The Technical Foundations of M2M and the Internet of Things

Friedemann Mattern

ETH Zürich

The Technical Foundations of M2M and the Internet of Things

Converging?

Telemetry

Cellular technologies
(telcos and mobile
phone manufacturers)

Phone
(H2H)

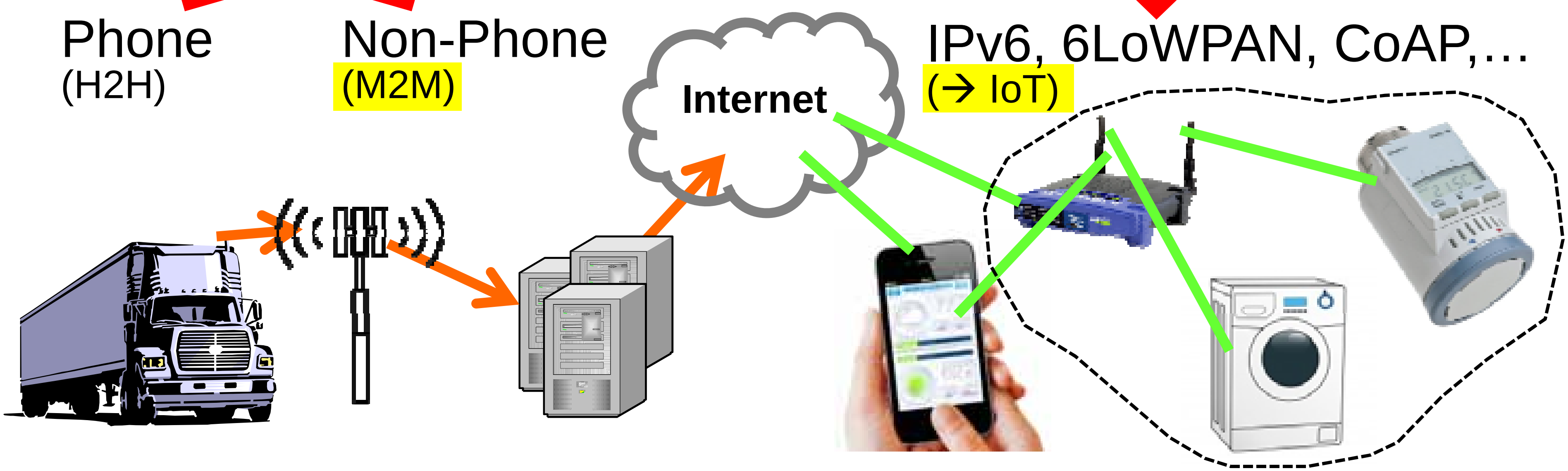
Non-Phone
(M2M)

Ubiquitous Computing

Sensor networks, RFID,…

Short distance networks
(WiFi, 802.15.4,…)

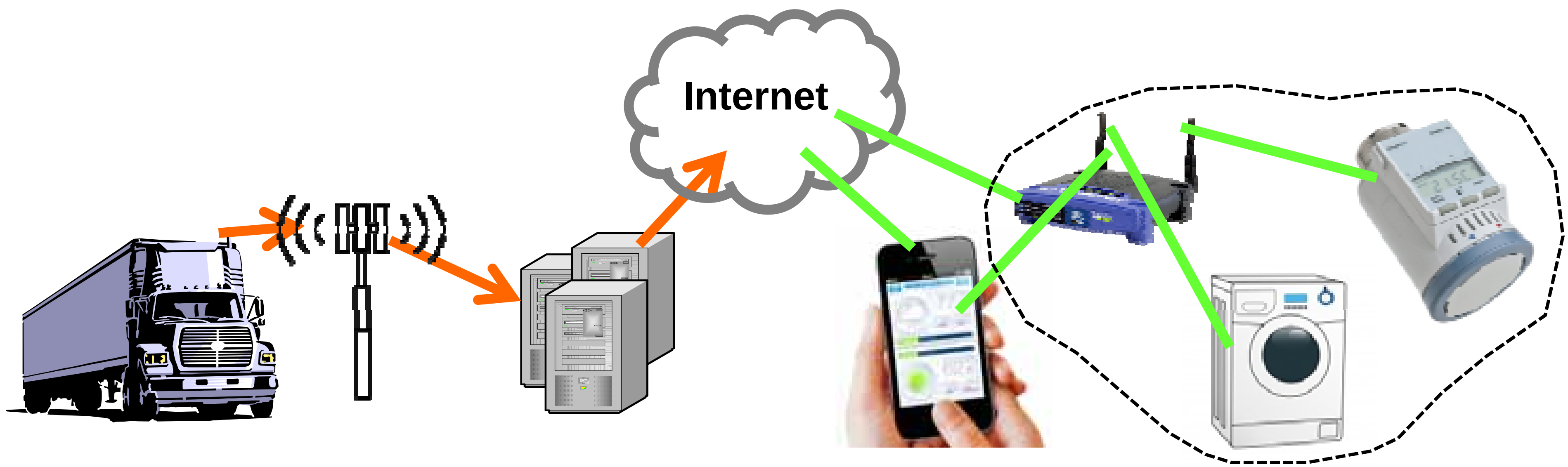
IPv6, 6LoWPAN, CoAP,…
(→ IoT)



M2M and the Internet of Things

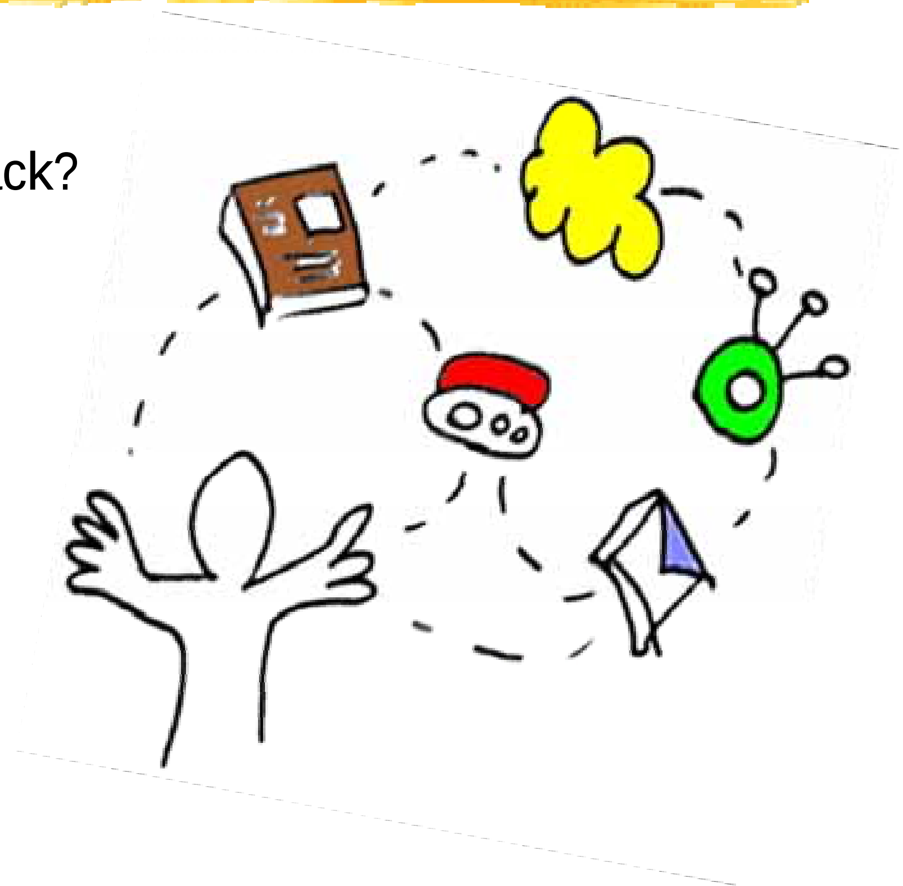
→Which technologies are appropriate for a particular scenario or business case?

→ How will technology progress?



Technical Challenges when Connecting Things to the Web

- Communication
  - embedded WiFi-IPv6-http stack?
- „Arrive and operate“
  - “plug and play”
- Security
  - privacy, resilience, safety
- Interoperability, scalability
  - standards
- Energy supply
  - harvesting?
- Reliability
- ...



M2M ("Machine to Machine")

B2B applications

- Logistics, track and trace
- Fleet management
- Security and safety
- Field force, maintenance
- Vending machines

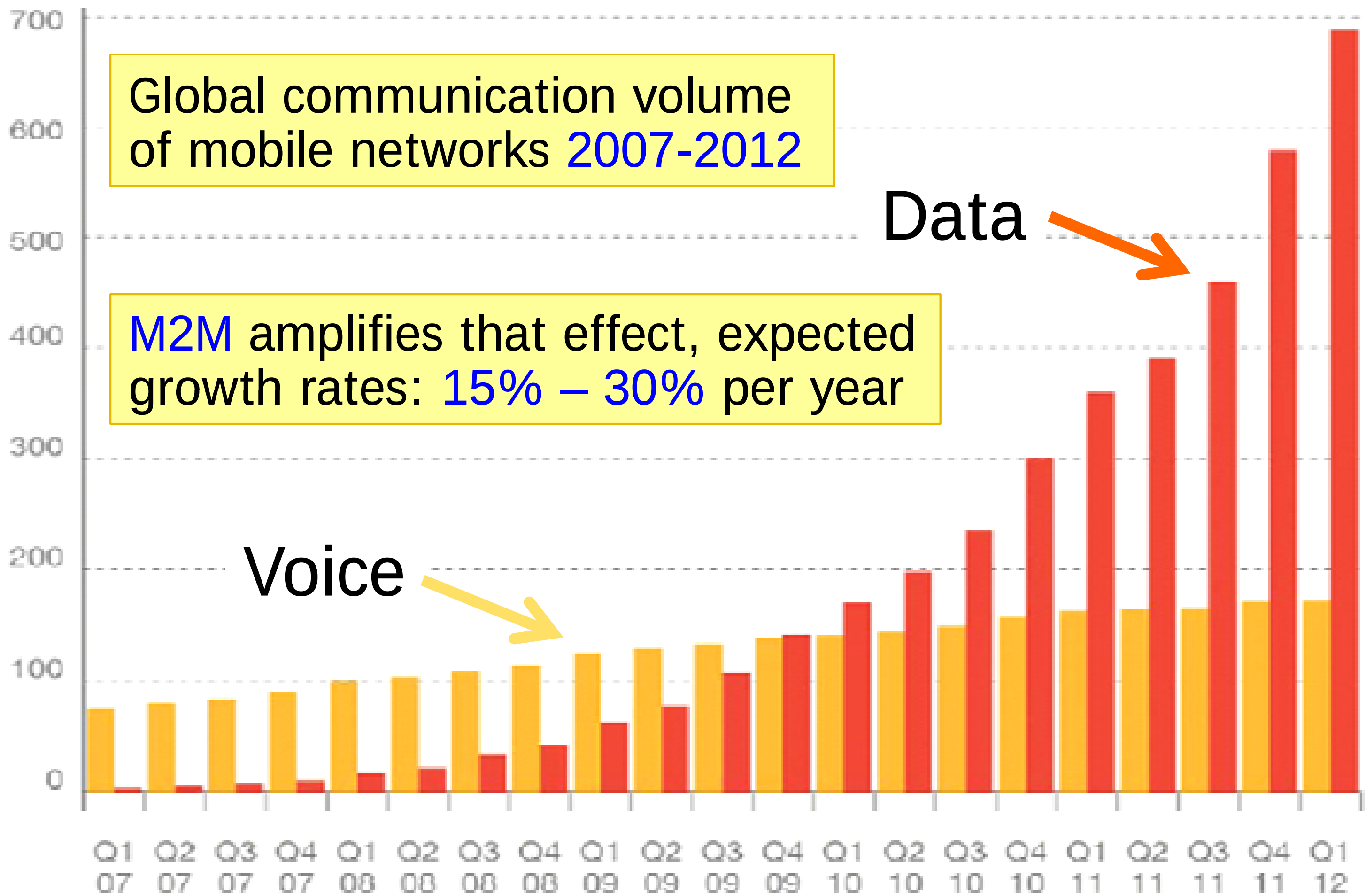
Technology

- Basically stripped-down mobile phones: GSM, GPRS, 3G,...
- Interface for data and sensors (e.g., GPS, motion,...)
- SIM-cards

- With progress in technology (smaller, cheaper, less energy,...) and decreasing cost due to scaling effects, new business scenarios become feasible
- Can be “mashed up” with existing Web services to generate additional customer experience and value
- Real-world search will become an important issue with IoT

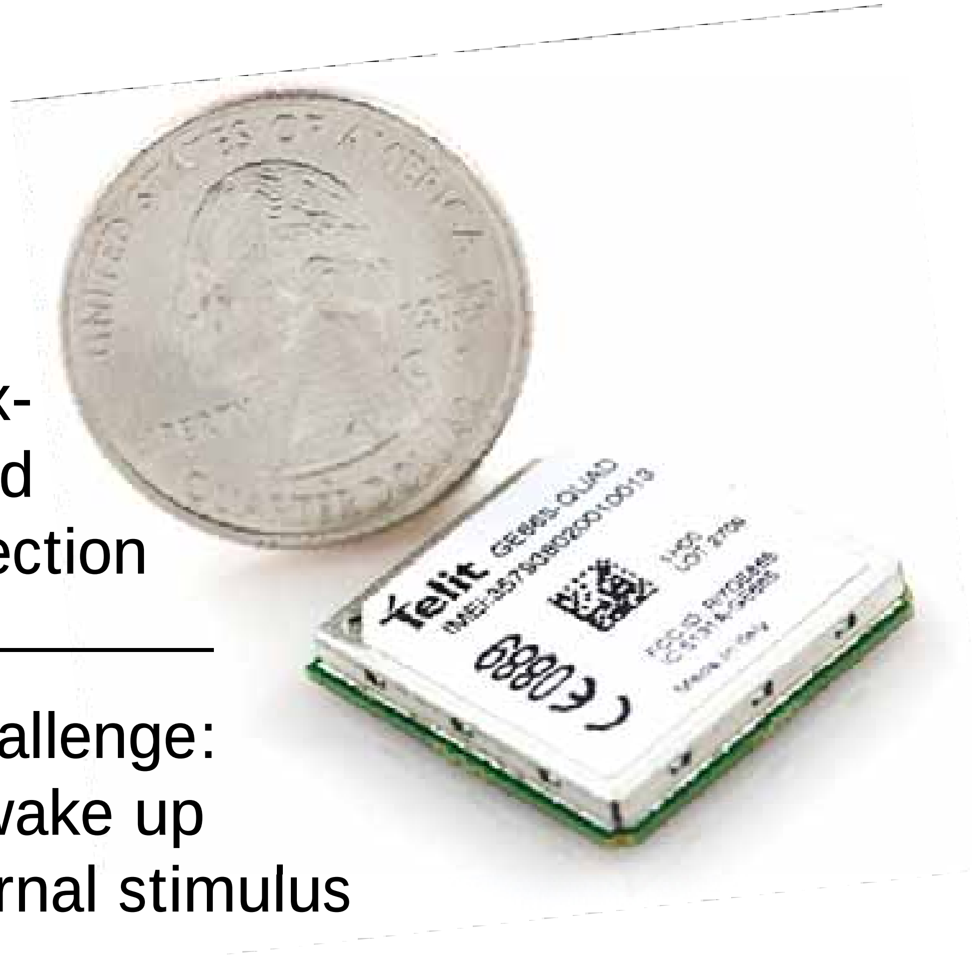
Yet Another Such Example – Smoke Detectors with SIM Cards

Mobile Networks are Now Primarily Used for Data Transmissions



Technical Progress with M2M?

- M2M modules are getting smaller (and cheaper)
  - e.g., GSM/GPRS module from Telit: 22x22x 3mm
- This one still requires an external SIM card socket and an external antenna connection



- Energy issue remains a challenge: Long deep sleep modes; wake up periodically or due to external stimulus

Technical Progress with M2M?

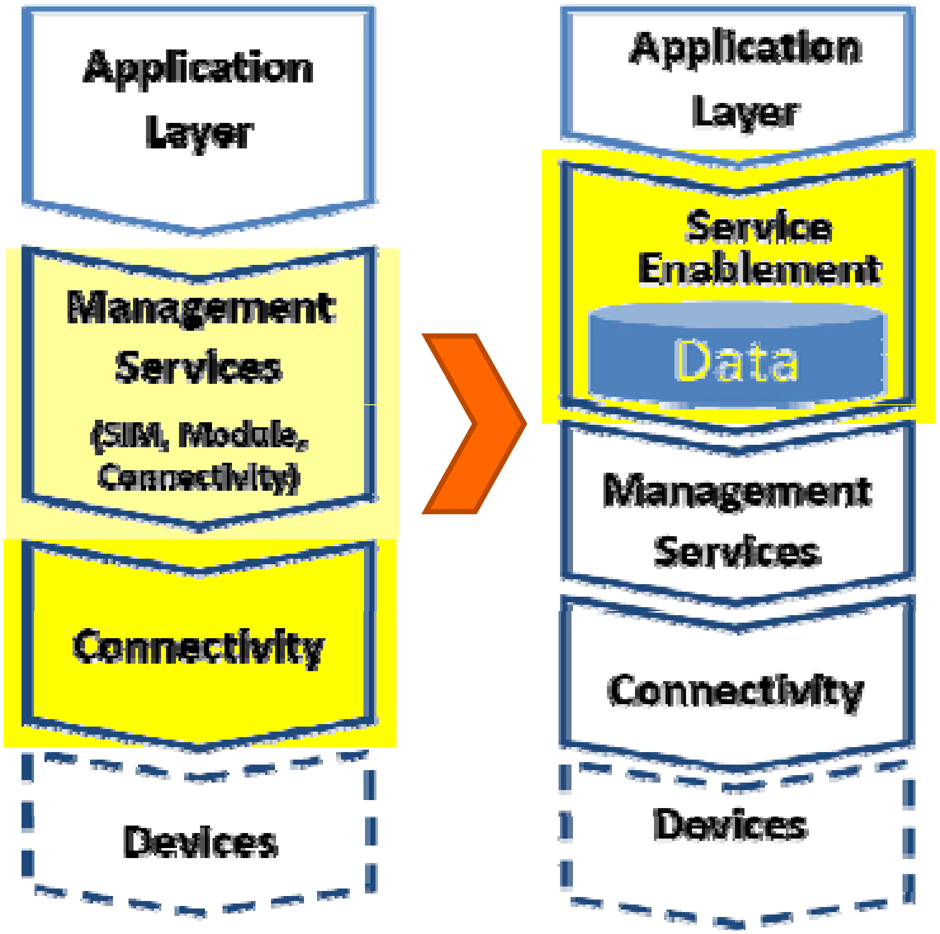
- Smaller „embedded“ SIMs
  - can be soldered directly onto a circuit board
- However: less flexible and bound to a specific telco
  - remotely activated, deactivated, configured

A Dedicated M2M Infrastructure?

- Some suggest a dedicated cellular network for M2M
  - e.g., Neul (Cambridge, UK) or Sigfox (France)
  - using TV “white space” or other unused radio spectrum
- Lower frequencies would have two benefits
  - fewer base stations (“towers”) because of longer range
  - easier penetration of buildings
- Dedicated low throughput protocols would save energy
  - for example with a one-way, unacknowledged service class (this is inherently unreliable, however)
- Unclear whether these suggestions will lead to something

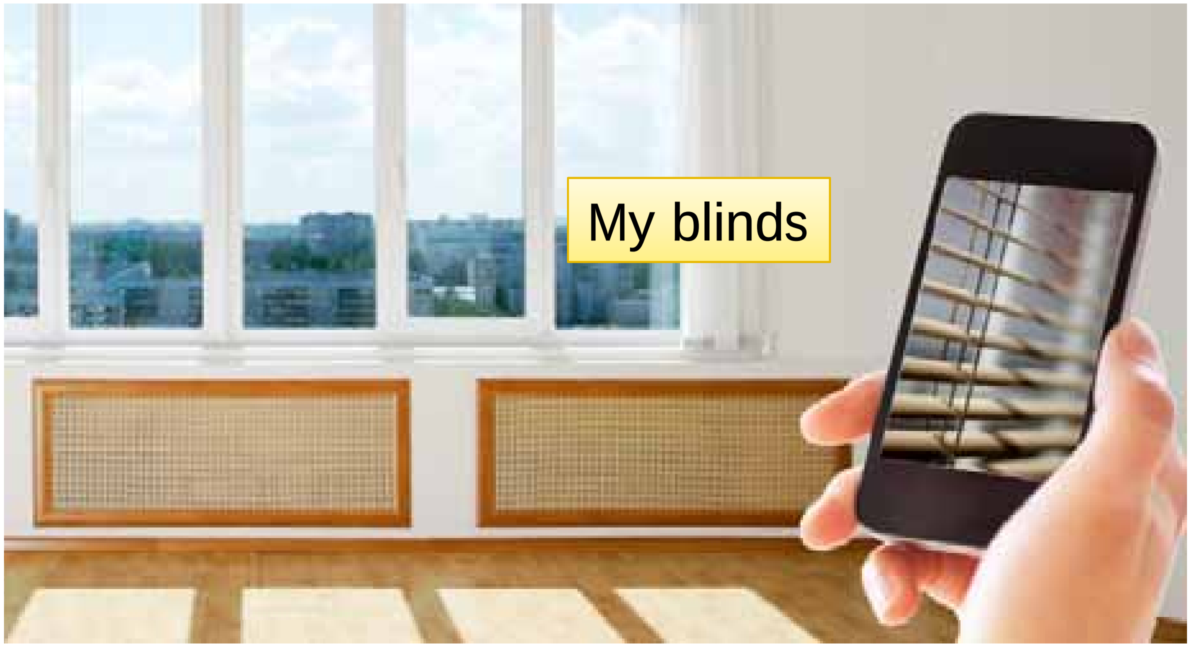
Development of the M2M Industry?

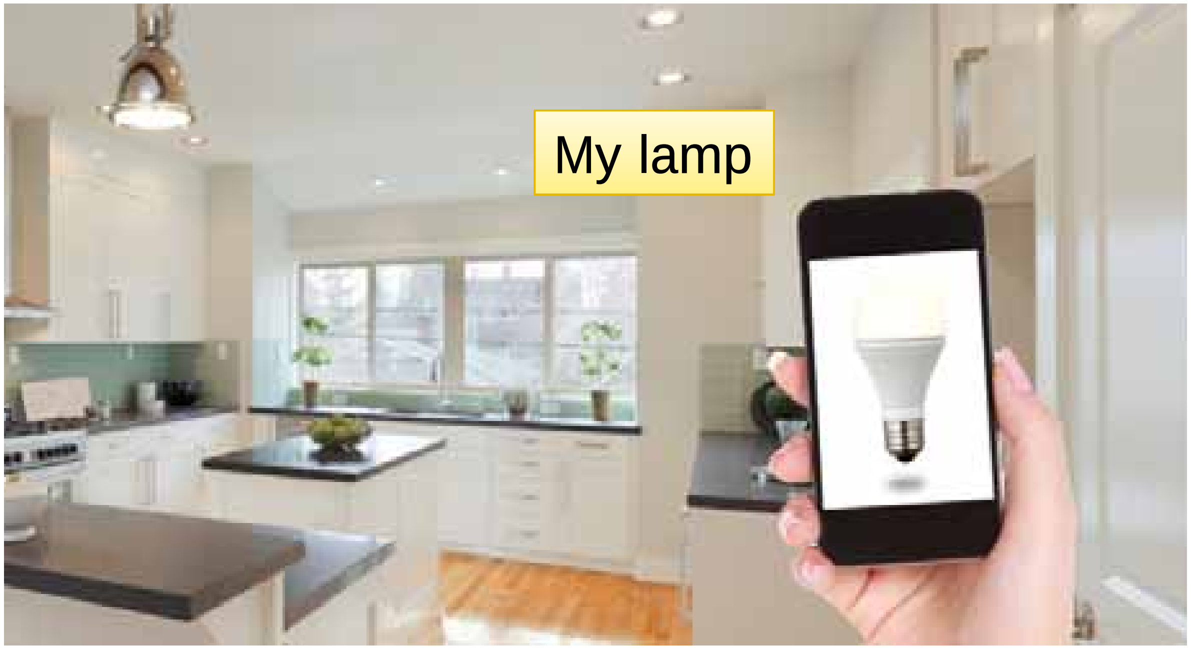
- Today telcos essentially provide connectivity service and some management service for SIM cards and M2M modules
- They mainly support B2B scenarios
- Will they in the future provide additional services (e.g., data storage & access) as an added value for additional revenue?
- Can they also serve the emerging B2C market?
- And connect people to “their” own objects?



Rapidly increasing sector

- And connect people to "their" own objects?





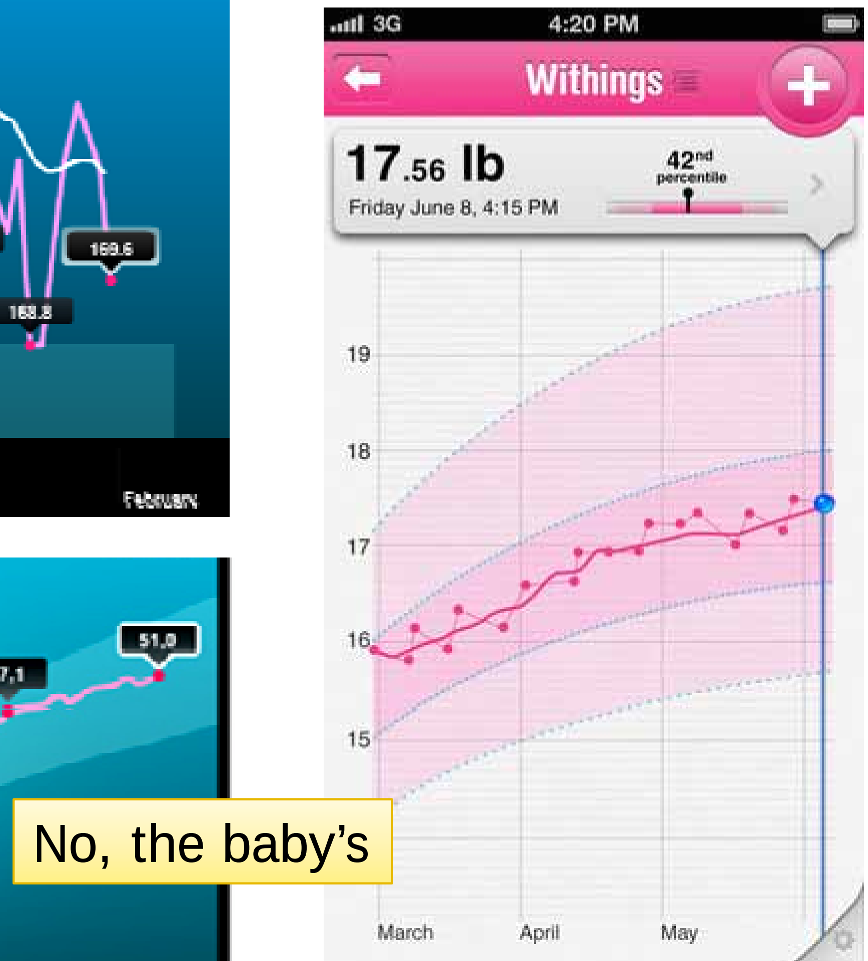
Pictures credit: Thingsquare

My washing machine

My bathroom scale


My scale?
No, my wife's
2011
November
December
2012
January
February

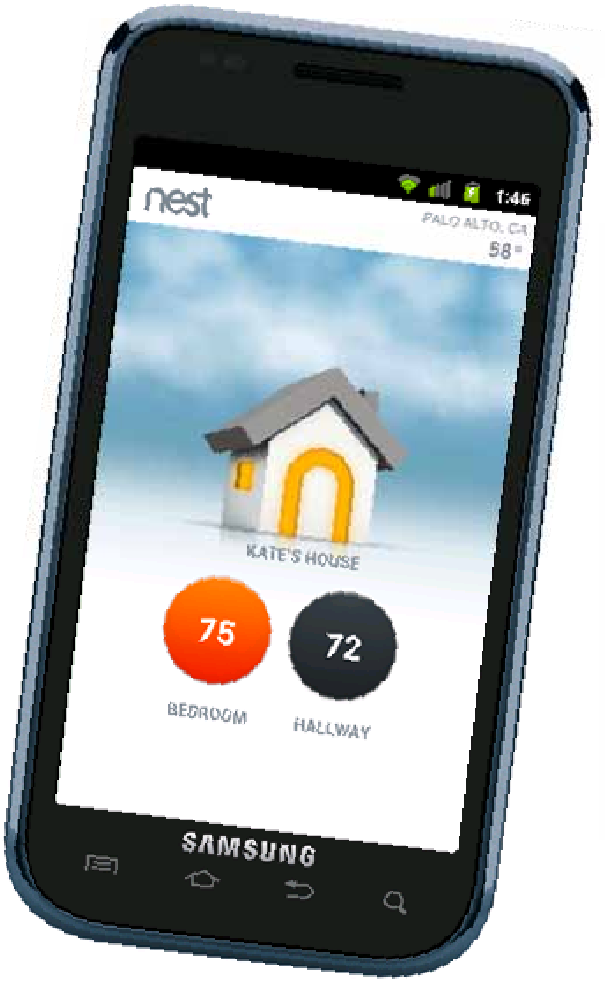

My scale?
No, the baby's


3G
4:20 PM
Withings
17.56 lb
Friday June 8, 4:15 PM
42nd percentile
March
April
May

My Weather Station

Netatmo

My Thermostat



My Light Bulb

WiFi-enabled LED bulb:

"Each bulb has its own IP address. The bulbs communicate over the home network or even over the Internet using a smartphone or tablet app. Customers can create pre-set dimmers or timers to control lights." (GreenWave Reality)

Hardware Platforms? Communication Standards?

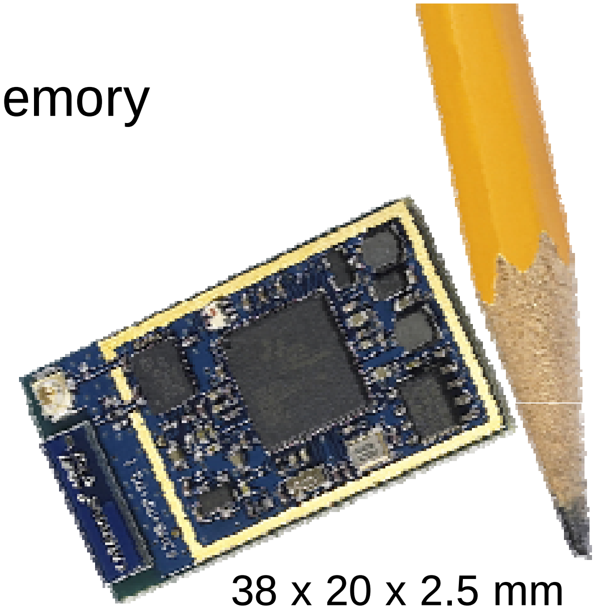
- Example: a WiFI module →
  - which we used in several prototypes
  - similar / newer platforms are available from various vendors

Low Power WiFi Systems

RN-134 / G2M5477 Roving Networks

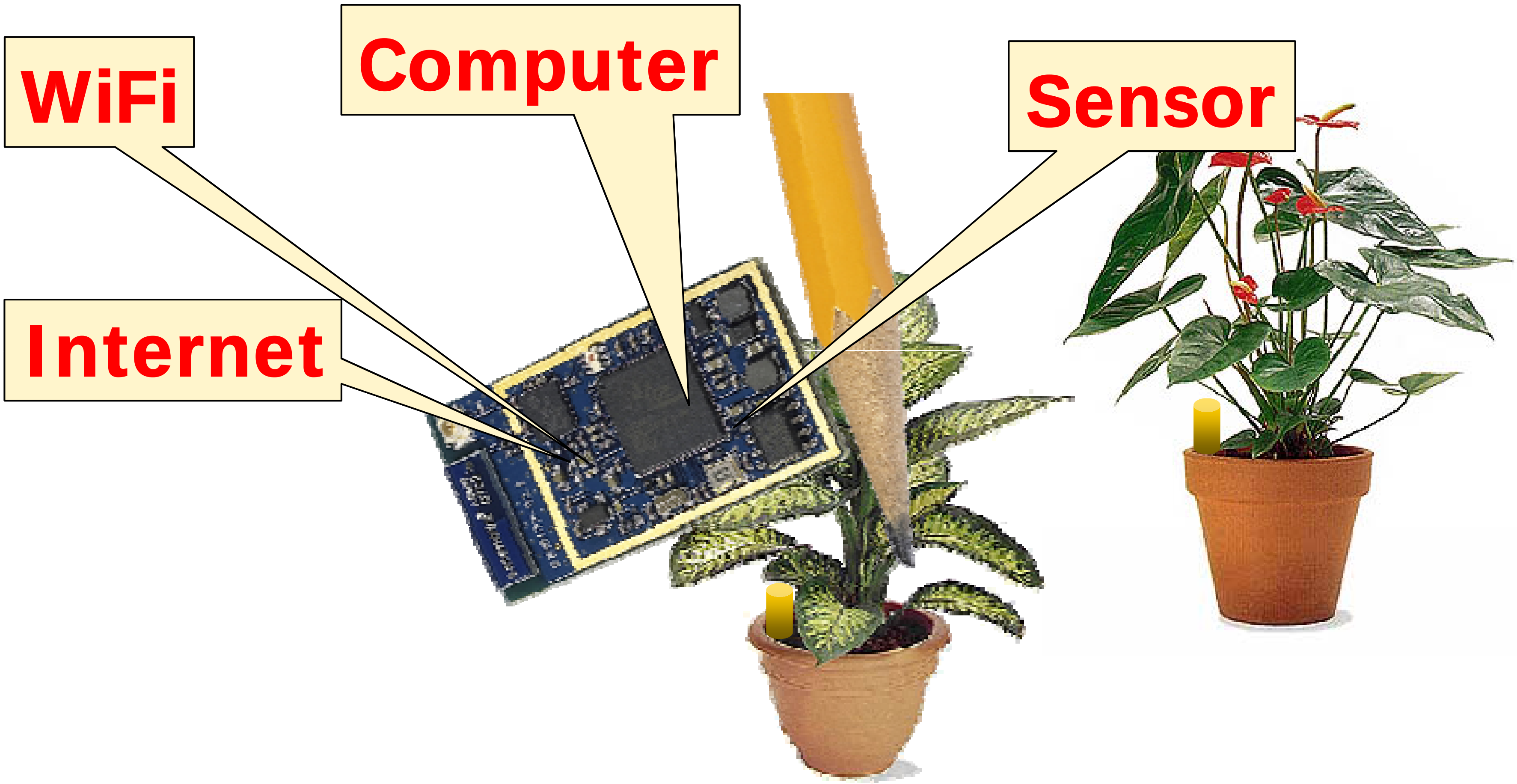
Commercial product

- 44 MHz processor
  - application programs stored in flash memory
  - 128 kB RAM, 512 kB ROM, 1 MB flash
- WiFi
  - wake up and join a secure network (WPA2): < 35 ms
- TCP/IP stack installed in ROM
- Low power
  - 4 µA sleep mode (wake-up: sensor input or timer)
  - 40 mA receive data, 210 mA transmit data



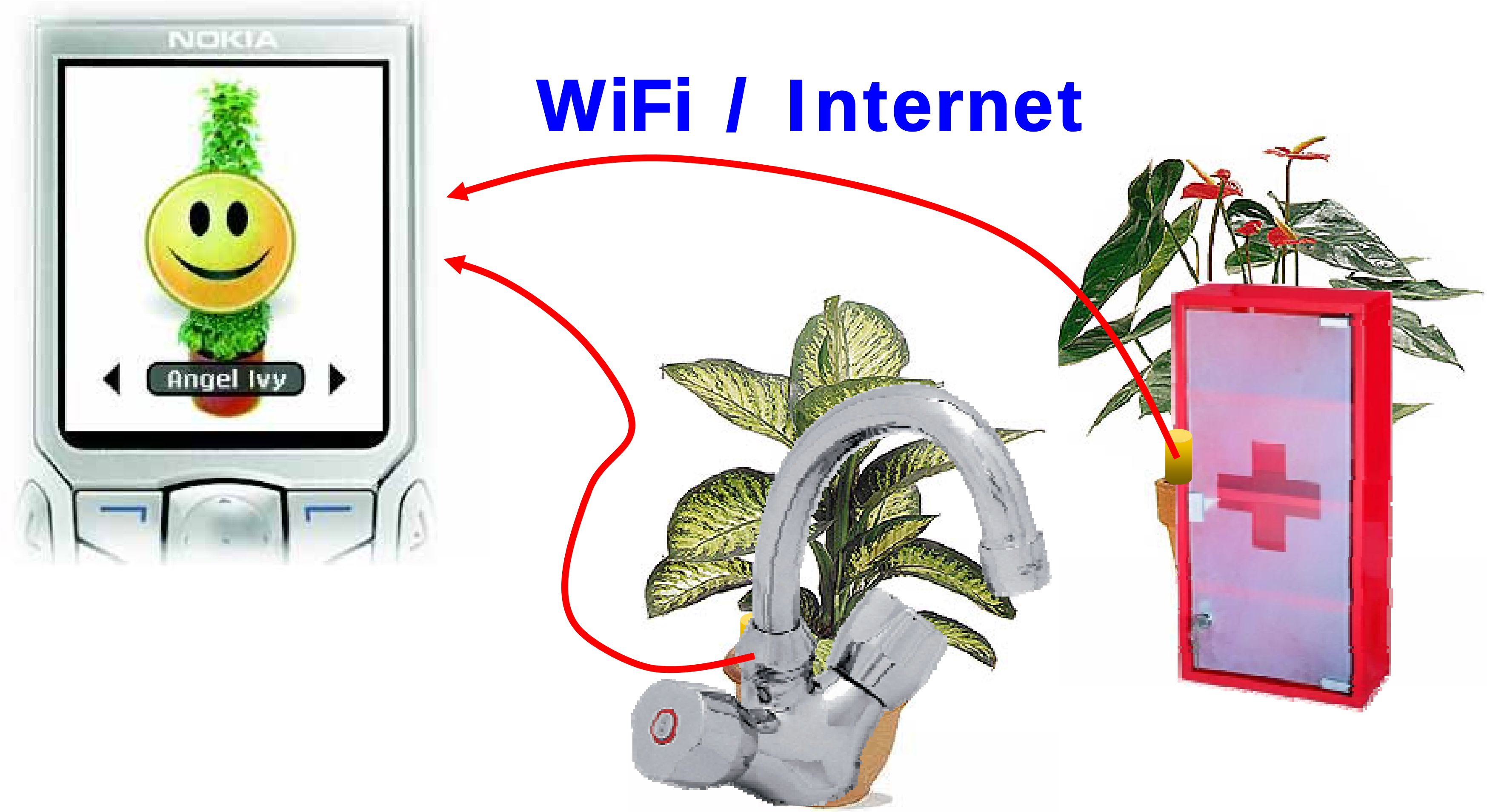
38 x 20 x 2.5 mm

Low Power WiFi Systems



Communication with Plants

Communication with ~~Plants~~ the Internet of Things



Koubachi

ETH spin-off: Philipp Bolliger, Moritz Köhler

koubachi mobile app

Give your plant a voice!

Connecting Things to the Web using Programmable Low-power WiFi Modules

Benedikt Ostermaier, Matthias Kovatsch, Silvia Santini
Institute for Pervasive Computing, ETH Zurich
Zurich, Switzerland
{ostermaier, kovatsch, santinis}@inf.ethz.ch

ABSTRACT

We present first experiences of using programmable low-power WiFi modules for connecting things directly to the Web. Instead of relying on dedicated low-power radio technology and specialized protocols, we leverage the ubiquity of IEEE 802.11 access points and the interoperability of the HTTP protocol. Using a loosely coupled approach, we enable seamless association of sensors, actuators, and everyday objects with each other and with the Web. Our experimental results show that low power WiFi modules can achieve long battery lifetime despite the fact that we are using HTTP over TCP/IP for communication.

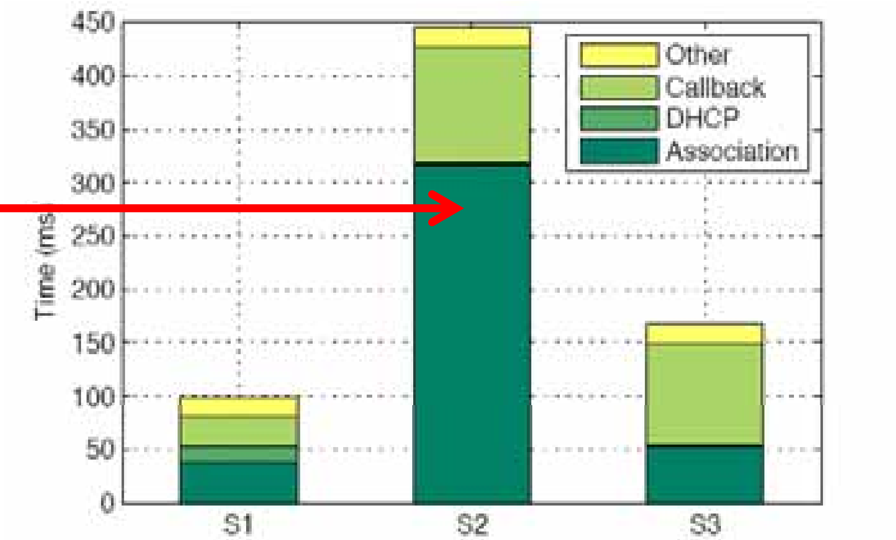
1. INTRODUCTION

PAN [9], or CoAP [15], we rely on the ubiquity of WiFi and the interoperability of HTTP. No gateways nor protocol translations are necessary in order to make physical objects fully Web-enabled. This represents a significant advantage with respect to efforts that rely on more energy-efficient, but less interoperable protocols for low-power networks.

In the next section, we briefly discuss related work. In Sect. 3, we provide background information and present our approach for connecting things to the Web. Sect. 4 describes the hardware platform we leveraged to support our investigations. In Sect. 5, we discuss the prototypical implementation of our approach. Preliminary experimental results that demonstrate the feasibility of our approach are presented in Sect. 6. Finally, Sect. 7 concludes the paper and provides an outlook on further research.

Measurement Results

- With good WiFi routers (S1, S3):
  > 99% successful http callbacks,
  100 – 150 ms
  - Use repetitions to reach “100%”
- Bad router S2: increased delay
  - MAC retransmissions, congestion
- Two 1100 mAh AAA batteries →
  8 years live time with 100 events/d
  - Not considering battery self-discharge



- Limited WiFi distance (~15m, one floor above / below)
- Varying network quality caused by interference in the 2.4 GHz band
- Bootstrapping complexity: Specification of SSID and authentication key

Web
The ~~Internet~~ of Things

- Communication with things simply via URLs:
  - GET or POST on
  - http://myhome.com/**fridge/temp**
- A network of things, based on general Web-Standards
  - http / REST principle
  - HTML, JSON, XML
  - use of the „Web-ecosystem“
- No TCP (too heavyweight)
  - IP end-to-end connectivity
  - new higher-level protocol (CoAP?)

Connecting Everyday Objects to the Web!

The Web [2.0] Era

Social Networks

Web APIs to Services

Web Languages / Frameworks

Universal Browsers

New interaction devices

Connecting Everyday Objects to the Web!

The Web [2.0] Era

A flexible, mighty, ubi-quitous “ecosystem”

→ Make that available to smart objects!

Social Networks

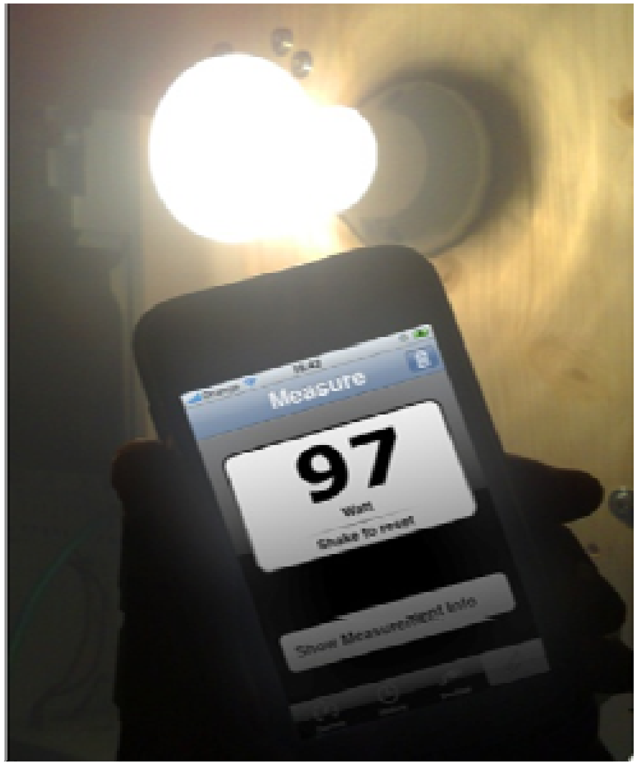
Web APIs to Services

Web Languages / Frameworks

Universal Browsers

New interaction devices

Power Consumption of Household Devices – a WoT-based Solution



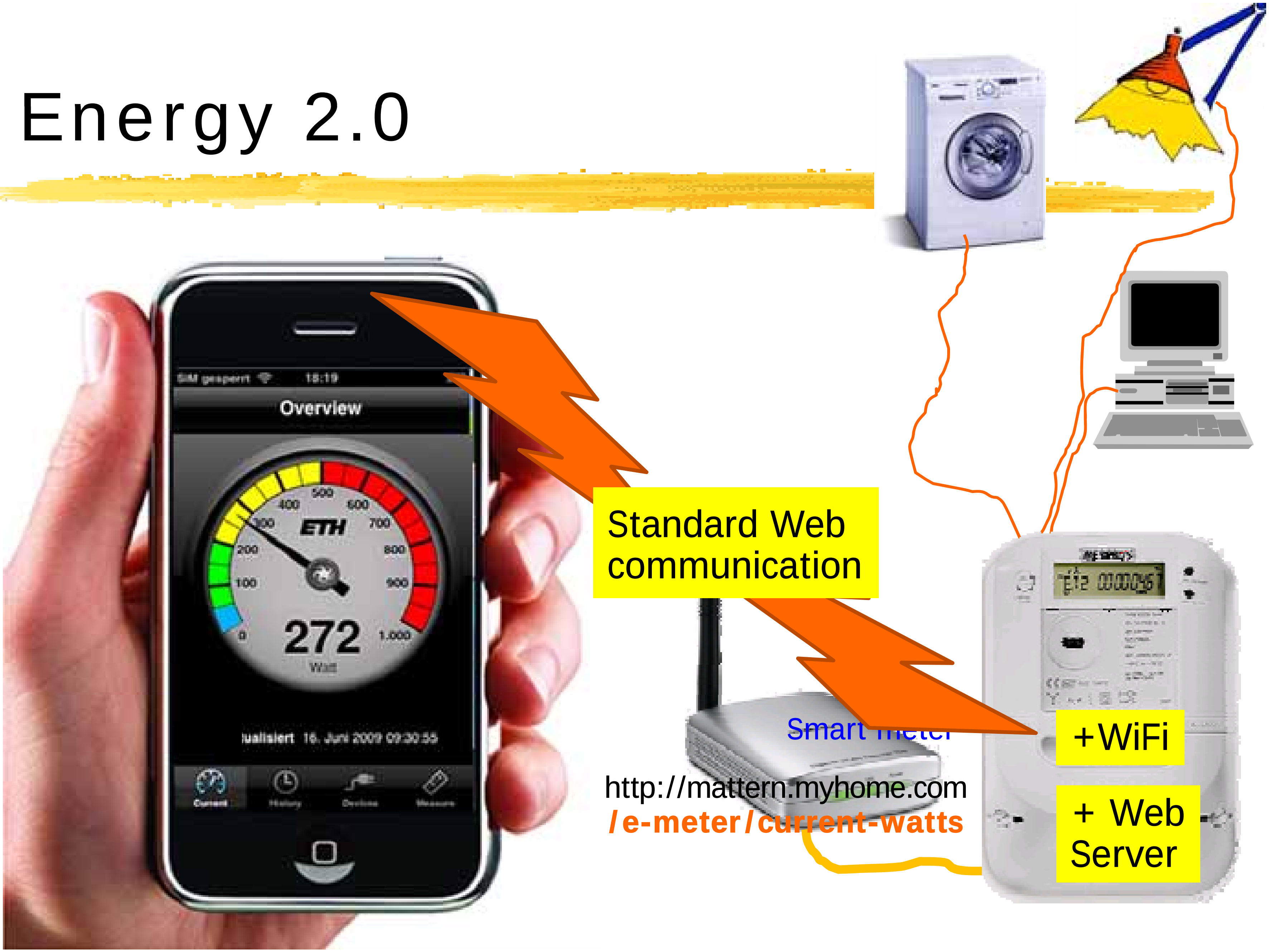
Switch on / off device for a second

Energy 2.0


SIM gesperrt
18:19
Overview
ETH
0
100
200
300
400
500
600
700
800
900
1.000
272
Watt
ualisiert 16. Juni 2009 09:30:55


0444698
kWh

Energy 2.0

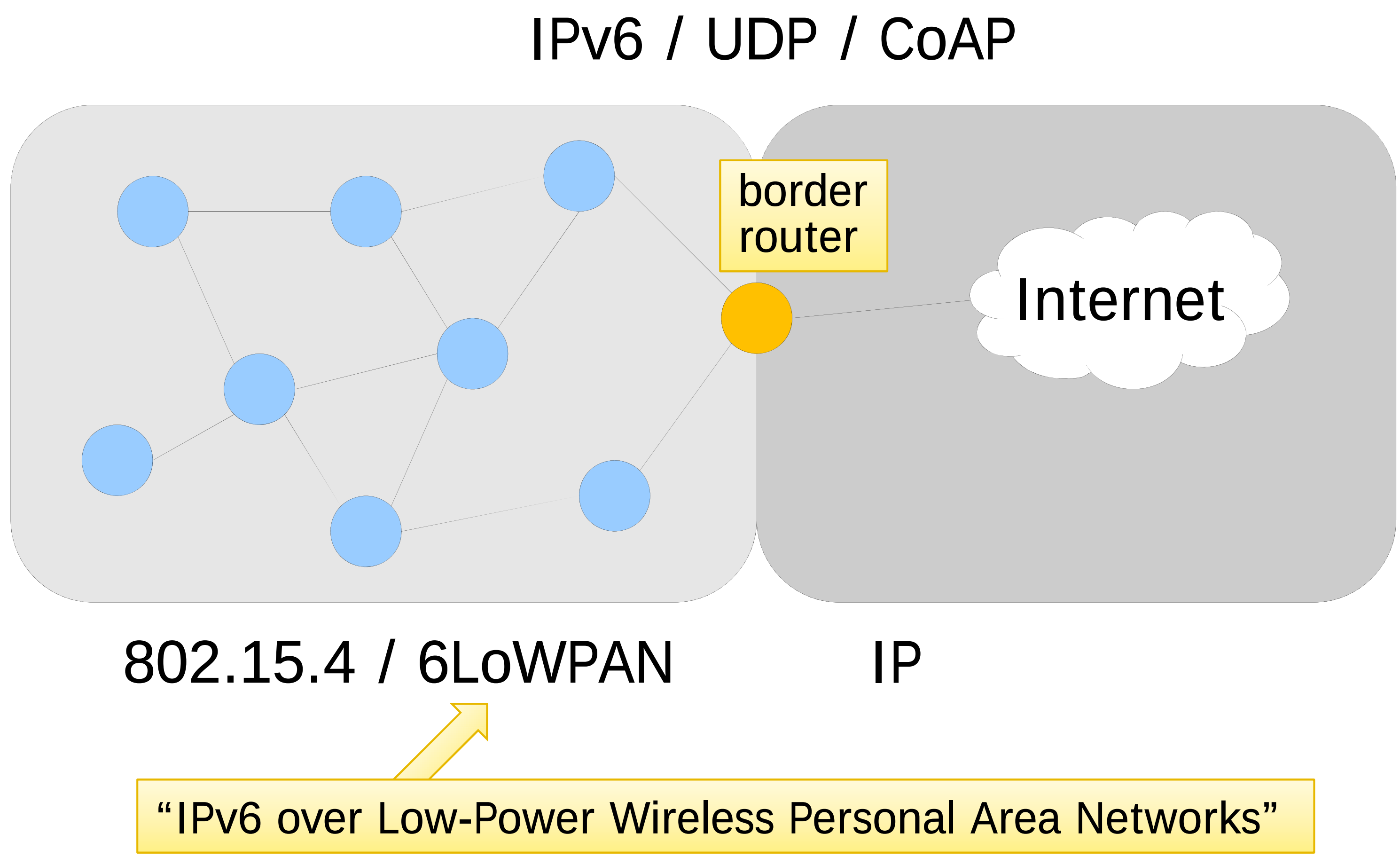


SIM gesperrt 18:19
Overview
ETH
272
Watt
ualisiert 16. Juni 2009 09:30:55
Standard Web communication
Smart
http://mattern.myhome.com
/e-meter/current-watts
+WiFi
+ Web Server

“Web of Things”


KAFFEE
BEREIT
Measure
1463
Watt
Show Measurement info
Continue
jura
IMPRESSA S70

Connecting Resource-Constrained Devices to the Internet



A Typical IoT / WoT Protocol Stack

Layer	Protocol
Application	Constrained Application Protocol (CoAP)
Transport	UDP
Network	IPv6 / RPL
Adaption	6LoWPAN
MAC	CSMA / link-layer bursts
Radio Duty Cycling	IEEE 802.15.4e (“ContikiMAC“)
Physical	IEEE 802.15.4

No TCP

COAP: An Application Layer Protocol for the IoT / WoT

- IETF Constrained Application Protocol (CoAP)
  - RESTful Web services for resource-constrained devices
  - URIs, simple http mapping
  - Asynchronous message exchange
  - Reliable UDP transport («confirmable»)
  - Alternative transport bindings (e.g., SMS)
  - Push notifications (observer paradigm)
  - Multicast
  - Resource discovery
  - Binary (optimized for parsing)
  - Supports sleepy nodes, bulky data
  - Datagram Transport Layer Security (DTLS)

IETF

draft-ietf-core-coap-12

Short Distance Communication Standards

Besides WiFi and 802.15.4 (+ 6LoWPAN or Zigbee) there are several other classical and new standards

- Z-Wave and Wireless M-Bus (home automation)
- Bluetooth

- WiFi Direct: simple connection of devices without a wireless access point or router; several proximity pairing options
- Bluetooth low energy (BLE) – Bluetooth SMART / Bluetooth 4.0: much shorter setup time
- DECT ULE – ultra low energy: 1.9 GHz band (cordless handsets)
- OMA LWM2M (Open Mobile Alliance Lightweight Machine to Machine Technical Specification): Based on CoAP principles

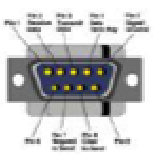
The CloudThink Project @ MIT Massachusetts Institute of Technology

An open data / open source standard for vehicles

- Cars are big data producers

The CloudThink Project @ MIT Massachusetts Institute of Technology

An open data / open source standard for vehicles

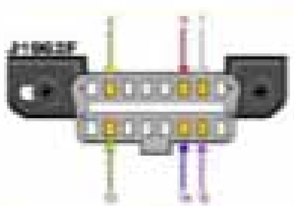


CAN Bus

Motor current/voltage/temperature
Battery current/voltage/temperature/SOC
Vehicle speed > 5 Hz
Various high-frequency power train data

Ghost car in the cloud

- Car data synchronized with cloud
- Applications run in the cloud



OBD-II

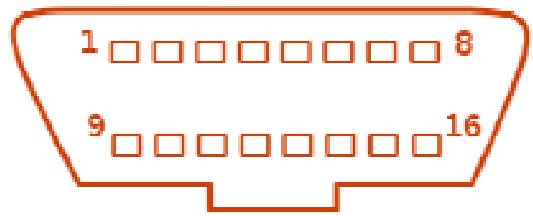
Speed < 5 Hz
Distance (approx.)
Barometric pressure
Engine RPM
Engine torque

Calculated engine load
Throttle position
Mass air flow rate
Fuel trim
Fuel consumption (calc.)

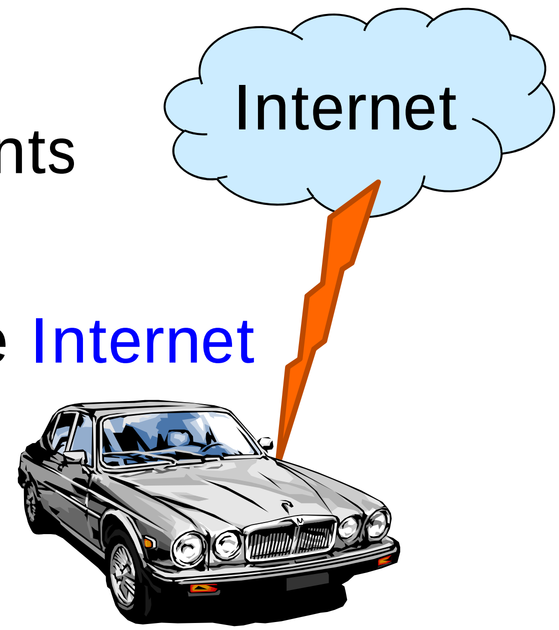
Engine fuel rate
Engine temperature
Emission system status
Diagnostic trouble codes

OBD II Standard

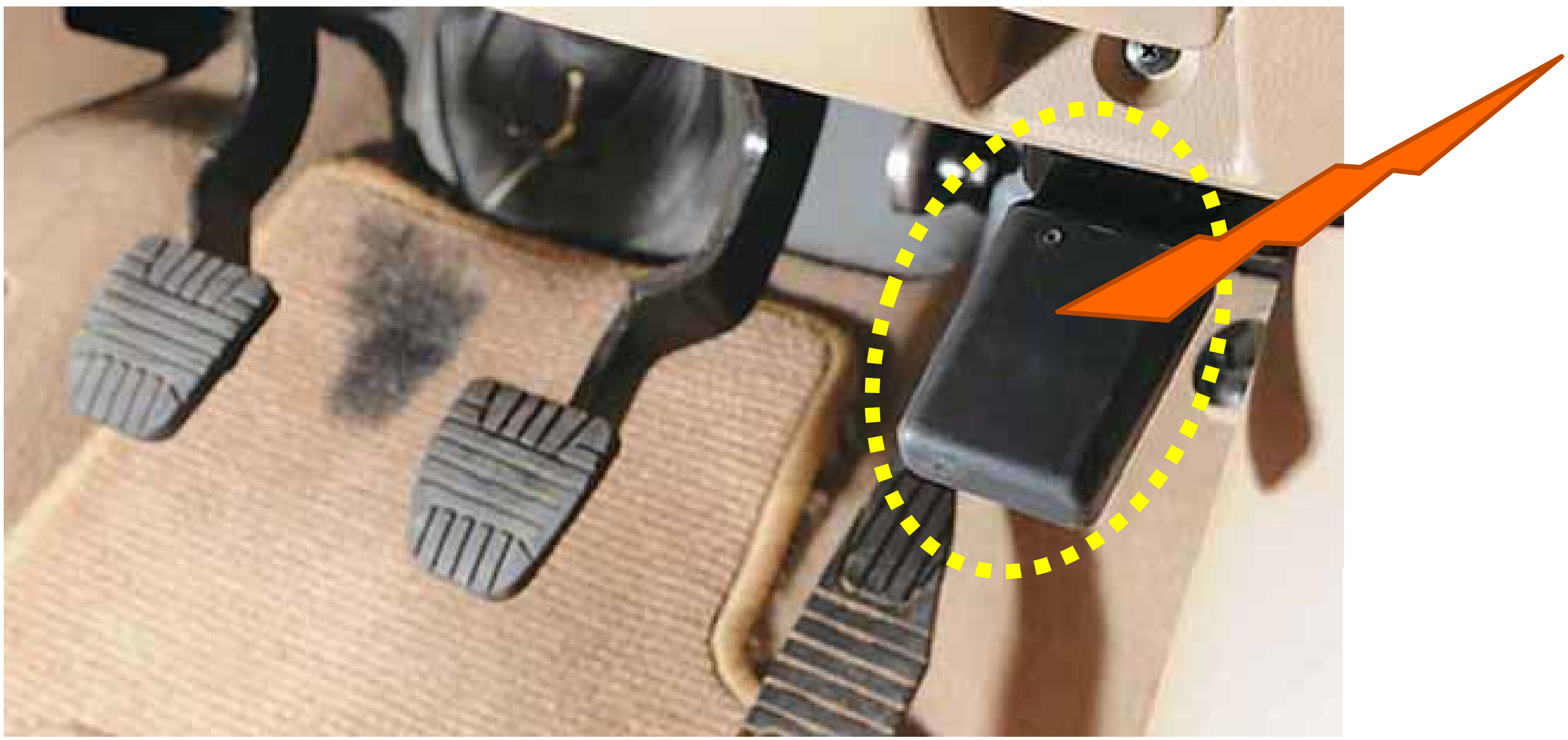
- Originally "On-Board Diagnostics"
  - access to state of health information for various vehicle sub-systems



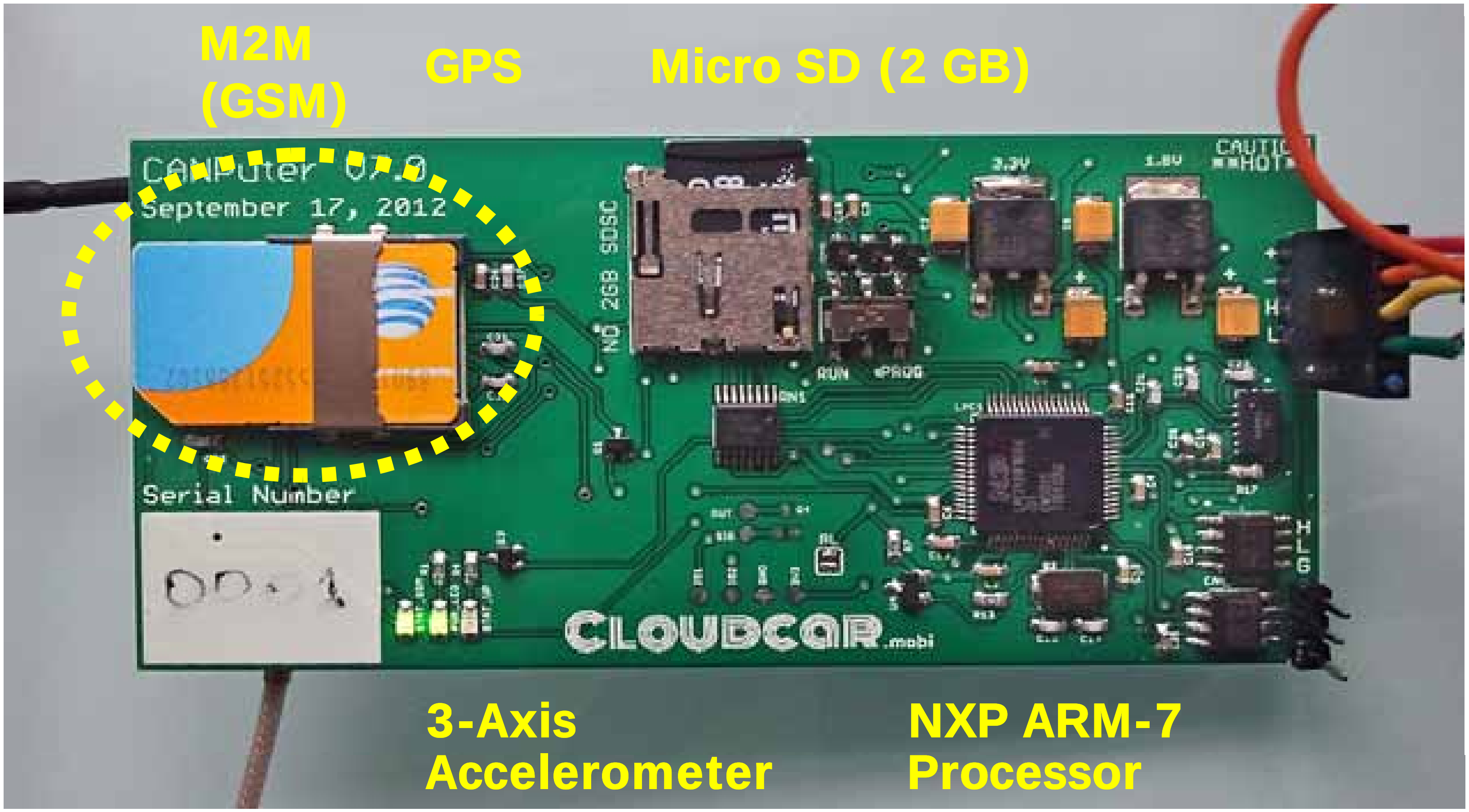
- Access the OBD-II data via connector
  - e.g., car location via on-board GPS
- Query the on-board computer
- Gain control over many vehicle components
  - lock doors, activate breaks,...
- CloudThinks: Make this accessible via the Internet
  - the cloud stores the data and hosts services



Smart OBD II Plug



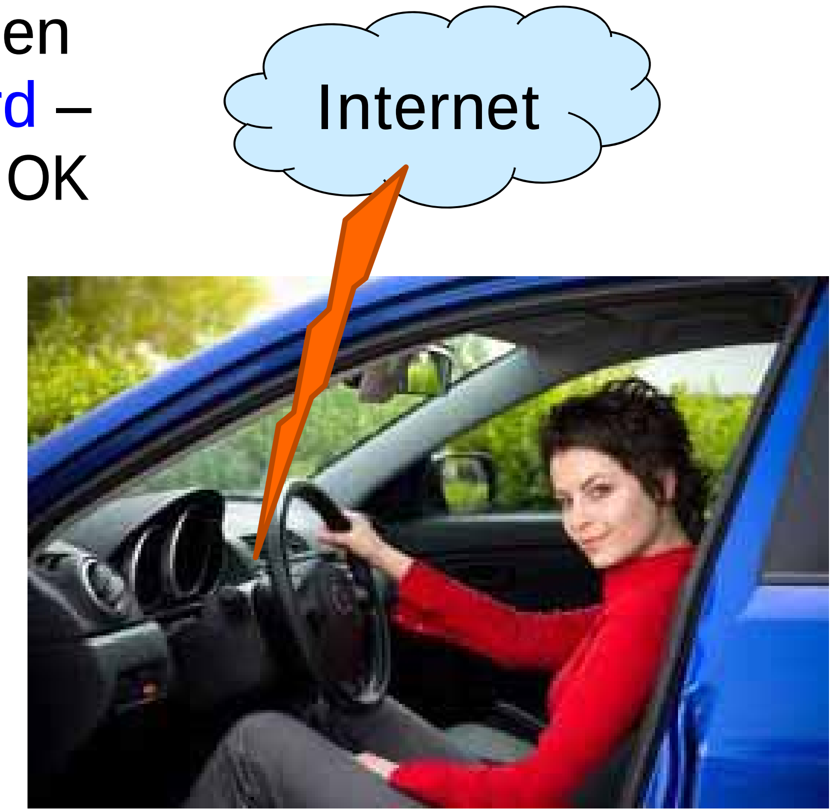
Inside the Smart Plug



Production cost: ~100 USD, available under open-source license

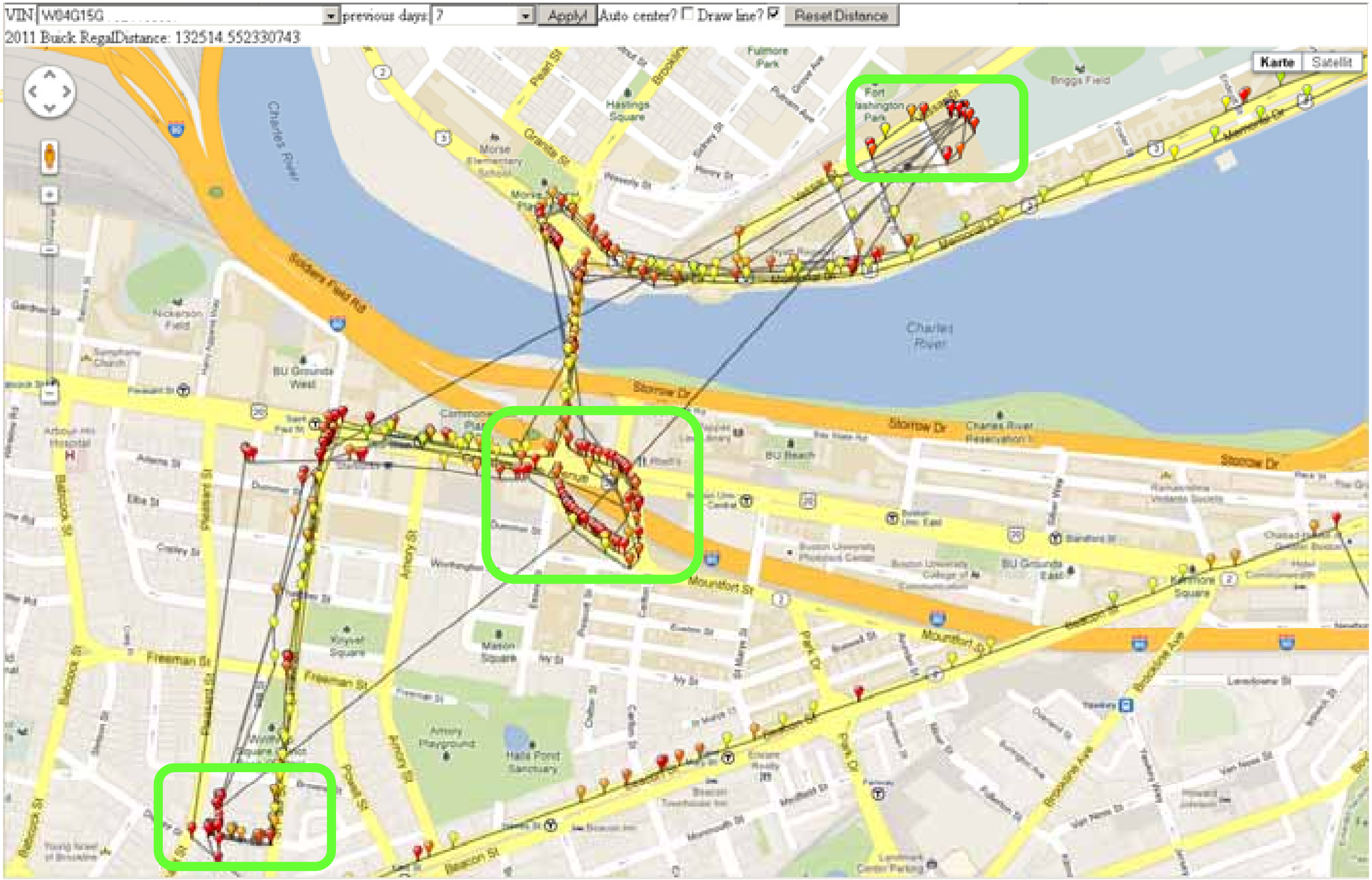
Plug-and-forget

- Connect device to OBD-port, then insert memory card and SIM card – if the light blinks, everything is OK

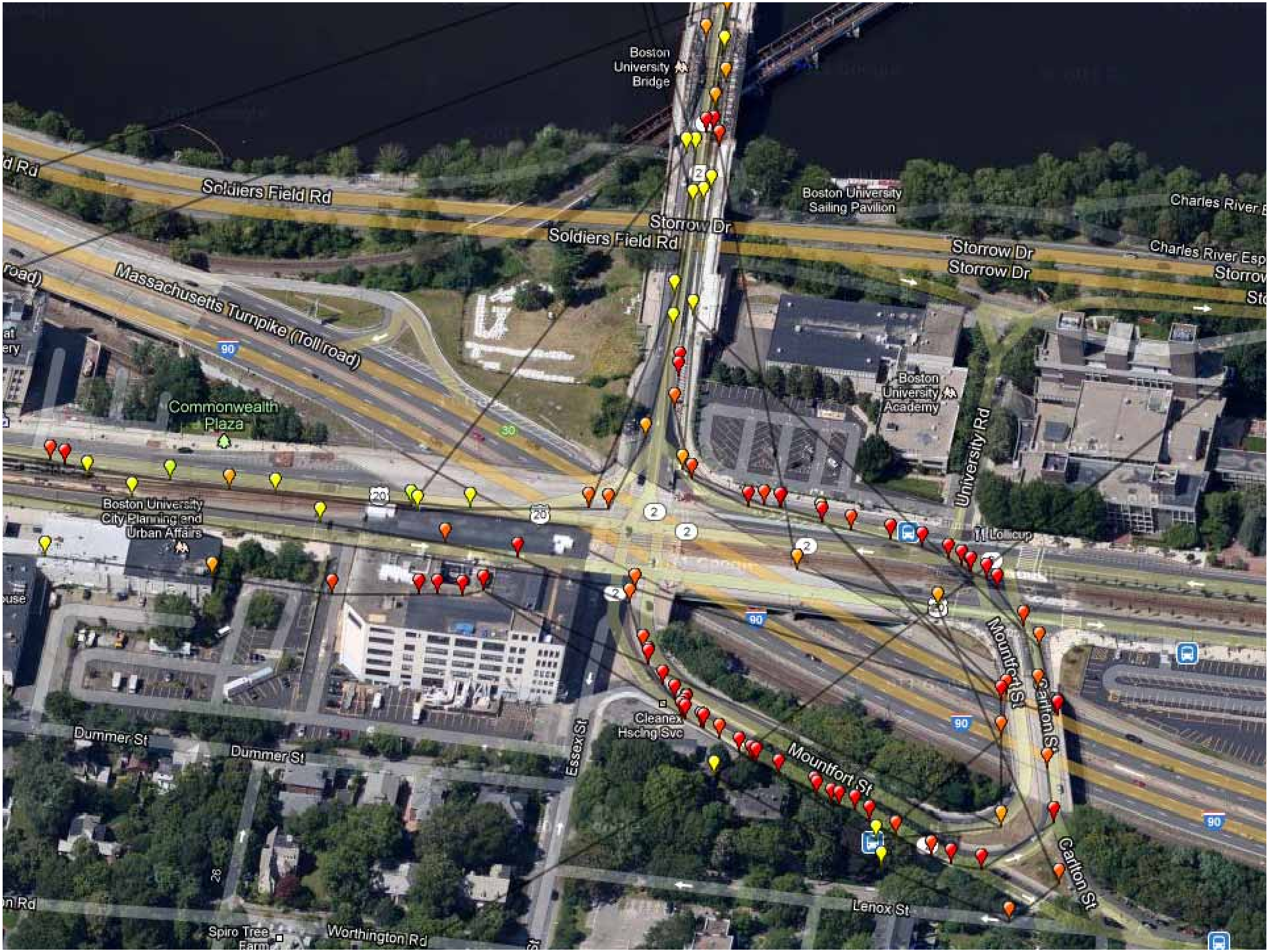


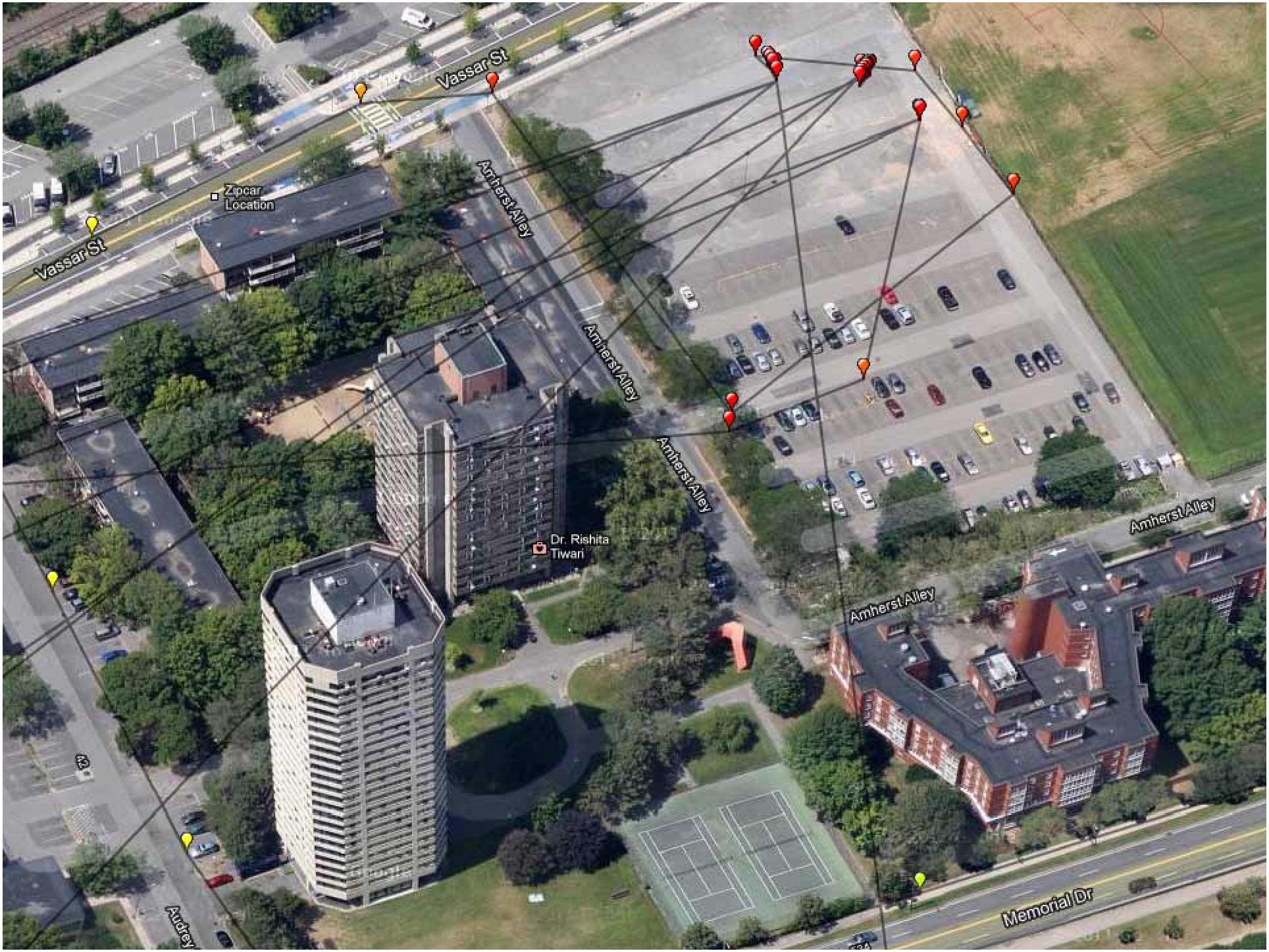
- Car makers now introduce their own proprietary systems – we strive for an open-data system while respecting privacy

Example: Google Maps Mashup



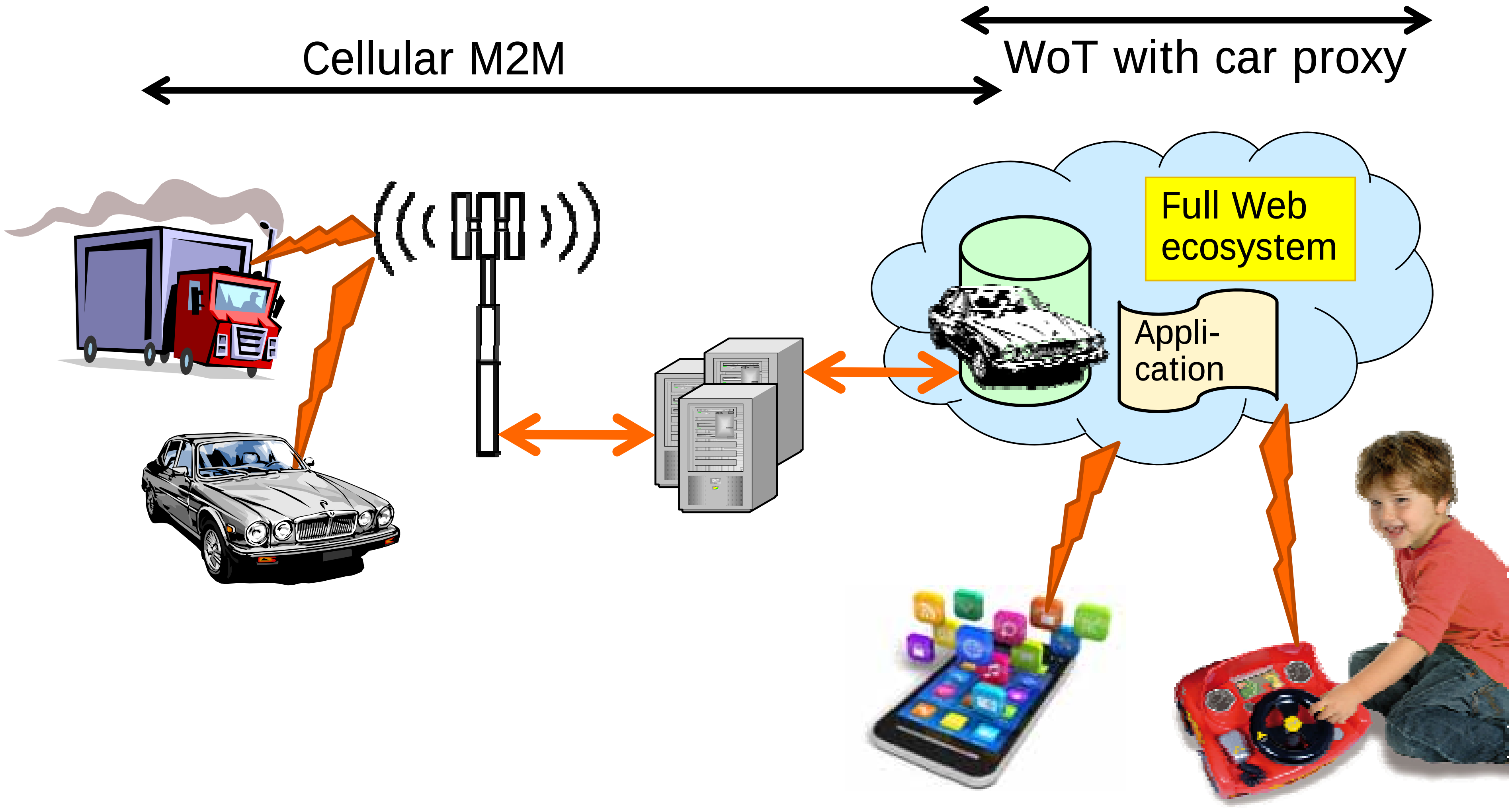
Pleasant St
Pleasant St
Parkman St
Parkman St
Parkman St
Jenny M.
Gibbs Design


Boston University Bridge
Soldiers Field Rd
Boston University Sailing Pavilion
Storrow Dr
Charles River Esp
Massachusetts Turnpike (Toll road)
Commonwealth Plaza
Boston University Academy
University Rd
Boston University City Planning and Urban Affairs
Lollicup
Mountfort St
Carlton St
Dummer St
Essex St
Cleanex Hsclng Svc
Lenox St
Worthington Rd
Spiro Tree Farm



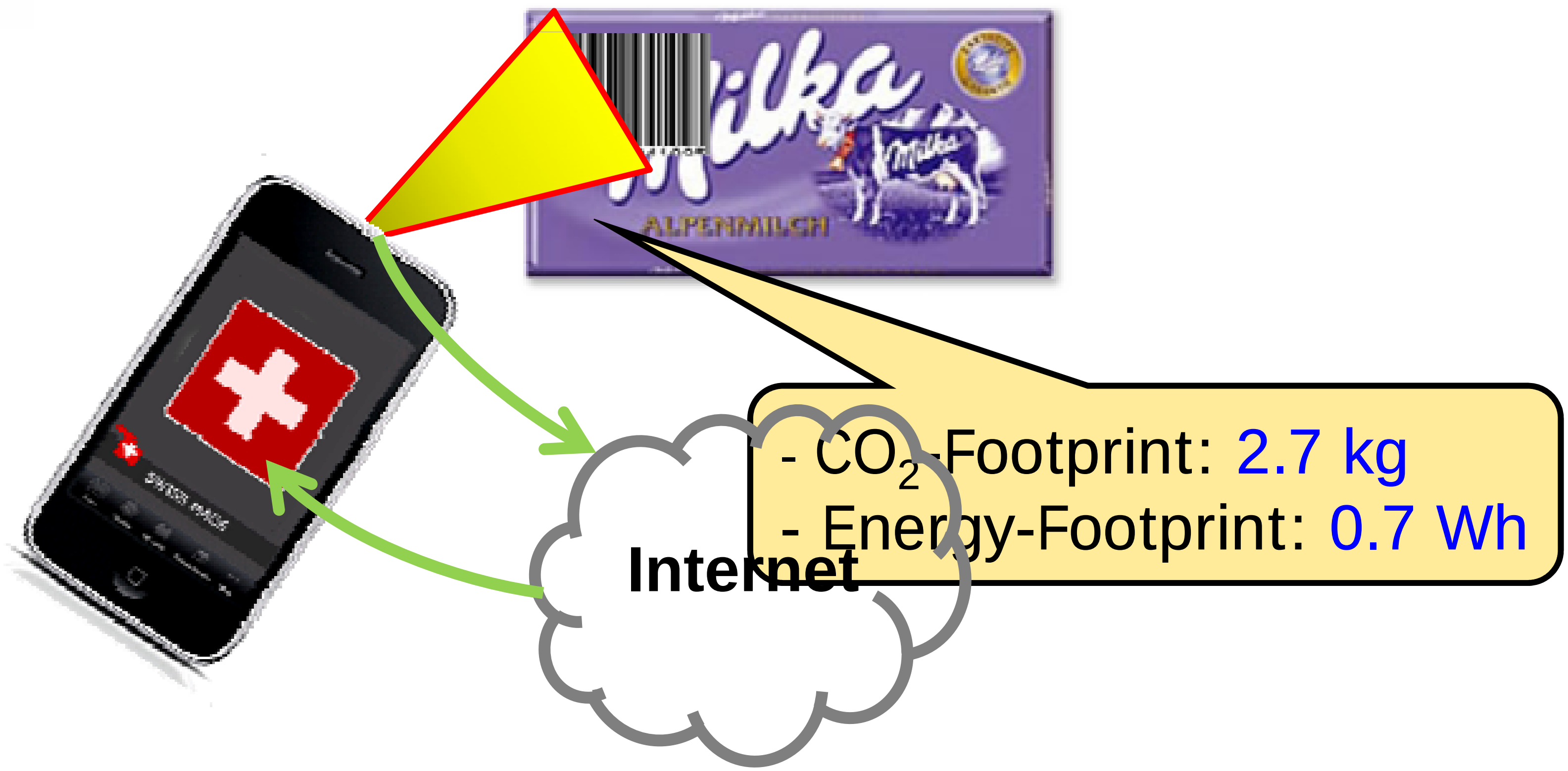
Vassar St
Vassar St
Zipcar Location
Amherst Alley
Amherst Alley
Amherst Alley
Amherst Alley
Amherst Alley
Dr. Rishita Tiwari
Memorial Dr
Audrey

Car Proxy Bridges the Two Worlds



Proxies for Really Dumb Things

Swissness Indicator



Proxies for Really Dumb Things

- The smartphone acts as a proxy or mediator for the dumb object
- NFC and RFID technologies can be used in similar scenarios

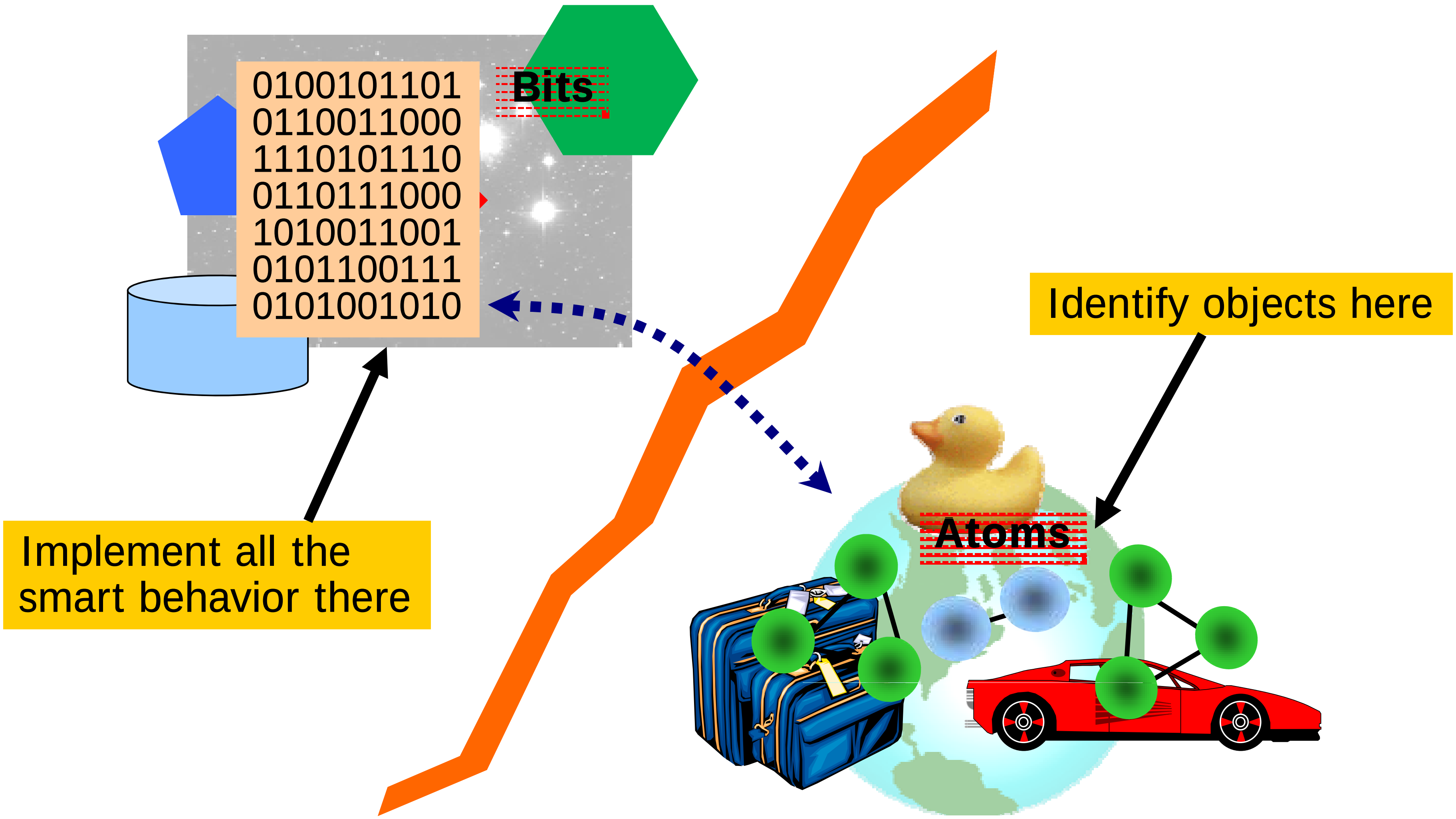
Proxies for Really Dumb Things Make Them to Appear Smart

Interactive physical products

Picking up an RFID tagged product will trigger the sign to display related informational and promotional content such as similar product recommendations, user reviews, pricing, or a feature tour

PATHIC
VITAMINS
PharmaTech DataPoint
Product Information:

Connecting Atoms and Bits



http://people.inf.ethz.ch/mattern/publ.html

Friedemann Mattern, Christian Floerkemeier: From the Internet of Computers to the Internet of Things. In: Kai Sachs, Ilia Petrov, Pablo Guerrero (Eds.): From Active Data Management to Event-Based Systems and More. Springer, LNCS Vol. 6462, pp. 242-259, 2010

From the Internet of Computers to the Internet of Things

Friedemann Mattern and Christian Floerkemeier

Distributed Systems Group, Institute for Pervasive Computing, ETH Zurich
{mattern,floerkem}@inf.ethz.ch

Abstract. This paper[1] discusses the vision, the challenges, possible usage scenarios and technological building blocks of the "Internet of Things". In particular, we consider RFID and other important technological developments such as IP stacks and web servers for smart everyday objects. The paper concludes with a discussion of social and governance issues that are likely to arise as the vision of the Internet of Things becomes a reality.

Keywords: Internet of Things, RFID, smart objects, wireless sensor networks.

In a few decades time, computers will be interwoven into almost every industrial product.

Karl Steinbuch, German computer science pioneer, 1966

1 The Vision

The Internet of Things represents a vision in which the Internet extends into the real world embracing everyday objects. Physical items are no longer disconnected from the virtual world, but can be controlled remotely and can act as physical access points to Internet services. An Internet of Things makes computing truly ubiquitous – a

Vom Internet der Computer zum Internet der Dinge

Friedemann Mattern, Christian Flörkemeier

http://people.inf.ethz.ch/mattern/publ.html

Es wird in wenigen Jahrzehnten kaum mehr Industrieprodukte geben, in welche die Computer nicht hineingewoben sind.
Karl Steinbuch, 1966

Das Internet der Dinge steht für eine Vision, in der das Internet in die reale Welt hinein verlängert wird und viele Alltagsgegenstände ein Teil des Internets werden. Dinge können dadurch mit Information versehen werden oder als physische Zugangspunkte zu Internetservices dienen, womit sich weitreichende und bis dato ungeahnte Möglichkeiten auftun.

Die Vision

Die Vision vom Internet der Dinge beruht auf der Extrapolation des anhaltenden und uns fast zur Selbstverständlichkeit gewordenen Fortschritts von Mikroelektronik, Kommunikationstechnik und Informationstechnologie. Indem aufgrund ihrer abnehmenden Größe und ihres ständig zurückgehenden Preises und Energiebedarfs immer mehr Prozessoren, Kommunikationsmodule und andere Elektronikkomponenten in Gegenstände des täglichen Gebrauchs integriert werden, dringt Informationsverarbeitung, gekoppelt mit Kommunikationsfähigkeit, fast überall ein, sogar in Dinge, die zumindest auf den ersten Blick keine elektrischen Geräte darstellen. Damit rückt die bereits Anfang der 1990er-Jahre von Mark Weiser mit „Ubiquitous Computing" [33] bezeichnete Vorstellung einer umfassenden Informatisierung und Vernetzung der Welt und ihrer vielen Gegenstände in greifbare Nähe. Diese schleichende aber nachdrückliche Entwicklung eröffnet große Chancen für Wirtschaft und Privatleben, birgt jedoch auch Risiken und stellt zweifellos eine gewaltige technische und gesellschaftliche Herausforderung dar.

The Technical Foundations of M2M and the Internet of Things

Friedemann Mattern

ETH Zürich