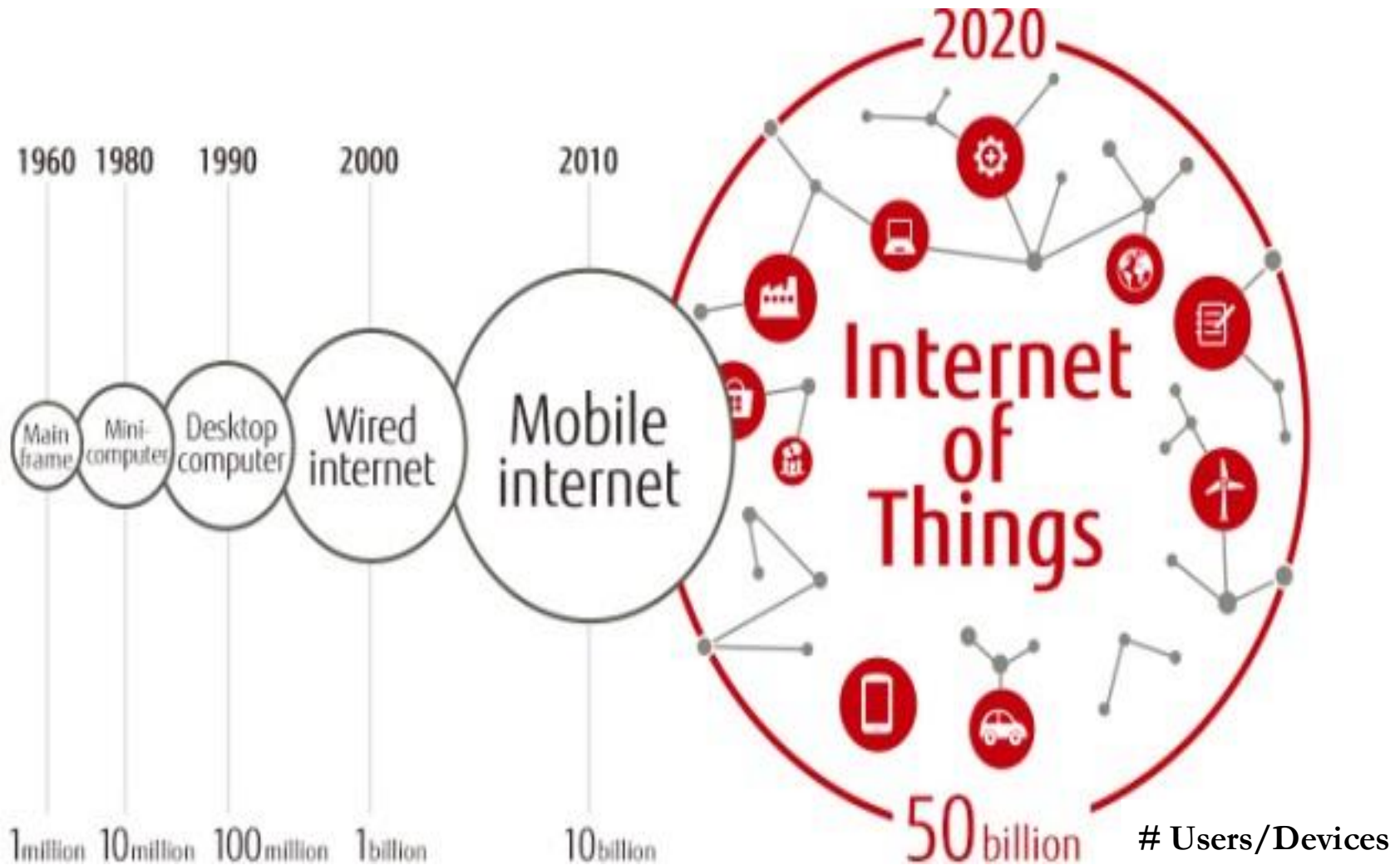


# Mobile Crowdsensing and Computing

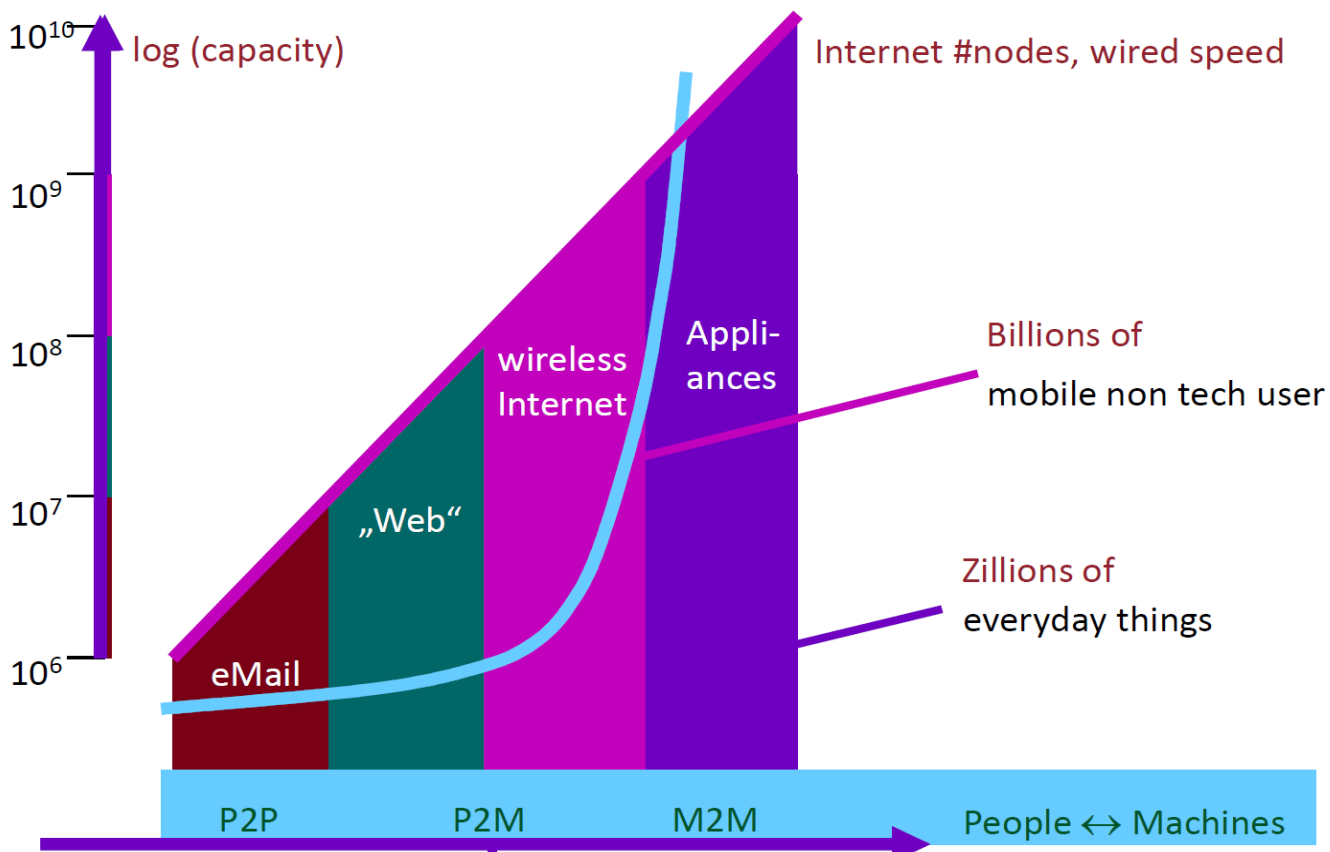
A.Y. 2017/2018  
Brain Mind and  
Computer Science

# A brief history of computing



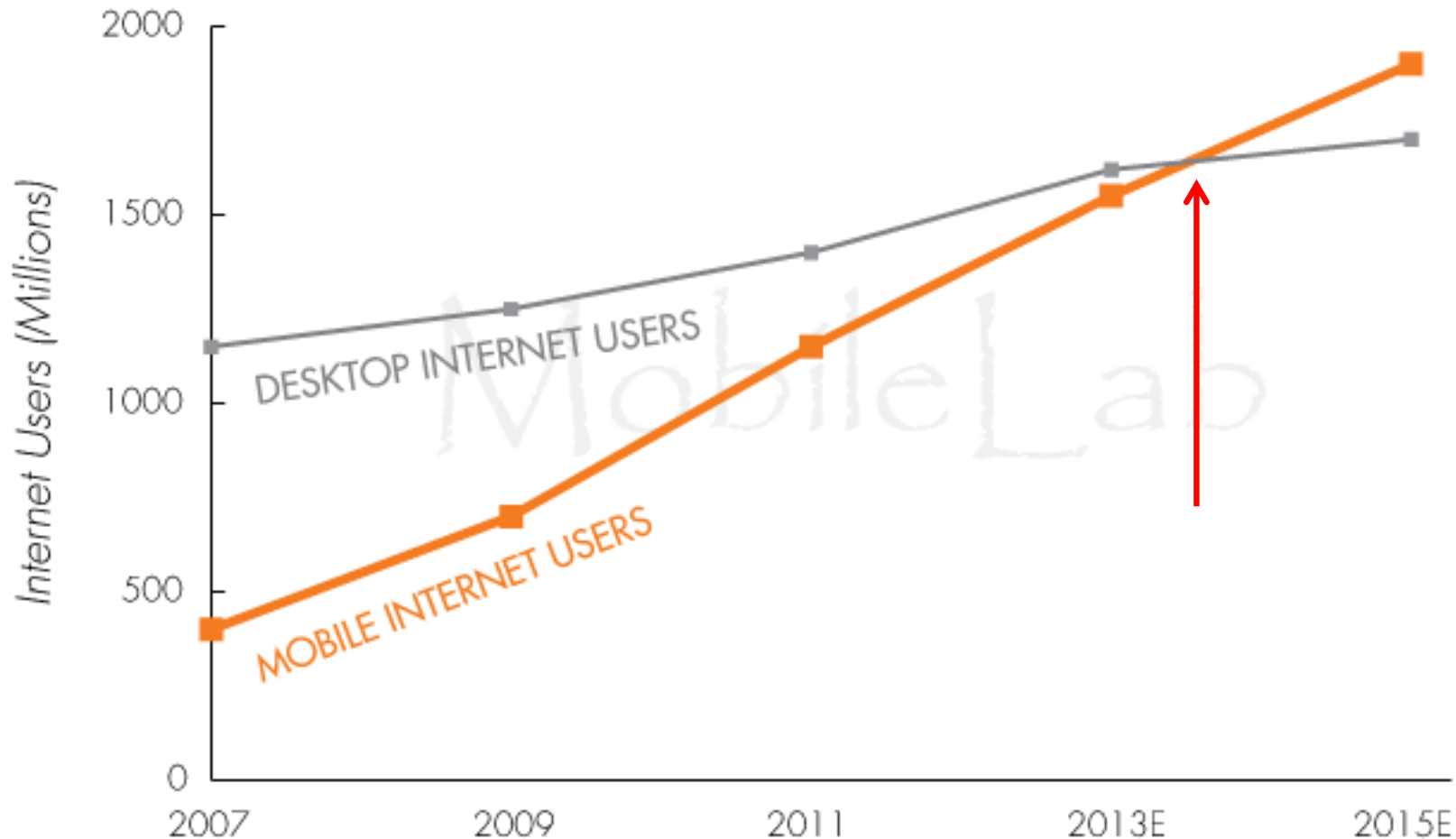
# Explosion of nodes

**issue:** on the networking side, the **exponential growth** (# of nodes connected in the Internet) continues way beyond the world's population consequence: **scalability** becomes even more crucial



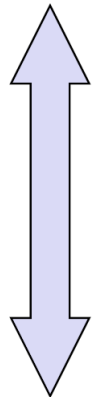
# Mobile surpassing desktop users

## Desktop vs. Mobile Web Usage Trends & Projections

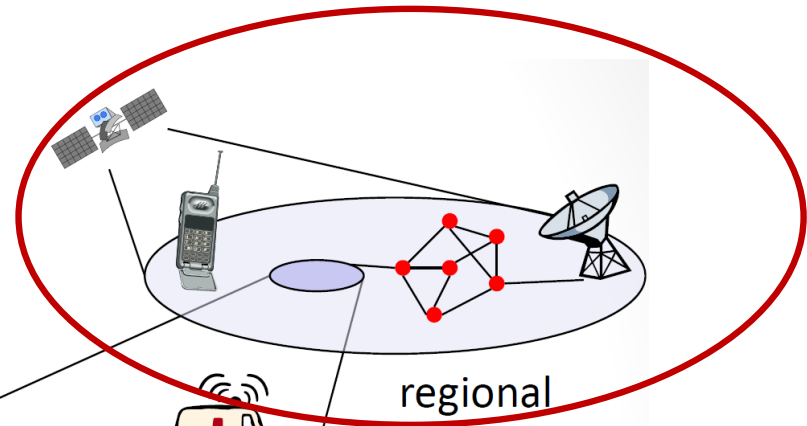


# An Overlay of Networks

integration of heterogeneous fixed and mobile networks with varying transmission characteristics

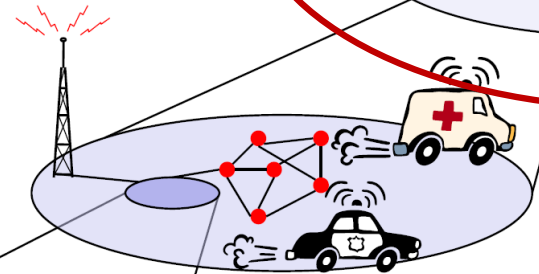


vertical hand-over



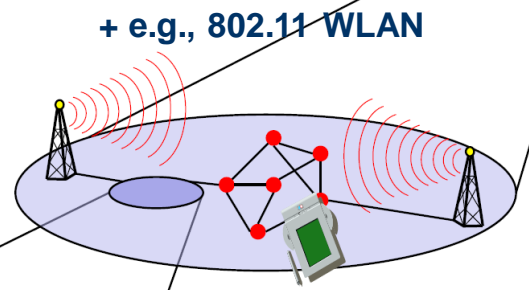
regional

+ e.g., satellite, cellular



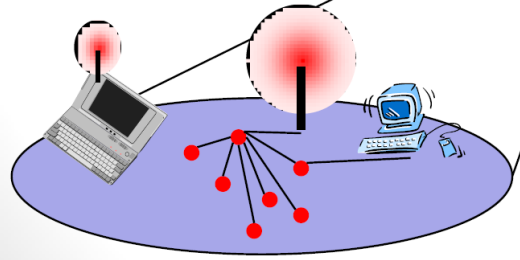
metropolitan area

+ e.g., 802.16 MAN (WiMax)



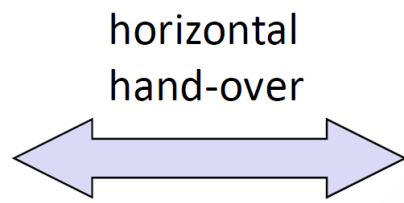
+ e.g., 802.11 WLAN

campus-based



802.15 PAN, ZigBee, BLE ...

in-house



horizontal hand-over

# On-going research: Nano-Satellites

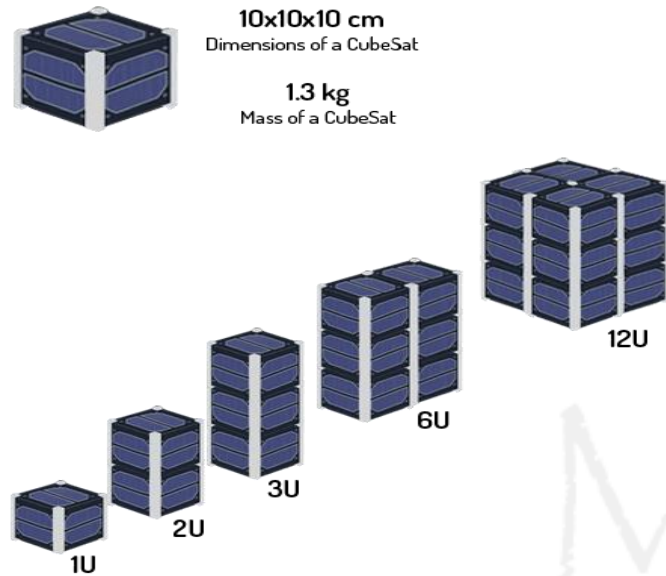


Figure: CubeSat taxonomy

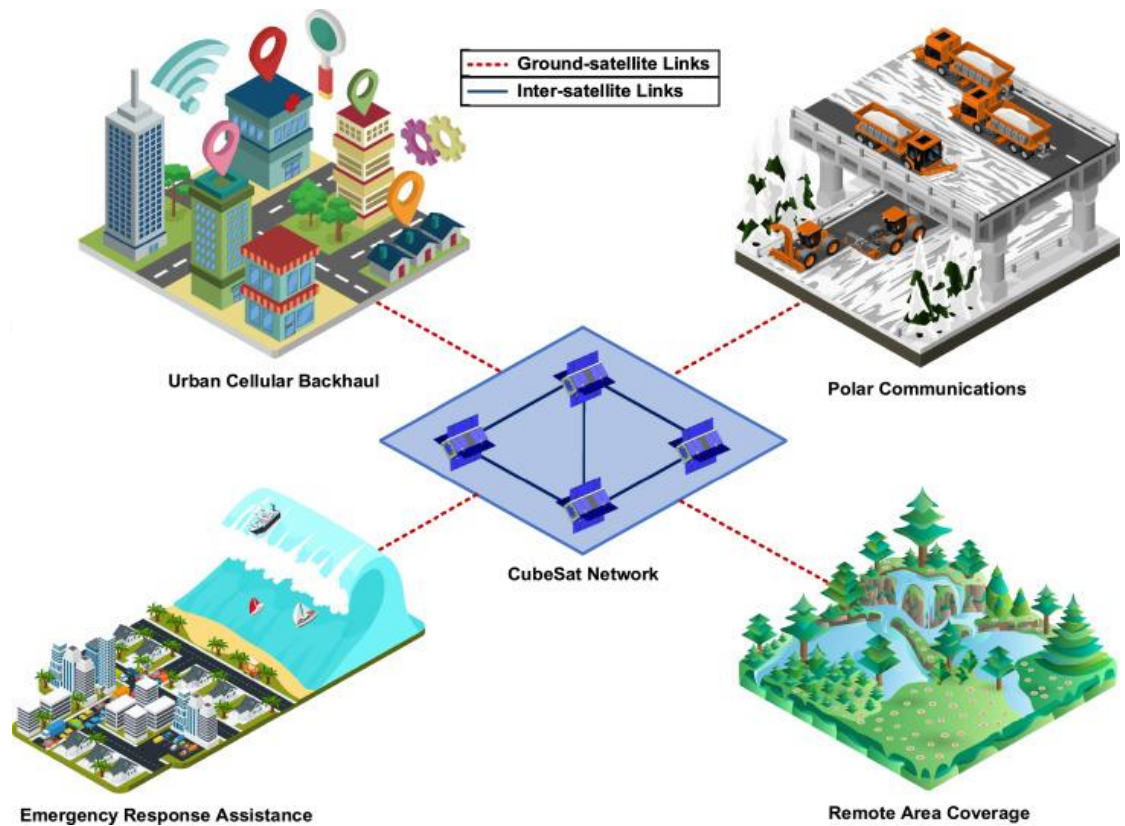


Figure: In-space backhaul scenarios.

Figure: CubeSat launch from ISS in 2012, over 1000 launched till 2019.

# Internet of Space Things (IoST)



# Internet of Space Things (IoST)





# Evolution from 1G to 5G

1G

**Analog**

*voice capability,  
limited coverage  
and mobility*

2 kbps

AMPS



1980

1990

2G

**Digital**

*better voice,  
improved coverage,  
text messaging*

64 kbps

GSM, CDMA



2000

3G

**Mobile Data**

*basic Internet,  
multimedia,  
smaller phones*

2 Mbps

HSPA, EVDO



2010

4G

**Mobile  
Broadband**

*high-speed data,  
smartphones*

1 Gbps

LTE, LTE-A



5G

**Extreme Speed,  
Connectivity &  
Reliability**

*a platform for  
future innovation*

10+ Gbps



2020

# The NFV Concept

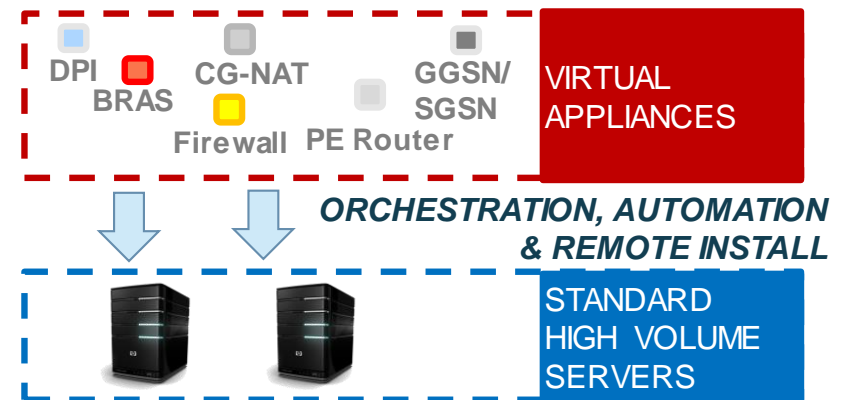
A means to make the **network more flexible and simple** by **minimising dependence on HW constraints**

## Traditional Network Model: APPLIANCE APPROACH



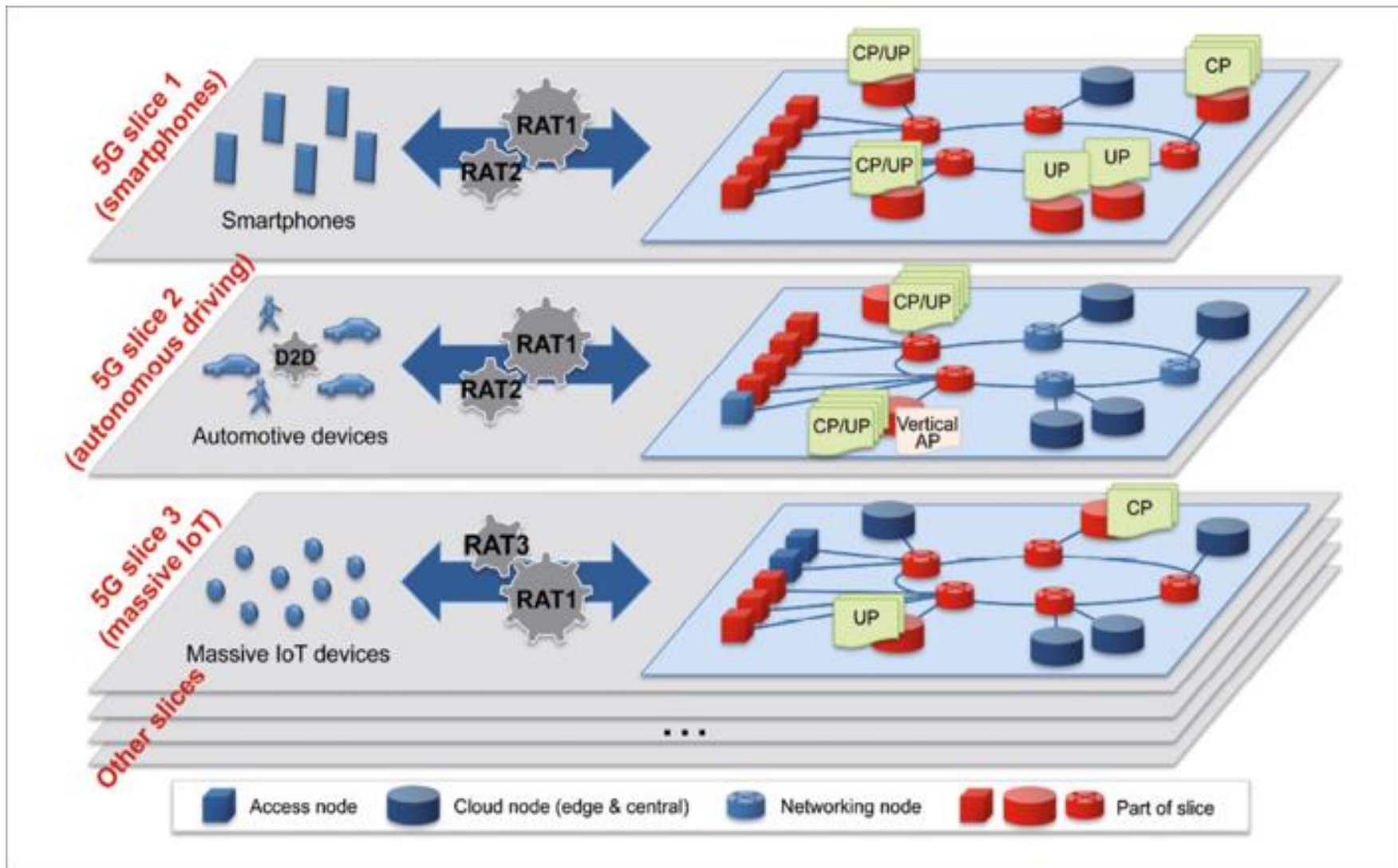
- Network Functions are **based on specific HW&SW**
- **One physical node per role**

## Virtualised Network Model: VIRTUAL APPLIANCE APPROACH



- Network Functions are **SW-based over well-known HW**
- **Multiple roles over same HW**

# 5G – Network Slicing Concept



# The Internet Of Things?



# History of Internet of Things

**1800s**



The first electronic communication devices are created, including the telegraph, fax machine, and radio

**1989**



**Tim Berners-Lee** proposed the **World Wide Web**

**MID 1990s**



The **rise of the Internet** and more experimental devices



1993 Trojan Room Coffee Pot



1998 inTouch Project



1998 Mark Weiser's Stock Market Water Fountain

**1926**

**Nikola Tesla** envisions a wirelessly interconnected world



*"When wireless is perfectly applied the whole earth will be converted into a huge brain."*

**1990**

The first connected devices are created – a toaster and drink machine



**1999**

**Kevin Ashton** coins 'Internet of Things' and founds the **MIT Auto-ID Center**



**2000**



**LG** announces plans for the first Internet refrigerator

**2005**



**The United Nations** first mentions IoT in a published **International Telecommunications Union** report

*A new dimension has been added to the world of information and communication...from anytime, anyplace connectivity for anyone, we will now have connectivity for anything. Connections will multiply and create an entirely new dynamic network of networks – an Internet of Things.*

**2011**



**Internet Protocol version 6 (IPv6)** launches, which allows around 340 undecillion IP addresses (340,282,366,920,938,463,463,374,607,431,768,211,456)

*"We could assign an IPv6 address to every atom on the surface of the earth, and still have enough addresses left to do another 100+ earths."*

**2002**

**Ambient Orb** is released, which displays Dow Jones, personal finance, and weather information based on Internet data



**2008**

**IPSO** alliance launches to promote the use of Internet Protocol (IP) in connected devices



**2013**

**Intel** launches 'Internet of Things Solutions Group'



# Core stages of an IoT architecture



End-to-End, Proactive,  
Defence-in-depth  
**Security**



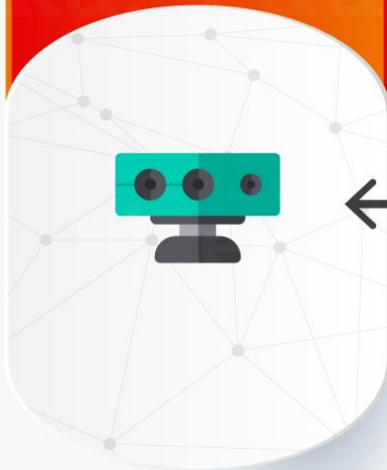
Open, Extensive,  
Partner driven  
**Ecosystem**



Advise, Transform,  
Integrate, Operate, Manage  
**Services**

**STAGE 1**

**Sensors/Actuators**  
(wired, wireless)



**STAGE 2**

**Sensors/Actuators,  
Data Acquisition  
Systems**  
(data aggregation, A/D,  
measurement, control)



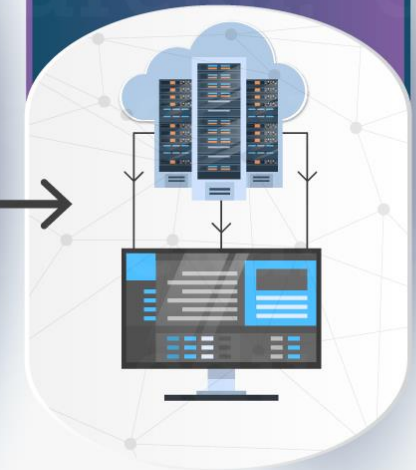
**STAGE 3**

**Edge IT**  
(analytics, pre-processing)



**STAGE 4**

**Data Centre / Cloud**  
(analytics,  
management, archive)



**Analytics  
Management  
Control**



**Analytics  
Management  
Control**



**Analytics  
Management  
Control**



**Analytics  
Management  
Control**





# Smart Systems and the Internet of Things are driven by a combination of:

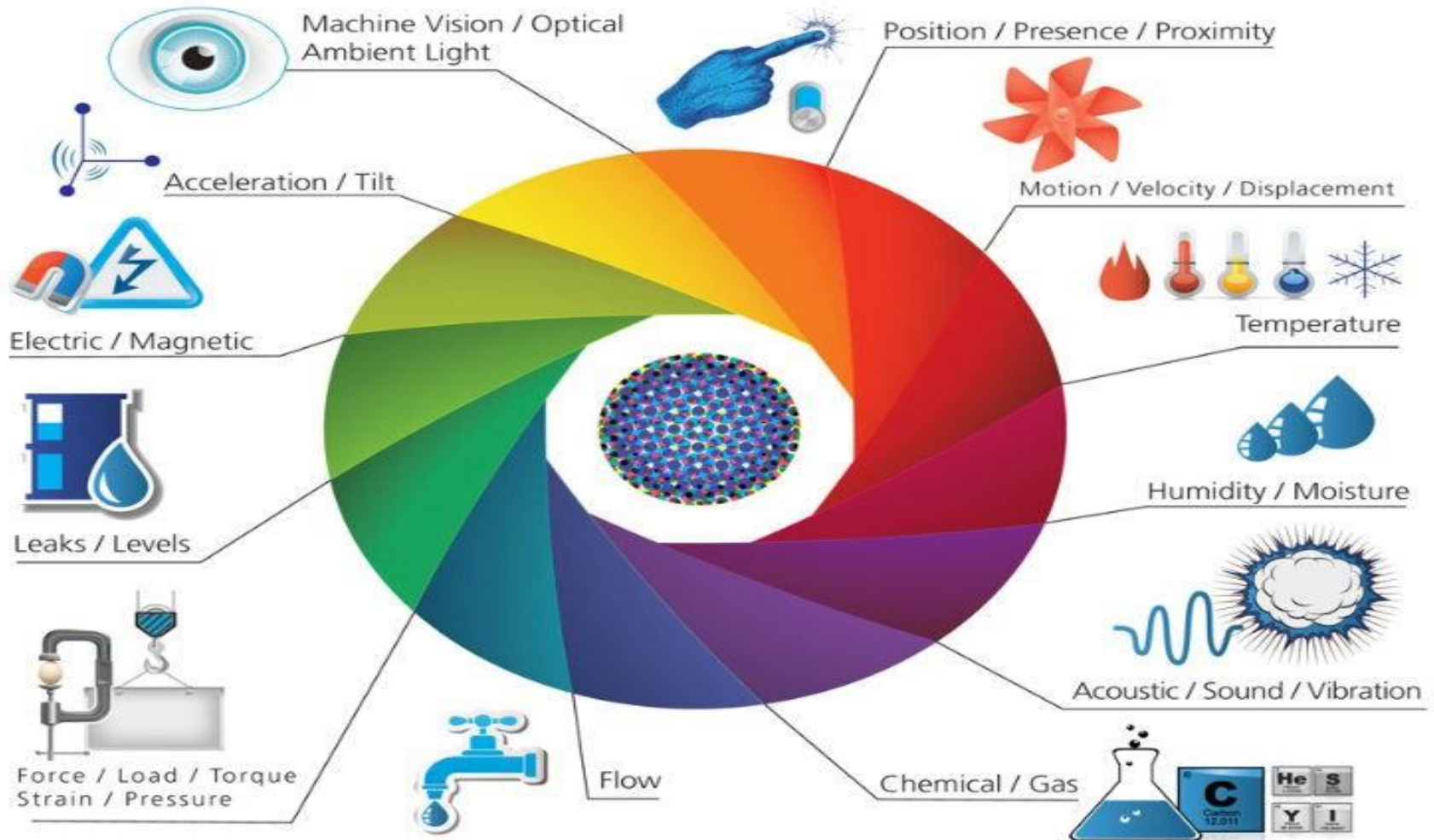
**1** **SENSORS**  
& ACTUATORS

**2** **CONNECTIVITY**

**3** **PEOPLE &  
PROCESSES**

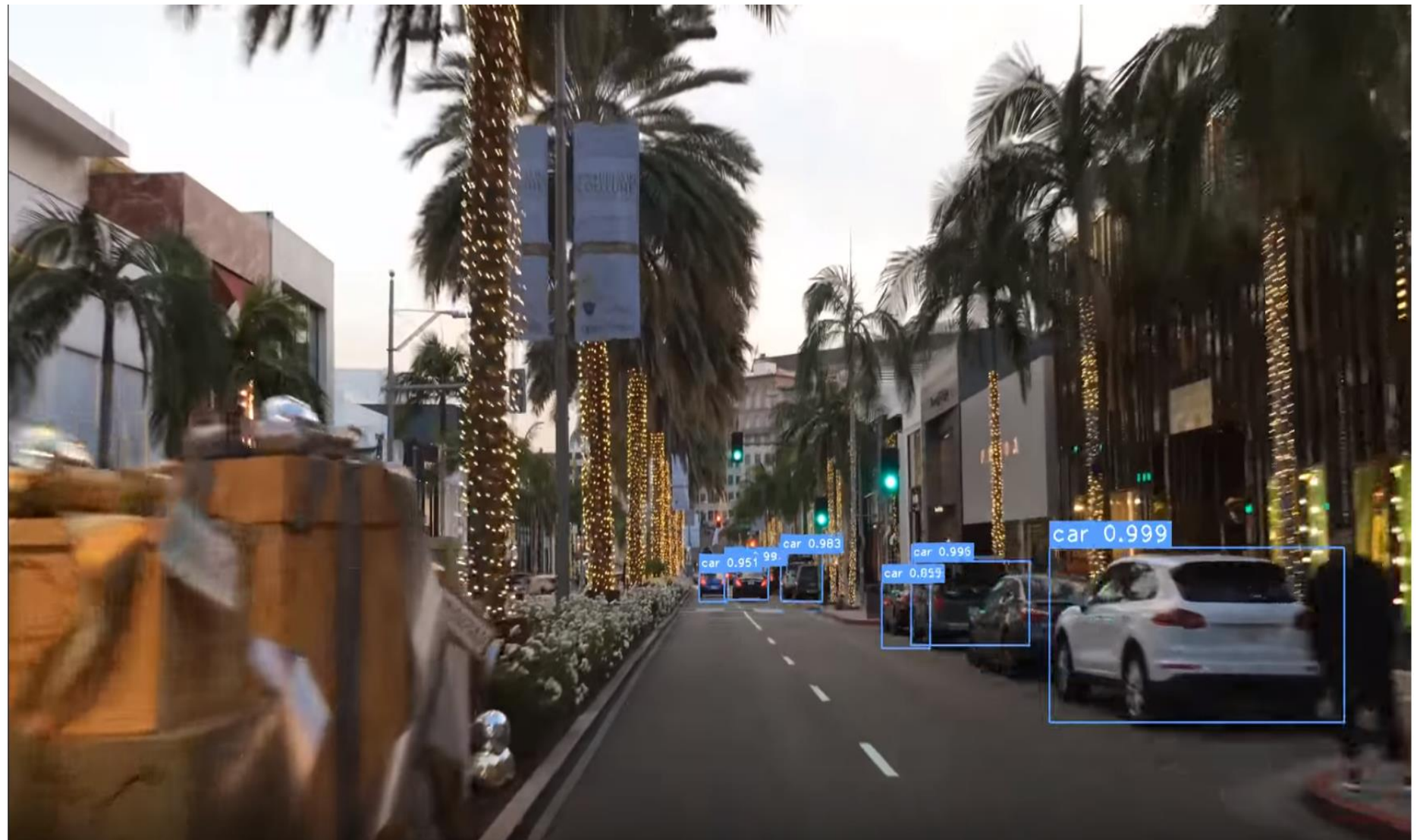
# 1 SENSORS & ACTUATORS

We are giving our world a digital nervous system. Location data using GPS sensors. Eyes and ears using cameras and microphones, along with sensory organs that can measure everything from temperature to pressure changes.





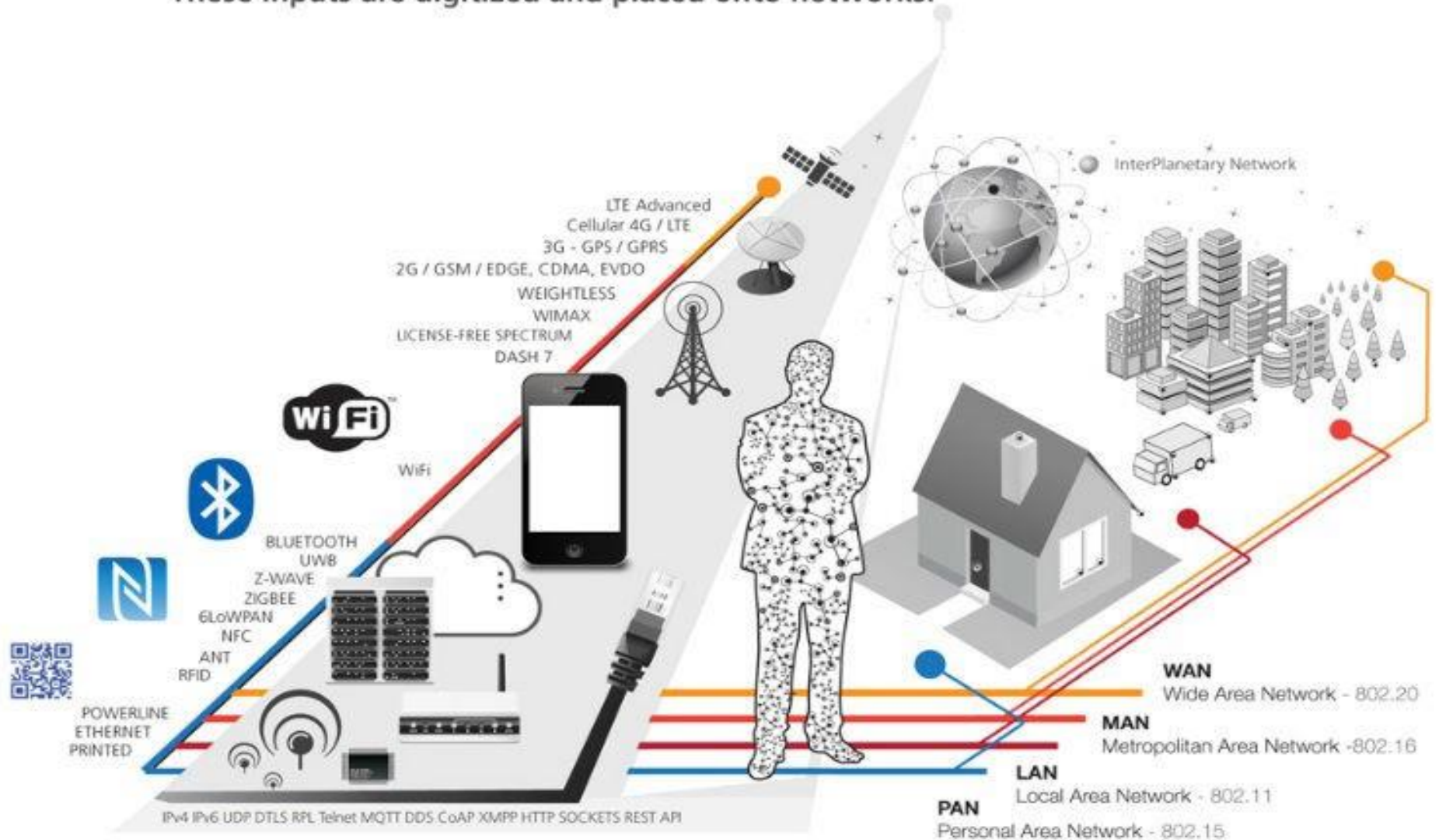
# What a driverless car sees



[Google's driverless car program](#)

# 2 CONNECTIVITY

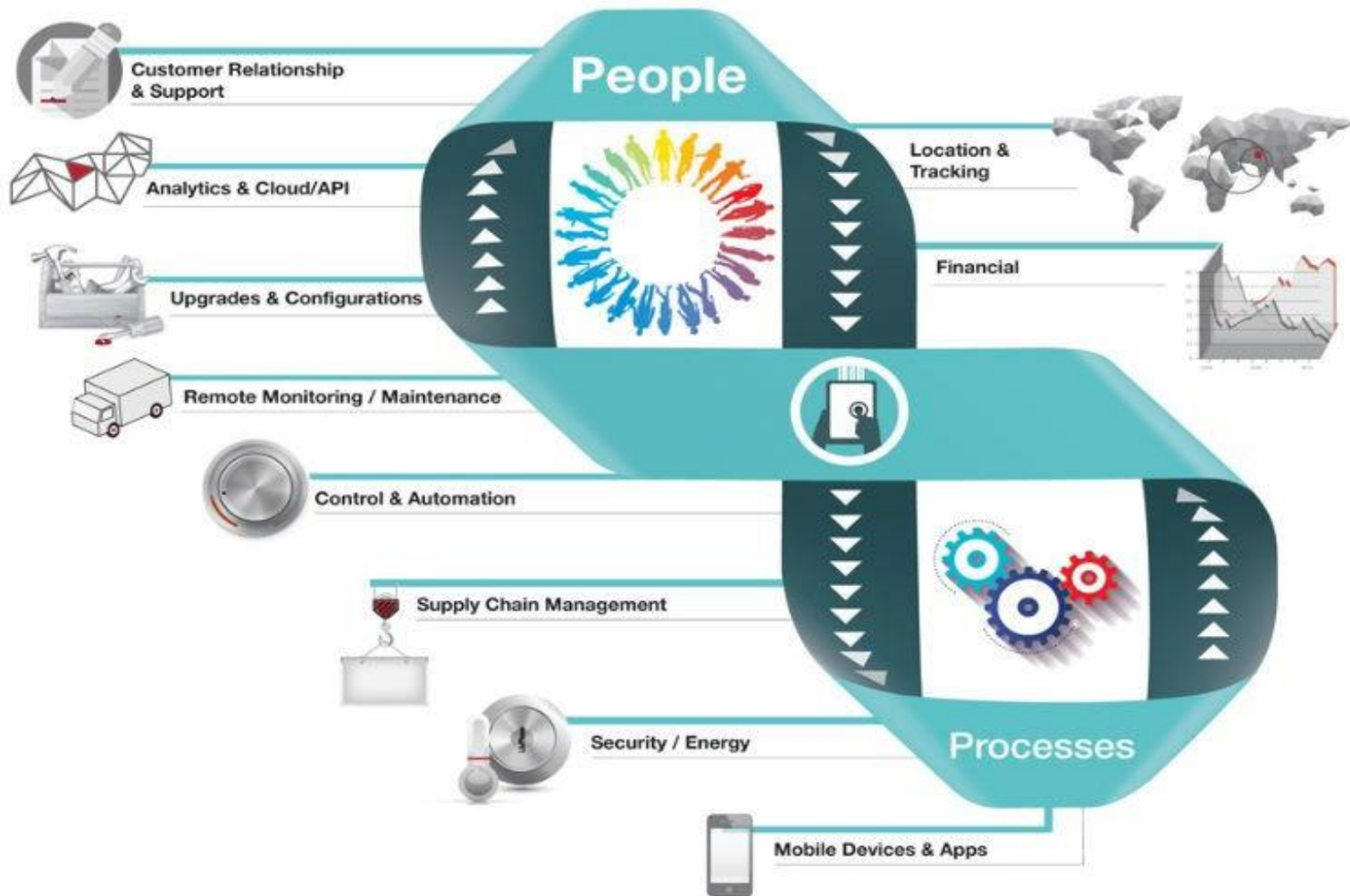
These inputs are digitized and placed onto networks.



[Source: Postscap - <http://postscapes.com/what-exactly-is-the-internet-of-things-infographic/>]

# 3 PEOPLE & PROCESSES

These networked inputs can then be combined into bi-directional systems that integrate data, people, processes and systems for better decision making.



# Unlocking the Massive Potential of IoT

---



Improved  
Performance

Reduced Costs

Create Innovative  
Services

New Revenue  
Stream

# The interactions between these entities are creating new types of smart applications and services.

SENSORS + CONNECTIVITY + PEOPLE + PROCESSES

Starting with popular connected devices already on the market



## SMART THERMOSTATS

nest



Save resources and money on your heating bills by adapting to your usage patterns and turning the temperature down when you're away from home.

## CONNECTED CARS

CAR  
2GO



Tracked and rented using a smartphone. Car2Go also handles billing, parking and insurance automatically.

## ACTIVITY TRACKERS

BASIS



Continuously capture heart rate patterns, activity levels, calorie expenditure and skin temperature on your wrist 24/7.

## SMART OUTLETS

belkin



Remotely turn any device or appliance on or off. Track a device's energy usage and receive personalized notifications from your smartphone.

## PARKING SENSORS

STREETLINE  
CONNECTING THE REAL WORLD



Using embedded street sensors, users can identify real-time availability of parking spaces on their phone. City officials can manage and price their resources based on actual use.

# Smart Building

main navigation BASE LEVEL ver 2.07  
REG. 35542 t

BUILDING SAFETY & SECURITY ENERGY TECHNICAL SERVICES WATER

EXIT

Tower 364 - Area 12 - FLOOR63  
ident. 644x64c 00f  
0:43:84:21

NE  
BLD  
OV  
EX

```
SOIARY_ENTRIES =  
  '122699', '122499', '122  
  '010200', '010500', '010  
  '070700', '012200', '021  
  '072800', '072800', '073  
  '042701',  
  SORT(SOIARY_ENTRIES, S  
  SAS_TIMESTAMPS = ARRAY;  
  si = 0;  
  FOREACH(SOIARY_ENTRIES AS $S) {  
    $MONTH = SUBSTR($S, 0, 2);  
    $DAY = SUBSTR($S, 2, 2);  
    $YEAR = SUBSTR($S, 4, 2);  
    $UNIX_TIMESTAMP = MKTIME($S.D, $MONTH)  
    $UNIX_TSI = UNIX_TIMESTAMP("-$R-");  
    $SAS_TIMESTAMPS($I) = UNIX_TIMESTAMP  
    $I++;  
  }  
  FOREACH($SAS_TIMESTAMPS AS $ST) {  
    $ST = $ST - $UNIX_TSI;  
    $ST = UNIX_TIMESTAMP($ST);  
    $ST = $ST - $UNIX_TSI;  
  }  
}
```

Poised to generate **\$100Billion** by lowering operating costs by reducing energy consumption through the integration of HVAC and other systems.



# Gas Monitoring

Generate **USD 69Billion** by reducing meter-reading costs and increasing the accuracy of readings for citizens and municipal utility agencies.

[Source: <http://www.tel.com/resources.com/2014/01/14/cisco-study-says-ioe-can-boost-savings/>]

# Smart Parking

Create **USD 41 Billion** by providing visibility into the availability of parking spaces across the city.



Residents can identify and reserve the closest available space, traffic wardens can identify non-compliant usage, and municipalities can introduce demand- based pricing.

[Source: <http://www.telecomreseller.com/2014/01/11/cisco-study-says-ioe-can-create-savings/>]



# Water Management

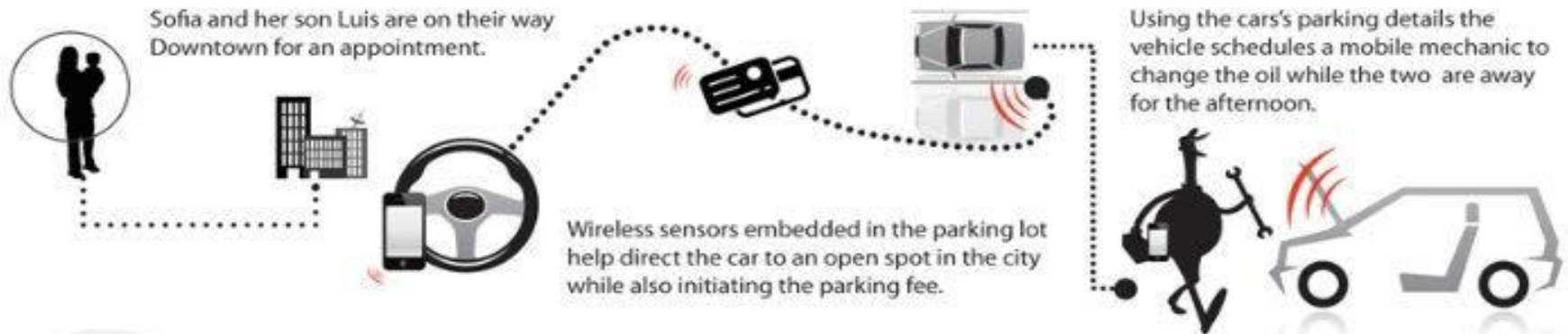


Could generate **USD 39Billion** by connecting the household water meter over an IP network to provide remote information on use and status

# FOR EXAMPLE



## TRANSPORTATION + SMART CITIES



***In Downtown San Francisco 20-30% of all traffic congestion is caused by people hunting for a parking spot.***

- San Francisco Municipal Transportation Agency (SFMTA)

## HEALTHCARE + SMART HOME



Aging uncle Earl is still living isolated at his home and you are concerned about his safety.



Wireless sensors throughout his house help measure healthy activity levels, sleeping patterns and medication schedules.



Alerts are automatically sent to health care services and authorized family members if any abnormal activity is detected.

**40 million adults age 65 and over will be living alone in the U.S, Canada and Europe.**

- U.S. Department of Health and Human Services: Administration for Community Living (ACL)

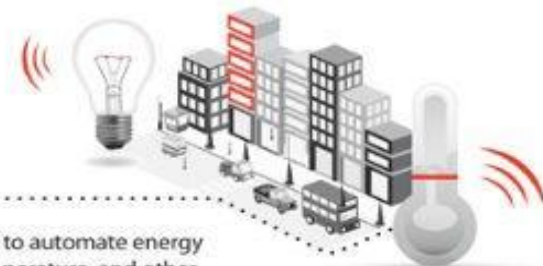
## SMART BUILDINGS + MOBILITY



Anna is being pressured to reduce her company's expenses for their new corporate office.



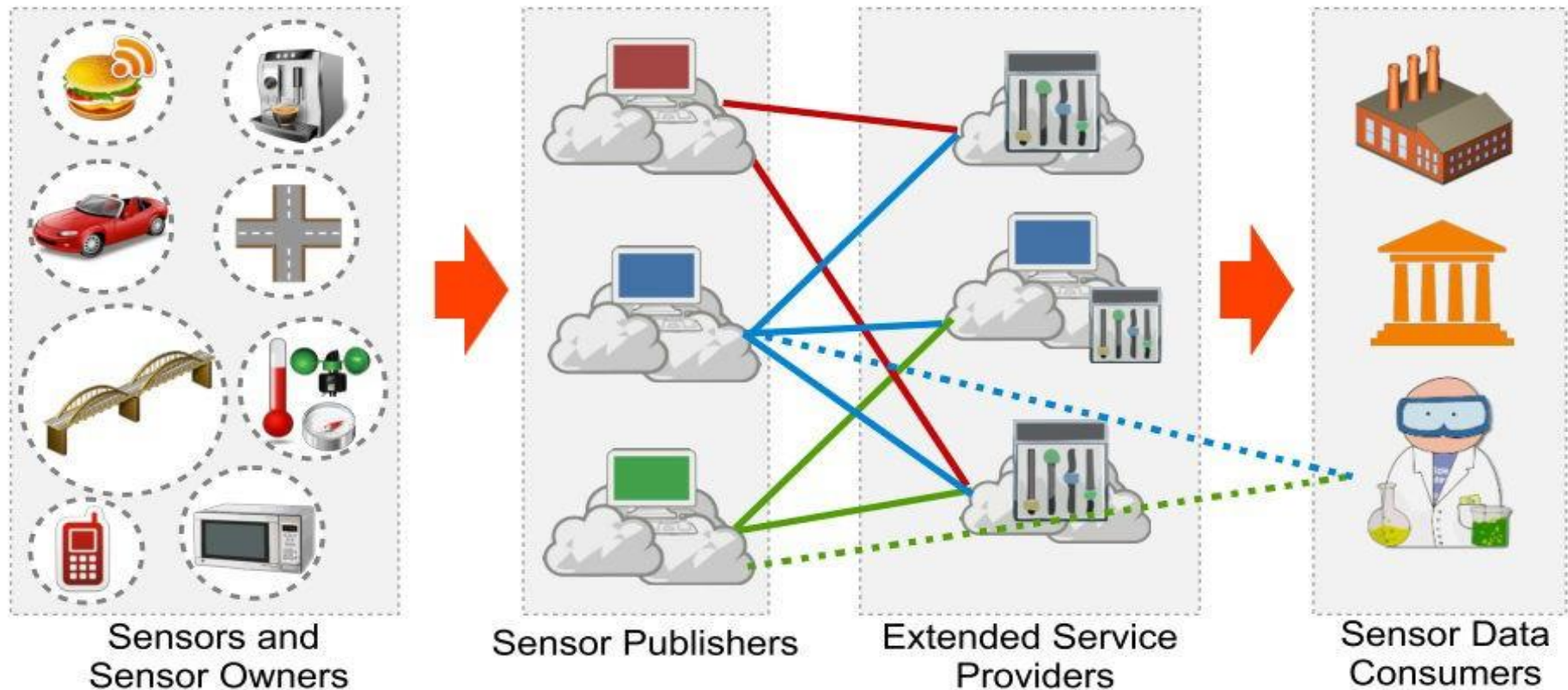
After speaking with experts she decides to install sensors to automate energy usage according to building occupancy, people flow, temperature, and other ambient conditions – improving the building's overall efficiency.



**Energy used by commercial and industrial buildings in the US creates nearly 50% of our national emissions of greenhouse gases.**

- United States Environmental Protection Agency

# The Sensing-as-a-Service Model





*Vehicle, asset, person & pet monitoring & controlling*



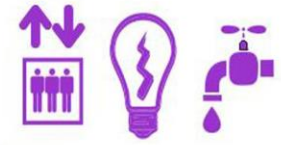
*Agriculture automation*



*Energy consumption*



*Security & surveillance*



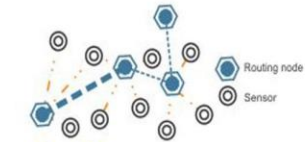
*Building management*



*Embedded Mobile*

## Internet of things

Everyday things get connected  for smarter tomorrow



*M2M & wireless sensor network*



*Everyday things*



*Smart homes & cities*

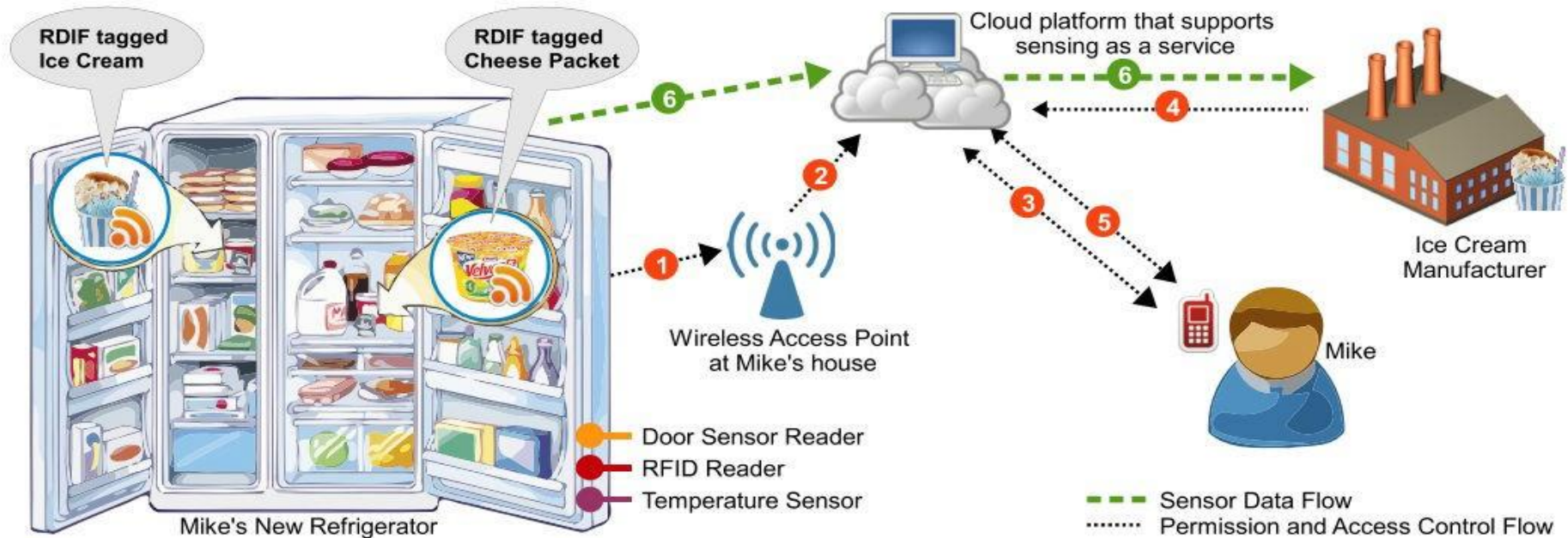


*Telemedicine & healthcare*

Sensing-As-A-Service

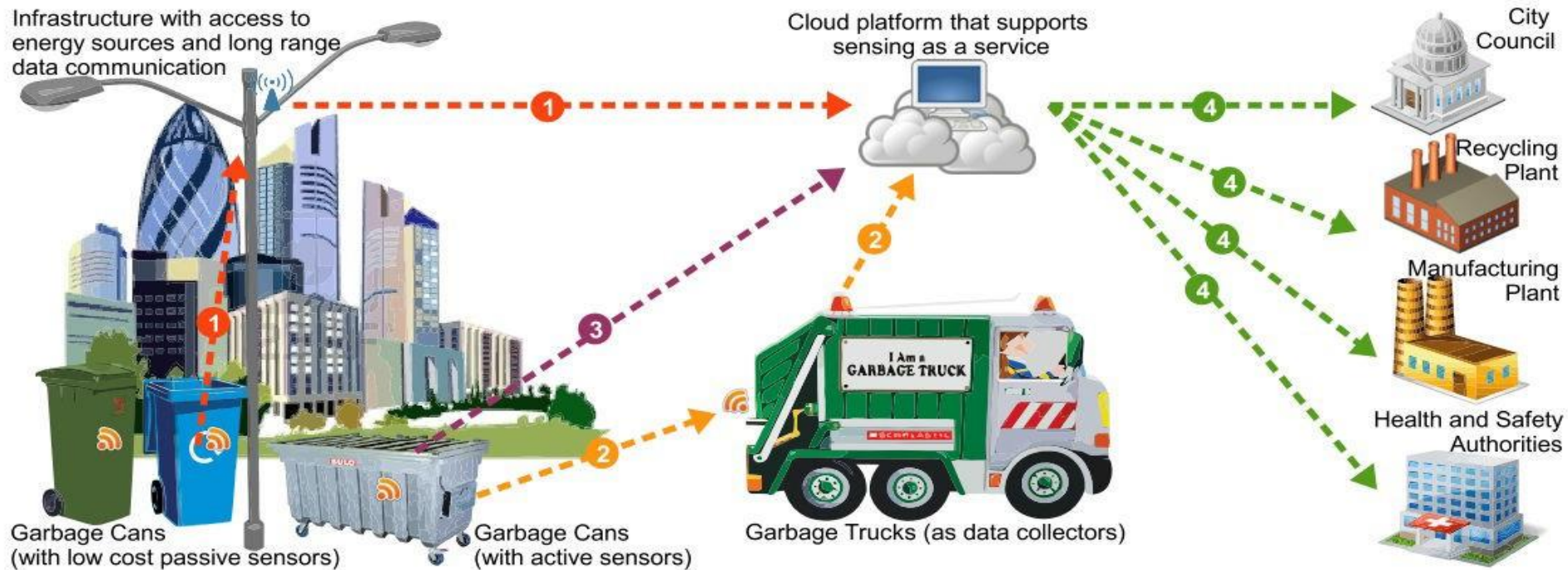
# BENEFITS

# Smart Home Scenario – Interactions in Sensing-as-a-Service Model



[Source: "Sensing as a Service Model for Smart Cities Supported by Internet of Things", Charith Perera et. al., Transactions on Emerging Telecommunications Technology, 2014]

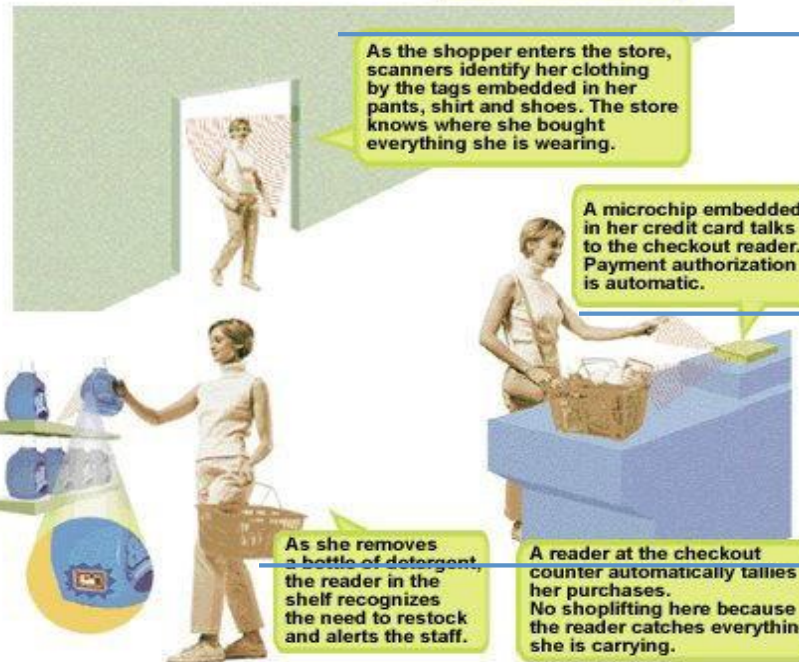
# Efficient Waste Management in Smart Cities Supported by the Sensing-as-a-Service



# IOT Application Scenario - Shopping



(2) When shopping in the market, the goods will introduce themselves.



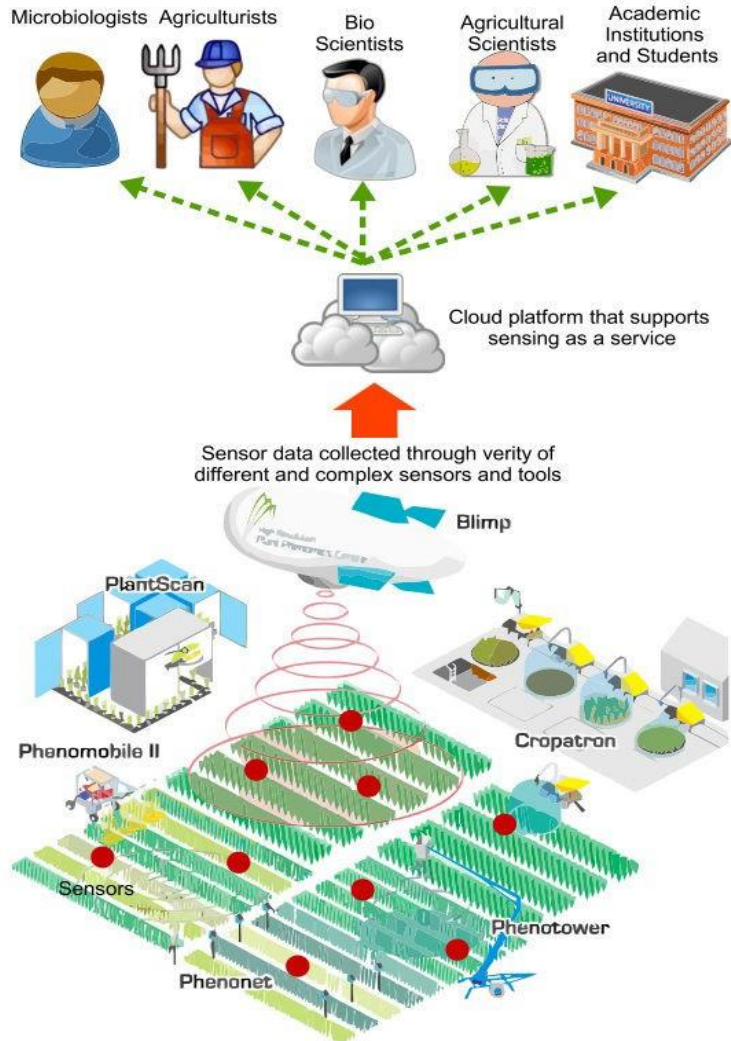
(1) When entering the doors, scanners will identify the tags on her clothing.

(4) When paying for the goods, the microchip of the credit card will communicate with checkout reader.

(3) When moving the goods, the reader will tell the staff to put a new one.

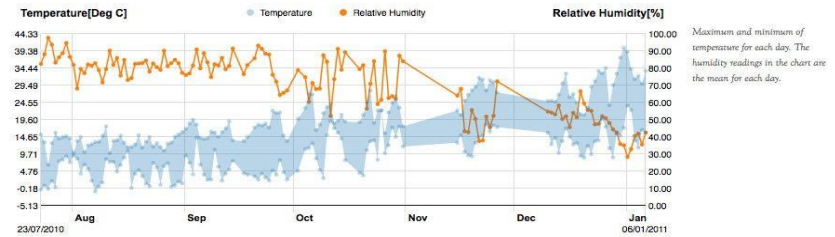
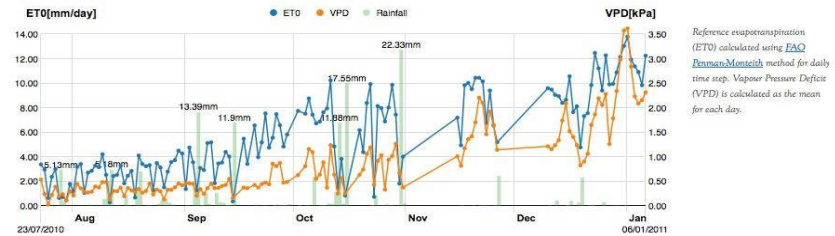


# Efficient and Effective Collaborative Research Supported by Sensing-as-a-Service Model



## Phenonet Distributed Sensor Network for Phenomics

### Yanco Field Analysis

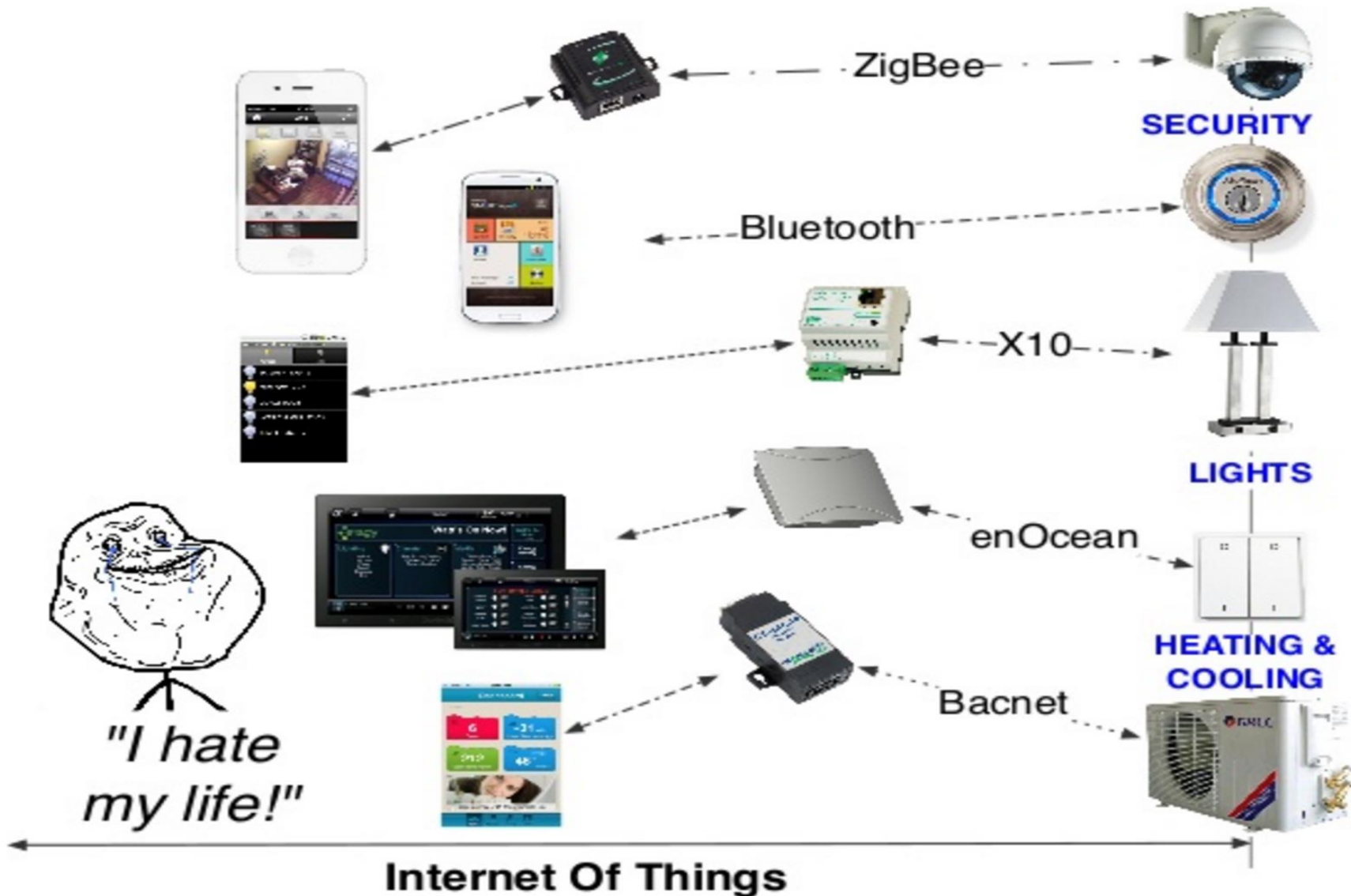


The sensing-as-a-service model allows researchers to share resources across borders and understand phenomenon which are not available in their own countries.

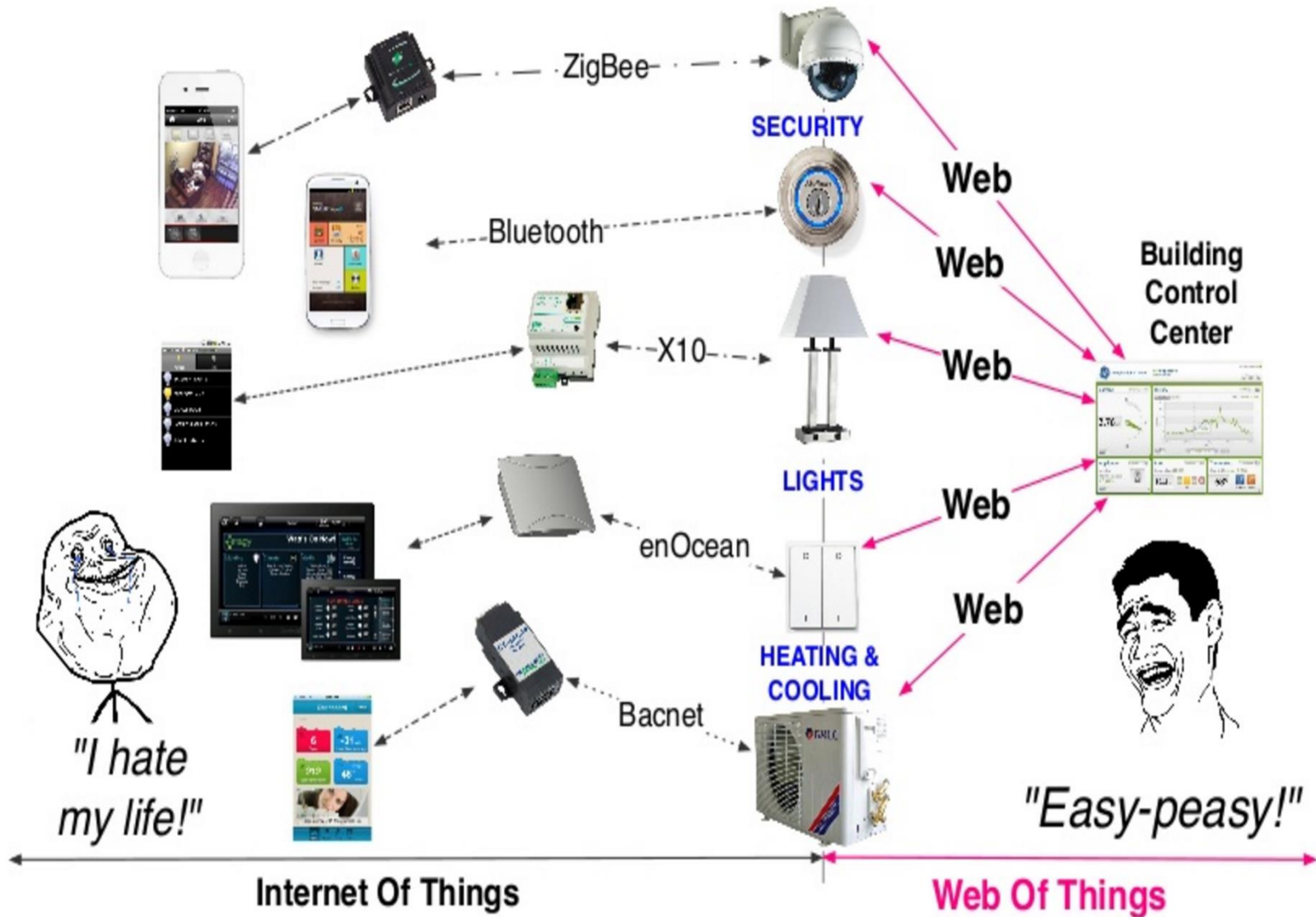
# The Web Of Things

MobileLab

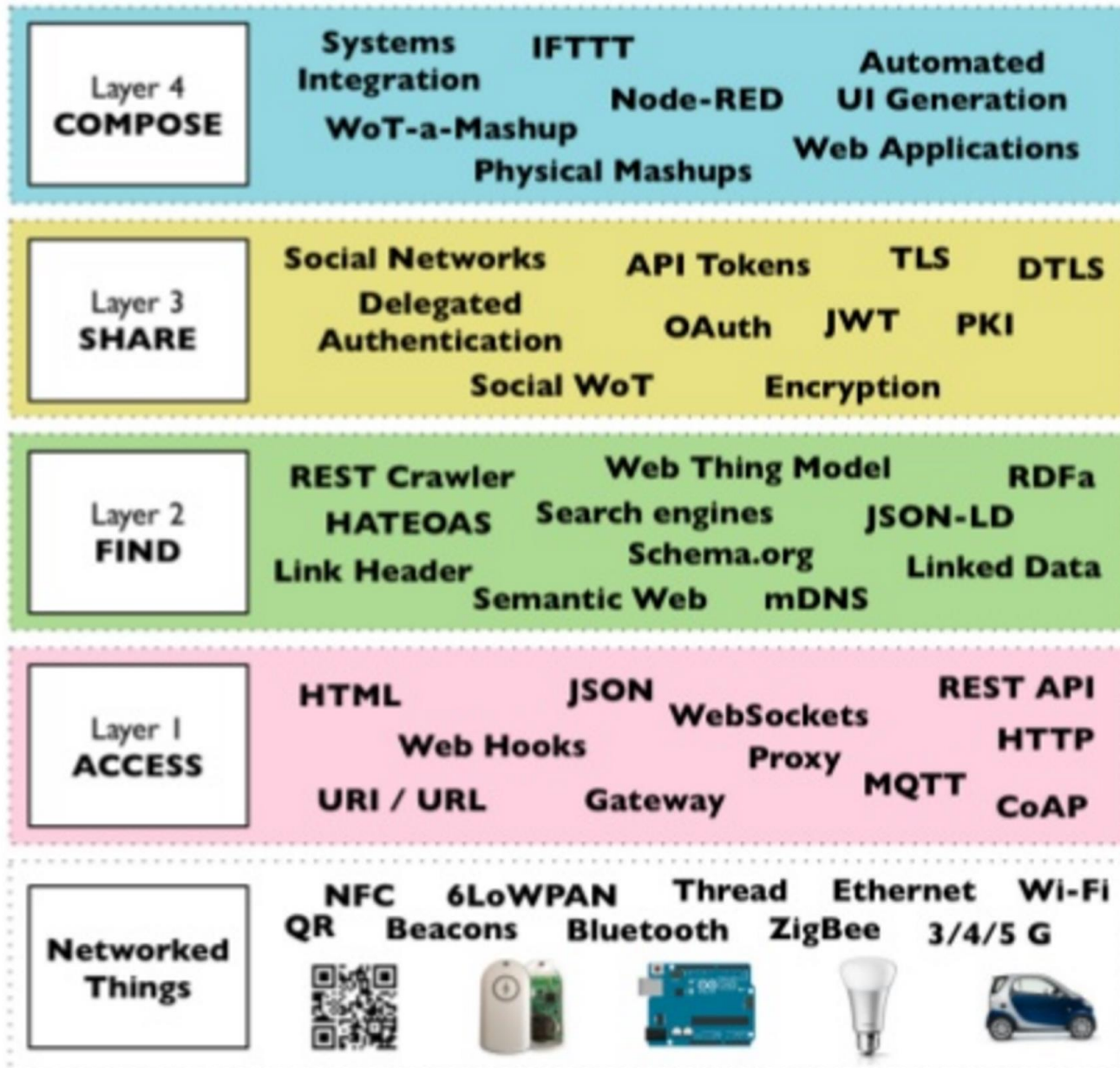
# IoT Problem



# Solution is the Web of Things (WoT)



# IoT: Web of Things



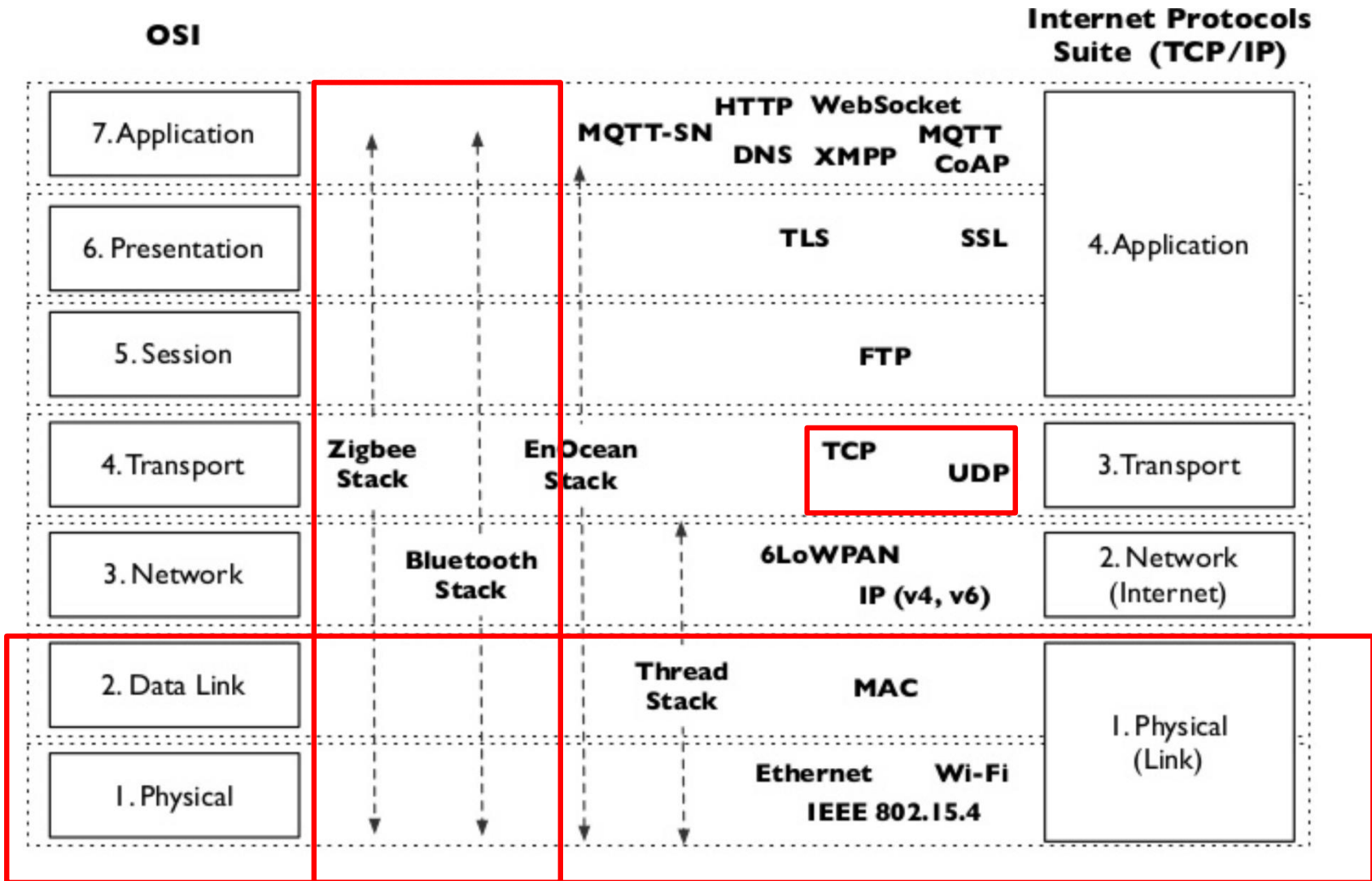
# IoT – Network Layer

**Networked  
Things**

**NFC    6LoWPAN    Thread    Ethernet    Wi-Fi**  
**QR    Beacons    Bluetooth    ZigBee    3/4/5 G**



# Network Layer – Choose a Physical Protocol



We previously discussed some pieces fitting here !

# IoT – N. Layer



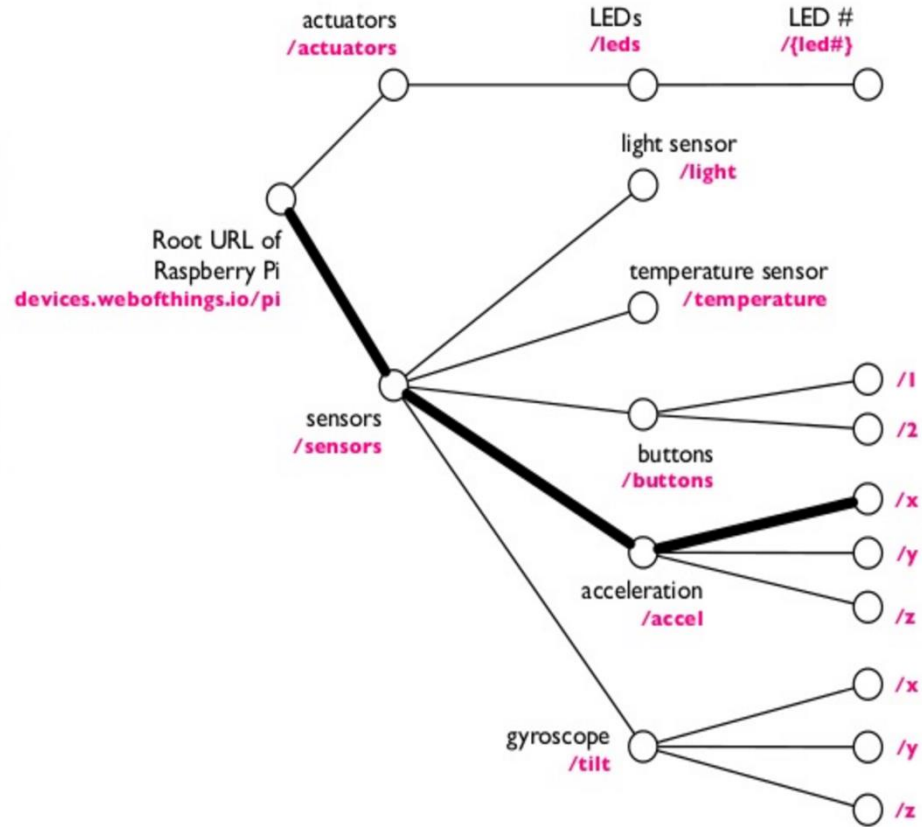
Accessing the Things in a standard and transparent way



# IoT – N.L: Basic Access Scheme



**A URL for each Thing**



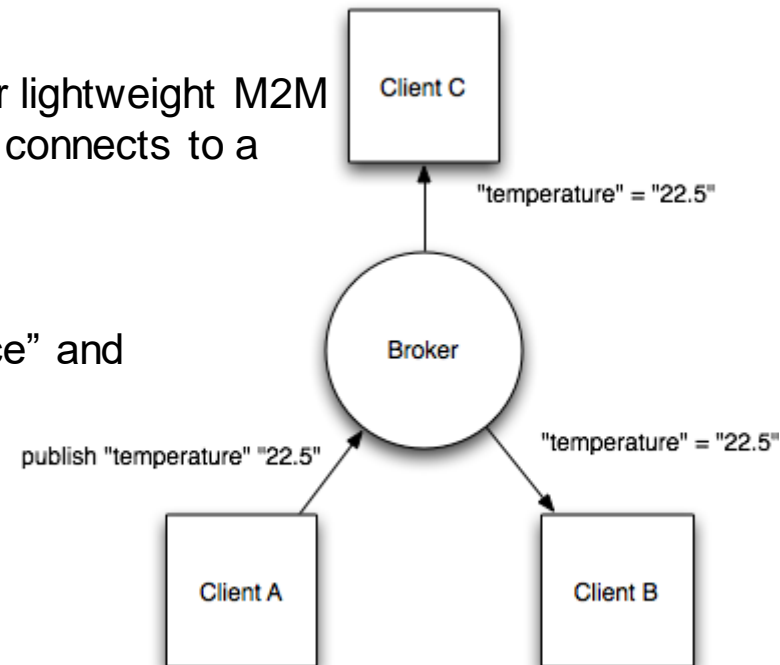
**And a RESTful API**

# IoT – N.L: Not all speak HTTP

	Typical MQTT Protocol Stack	Typical MQTT-SN Protocol Stack	Typical CoAP Protocol Stack	
<b>4. Application</b>	MQTT	MQTT-SN	CoAP CoRE	Required
<b>3. Transport</b>	TCP	UDP	UDP	
<b>2. Network (Internet)</b>	IP	Not specified	6LoWPAN	Recommended
<b>1. Physical (Link)</b>	Not specified	Not specified	IEEE 802.15.4	

**MQTT:** publish/subscribe messaging protocol designed for lightweight M2M

- client/server model, where every sensor is a client and connects to a server (a.k.a. broker)
- clients subscribe to topic channels of interest
- topic channels are hierarchical (e.g., room2BC/heating)
- 3 QoS Levels: “Fire and forget”, “delivered at least once” and “delivered exactly once”.
- username/password authentication.  
TCP over SSL/TLS



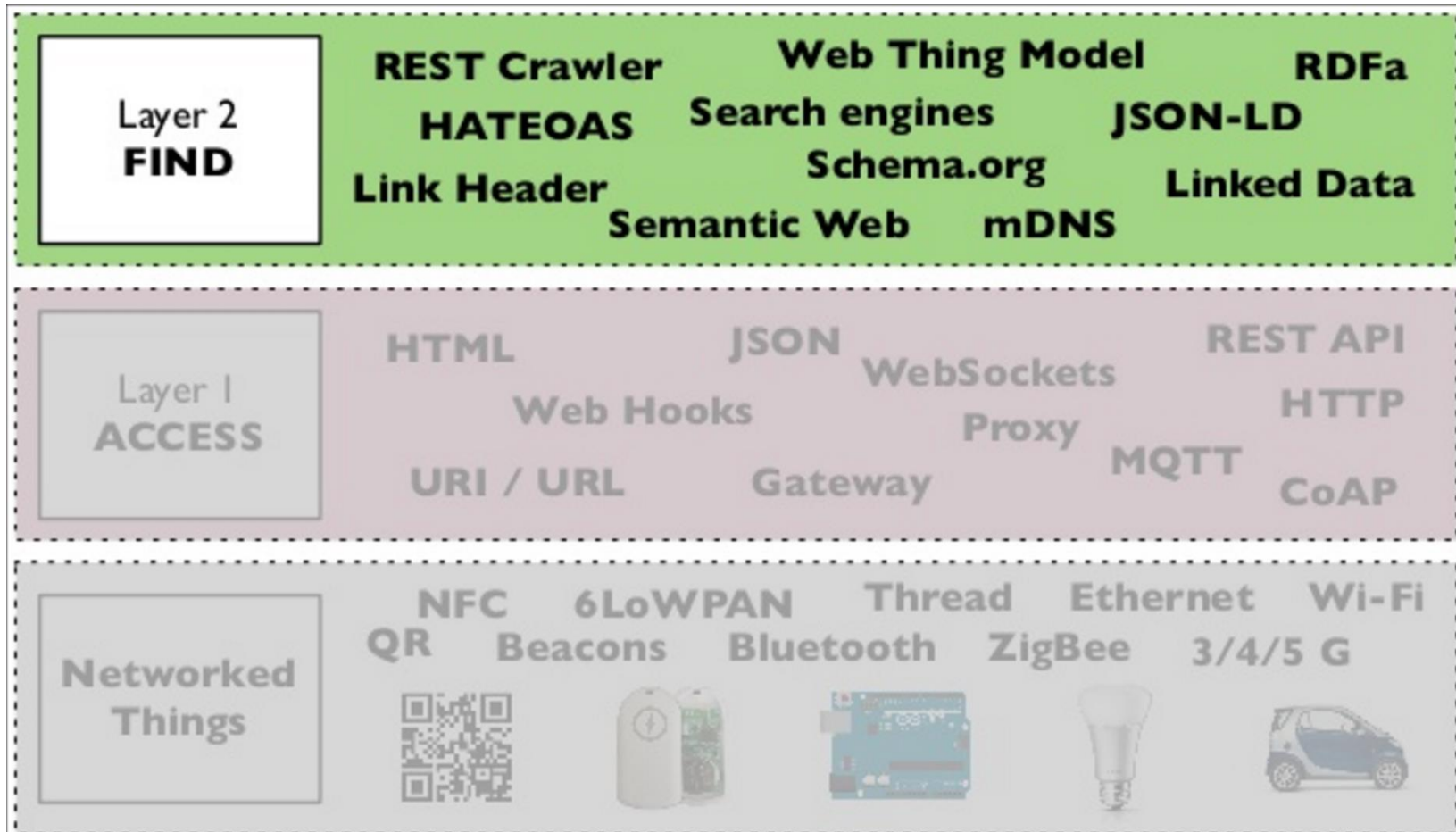
# IoT – N.L: Not all speak HTTP

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<b>4. Application</b>	MQTT	MQTT-SN	CoAP CoRE	Required
<b>3. Transport</b>	TCP	UDP	UDP	
<b>2. Network (Internet)</b>	IP	Not specified	6LoWPAN	Recommended
<b>1. Physical (Link)</b>	Not specified	Not specified	IEEE 802.15.4	

**CoAP:** Constrained Application Protocol from the CoRE (Constrained Resource Environments) **RFC 7252**

- document transfer protocol designed for the needs of constrained devices;
- packets are much smaller than HTTP TCP flows;
- simpler and faster to parse with small memory footprint;
- over UDP, interoperates with HTTP and the RESTful web through simple proxies;
- client/server model where clients may GET, PUT, POST and DELETE resources
- DTLS capable CoAP devices support RSA and AES or ECC and AES.

# IoT – Find Layer



Web protocols cover the “How” not the “What”

**The findability problem:** describe and discover the Things !

1. How do I find the Root URLs of Web Things near me?
2. What messages (verbs, payloads, etc.) can I send to those Web Things?
3. What do those resources/ messages mean and do?



**Mobile App for Hotel Guests**

## Hotel Room 202

[hotel.io/room202/heating](http://hotel.io/room202/heating)  
URL of the heating unit in room 202



**Heating System**

Wi-Fi

## Light System

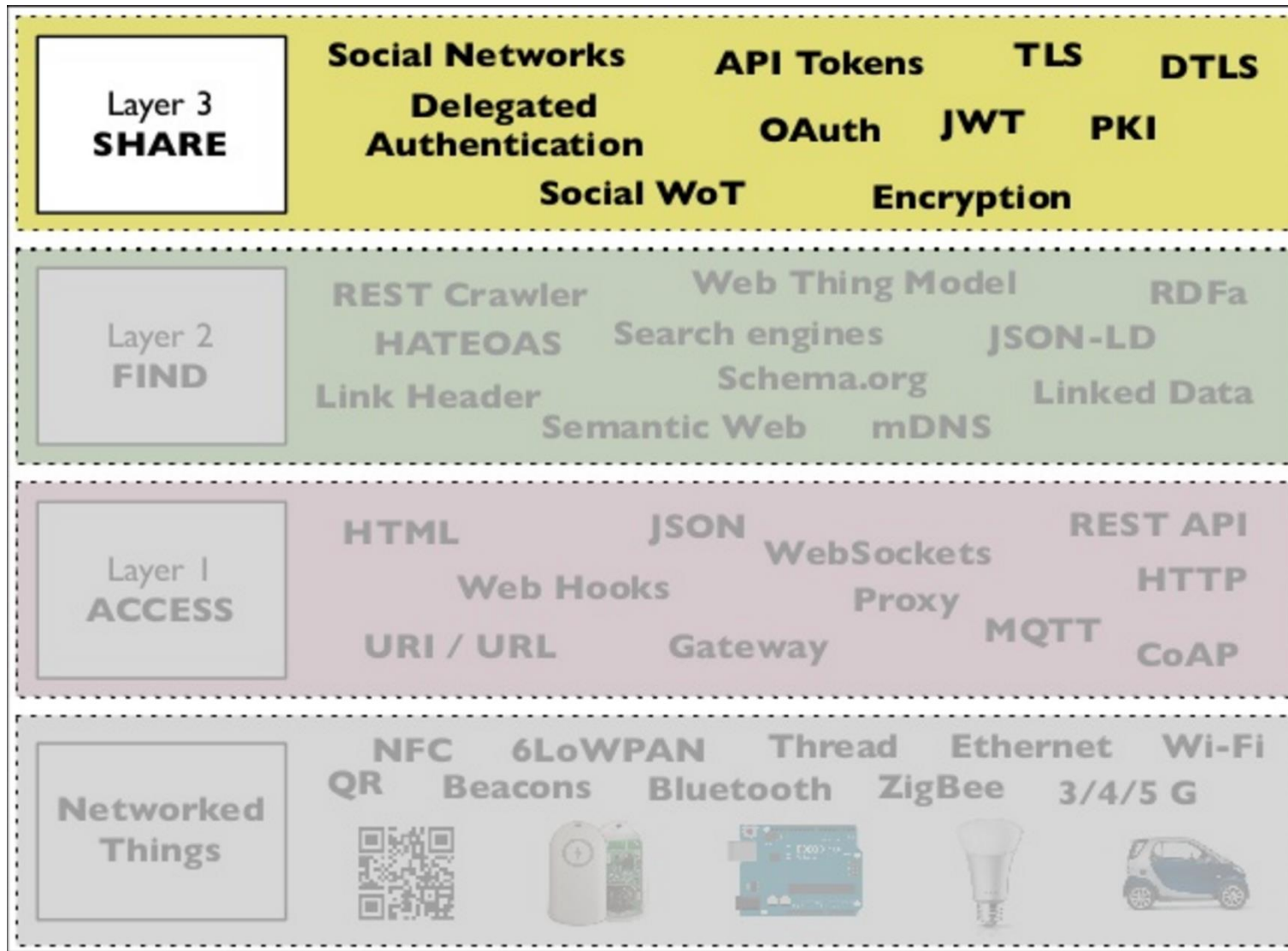


Wi-Fi

[hotel.io/room202](http://hotel.io/room202)  
URL of the hotel room

[hotel.io/room202/lights](http://hotel.io/room202/lights)  
URL of the light system in room 202

# IoT – Share Layer



**Securing and sharing Things !**

# IoT: Sh. Layer – The Social Web of Things



**About Authentication Resources Gateways Shares**

Here you can see all Resources that have been shared with you. You can either open a resource in a new browser window, display it directly in friends & things or you can make custom RESTful HTTP requests to it. Further you can register Feeds in order to send updates to it in regular time periods.

- localhost:8082/EnergyMonitor
- localhost:8082/EnergyMonitor/ploggs.html
- localhost:8082/EnergyMonitor/ploggs/Kettle/status.html

Accessed twice.

POST /gateways/localhost:8082/resources/EnergyMonitor/ploggs/Kettle/status.html

**Request Data:**  
URL-encoded data to be sent to the resource, e.g.: key1=value1&key2=value2.

status=off

**Status of Kettle**  
Status: off



**About Authentication Resources Gateways Shares**

Here you can see all Resources that you have shared with your friends or you can share new Resources. For existing Shares, you can display usage statistics in order to see whether it was worth sharing that Resource.

**Gateway:**  
Select a gateway.  
localhost:8082

**Social Network:**  
Select a Social Network to display friends.

**URL:**  
Select a Resource to be shared. Loading all available resources might take some time, please be patient.

**User:**  
Select a friend so share a resource with.

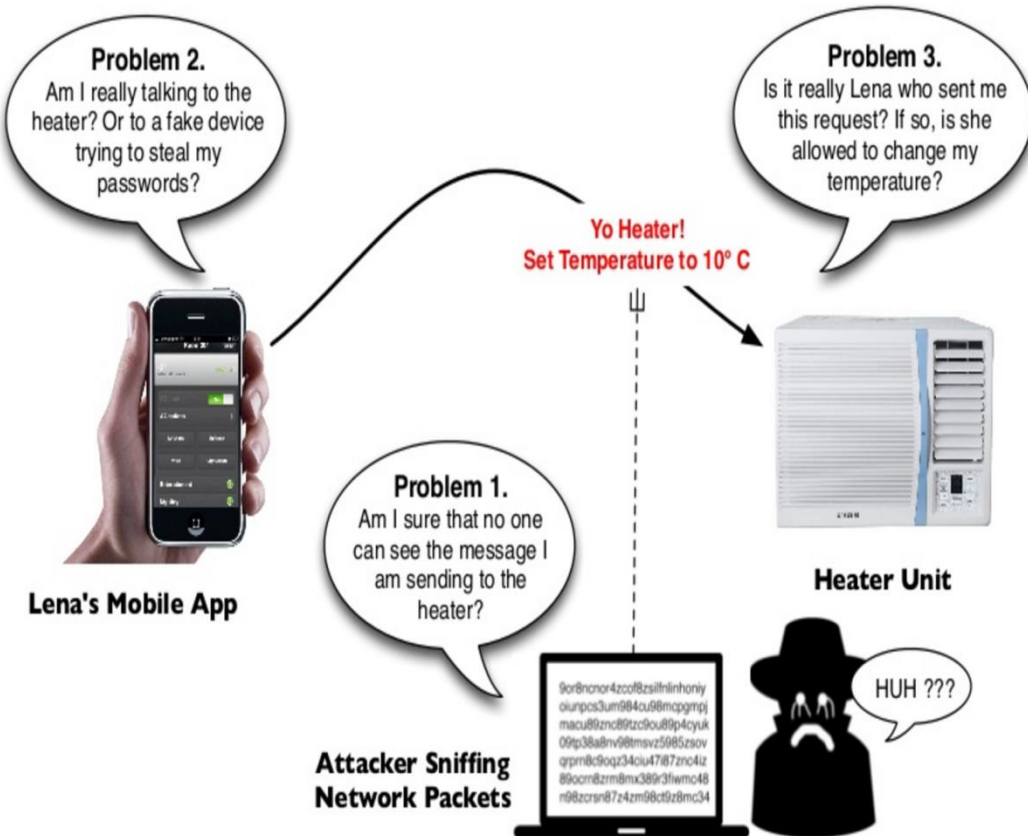
- EnergyMonitor (/EnergyMonitor)
- Overall load of the current place (0-100) (/EnergyMonitor/load.html)
- List all Ploggs (/EnergyMonitor/ploggs.html)
- Kettle (/EnergyMonitor/ploggs/Kettle.html)**
- EnergyMonitor/ploggs/Kettle/status.html
- All Ploggs (/EnergyMonitor/ploggs/all)

# IoT: Sh. Layer – The Social Web of Things





# IoT: Sh. Layer - Security



## Security by obscurity never helps

- Better off with open protocols!

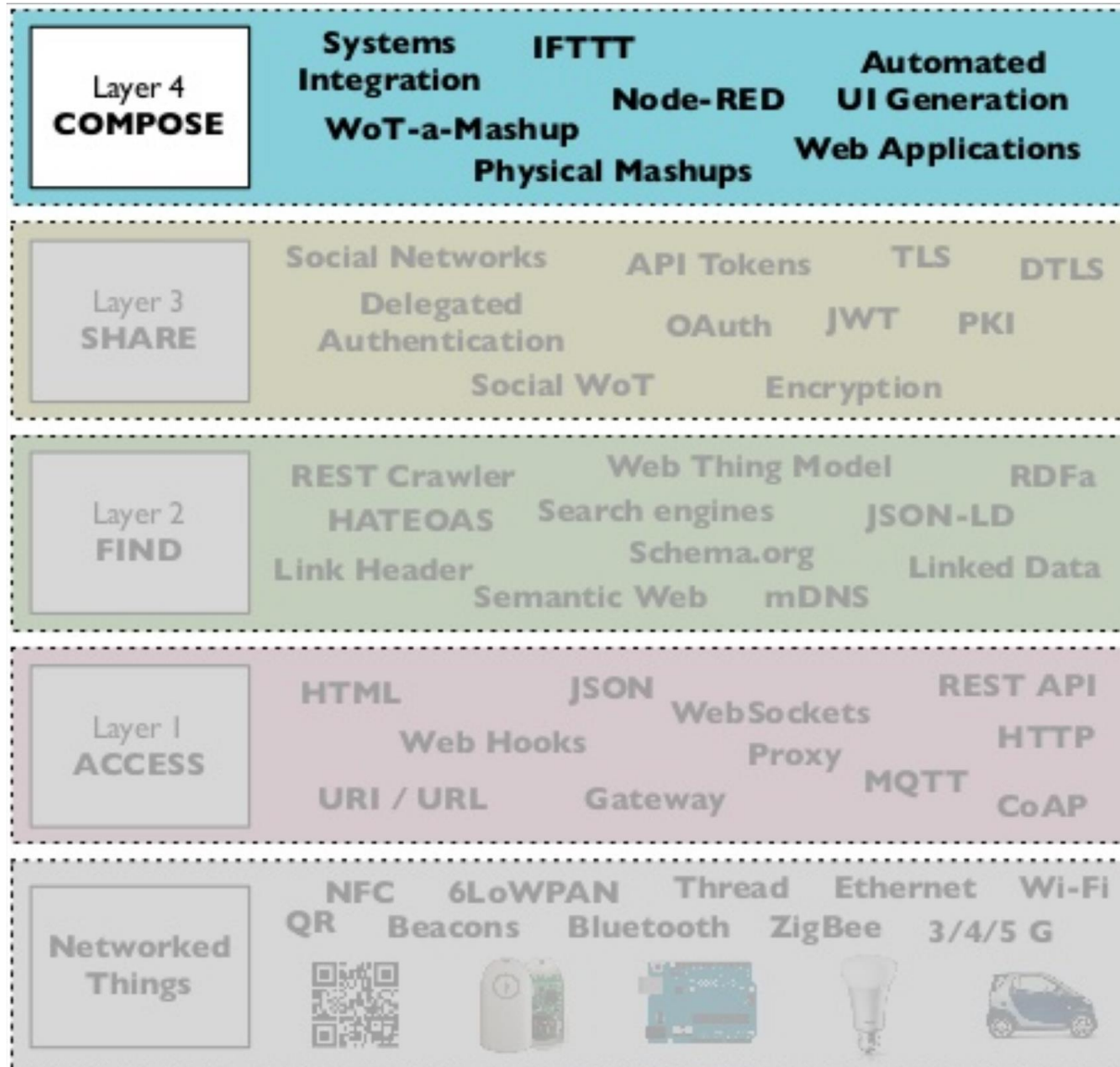
## Technical challenges

- TLS can be heavy for resource constrained devices
- DTLS, TLS on UDP for constrained devices

## Things on the Web = Things on the Web!

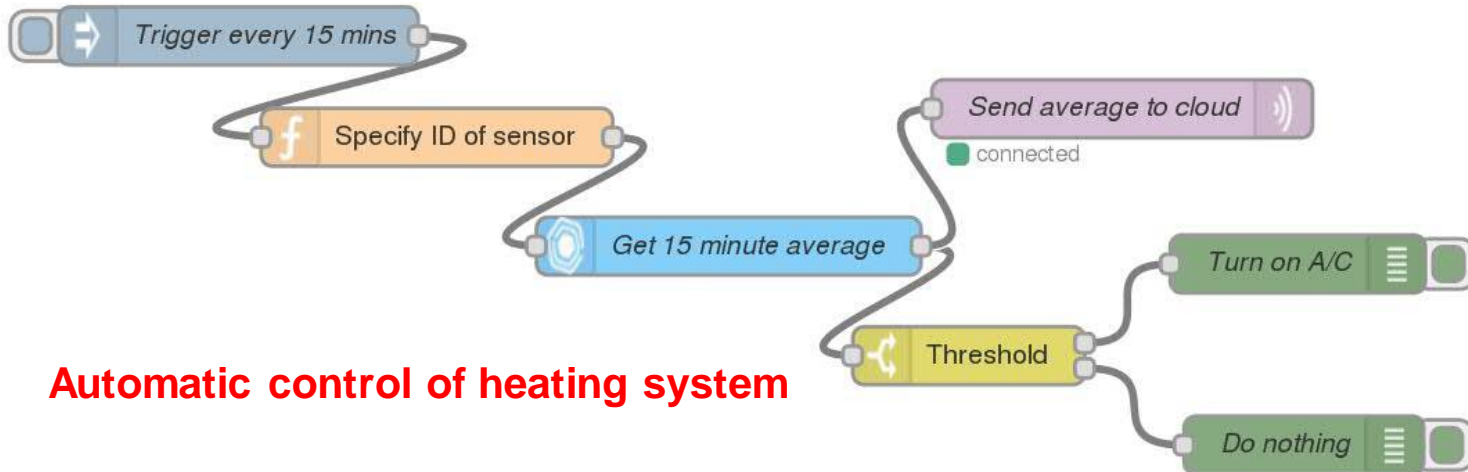
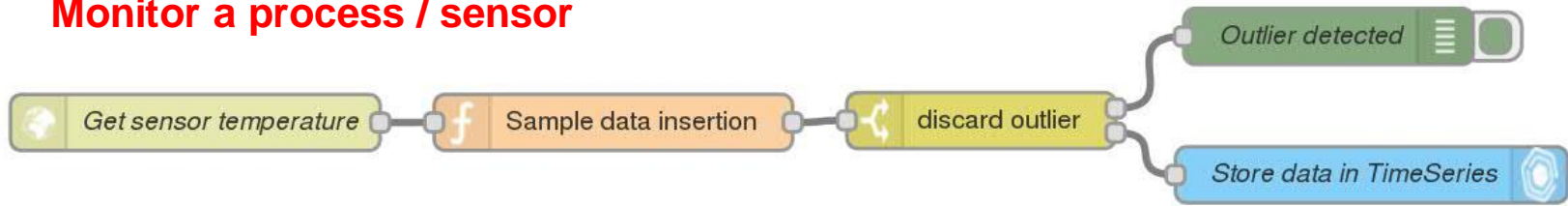
- DDoS attacks
- UDP flooding / TCP SYN attacks
- Hacking the physical world
  - e.g., **Shodan**, Baby Monitors

# IoT – Compose Layer



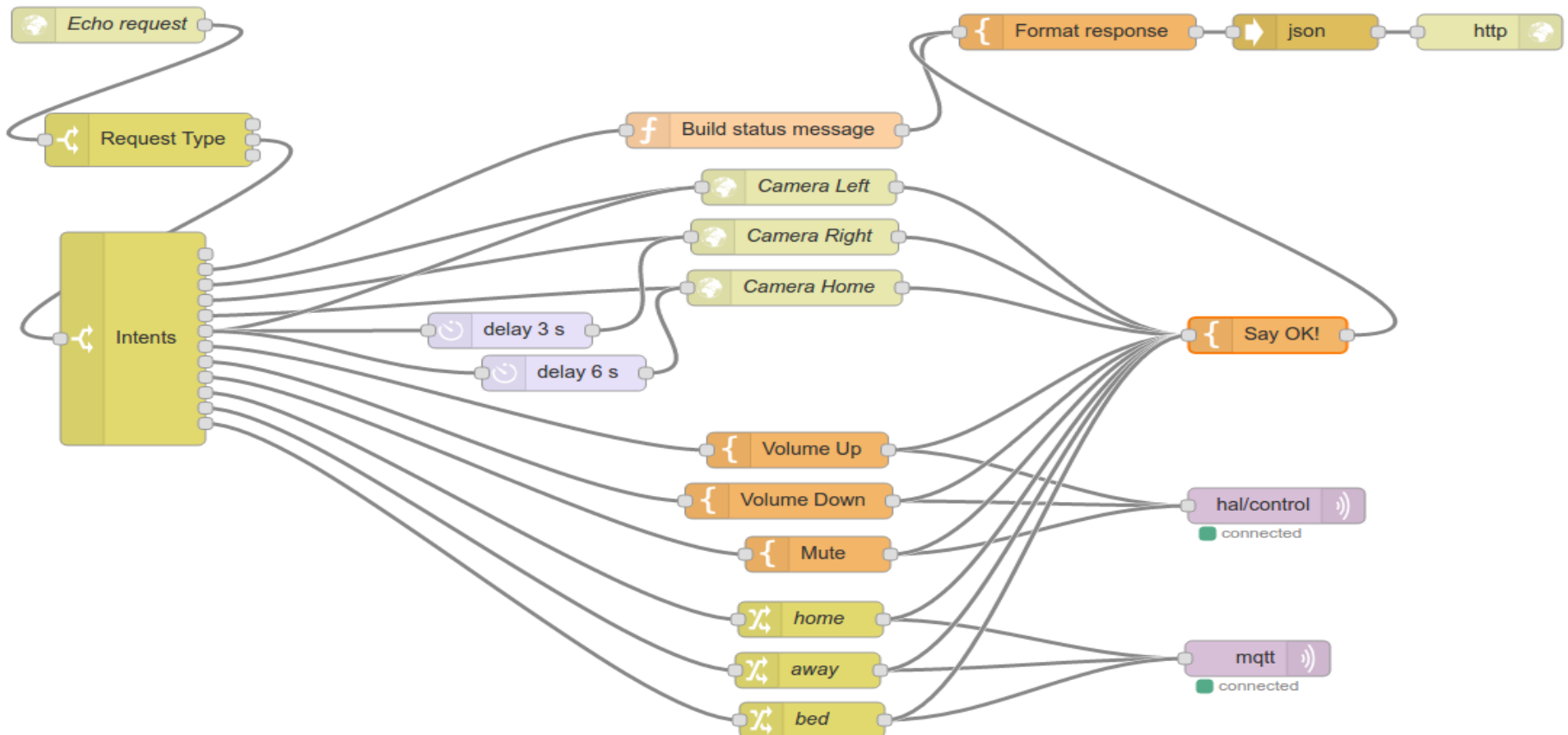
# IoT – Layer 4

## Monitor a process / sensor



## Automatic control of heating system

# IoT – Layer 4



- **Node-red**: tool for composing together hardware devices, APIs and online services
- And a lot of other interesting frameworks...

# The S.C.A.L.E Taxonomy (Challenges)

# The S.C.A.L.E scheme

## Major UC challenges, on a very high level:

### 💣 S – SCALABILITY

- how to support cooperation of “zillions” of components?
- how to support nomadic users around the globe?

### 💣 C – CONNECTIVITY

- how to “easily” connect these zillions? Several levels of abstraction:
  - wireless networks – a blessing and a curse (unreliable!)
  - most issues come *above* wired/wireless net (note: overlap with scalability):
    - how to find/understand your peers? How to enable zero configuration
    - how to design networks for zillions<sup>2</sup> of connections, without central-server bottleneck

### 💣 A – ADAPTABILITY

- usage during daily work, surrounded by 100s of components: need *minimal* interaction
- major approach: context-aware computing – use it to automate tasks & reduce options
- why “adaptability”? adapting-to-particular-user (user *modeling*) focused beyond context-awareness

### 💣 L- LIABILITY

- term indicates: we must go beyond today’s **IT security** solutions (not goals), since
  - today’s solutions do not scale (centralized components?), are not “humane” (see below), ...
  - ... & don’t flexibly consider conflicting (privacy, traceability) & related goals (dependability etc.)

### 💣 E – EASE-OF-USE

- adaptability permits “minimal” ..., ease-of-use means “optimal” interaction (related!)
- issue: optimal use & combination of modalities, advancement of specific modalities
- issue: “understanding” natural input: a) xxx-to-text: b) text-to-meaning: “intelligence”?

## S – SCALABILITY

(is a “top priority” challenge → reflected in acronym: scale)

A. **Network Scalability:** UC leads to (potential) cooperation of “zillions” of devices

- thus, solutions need to work efficiently with zillions of components

most relevant areas (basically, *alternatives* for addressing technical scalability):

1. **bionics** i.e. bio-analog computing
  - neural networks, cooperating robots: huge fields, only marginal importance for UC
  - ant colonies – often simulated / executed on single computer today; swarms, autonomous computing ...
2. **Future communication/cooperation (pub/sub; P2P, Grid)**  
– see further below (C – connectivity)
3. **Locality of data and content**
  - Not everything needs to be available and accessible globally
  - Data aggregation at intermediate points

# An example - Localized, aggregate data



[Qualcomm's LTE-Direct presentation](#)



**Global interconnection of UC components is related to the following (and to “scalability” above):**

## A. Scalable Communication

1. **wireless networks:** (often!) a prerequisite for higher layers.  
5G the solution?
2. **event based communication:** praised as *the* UC connectivity approach
  - means “push” paradigm, a prerequisite for scalable open cooperation of components (supersedes client/server!);
  - remaining problems (advertising, openness, integration of other paradigms)
  - plus: what else is needed in UC middleware (e.g., disconnections are a norm rather than an exception)

## B. Scalable Cooperation

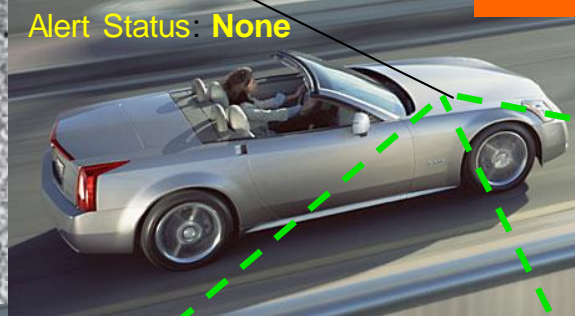
1. **Overlay Nets:** overlay networks in the Internet; at least 3 classes:
  - a. **Peer-to-Peer Networks:** no centralized bottleneck, scale well?
  - b. **Opportunistic Networks:** ad hoc net (node proximity) parallels global human “network”
  - c. **Cloud Computing:** dynamically available resources parallel fluctuating resource demands
2. **Service Discovery:** prerequisite for zero configuration

# An Example – V2V communication

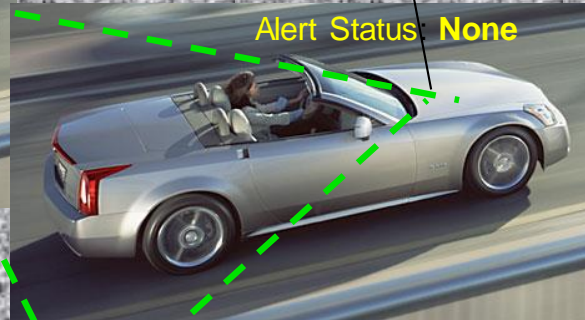
Vehicle type: Cadillac XLR  
Curb weight: 3,547 lbs  
Speed: 75 mph  
Acceleration: **+ 20m/sec<sup>2</sup>**  
Coefficient of friction: .65  
Driver Attention: Yes  
Etc.

Vehicle type: Cadillac XLR  
Curb weight: 3,547 lbs  
Speed: 65 mph  
Acceleration: **- 5m/sec<sup>2</sup>**  
Coefficient of friction: .65  
Driver Attention: Yes  
Etc.

Alert Status: **None**



Alert Status: **None**



Alert Status: **Inattentive Driver on Right**  
Alert Status: **Slowing vehicle ahead**  
Alert Status: **Passing vehicle on left**



Vehicle type: Cadillac XLR  
Curb weight: 3,547 lbs  
Speed: 75 mph  
Acceleration: **+ 10m/sec<sup>2</sup>**  
Coefficient of friction: .65  
Driver Attention: **Yes**  
Etc.

Alert Status: **Passing Vehicle on left**



Vehicle type: Cadillac XLR  
Curb weight: 3,547 lbs  
Speed: 45 mph  
Acceleration: **- 20m/sec<sup>2</sup>**  
Coefficient of friction: .65  
Driver Attention: **No**  
Etc.

# An example – CarFi Demo

## Enabling V2X in Urban Landscapes

### Enabling Vehicle V2X in Urban Landscapes

Giovanni Pau  
Excellence Chair Professor in Smart Mobility @ UPMC / Paris 6  
UCLA - Computer Science Department  
[giovanni.pau@upmc.fr](mailto:giovanni.pau@upmc.fr)



# S.C.A.L.E - Adaptability

## A. Context Awareness (adaptation to “situation of use”)

- **sensed context:** what sensors can measure (temperature, shock, location, ...)
- **modeled context:** info held in “other” software/DB: tasks & activities etc.
- **inferred context:** built from (several?) sensed or modeled contexts, e.g., GPS → street ... co-located chemicals → dangerous!, is always modeled
- note: context “ages”, is “probabilistic”/maybe contradictory (sensor imprecise? calendar entry gives different location than GPS sensor?)
- most investigated context: **location**
  - maybe absolute or relative, outdoor or indoor

## B. User Awareness (adapt to user(s) - and, mid term, provider?)

- technology? “usual suspects”: **user models**, profiles&preferences, user agents
- *great challenge:* the huge crowd of “new” users
  - *unexperienced, hands/eyes free, little attention*
  - *understand their actions → support them!*

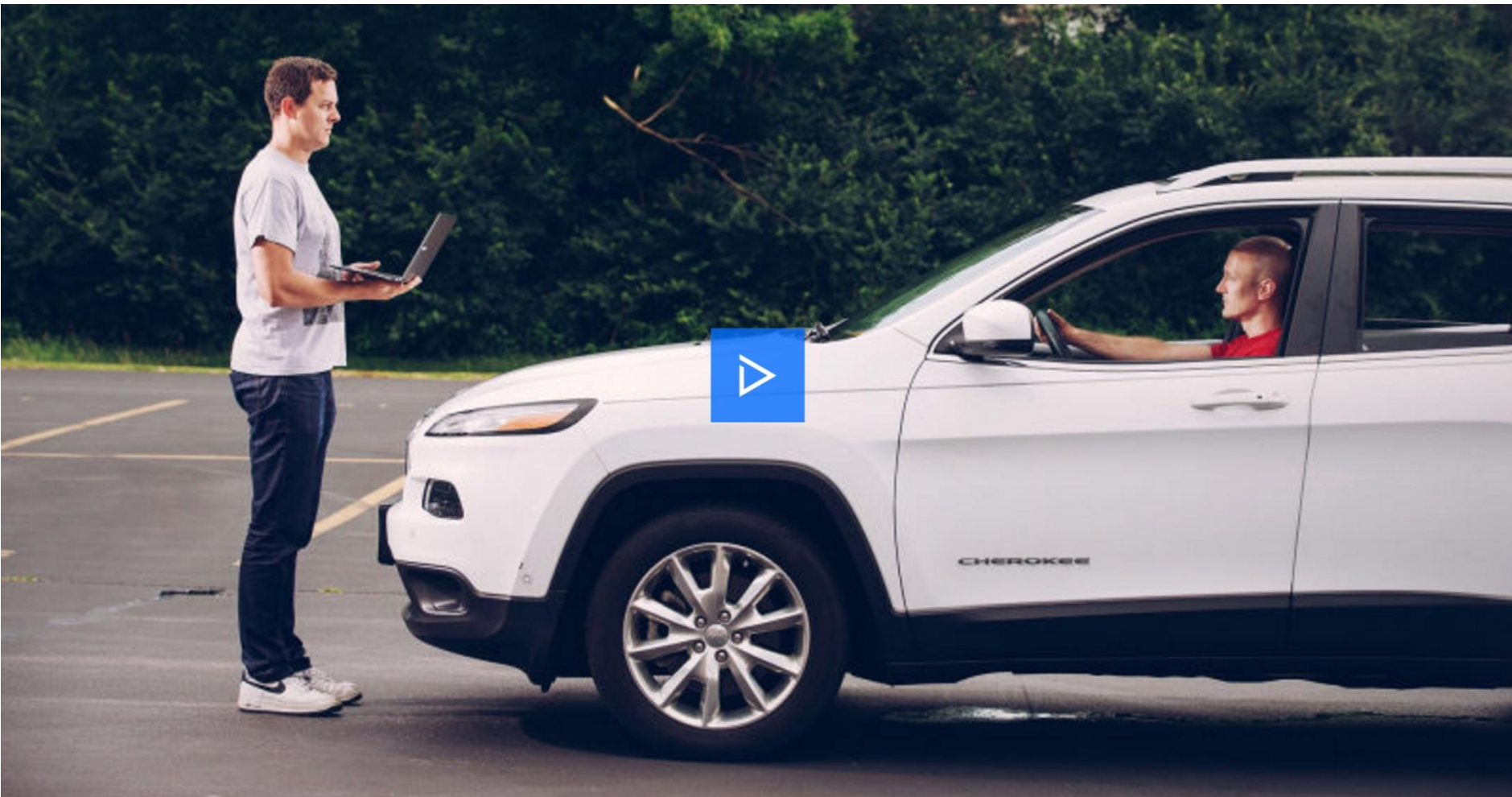
**Liability** ::= protection of actors *and* those concerned by actions (peers, third parties, society) through “right” mix of protection/prosecution – all in presence of zillions of peers; liability = “security and beyond”

## A. Scalable security:

- Machine-2-machine communication, ad hoc “encounters”: PKI not viable
  - cannot check certificate chain with (central!) roots zillions of times per second!
  - even if so: a party may change (e.g., due to virus) zilliseconds after check
  - maybe: not always/reliably connected!
  - early approaches: resurrecting duckling++, TCI, ... : → viable overall solution?
- there ain't no end-2-end encryption (cf. https-connection vs. “frontend” password-spyware)

# An example – what can possibly go wrong???

## Wired – Car hijacked remotely



# How ?

- “ by sending carefully crafted messages on the vehicle’s internal network known as a CAN bus”
- Which was the “attack vector” ?
- Controller Area Network(CAN)-bus
  - Message-based for the vehicle-bus designed to microcontrollers to communicate with each-other
  - No security features in the standard
  - applications are expected to deploy their own security mechanisms
- Read [This](#) if curious

**remember: optimal use & combination of modalities (UI-adaptability may be considered a subset of ease-of-use)**

## **A. “multimodal interaction”**

simple distinction: hands&eyes- vs. mouth&ears-interaction →

1. **advanced hands&eyes interaction:** GUIs predominant, but further developments needed
    - examples: focus + context-displays, 3rd dimension (VR), 4th dimension (dynamic displays), immersion, narration
  2. **mouth&ears interaction:** voice underdeveloped today, great potential! → nomadic (hands-/eyes free) operation
    - but: needs speech understanding, AI recent improvements
  3. **integration of HCI and SWE(ng):** the grand challenge!
    - today: HCI before & after SWE – but “incompatible”
- **Check This**



# The NFV Concept

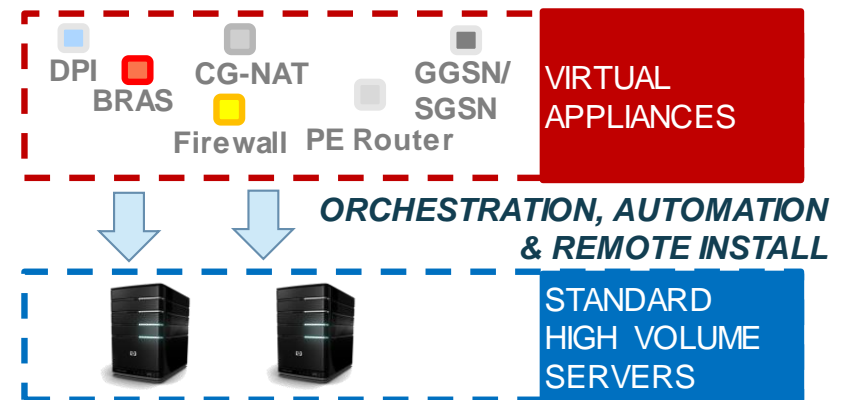
A means to make the **network more flexible and simple** by **minimising dependence on HW constraints**

## Traditional Network Model: APPLIANCE APPROACH



- Network Functions are **based on specific HW&SW**
- **One physical node per role**

## Virtualised Network Model: VIRTUAL APPLIANCE APPROACH



- Network Functions are **SW-based over well-known HW**
- **Multiple roles over same HW**

# 5G – Network Slicing Concept

