MOBILE & CYBER-PHYSICAL SYSTEMS

STEFANO CHESSA

NETWORKS WITHOUT INFRASTRUCTURE: MOBILE AD HOC NETWORKS

(MANETS)

MOBILE AD HOC NETWORKS

- AUTONOMOUS SYSTEM OF MOBILE HOSTS CONNECTED BY WIRELESS LINKS
  - THE NODES ARE AUTONOMOUS AND INDEPENDENT
    - BATTERY POWERED
    - MOBILE
    - NODES COMMUNICATE BY EXCHANGING PACKETS VIA RADIO WAVES
    - COOPERATE IN A PEER-TO-PEER FASHION
  - NO FIXED NETWORK INFRASTRUCTURE
    - PURE DISTRIBUTED SYSTEM
    - NO CENTRALIZED COORDINATORS
    - THE NETWORK CAN BE (RE-)CONFIGURED ON-THE-FLY

MOBILE AD HOC NETWORKS

- FEATURES:
  - RAPIDLY DEPLOYABLE
  - EASILY CONFIGURABLE
  - ROBUST
  - HETEROGENEOUS

MOBILE AD HOC NETWORKS

APPLICATIONS:

- COMMUNICATION IN REMOTE OR HOSTILE ENVIRONMENTS
- MANAGEMENT OF EMERGENCIES
- DISASTER RECOVERY
- AD HOC COMMERCIAL INSTALLATIONS
- SENSOR NETWORKS

MOBILE AD HOC NETWORKS

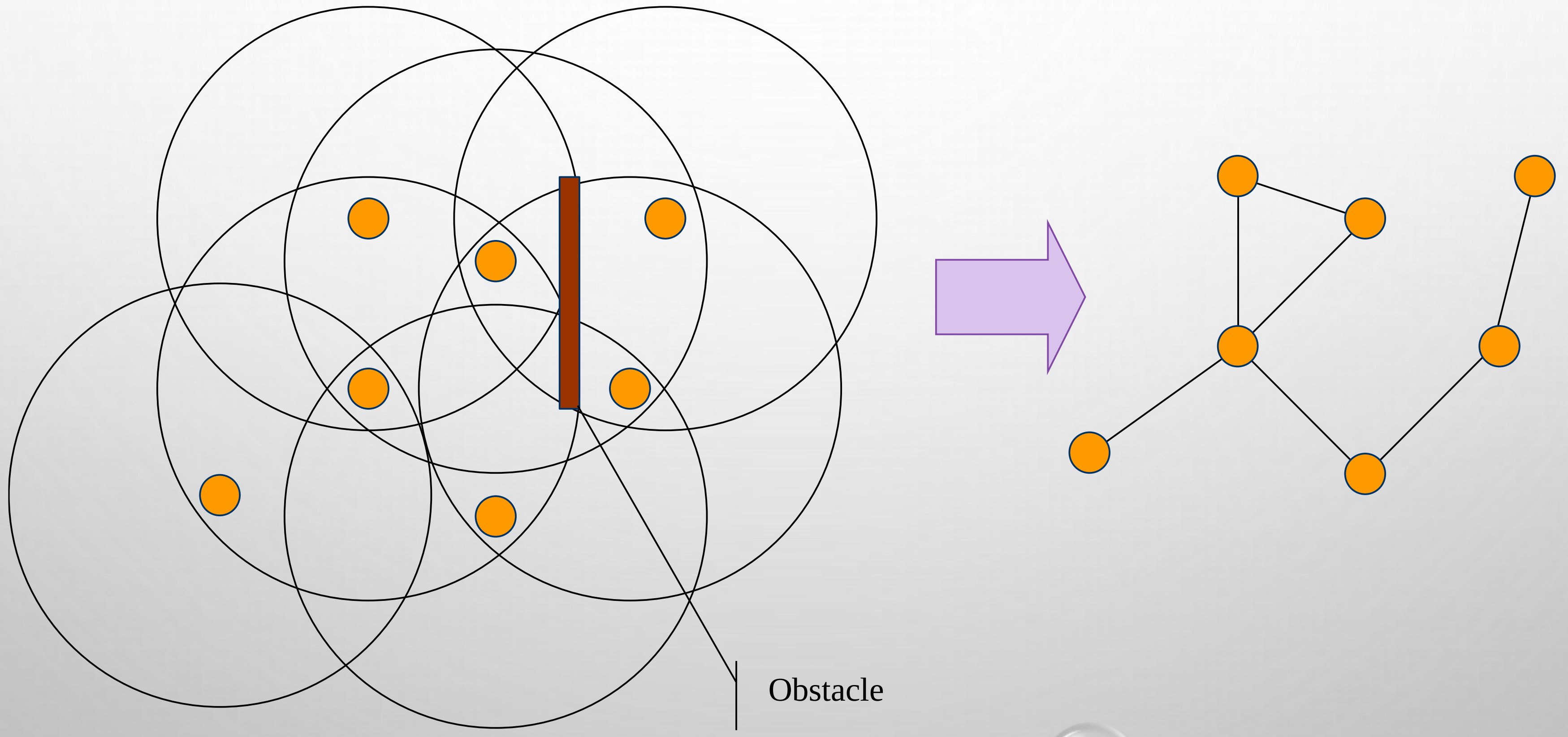
Wireless communications:

- Transmission range of the nodes is limited
- Obstacles may prevent direct communication between a pair of nodes

Point-to-point Network

- Communication between non-adjacent nodes must be supported by other nodes

MOBILE AD HOC NETWORKS



MOBILE AD HOC NETWORKS

UNIT DISK GRAPH MODEL:

- $G = (V, E)$
- $V = \{u \colon u\ is\ a\ node\ in\ the\ network\}$
- $edge(u, v) \in E \iff d(u, v) \leq r$, WHERE:
  - $d(u, v)$ IS THE EUCLIDIAN DISTANCE BETWEEN NODES u AND v
  - r IS THE TRANSMISSION RANGE OF THE NODES

MOBILE AD HOC NETWORKS

SEVERAL RELEVANT ISSUES:

- ACCESS TO THE SHARED WIRELESS CHANNEL
  - REQUIRES A (WIRELESS) MEDIA ACCESS CONTROL (MAC)
- LIMITED TRANSMISSION RANGE:
  - PROTOCOLS BASED ON NEIGHBOR KNOWLEDGE
  - THE NETWORK IS MULTI HOP
  - NEED FOR A MULTIHOP ROUTING PROTOCOL
- WIRELESS COMMUNICATION:
  - EAVESDROPPING OF ONGOING COMMUNICATIONS
  - SECURITY ISSUES

MAC-LEVEL ISSUES

- DUE TO PHYSICAL LAYER PROPERTIES:
  - ATTENUATION OF SIGNAL DEPENDS ON RECEIVER AND TRANSMITTER DISTANCE
  - NO DEFINITE BOUNDARIES FOR RADIO WAVES
  - HIGH BIT ERROR RATE (BER)
  - ASYMMETRIC CHANNEL QUALITIES
- CONCEPT OF “NEIGHBORS:” NODES WITHIN EACH OTHER TRANSMISSION RANGE: ONLY NEIGHBORS DETECT THE CARRIER ON THE CHANNEL

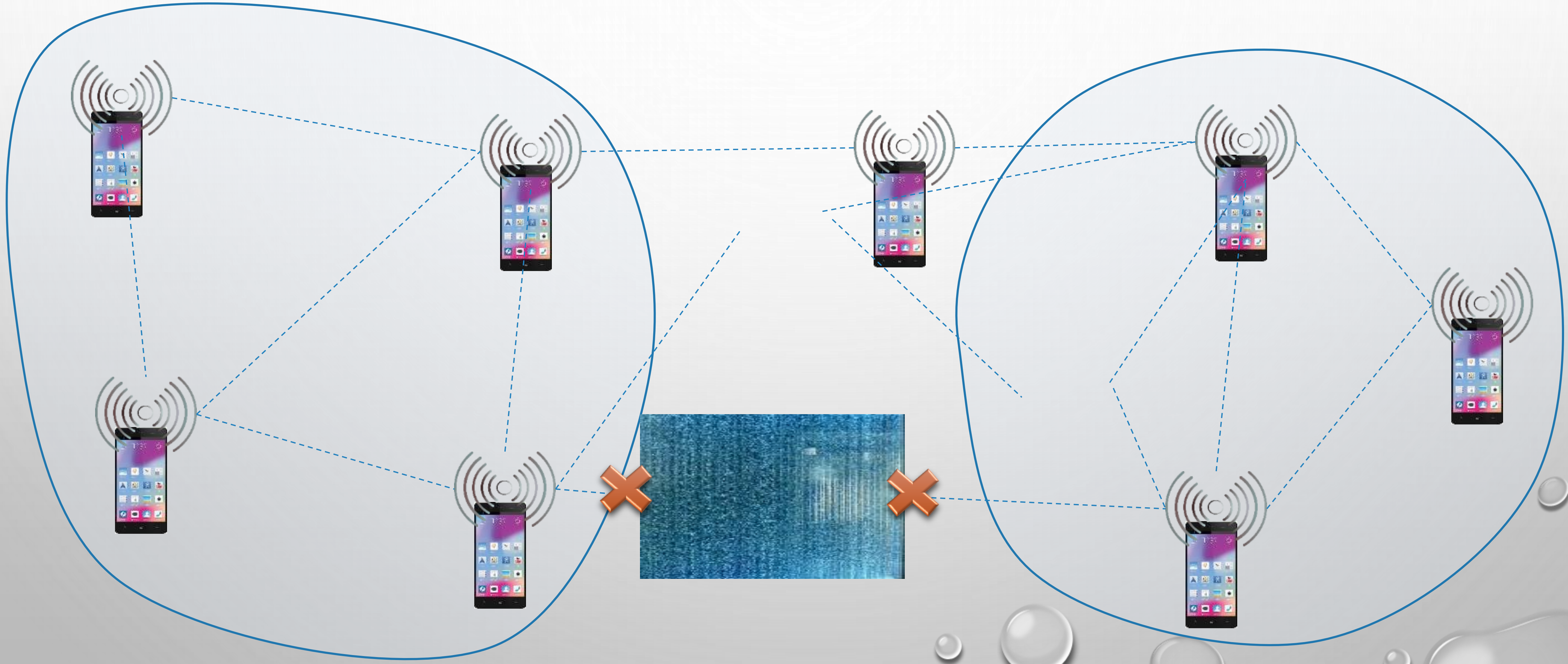
NETWORK-LEVEL ISSUES

- DISTRIBUTED CONTROL
- HETEROGENEITY OF NODES
  - BATTERY, PROCESSING, STORAGE CAPACITY
  - LAPTOPS/TABLETS, SMARTPHONES, SENSORS, ETC.
- ENERGY MANAGEMENT IS IMPORTANT
- MOBILITY IS A CHALLENGE
  - FREQUENT LINK/NODE FAILURES
  - THE NETWORK TOPOLOGY CHANGE ARBITRARILY
  - NODES' DISCONNECTIONS/NETWORK PARTITIONING

NETWORK-LEVEL ISSUES

- NODES ARE ROUTERS:
  - NEED FOR A MULTIHOP ROUTING PROTOCOL
- ADDRESSES DO NOT REFLECT THE POSITION OF THE NODES IN THE NETWORK ANYMORE!
  - NEED FOR DYNAMIC ROUTING
- NODES ARE MOBILE, THE NETWORK TOPOLOGY CHANGES FREQUENTLY
  - ROUTES MAY FAIL FREQUENTLY
  - NEED FOR FAST ROUTE UPDATE

MOBILE AD HOC NETWORKS



MANET PROTOCOL STACK

Application layer			
App1	App2	App3	…

Transport layer	
TCP	UDP

Network layer
Non-IP Routing (!/?)

Datalink layer
MAC for wireless links

Physical layer
Network interface

WIRELESS SENSOR NETWORKS

(WSN)

ENVIRONMENTAL MONITORING WITH SENSORS

- CONVENTIONAL APPROACH:
  - THE SENSORS ARE JUST TRANSDUCERS
  - CONNECTED BY A CABLE TO A CENTRALIZED CONTROL DEVICE
- EXAMPLES
  - SENSORS IN AUTOMOTIVE
  - SENSORS IN INDUSTRIAL PLANTS
  - HOUSE ALARMS

WIRELESS SENSOR NETWORKS

DIFFERENCES WITH THE CONVENTIONAL MODEL:

- THE SENSORS ARE “INTELLIGENT”
  - MICROSYSTEMS (PROCESSOR, MEMORY, TRANSDUCERS,…)
  - CAN PROCESS SENSED DATA
- THE SENSORS COMMUNICATE VIA WIRELESS TECHNOLOGIES
  - RADIO
  - OPTICAL
  - ACOUSTIC, …
- THE SENSORS BUILD A NETWORK
  - NOT JUST DIRECT COMMUNICATION TRANSDUCER-CENTRALIZED CONTROL
- NETWORK EASILY DEPLOYABLE
  - NO NEED FOR FIXED INFRASTRUCTURE

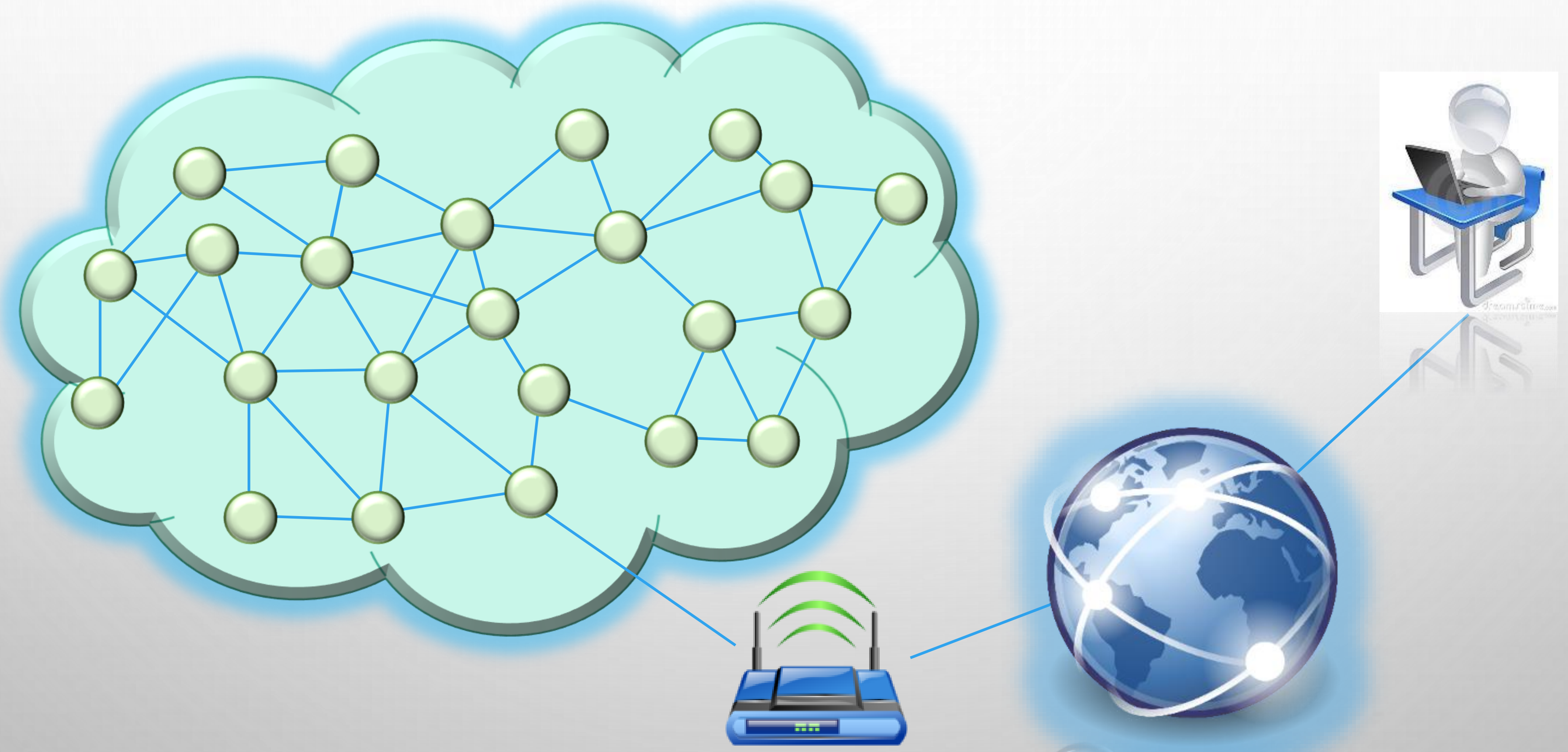
WIRELESS SENSOR NETWORKS

- SENSORS ARE DEPLOYED IN THE ***SENSING FIELD***
- A TYPICAL CONFIGURATION COMPRISES:
  - ONE (OR MORE) SINK NODES
    - INTERFACE THE WSN WITH THE EXTERNAL WORLD
  - A SET OF WIRELESS SENSORS
- EACH SENSOR :
  - LOW POWER, LOW COST SYSTEM
  - SMALL
  - AUTONOMOUS

WIRELESS SENSOR NETWORKS

- EACH SENSOR EQUIPPED WITH:
  - PROCESSOR
  - MEMORY
  - RADIO TRANSCEIVER
  - TRANSDUCERS
    - FOR EXAMPLE: ACCELERATION, PRESSURE, HUMIDITY, LIGHT, ACOUSTIC, TEMPERATURE, GPS, MAGNETIC, …
  - ANALOG TO DIGITAL CONVERTER (ADC)
  - BATTERY, SOLAR CELLS, …

WSN: A TYPICAL CONFIGURATION



WIRELESS SENSOR NETWORKS

- EACH SENSOR SAMPLES ENVIRONMENTAL PARAMETERS
  - PRODUCES STREAMS OF DATA
  - DATA STREAMS CAN BE PRE-PROCESSED LOCALLY AND THEN FORWARDED TO A SINK
- THE SINKS MIGHT BE TEMPORARILY UNAVAILABLE
  - THE NETWORK OPERATES AUTONOMOUSLY
  - PRE-PROCESS AND STORE SENSED DATA
  - SENSORS MAY ACT AS LOGGERS (STORE DATA)

ADVANTAGES OF WSN

- SENSOR NETWORK DEPLOYMENT IS EASY AND CHEAP
  - NO NEED FOR CABLES
  - THE NETWORK IS SELF-CONFIGURABLE
  - THE NUMBER OF SENSORS CAN SCALE UP
  - THE SENSORS CAN BE REDUNDANT (FAULT-TOLERANCE)
- SENSORS CAN BE MOBILE
  - FOR INSTANCE SENSORS ON PEOPLE OR ANIMALS
- NO NEED FOR CENTRALIZED CONTROL
- THE SENSORS CAN FILTER/PROCESS DATA
  - THE NETWORK CAN BE PROGRAMMED DYNAMICALLY

DIFFERENCES WITH AD HOC NETWORKS

- NUMBER OF SENSOR NODES CAN BE SEVERAL ORDERS OF MAGNITUDE HIGHER
- SENSOR NODES ARE STRONGLY CONSTRAINED IN POWER, COMPUTATIONAL CAPACITIES, AND MEMORY
- SENSOR NETWORK ARE DENSER AND SENSORS ARE PRONE TO FAILURES
- THE TOPOLOGY OF A SENSOR NETWORK CHANGES MAINLY DUE NODE FAILURES (AND MOBILITY?)
- NEED FOR A TIGHT INTEGRATION WITH SENSING TASKS

WSN APPLICATIONS

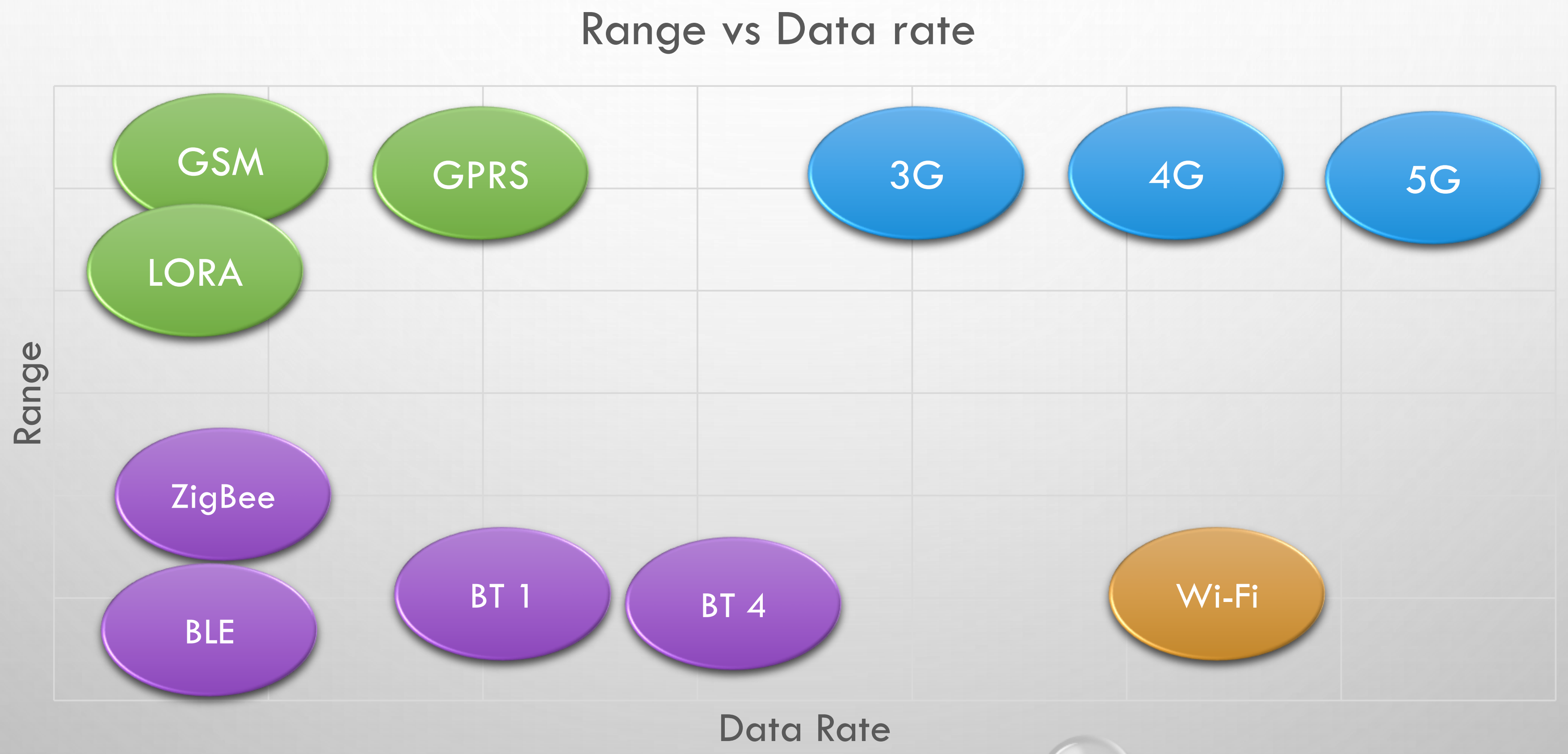
- ENVIRONMENTAL
  - TRACKING ANIMALS, …
  - POLLUTION CONTROL, …
- DISASTER RECOVERY
  - MONITOR DISASTER AREAS,
  - FIRE/FLOODING DETECTION, …
  - METEOROLOGICAL RESEARCH
- SECURITY
  - NUCLEAR, BIOLOGICAL AND CHEMICAL (NBC) ATTACK DETECTION
  - MONITORING BATTLEFIELD,
  - SURVEILLANCE, …
- HEALTH
  - DIAGNOSTICS
  - MONITORING
  - SUPPORT TO DISABLED
- COMMERCIAL
  - INVENTORY MANAGEMENT
  - VEHICLE TRACKING
  - TOYS
  - DOMOTICS
- ART
- SPACE EXPLORATION
- …

REFERENCE STANDARDS

MAIN STANDARDS FOR AD HOC & SENSOR NETWORKING

- IEEE 802.11 (WI-FI)
  - GENERAL PURPOSE WIRELESS ACCESS
- IEEE 802.15.1 & BLUETOOTH
  - CABLE REPLACEMENT, SENSORS, …
- IEEE 802.15.4 & ZIGBEE
  - SENSOR AND ACTUATOR NETWORKS
- IEEE 802.16 (WIMAX)
  - METROPOLITAN WIRELESS ACCESS NETWORKS

WIRELESS TECHNOLOGIES



IEEE 802.15.4 AND ZIGBEE VS BLUETOOTH

Name	ZigBee	WiFi	Bluetooth (1&2)
Standard	802.15.4	802.11 a,b,g	802.15.1
Applications	Monitoring and control	Web, e-mail, video	Cable replacement
System resources	50 to 60 Kbytes	>1 Mbytes	>250 Kbytes
Battery life (days)	100 to > 1000	1 to 5	1 to 7
Network size	64K nodes	~ 100 nodes	7 nodes
Bandwidth (Kbps)	20 to 250 Kbps	~ 100 Mbps	~ 1 Mbps
Maximum transmission range	100+ meters	100 meters	10 meters
Success metrics	Reliability, power, cost	Speed, flexibility	Cost, convenience

WSN

v.s.

RFID & … BARCODES!

WSN, BARCODES AND RFIDS

- BARCODES & QR CODES:
  - EXTREMELY CHEAP (THE COMPLEXITY IS IN THE READER)
  - DEEP USER INVOLVEMENT
  - SHORT RANGE (A FEW CENTIMETERS)

https://elearning.di.unipi.it/course/view.php?id=76

TEC-IT.COM

WSN, BARCODES AND RFIDS

- RFID (RADIO FREQUENCY IDENTIFIERS):
  - CHEAP TECHNOLOGY (THE COMPLEXITY IS IN THE READER)
  - SIGNIFICANT USER INVOLVEMENT
  - SHORT RANGE (A FEW METERS)
    - RFID TAGS GIVE THEIR IDENTIFIER TO THE READER

WSN, BARCODES AND RFIDS

- RFID (RADIO FREQUENCY IDENTIFIERS):
  - PASSIVE TAGS (POWERED BY THE READER)
    - CAN PROVIDE TAG ID AND A FEW SAMPLED DATA TO THE READER
  - ACTIVE TAGS (BATTERY POWERED)
    - NO NETWORK, JUST TAG AND READER
    - NOT POWERED BY THE READER: SMALLER ANTENNA

WSN, BARCODES AND RFID

- WIRELESS SENSOR NETWORKS
  - NO USER INVOLVEMENT
  - MEDIUM RANGE (10-100 METERS)
    - RANGE CAN BE EXTENDED WITH MULTIHOP COMMUNICATIONS
  - ACTIVE SENSORS (BATTERY POWERED)
  - CAN CONNECT ALSO TO RFID TAGS

AN EXAMPLE: USER LOCALIZATION

- LOCALIZATION:
  - LOCATE A PERSON OR A DEVICE IN AN ENVIRONMENT
- WITH BARCODES:
  - A CODE DENOTES AN AREA
  - THE USER (EQUIPPED WITH A BARCODE READER) READS THE CODE
  - THE READER DETERMINES THE POSITION OF THE USER
  - USED IN SOME PILOT PROJECT IN MUSEUMS ETC..
- BARCODES SUITABLE FOR LOCALIZATION IN AREAS OF INTEREST

AN EXAMPLE: USER LOCALIZATION

- WITH RFIDS
  - A RFID READER DENOTES AN AREA
  - THE USER BRINGS AN RFID TAG
  - AS THE USER APPROACHES THE AREA THE READER DETECTS THE USER'S TAG
- TAGS SUITABLE FOR LOCALIZATION IN AREAS OF INTEREST

AN EXAMPLE: USER LOCALIZATION

- WITH A WSN
  - A WSN IS DEPLOYED IN A BUILDING
  - A USER BRINGS A SENSOR THAT CONSTANTLY EMITS RADIO BEACONS
  - THE WSN DETECTS THE PRESENCE AND POSITION OF THE USER’S SENSOR IN THE BUILDING
- SUITABLE TO COVER ALL THE BUILDING, NOT JUST AREAS OF INTEREST

WSN & IOT

WSN & INTERNET OF THINGS (IOT)

A LARGE, MAJOR CHANGE IN INTERNET COMPLETED IN THE LAST YEARS

THE TRANSITION FROM IPV4 TO IPV6

ENABLES UP TO

655.571 BILLION OF BILLIONS

OF DEVICES PER SQUARE METER ON EARTH (INCLUDED OCEANS!)

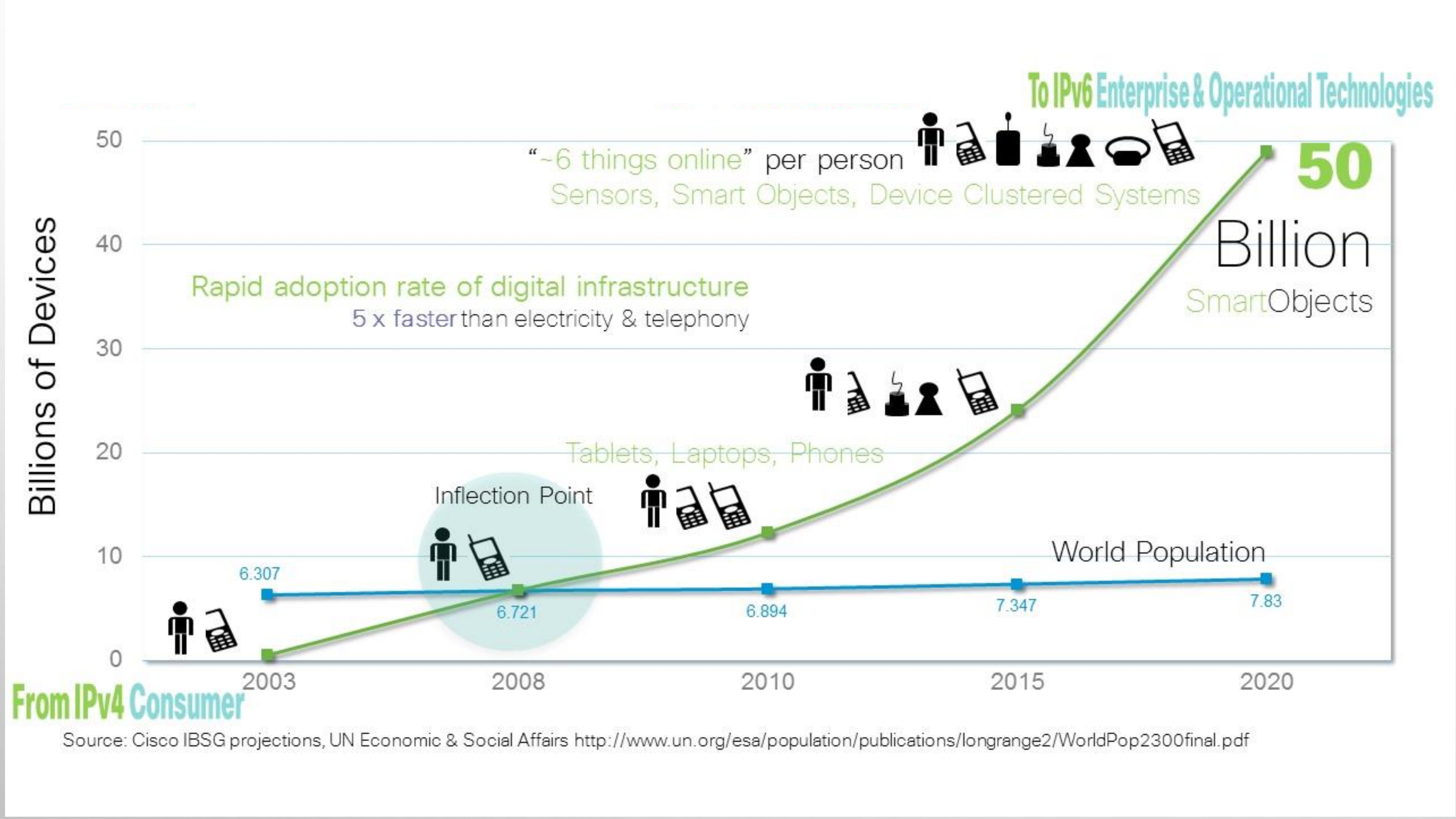
IS THERE ANY PURPOSE/NEED?

WHO NEEDS ALL THIS?

INTERNET OF THINGS (IOT)

- PHYSICAL OBJECTS («THINGS»)
- EMBEDDED WITH ELECTRONICS, SOFTWARE, SENSORS, NETWORK CONNECTIVITY

IOT DEVICES VS HUMANS



- 2003: THE TERM INTERNET OF THINGS WAS CONIED
- IN 2008 MORE DEVICES IN INTERNET THAN PEOPLE
- IN 2014 THE NUMBER OF **MOBILE** DEVICES ON INTERNET SURPASSED THE NUMBER OF HUMANS ON EARTH
- BY 2020 THE NUMBER OF DEVICES ON INTERNET WILL EXCEED 50 BILLIONS

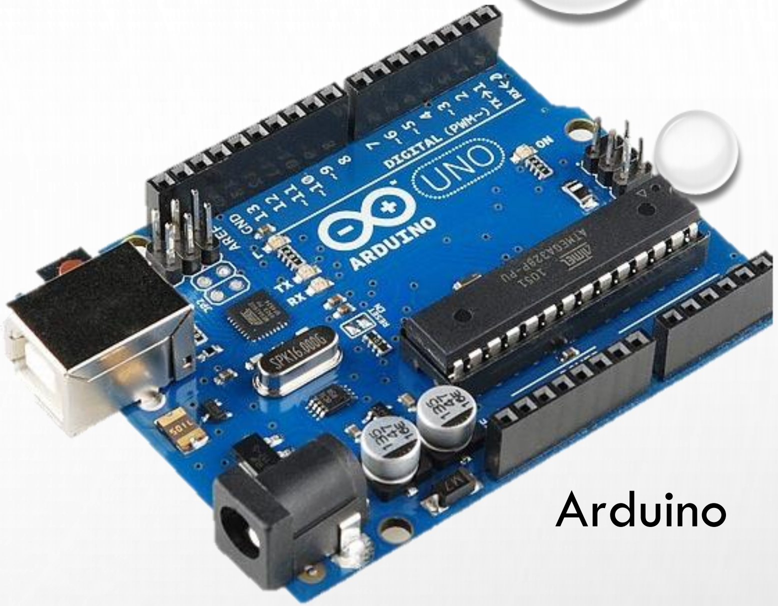
WSN & INTERNET OF THINGS (IOT)

- MOST OF THE DEVICES ARE NOT DIRECTLY IN USE BY HUMAN BEINGS
- INDEPENDENT PHYSICAL OBJECTS WITH THEIR OWN BUSINESS LOGIC
  - EMBEDDED WITH ELECTRONICS, SOFTWARE, SENSORS AND NETWORK CONNECTIVITY
  - MOSTLY SENSORS AND ACTUATORS
  - NOT HUMAN-OPERATED!

WEARABLE SENSORS

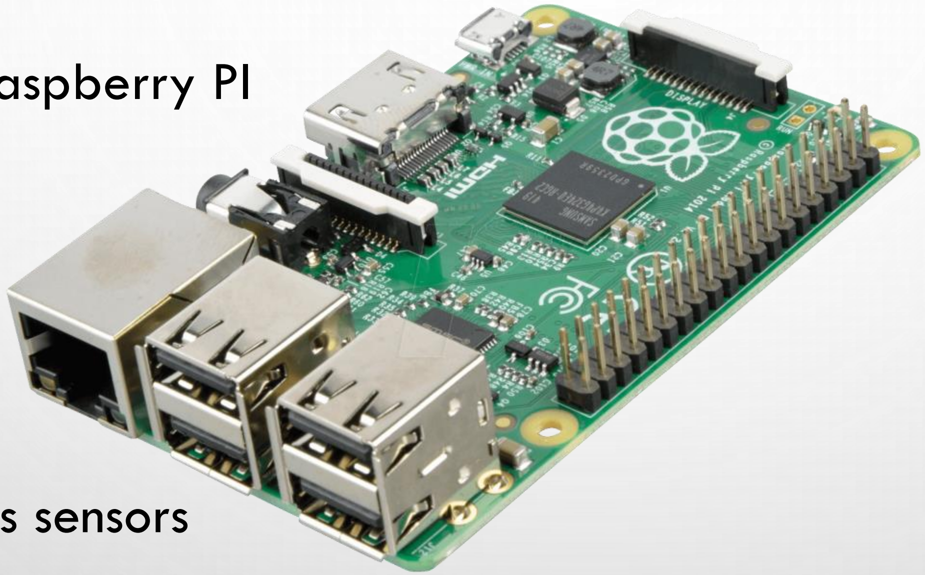
- Smartphones/smartwatches sensors (accelerometers, radio, gyroscopes, …)
- Fitness (heartrate, step counter, energy, …)
- Medical sensors (hearthbeat, ECG, blood pressure,…)
- Panic buttons and fall detectors
- …

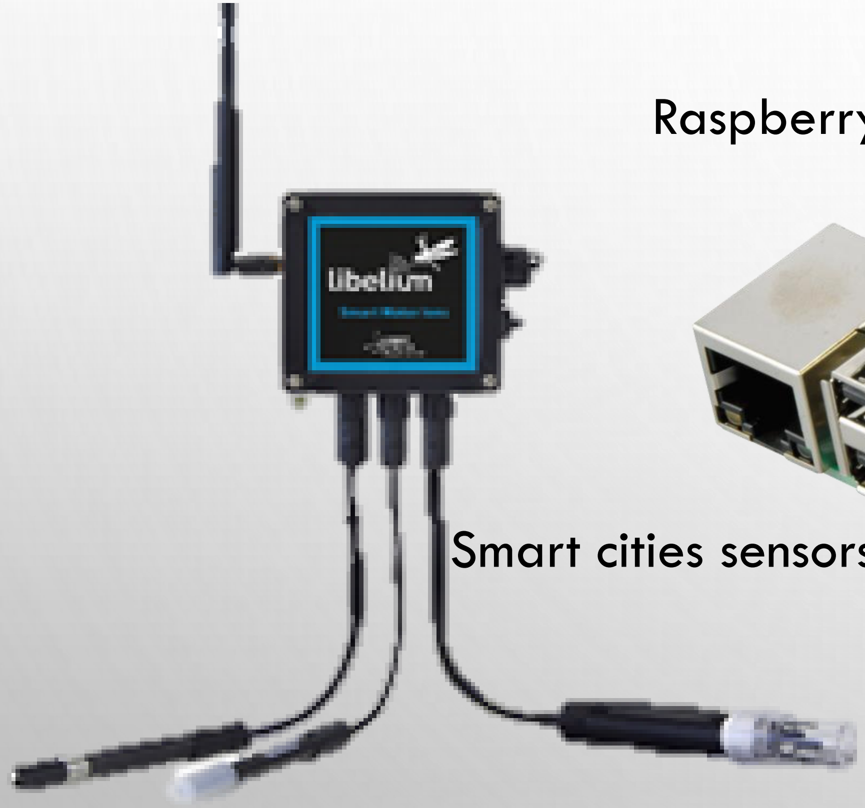
ENVIRONMENTAL SENSORS



Arduino

Raspberry PI





Smart cities sensors

Motes

iBeacon







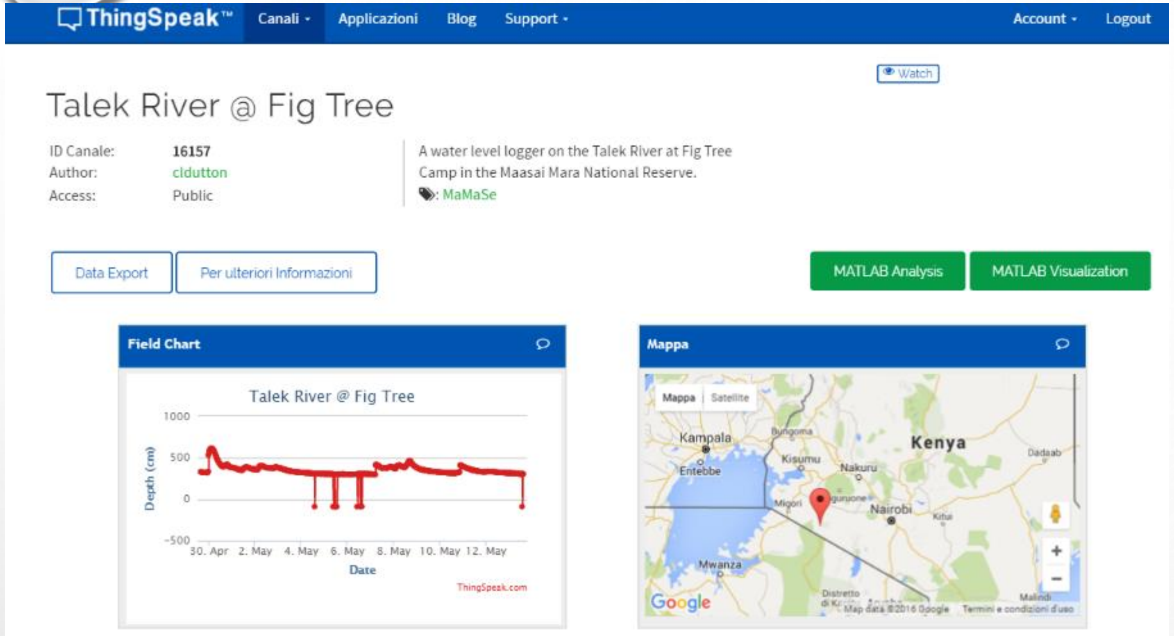
IOT & CLOUD

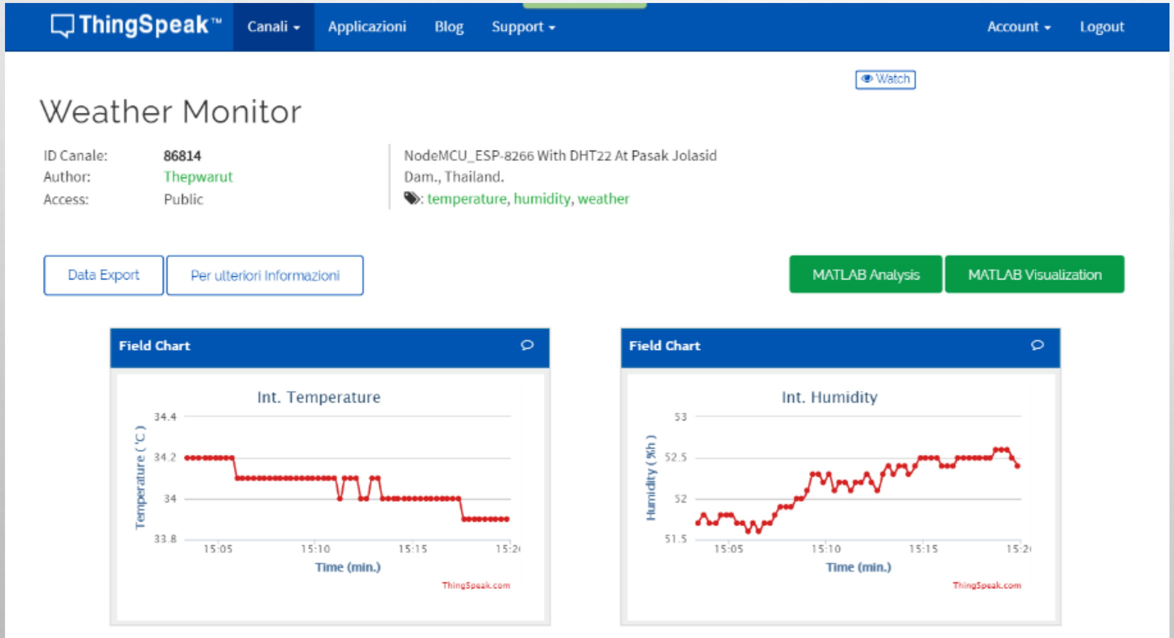
IOT & THE CLOUD…

- WSN (+ ACTUATORS) ARE THE EDGE OF THE CLOUD
- BEHIND INTERNET, DATA STORED/PROCESSED IN THE CLOUD

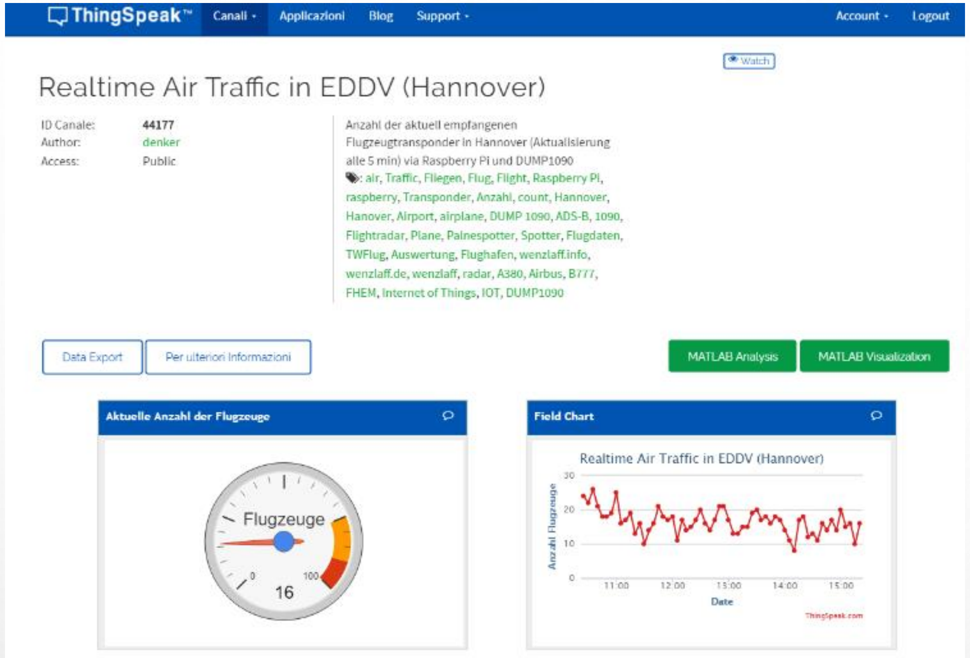
- EXAMPLE: THINGSPEAK
  - HTTPS://THINGSPEAK.COM
  - A WEB-BASED DB
  - CAN BE CONFIGURED TO STORE DATA FROM SENSORS
  - USE INPUT CHANNELS TO RECEIVE AND STORE SENSOR DATA.
  - SOME CHANNELS ARE PUBLIC

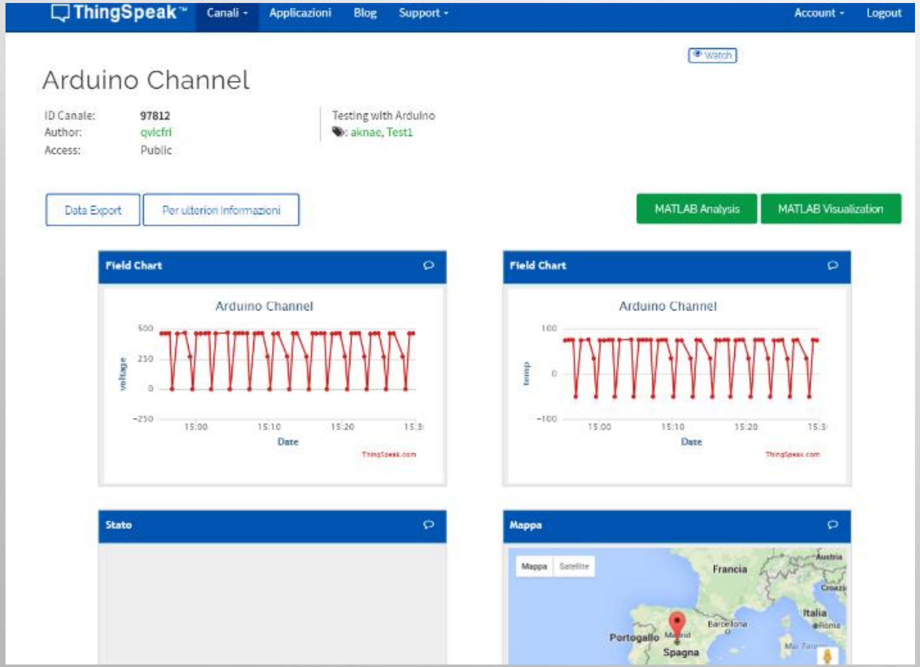
IOT & THE CLOUD…





IOT & THE CLOUD…





THINGSPEAK

- MORE INFO ON:

  HTTPS://THINGSPEAK.COM/

  - DOCUMENTATION, TUTORIAL, EXAMPLES AND FORUM

WHAT'S BEHIND : NO-SQL DATABASES

- NO-SQL DATABASES ARE USED IN BIG DATA AND REAL-TIME WEB APPLICATIONS
  - USED BY GOOGLE, AMAZON, FACEBOOK ETC.
  - SIMPLER DESIGN WITH RESPECT TO SQL
  - SCALE WELL ON "HORIZONTAL" CLUSTERS OF MACHINES

EXAMPLE: MONGODB

- RECORDS IN MONGODB ARE DOCUMENTS
- JSON (JAVASCRIPT OBJECT NOTATION)-LIKE DATA SYNTAX:
  - A DOCUMENT IS SIMILAR TO A JSON OBJECT
  - JSON: HTTP://JSON.ORG/
- IN A DOCUMENT:
  - DATA IS IN NAME/VALUE PAIRS
  - DATA SEPARATED BY COMMAS
  - CURLY BRACES HOLD OBJECTS
  - SQUARE BRACKETS HOLD ARRAYS

EXAMPLE: MONGODB

- EXAMPLE OF A MONGODB DOCUMENT:

```
{
 NAME:  "SUE",                    ← field : value
 AGE:  26,                        ← field : value
 STATUS:  "X";                    ← field : value
 GROUP:  ["NEWS",  "SPORT"]       ← field : value
}
```

EXAMPLE: MONGODB

- MONGODB DOCUMENTS:
  - DOCUMENTS CORRESPOND TO NATIVE DATA TYPES IN MANY PROGRAMMING LANGUAGES.
  - EMBEDDED DOCUMENTS AND ARRAYS REDUCE NEED FOR EXPENSIVE JOINS.
    - A VALUE CAN BE AN ARRAY OR ANOTHER DOCUMENT

MONGODB – COLLECTIONS

- DOCUMENTS ARE STORED IN COLLECTIONS
  - A COLLECTION CORRESPONDS TO A TABLE IN A RELATIONAL DB
  - DOCUMENTS IN A COLLECTION MAY NOT HAVE THE SAME STRUCTURE

MONGODB – QUERIES

- A QUERY TARGETS A SPECIFIC COLLECTION OF DOCUMENTS
- IT SPECIFIES CRITERIA AND CONDITIONS THAT IDENTIFY DOCUMENTS IN THE COLLECTION
  - MAY INCLUDE A PROJECTION THAT SPECIFIES THE FIELDS FROM THE MATCHING DOCUMENT TO RETURN
  - MAY INCLUDE MODIFIER OF THE OUTPUT (E.G. SORTING OF RESULTS)

MONGODB – QUERIES

Collection — Query criteria — Modifier

```
DB.SENSEDDATA.FIND({TIME:{$GT: 1900}}).SORT({TIME:1})
```

- {time:1760,temp:21,…}
- {time:1733,humid:8,…}
- {time:1845,temp:23,…}
- {time:1901,humid:7,…}
- {time:1920,temp:24,…}
- {time:1948,temp:23,…}
- {time:1939,humid:6,…}

sensedData collection

Query Criteria →

- {time:1901,humid:7,…}
- {time:1920,temp:24,…}
- {time:1948,temp:23,…}
- {time:1939,humid:6,…}

Modifier →

- {time:1901,humid:7,…}
- {time:1920,temp:24,…}
- {time:1939,humid:6,…}
- {time:1948,temp:23,…}

MONGODB – DATA MODIFICATION

- OPERATIONS THAT CREATE, UPDATE, OR DELETE DATA
  - UPDATE AND DELETE OPERATIONS CAN SPECIFY THE CRITERIA TO SELECT THE DOCUMENTS TO UPDATE OR REMOVE
- EXAMPLE: INSERT

```
DB.SENSEDDATA.INSERT(
{
 TIME:2011,
 HUMID: 5,
 …
}
```

```
{
 time:2011,
 humid: 5,
 …
}
```

Insert

```
{time:1760,temp:21,…}
{time:1733,humid:8,…}
{time:1845,temp:23,…}
{time:1901,humid:7,…}
{time:1920,temp:24,…}
{time:1948,temp:23,…}
{time:1939,humid:6,…}
{time:2011,humid:5,…}
```

MONGODB

FOR MORE DETAILS SEE THE MONGODB TUTORIAL:

- HTTPS://WWW.MONGODB.COM/
- HTTPS://DOCS.MONGODB.COM/MANUAL/INTRODUCTION/

RELEVANT ISSUES IN IOT

- COMMUNICATION MIDDLEWARE
  - HOW TO MEET DATA PRODUCERS (SENSORS) WITH CONSUMERS (USERS/ ACTUATORS/APPLICATIONS)
- PRESENTATION OF DATA
  - DATA FORMATS, STANDARDIZATION

Many standards already available

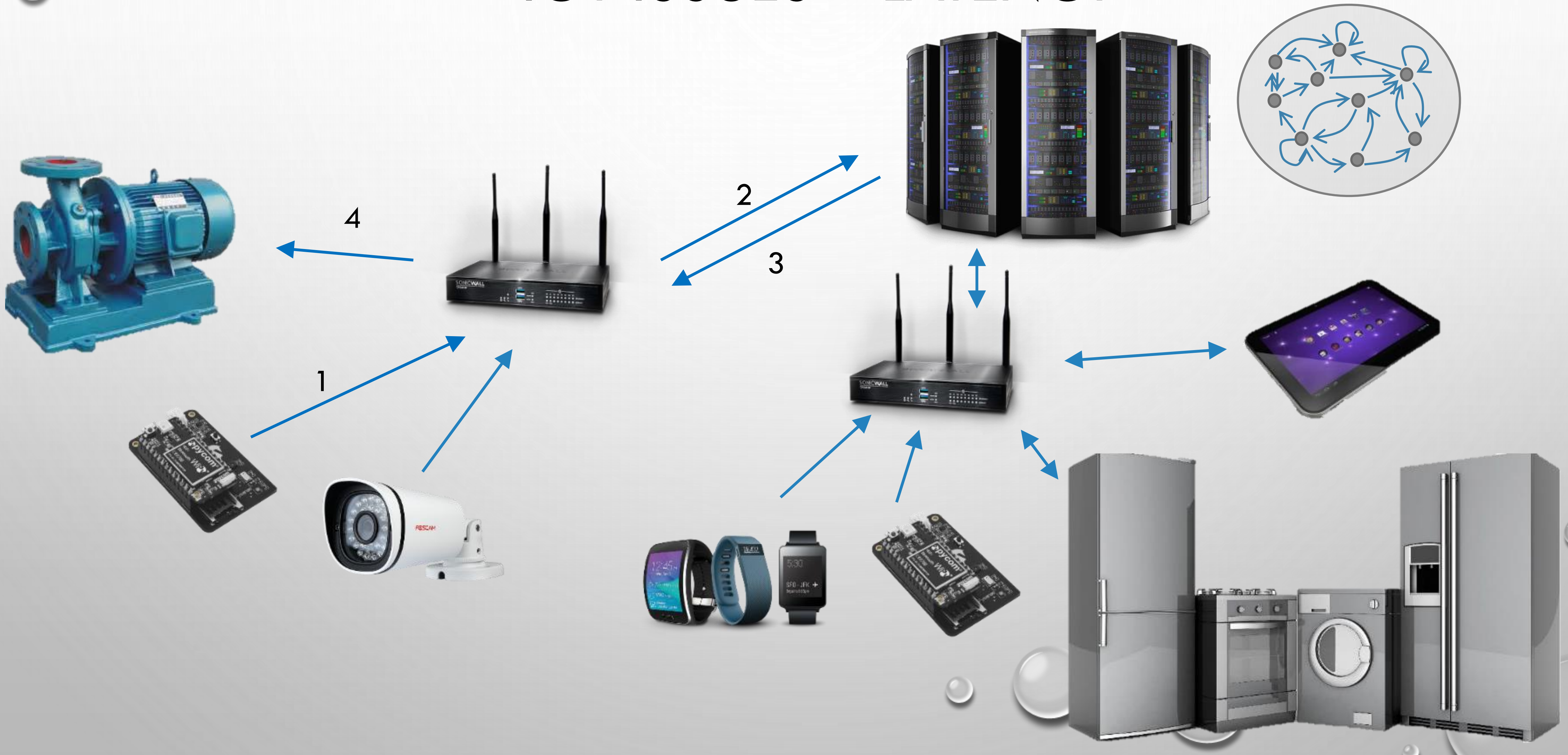
- At MAC level: Bluetooth, IEEE 802.15.4,…
- At network level: ZigBee, Bluetooth, 6LowPan,…
- At application level: MQTT, CoAP, oneM2M, …

RELEVANT ISSUES IN IOT

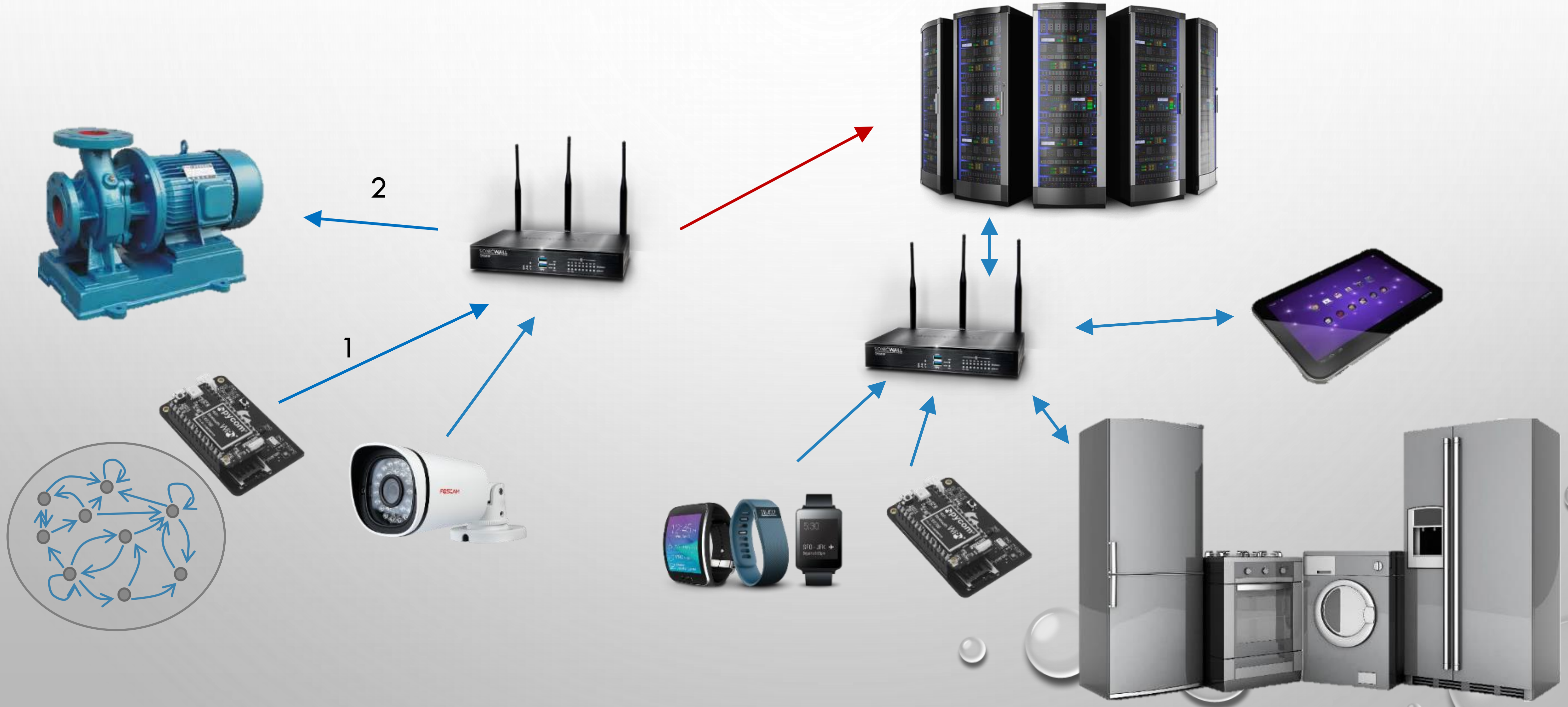
- PERFORMANCE
- ENERGY EFFICIENCY
  - SAME AS WSN
- DATA ANALYSIS/PROCESSING
  - ADAPTABILITY/PERSONALIZATION

Interesting links also with machine learning…

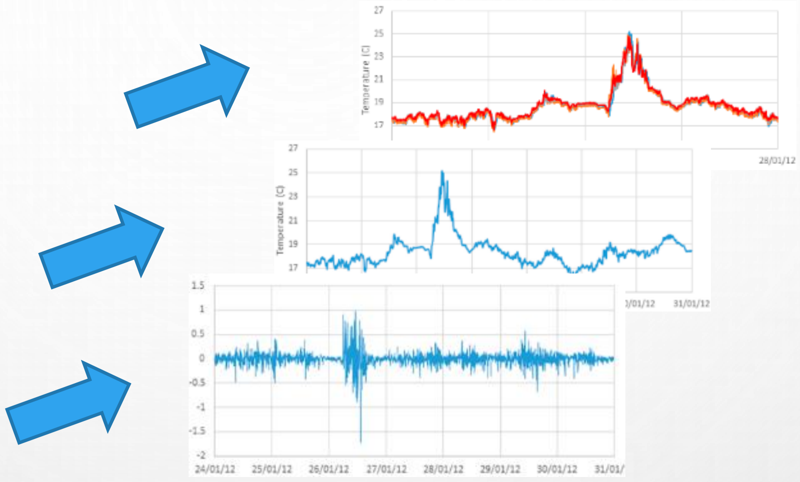
IOT ISSUES – LATENCY



IOT ISSUES – LATENCY



IOT ISSUES: LATENCY–ANALYSIS–EFFICIENCY



Producing fast-streaming heterogeneous sensed data

Context awareness & continuous adaptation

Power and **communication** constraints

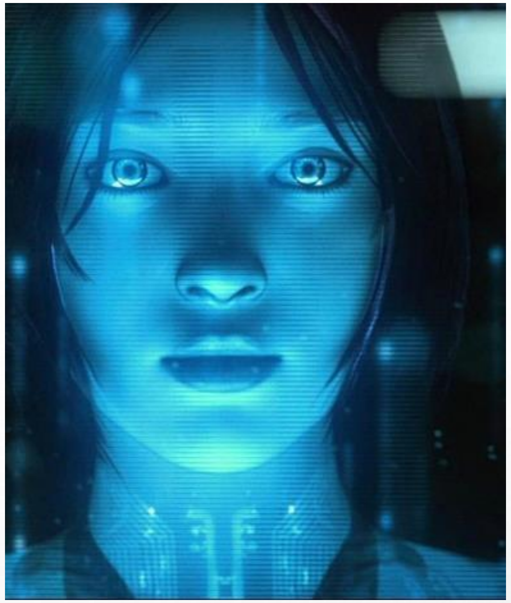
IOT &
ARTIFICIAL INTELLIGENCE

AI AIMS AT GETTING COMPUTERS TO BEHAVE IN A SMARTER MANNER

- EITHER THROUGH…
- … CURATED KNOWLEDGE…
- … OR THROUGH MACHINE LEARNING

CAPABILITIES OF AI AS OF 2017 INCLUDE:

- UNDERSTANDING HUMAN LANGUAGE (WATSON, SIRI, CORTANA, TRANSLATORS …)
- STRATEGIC GAME SYSTEMS (DEEP BLUE FOR CHESS, ALPHAGO FOR GO,…)



IBM Watson

AI THROUGH CURATED KNOWLEDGE

MANY WAYS OF REPRESENTING KNOWLEDGE, OFTEN BASED ON (A LARGE NUMBER OF) CAUSE/EFFECT RULES

EXAMPLES:

- PROPOSITIONAL LOGIC:

$$It\ is\ hot \rightarrow I\ wear\ shorts\ \land\ I\ drink\ ice\ tea$$

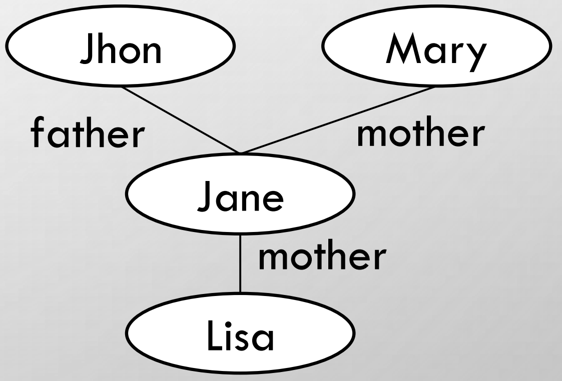
- PREDICATE LOGIC:

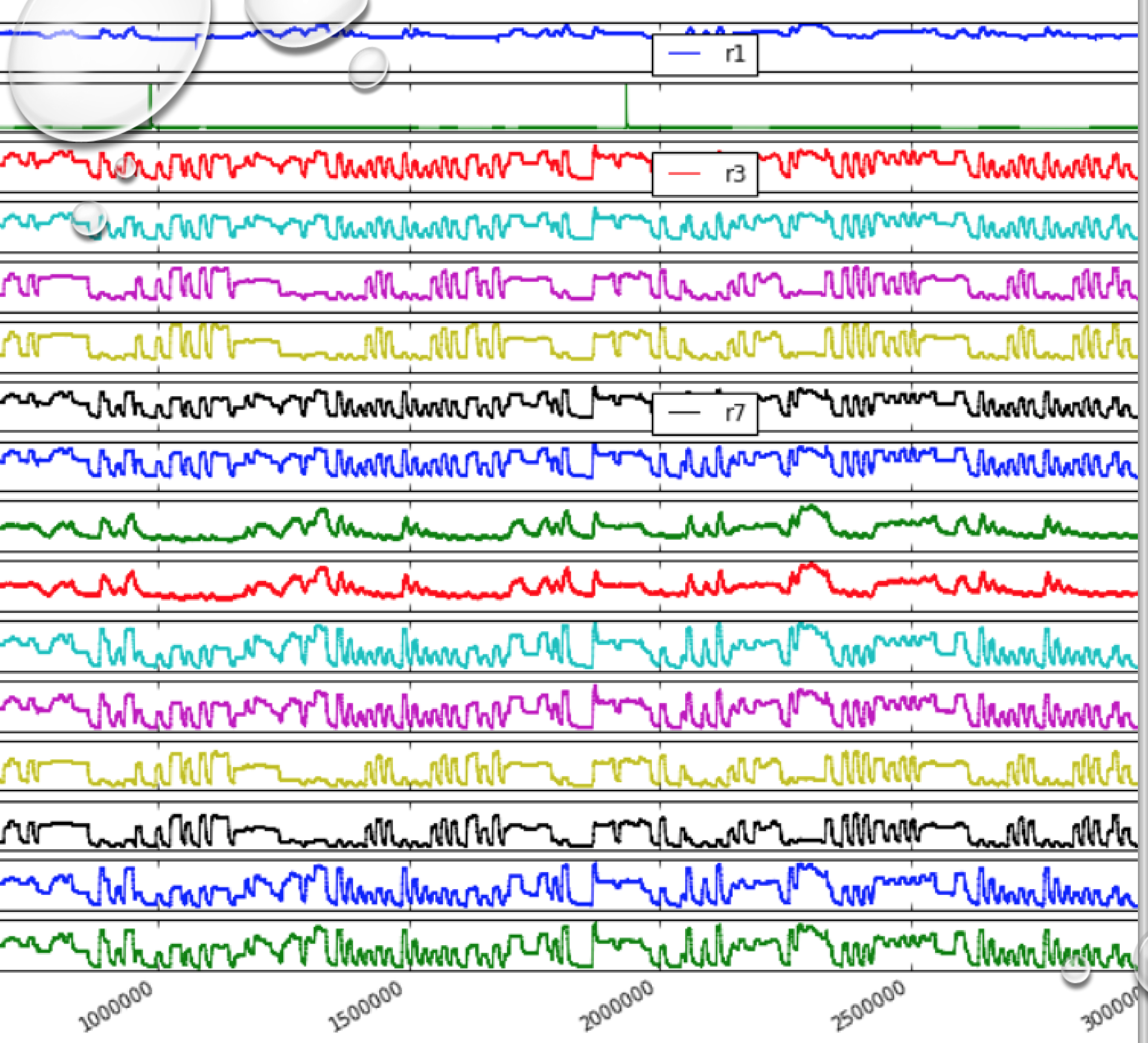
$$\forall x: day\_of\_week(x, wednesday) \lor day\_of\_week(x, friday)$$
$$go(me, football\_court) \land play(me, football)$$

- PRODUCTION RULES:

  $if\ having\ a\ sandwitch\ then\ hungry$

- SEMANTIC NETWORKS:





HETEROGENEOUS TIME-SERIES OF SENSED DATA

- FAST FLOWING
- NOISY
- REDUNDANT
- MISSING
- …

MACHINE LEARNING

- IT IS A SUBFIELD OF AI THAT DEALS WITH:

  «AUTOMATIC SYSTEMS THAT CAN LEARN FROM DATA»

- REPLACES «HUMAN WRITING CODE» WITH «HUMAN SUPPLYING DATA»
  - THE SYSTEM IS FED BY EXAMPLES TO LEARN HOW TO ASSOCIATE INPUT WITH OUTPUT
  - SOME EXAMPLES ARE USED TO TRAIN (TRAINING SET)
  - SOME EXAMPLES ARE USED TO TEST (TEST SET)
- WHEN GIVEN IN INPUT A DATA NEVER SEEN IN THE TRAINING PHASE THE SYSTEM PRODUCES ANYWAY AN OUTPUT
  - IF WELL TRAINED THE OUTPUT WILL BE (MOST LIKELY/HOPEFULLY) CORRECT…
  - DUE TO THE GENERALIZATION CAPABILITY OF ML

SEVERAL PARADIGMS OF ML:

- **UNSUPERVISED LEARNING**
  - ANALYSE DATA
  - FINDS STRUCTURES/RELATIONSHIPS/SIMILARITIES AMONG DATA POINTS
  - AIMS AT UNDERSTANDING THE PAST

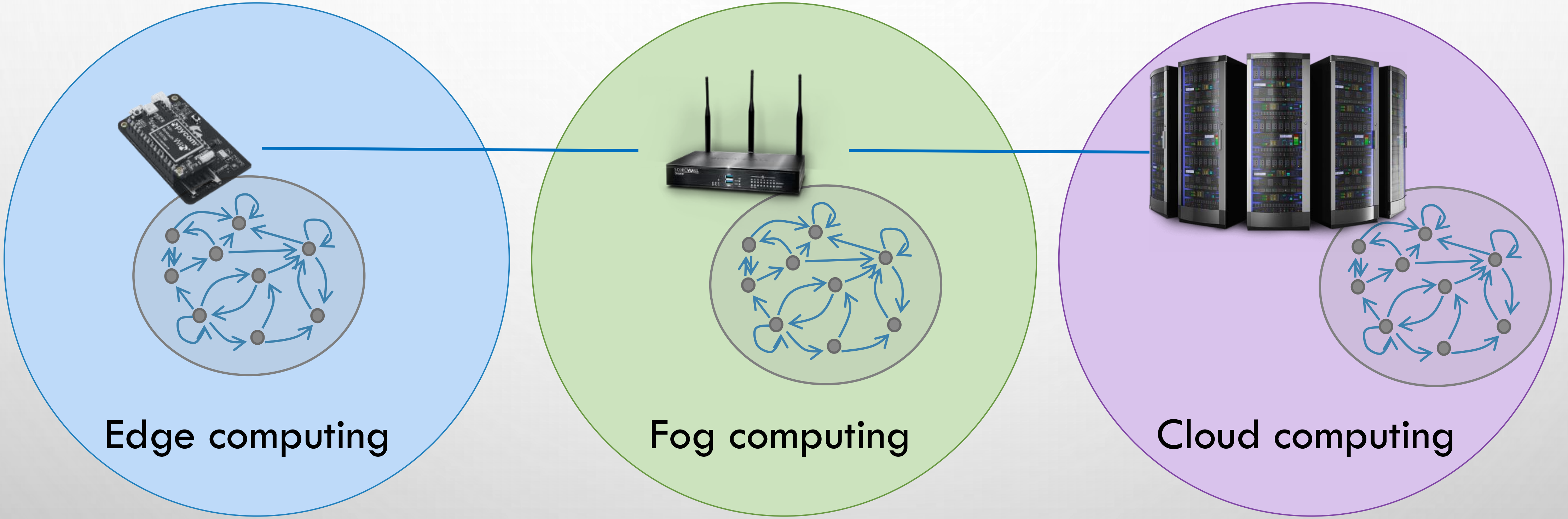
- **SUPERVISED LEARNING**
  - LEARN FROM PAST EXAMPLES
  - FOR EACH EXAMPLE REQUIRES INPUT + DESIRED OUTPUT
  - AIMS AT PREDICTING THE FUTURE OR INTERPRETING THE PRESENT

- **REINFORCEMENT LEARNING**
  - LEARNS FROM EXAMPLES
  - FOR EACH EXAMPLE REQUIRES ONLY INPUT AND A REWARD
  - E.G. TO LEARN A GAME THE REWARD CAN BE +1 FOR WINNING, -1 FOR LOSING, 0 OTHERWISE

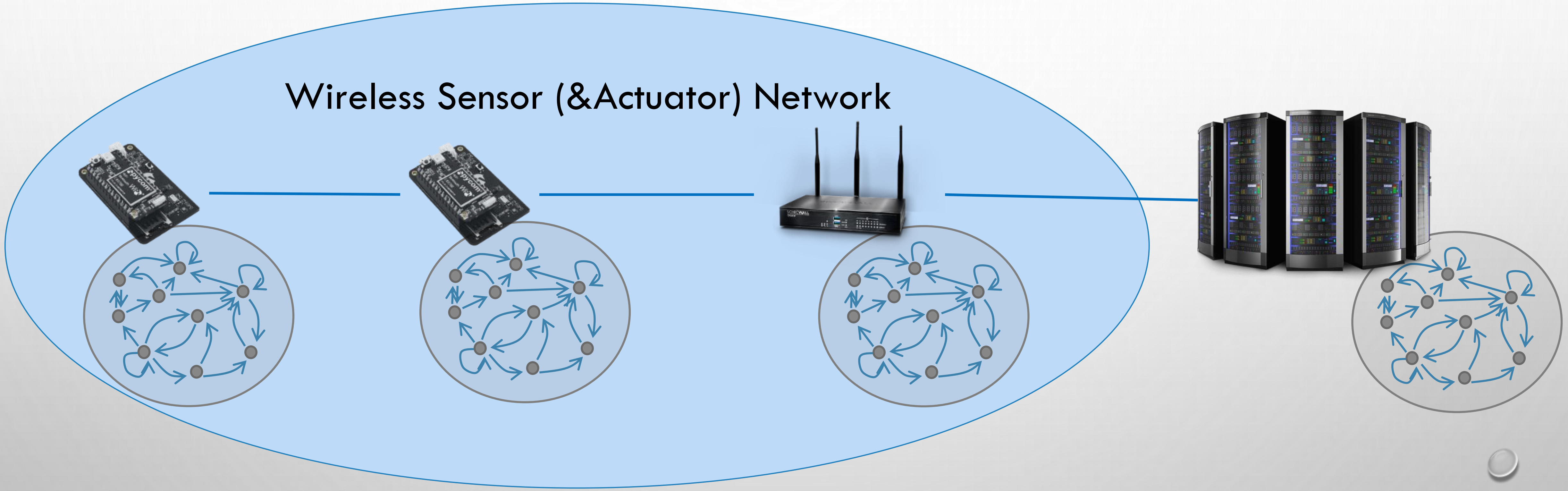
MACHINE LEARNING

THE OVERALL PICTURE…

CLOUD, FOG & EDGE COMPUTING



WSN, IOT



With IP address: IoT

With in-network processing: Edge computing

MOBILE COMPUTING