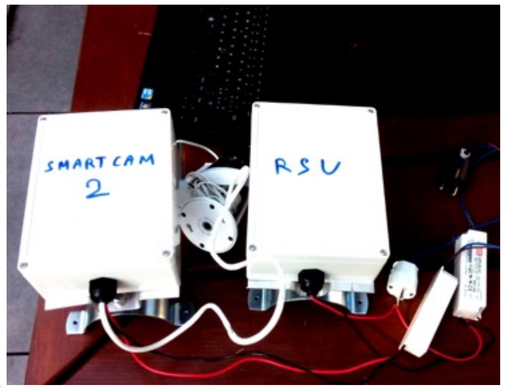

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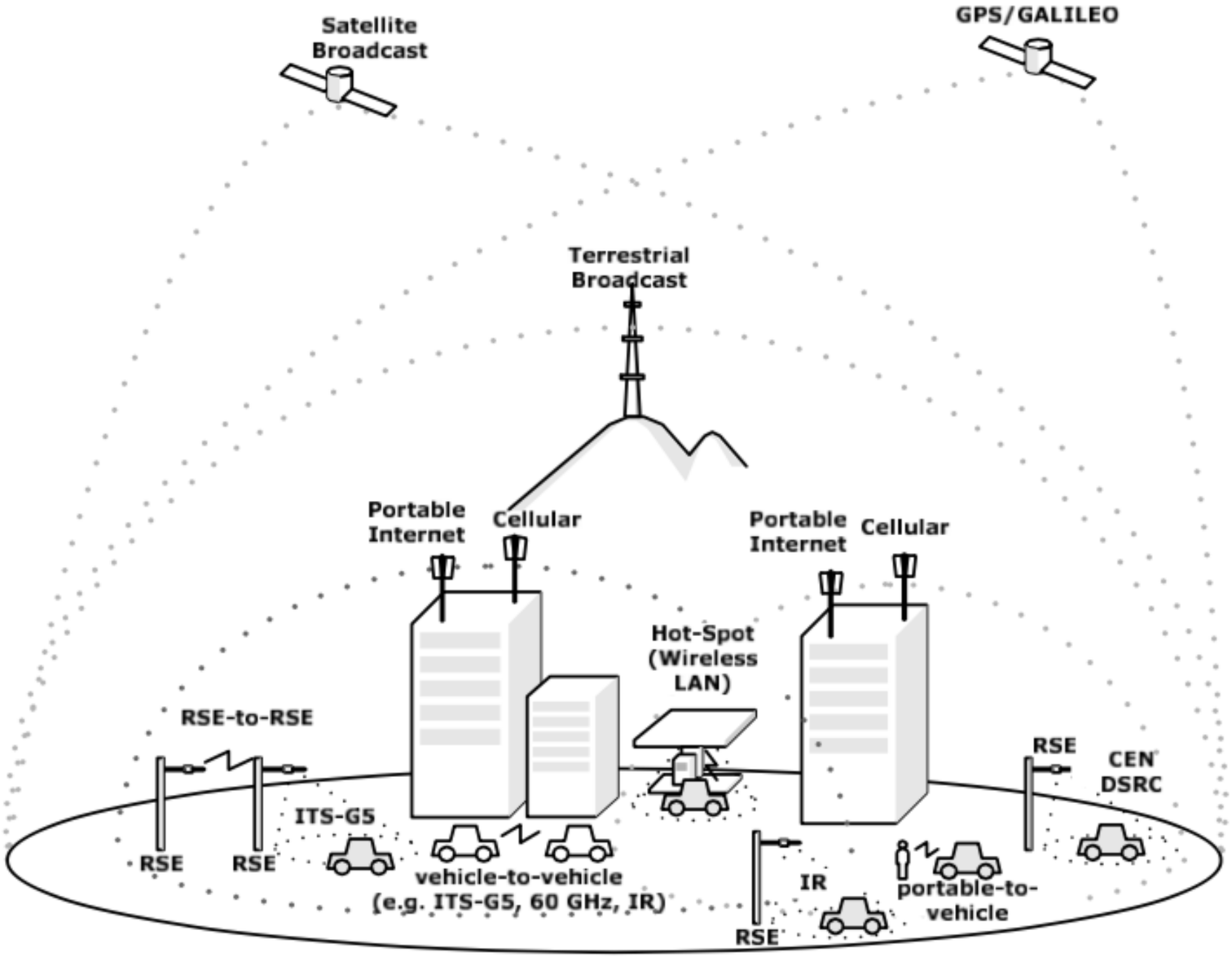
- New system **integrating IoT and C-ITS** was implemented
- **Feasibility** of one ITS application
- **Soundness** of the IoT/C-ITS architecture was demonstrated on field
- The designed framework led to a **fast and easy implementation** on the URBELOG use case

Thanks for your kind attention

Design and implementation of an ITS station to bridge automotive and IoT systems

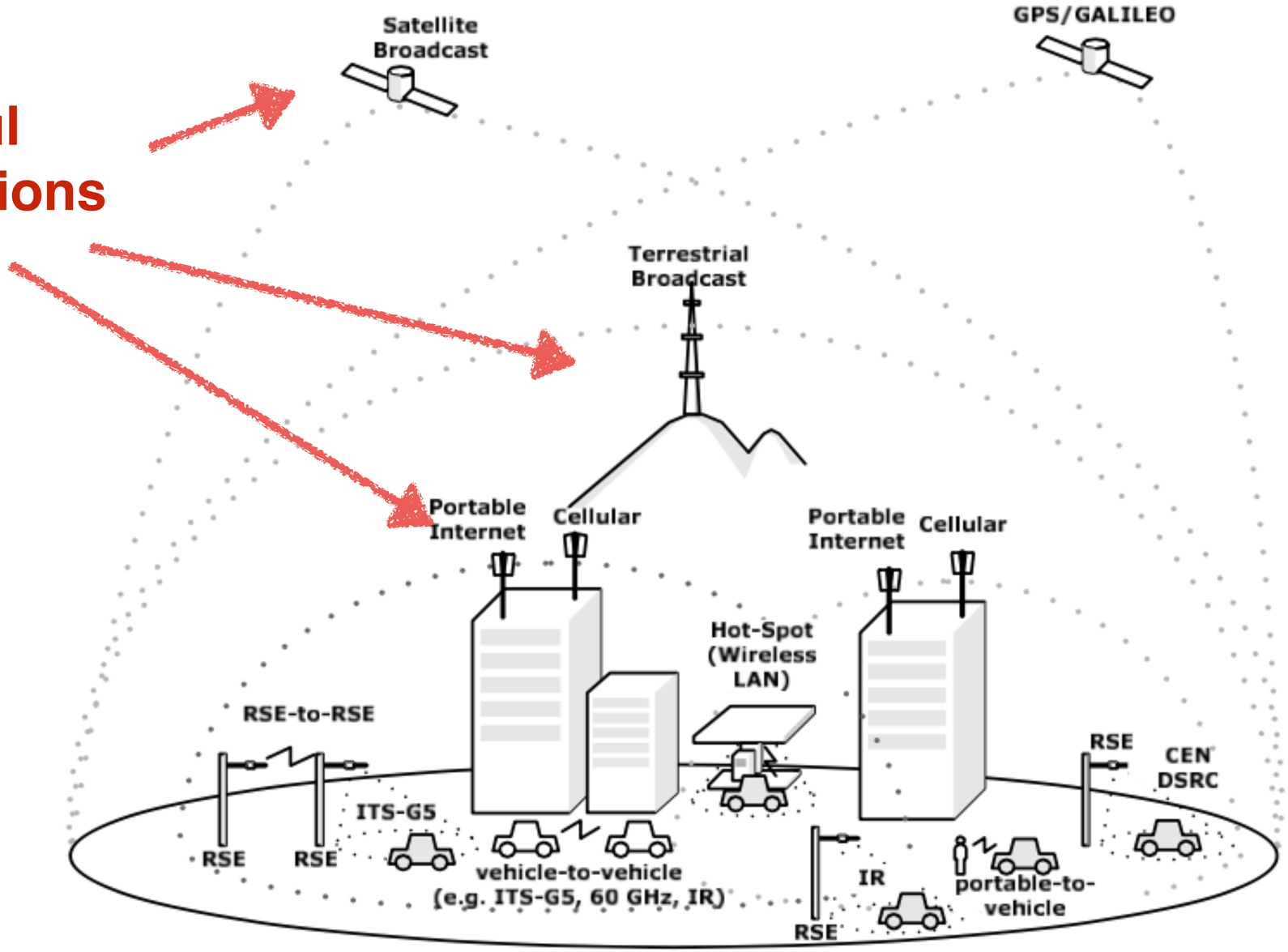
Candidate: Michele Carignani

ITS Scenario



ITS Scenario

Long haul communications



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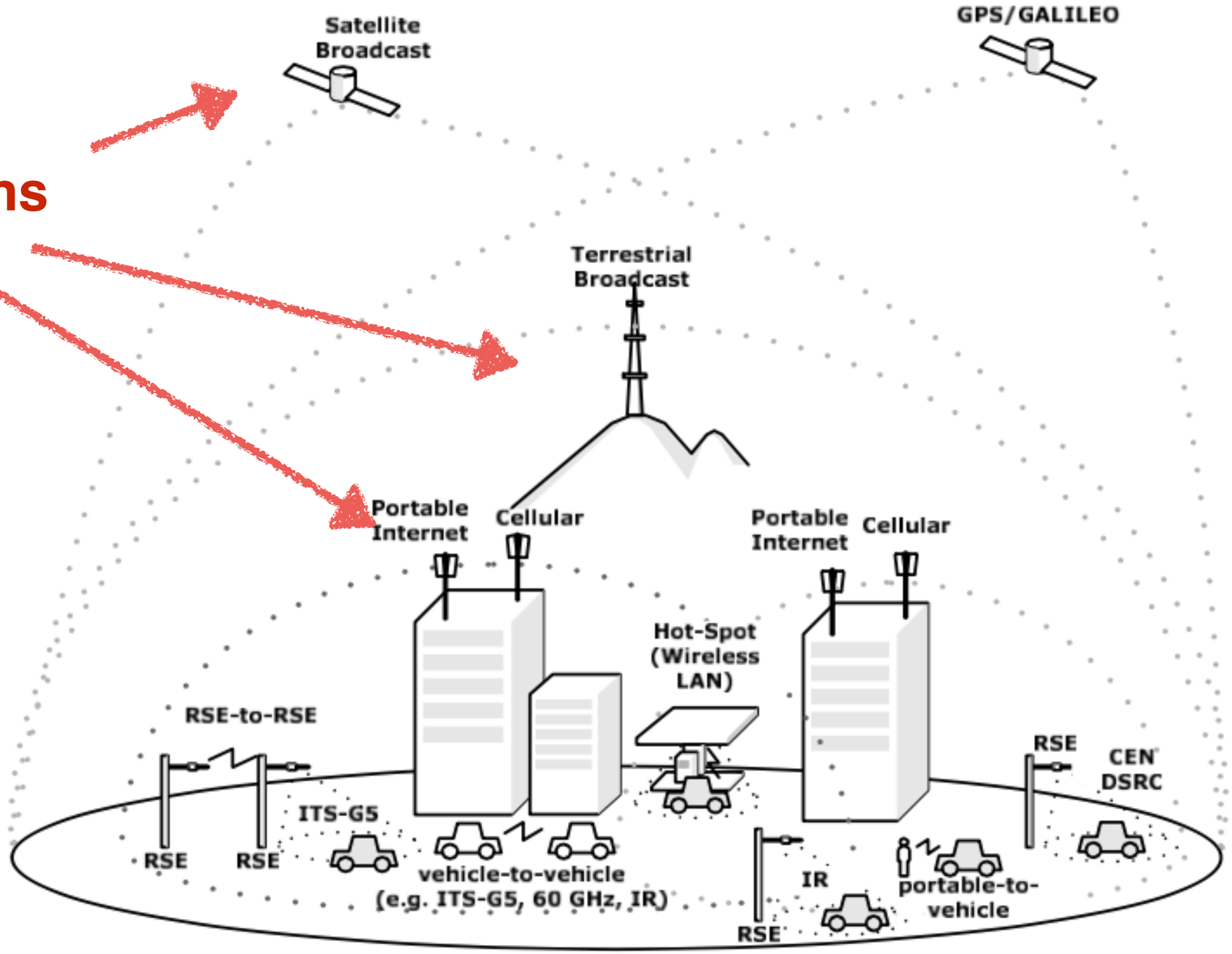
- eCall
- Tracking
- Infotainment



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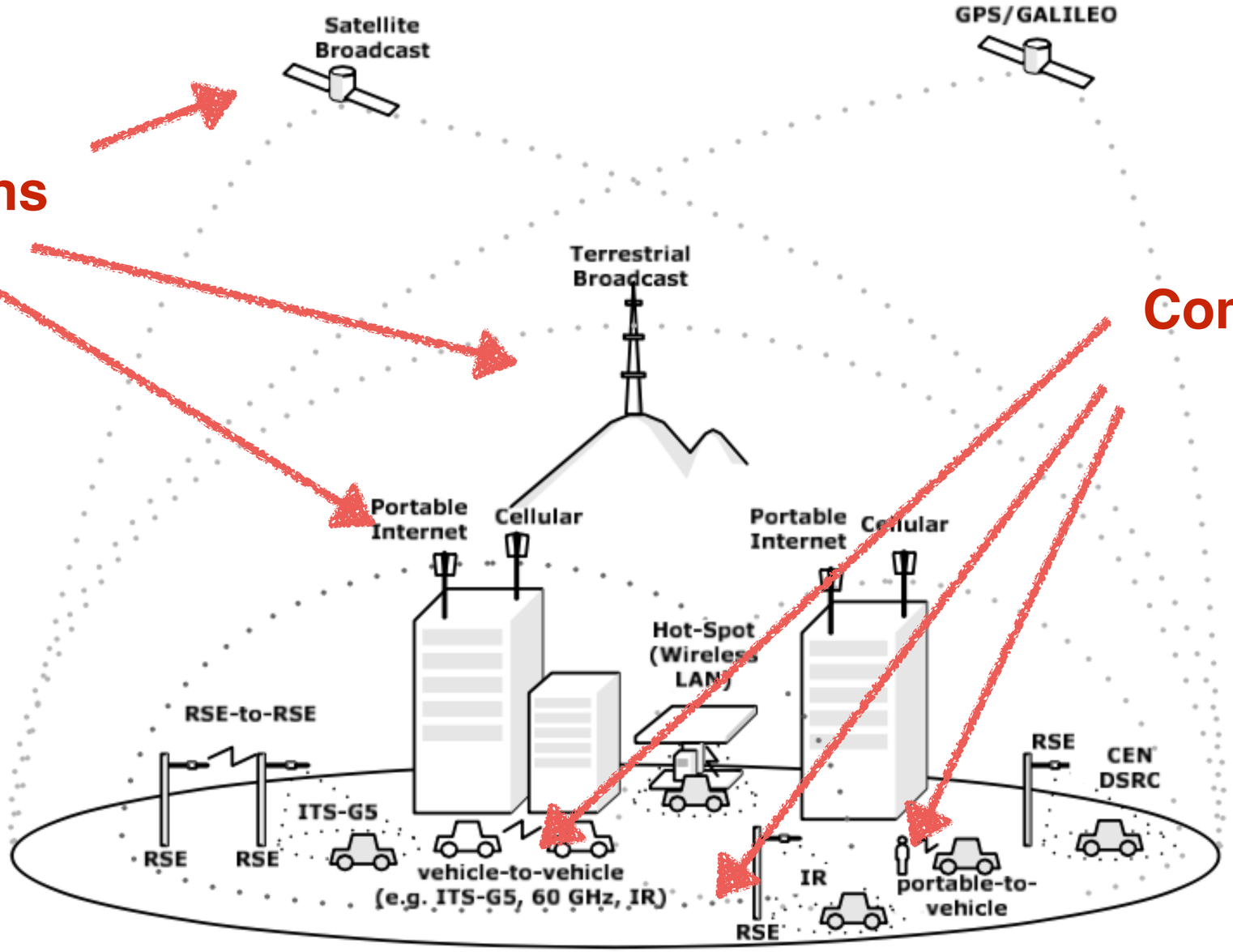

Dedicated Short Radio Communications

ITS Scenario

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- Tracking
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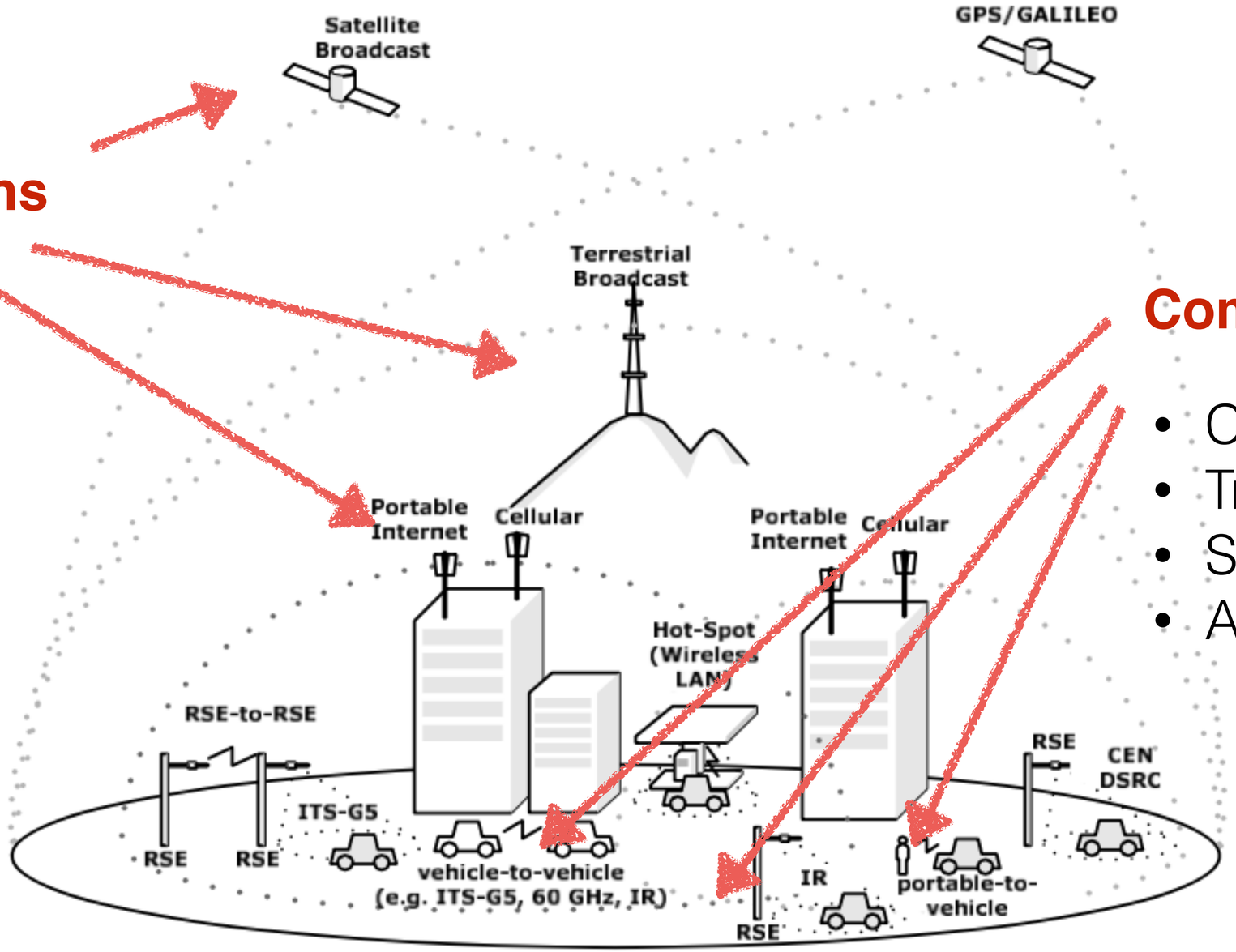
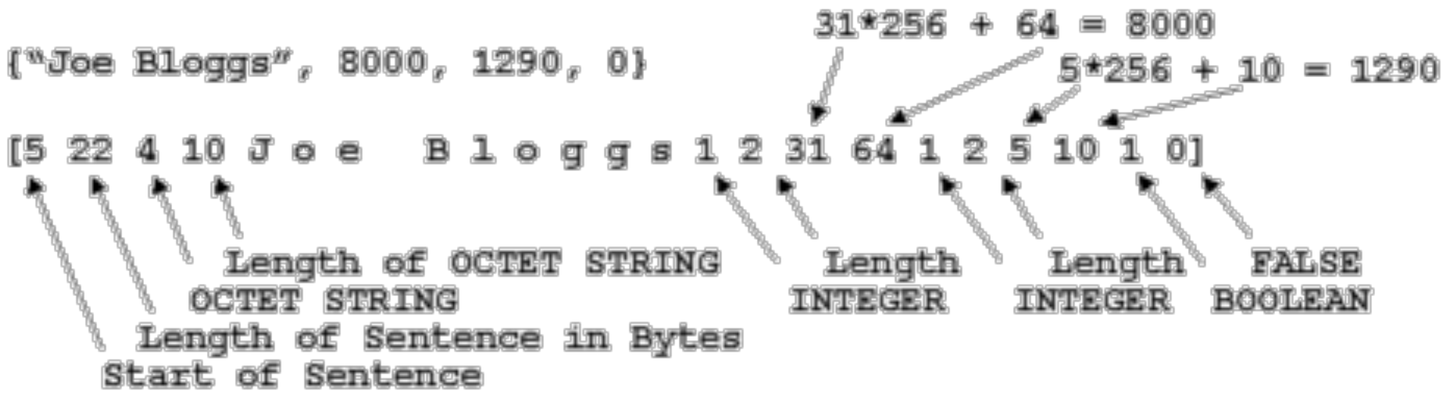


Dedicated Short Radio Communications

- Cooperative safety
- Traffic efficiency
- Signage
- Advertisement

Abstract Syntax Notation ASN.1

- ASN.1, a joint standard of ISO, IEC, and ITU-T.
- standard and notation that describes rules and structures for
  - representing,
  - encoding,
  - transmitting, and
  - decoding

```
struct employee {
char   name[32];
int    salary;
int    entryDate;
int    sex;
};
```

```
employee :: SEQUENCE {
Name          OCTET STRING, --32 characters
Salary        INTEGER,
EntryDate     INTEGER,
Sex           BOOLEAN
}
```