# IoT Planning and Deployment

**Workshop on Rapid Prototyping of Internet of Things Solutions for Science**
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UNESCO United Nations Educational, Scientific and Cultural Organization

# Goals

- Provide some guidance on the many aspects to consider when planning an ioT network.
- Regulatory aspects should be considered at an early stage for the choice of the best solution.
- Alternatives to consider:
  - Licensed or unlicensed spectrum?
  - Proprietary or  standard based?
  - Cellular or LPWAN?
  - Critical or Massive ?
  - Short range or wide area?

- Present some examples of applications

# Define your goals

1) Define your goals and characterize the desired output of your project, with measurable figures like:

- average usage (number of clients connected)
- average / peak throughput (overall / per user)
- latency and other network issues that can influence the services running on the network
- reliability (percentage of downtime)
- maintenance costs

# Understand constraints

2) Understand which are the constraints and limitations, like for example:

- local availability of equipment
- regulatory aspects (permits, fees, allowed frequencies and power, equipment homologation)
- limitations of the ISP
- access to sites and infrastructures
- availability of power (and its quality/reliability)
- human resources (for deployment/maintenance)
- financial constraints (budget)

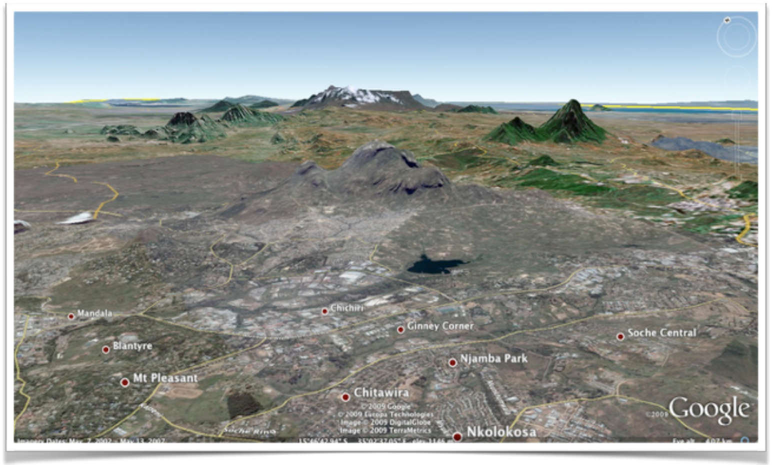
# Design and simulation

3) Feasibility check: **design** and **simulate** the architecture of your wireless network, considering aspects like:

- location of nodes and their access (maps...)
- equipment to be deployed in each node, weather resistant enclosures
- availability of antenna support structures for long distance
- RF power link budget and Line-of-Sight clearance for each hop (with the help of simulation tools)
- source of powering for each equipment
- co-location and interference issues in

# IoT networks requirements

- Low cost
- Energy efficiency
- Ubiquitous coverage
- Scalability to support massive deployments
- Extended coverage
- Security



# Specific inputs for IoT Planning

- Traffic pattern, payload size, periodicity, latency
- Identity and level of security required
- Reliability
- Sector specific regulations (for instance, health care)
- Analytics
- Billing and charging
- Service level agreements (SLA)
- QoS for specific equipment
- Mobility, positioning
- Capability to address group of devices with a single action

## Figure 4: Different IoT applications with Different Characteristics

| Example Applications | Data volume | Quality of Service | Amount of signaling | Time sensitivity | Mobility | Server initiated Communication | Packet switched only |
|---|---|---|---|---|---|---|---|
| Smart energy meters | low | low | intermediate | very low | no | yes | yes |
| Red charging | low | low | low | low | yes | no | yes |
| eCall | very low | very high | very low | very high | yes | no | no |
| Remote maintenance | low | low | high | high | no | yes | yes |
| Fleet management | low | low | very high | intermediate | yes | yes | no |
| Photo frames | intermediate | low | high | low | no | yes | yes |
| Assets tracking | low | low | very high | high | yes | yes | no |
| Mobile payments | intermediate | low | high | very high | yes | no | yes |
| Media synchronisation | high | low | high | intermediate | yes | yes | yes |
| Surveillance cameras | very high | very high | low | very high | no | yes | yes |
| Health monitoring | high | high | high | very high | yes | yes | yes |

very low · low · intermediate · high · very high

Source: *Handbook: Impacts of M2M Communications & Non-M2M Mobile Data Applications on Mobile Networks*, page 50. ITU (Geneva, 2012). Available at: www.itu.int/md/T09-SG11-120611-TD-GEN-0844/en.

# Some specific IoT needs

- Traffic pattern, payload size, periodicity, latency
- Identity and level of security required
- Reliability
- Sector specific regulations (for instance, health care)
- Analytics
- Billing and charging
- Service level agreements (SLA)
- QoS for specific equipment
- Mobility, positioning
- Capability to address group of devices with a single action

# IoT Network Planning

- Choice of technology
  - Short range
  - Long range
- Specific requirements
  - Number of end-devices and payload
  - Number of messages per day
  - Latency constraints
  - Energy consumption
- Radio coverage assessment
- Initial design
- Growth Assumption
- Cost calculation, might require iteration

# IoT Network Planning

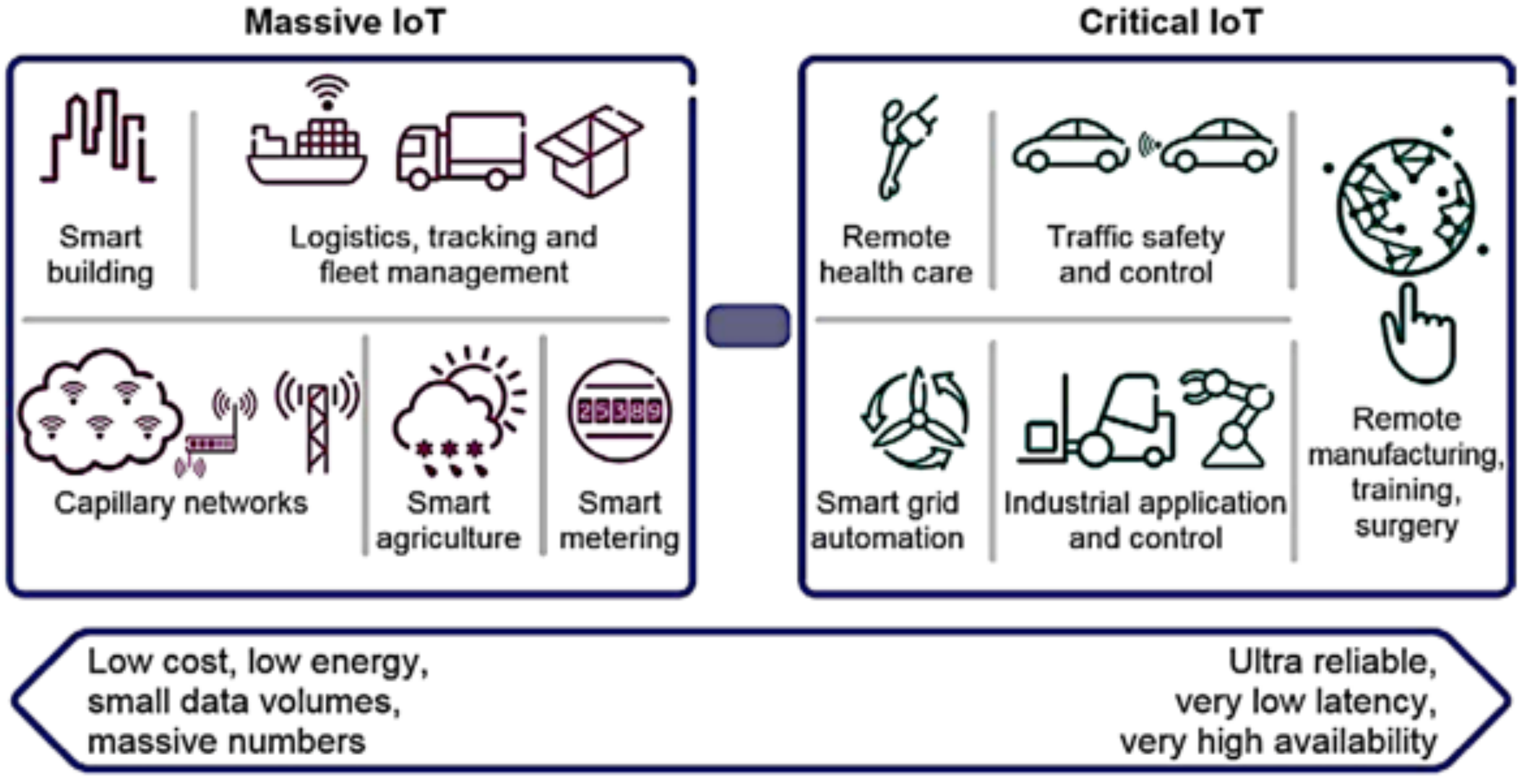
Short range or wide area?

Although wide area solutions might be employed also for short distances, this is normally not cost effective.

Short distance technologies are cheaper and simpler to design.

Sometimes a mix  of short and long range will be required.

# IoT Network Planning: Critical or Massive




From: Cellular Networks for Massive IOT, Ericsson white paper. January 2016.

# IoT Network Planning: Critical or Massive?

## Massive IoT

- Very cost sensitive
- Low consumption
- Small payloads
- Latency and loss tolerant
- Unlicensed frequencies acceptable
- Cloud back end
- Can be served by proprietary or cellular based solutions

## Critical IoT

- Very high availability
- Very low latency
- Very high availability
- Variable payloads
- Licensed frequencies required in many cases

  to guarantee reliability
- Best served by cellular based solutions

# IoT Network Planning for wide area

The first issues is to decide which of the two main architectures will better serve the needs of the network being planned

There are three options:

- LPWAN proprietary
- 3GPP standards
- Hybrid approach

# LPWAN Proprietary

## Advantages:

- Unlicensed spectrum.
- Low infrastructure cost.
- Can be independently managed or relay on existing service providers.
- Low power consumption.
- Might not incur in per device recurring cost.
- Currently greater market share.

## Disadvantages

- No  interference protection.
- No guarantee against future  users of the  same spectrum.
- No standards, fragmented market.
- New cellular based solutions are eroding market share.

# 3GPP solutions

## Advantages:

- Protection from interference.
- Standard based, will lead to great economies of scale
- Operator Managed, branding.
- Rich Ecosystem.

## Disadvantages

- 2G based solutions are being discontinued in many countries.
- LTE based solutions might not be available in many countries for several years.
- Higher power consumption.
- Might be overall more expensive.
- Recurring  per device cost.
- Reliance on a third party.

# Hybrid Solutions

Some vendors are offering modules that support cellular IoT solutions as well as LPWAN ones.

This opens up the possibility of building a LPWAN network now, with the prospect of migrating to an LTE-M or NB-IoT one in the future or even building from scratch a hybrid network in which devices can connect to several networks, depending for instance in coverage or cost.

# Cost considerations

- Total cost of ownership (TCO) is composed of the initial cost or (CAPEX), plus recurring costs (OPEX).
- Device costs are apt to decrease over time, as the demand increases and economies of scale are realized.
- Recurring costs might not decrease, in particular power provisioning costs might even increase.

# Cost considerations

In the planning process, it is often necessary to compare  options in which CAPEX maybe higher in one while OPEX maybe more attractive in another.
A method to find a common ground between the two types of expenses is called the "present value".
In essence, it allows to calculate what is the equivalent of spending a certain amount of money in a series of periodic installments to a bulk disbursement made at present time.

# Cost considerations

The standard formula to calculate the present value (P) corresponding to a series of yearly payments (PMT) over n years at an interest rate r is:

$P=PMT ((1-(1/(1+r)^{n}))/r)$

So, suppose you pay a rent of 10000 $ per year and you plan to live in an apartment for 15 years, how much would the money you spend for rent be worth today if the interest rate is 0.04?

$P=10000((1-(1/(1+0.04)^{15}))/r) = 111.183$ $

# Cost considerations

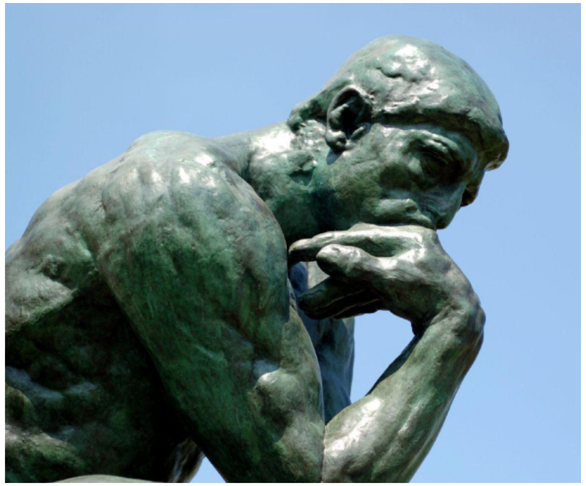
Then it becomes trivial to compare several options with completely different disbursement periods.
Although mathematically sound, the accuracy of this method is very dependent on two variables that must be entered in the calculations:

a) Interest rate
b) Inflation rate

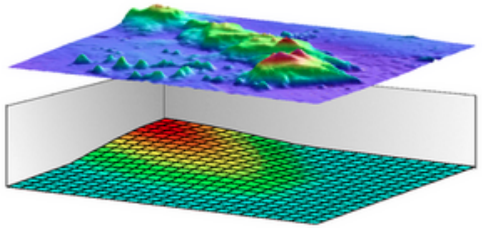
Slight changes in the value of these two variables can make a profound change in the results, so it is advisable to try several combinations of the two variables and project different scenarios.

# Factors to consider

- Availability of unlicensed frequencies and degree of occupancy
- Availability of service providers for different solutions
- Number of devices to be deployed
- Number and frequency of messages
- Minimum latency
- Maximum payload
- Battery duration
- In-house expertise

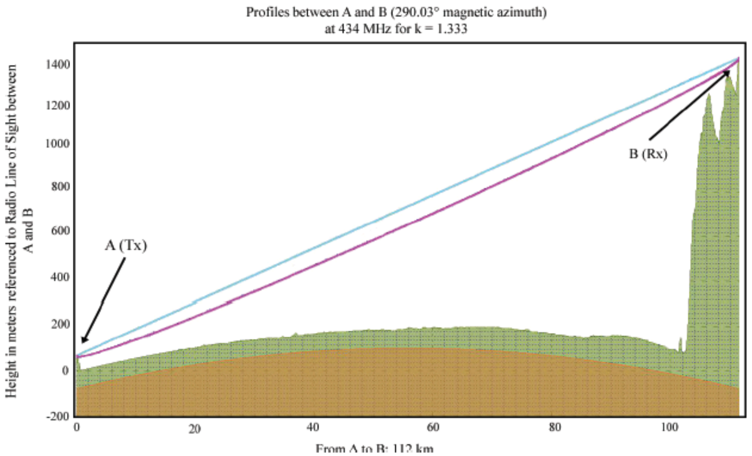


# Radio Coverage

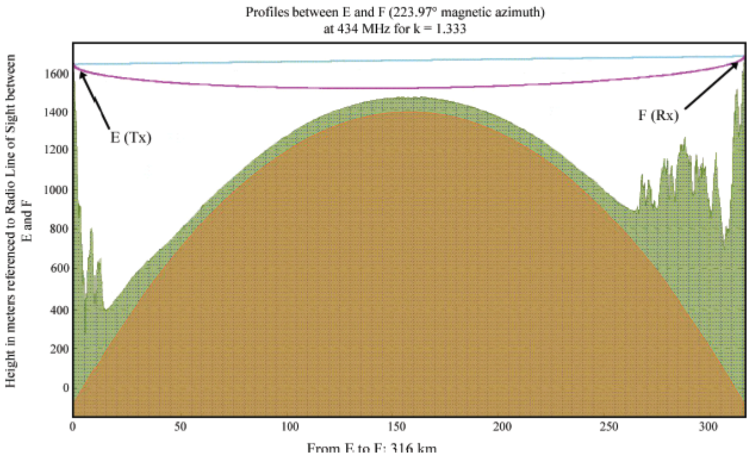


- Simulation tools like BotRf, Radio Mobile or similar can be used to assess the feasibility of long distance links since they use digital elevation maps.
- For shorter distances an estimate of the power budget can be obtained using formulas, but estimation of the absorption introduced by walls and multipath fading must be considered.
- In urban areas topography independent models like Okumura-Hata, Cost 231, etc. are adequate.
- All simulation tools provide only statistically significant results, so variations of several decibels in predicted signal reception strength are to be expected.

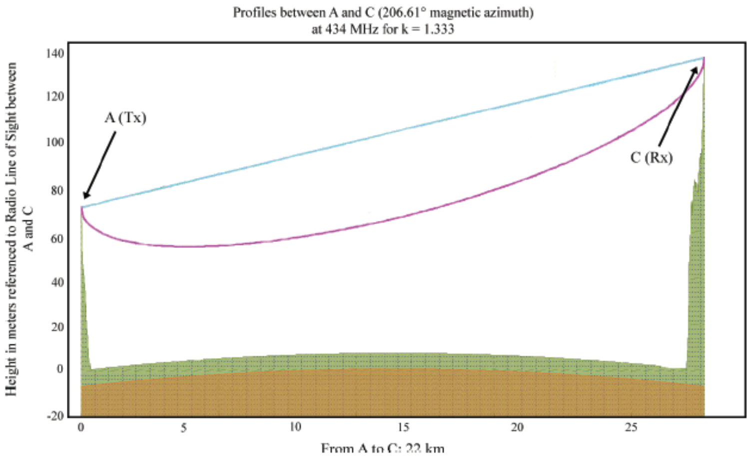
# Examples of long distance LoRa Tests



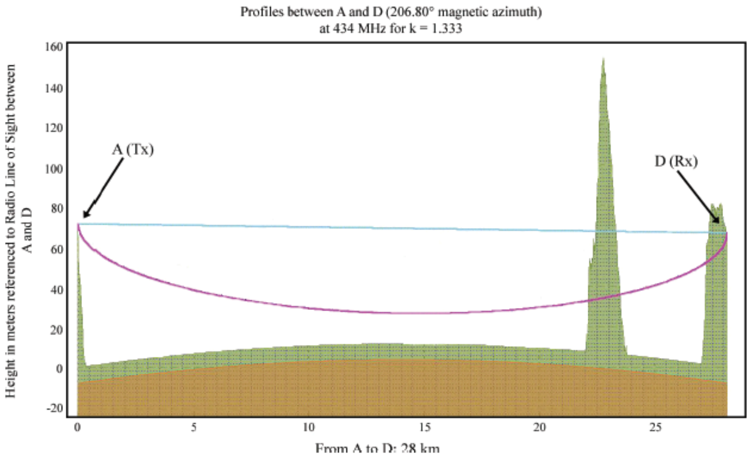

(a) Link A-B (112 km)




(b) Link E-F (316 km)




(c) Link A-C (22 km)




(d) Link A-D (28 km)

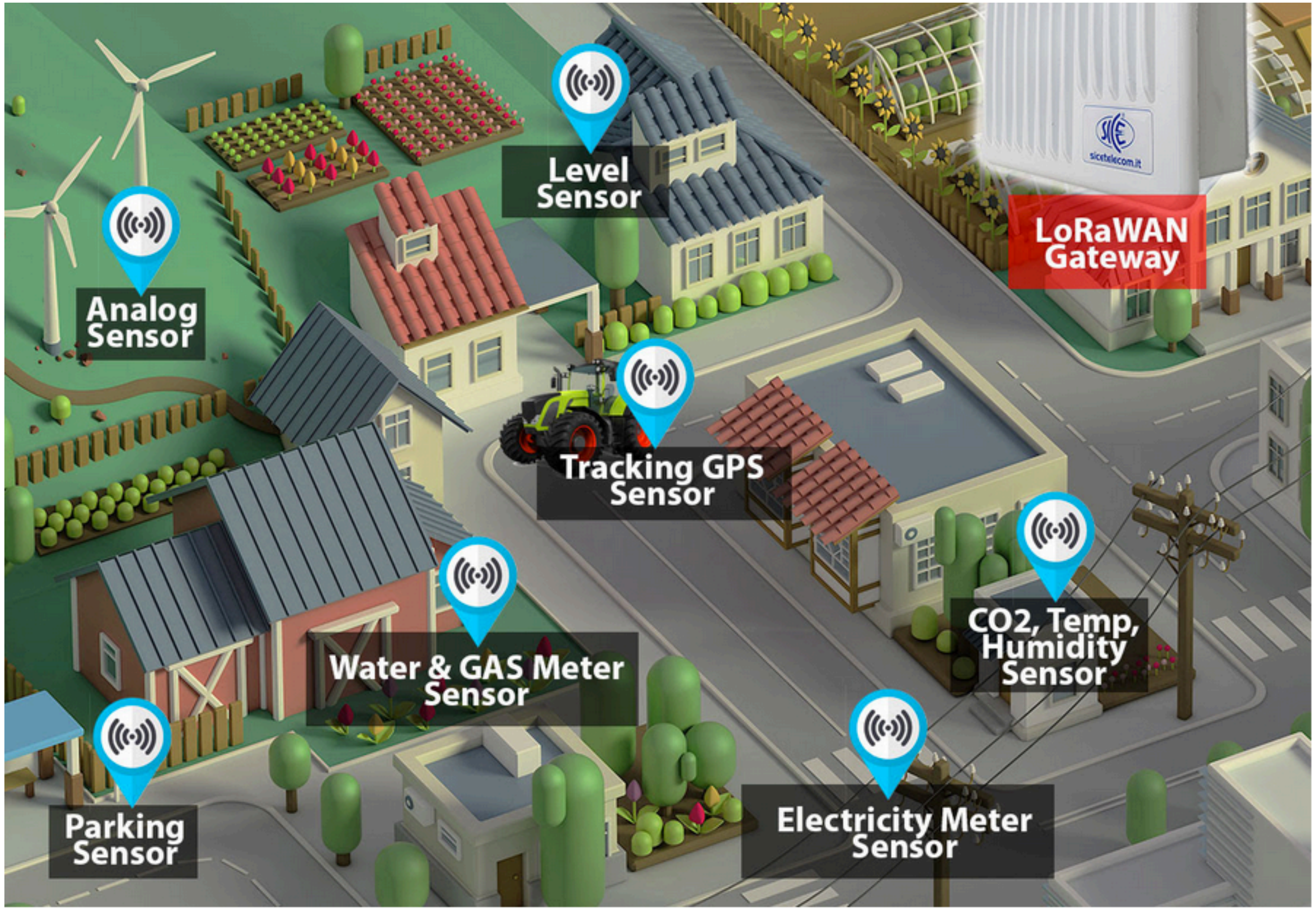
# Examples of long distance LoRa Tests

| **Testbed** | A-B | A-C | A-D | E-F |
|---|---|---|---|---|
| **Mode of propagation** | LOS over land | LOS over seawater | BLOS over seawater | LOS over land |
| **Length** | 112 km | 22 km | 28 km | 316 km |
| **Longley-Rice path loss (868 MHz)** | 131.91 dB | 118.26 dB | 176.7 dB | 152.82 dB |
| **Longley-Rice path loss (434 MHz)** | 125.91 dB | 112.25 dB | 166.12 dB | 145.96 dB |
| **Free-space path loss (868 MHz)** | 132.18 dB | 118.33 dB | – | 141.24 dB |
| **Free-space path loss (434 MHz)** | 126.16 dB | 112.31 dB | – | 135.22 dB |
| **Terrain shielding att. (868 MHz)** | −0.27 dB | −0.07 dB | 56.47 dB | 11.58 dB |
| **Terrain shielding att. (434 MHz)** | −0.26 dB | −0.06 dB | 51.91 dB | 10.74 dB |

# Design

- The actual design will depend on the technology chosen, the quality of service required and the cost.
- The latter factor might require changing the choice of technology in order to meet financial constraints.
- Design must be flexible enough to accommodate technological advances that will inevitably  happen in this highly competitive field, as well as possible changes in the regulatory environment.

# Some Smart City applications



# Some Smart City applications

- Smart metering
  - Electricity
  - Gas
  - Water
- Smart Parking
- Environment Monitoring
  - Air quality
    - Particulate matter
    - Atmospheric gases
    - Ozone level
  - Noise
  - Meteorological Data
  - Insect and pest control
  - Radiation measurement
- Public Transportation Management
- Facility Management
- Waste Management
- Vehicle tracking
- Road Traffic Monitoring and management
- Home Automation
- Safety
  - Street Lighting
  - Abnormal noise reporting
    - Gunshot detection
  - Infrastructure condition reporting
  - Flooding warning
- Precision Agriculture

# Smart electrical metering

Each electrical meter is configured to send a **four-byte payload** every **15 minutes** as an unconfirmed uplink and also one as a confirmed uplink once per day. Taking protocol overhead and security into account, the **total frame length is 17 bytes.** The gateways can decode simultaneously 8 different frequencies and each of the with different spreading factors.

The downlink messages have a fixed size (**10 bytes**) to configure reading intervals for confirmed and unconfirmed uplinks, as well as retries in case of unacknowledged confirmed uplinks.

from : www.semtech.

# Smart electrical metering

| Spreading Factor, BW= 125 kHz | Indicative bit rate (bit/s) | Time on Air (ms) |
|---|---|---|
| 12 | 250 | 1318.9 |
| 11 | 440 | 659.5 |
| 10 | 980 | 329.7 |
| 9 | 1760 | 164.9 |
| 8 | 3125 | 92.7 |
| 7 | 5470 | 51.5 |

# Smart electrical metering

The downlink is used to establish the different spreading factors and frequencies of operation that the end node will leverage to reduce the probability of collisions.

End nodes change the frequency of operation and the spreading factor in successive transmission assigning higher probabilities of occurrence to the lower spreading factors as compared to the higher spreading factors (which have a greater chance of collision due to their longer transmission time).

increasing the spreading factor by one will approximately double the air time of the packet.

The **network server** runs an **Adaptive Data Rate (ADR)** algorithm aimed at achieving an **average gateway receive diversity** of approximately 2 (that is**,** on average each packet will be received by 2 gateways) and with a **10 dB** modulation margin (the received signal strength expected to be at least 10 times stronger than the sensitivity of the receiver) for all devices

# Smart gas metering

Italy was the first European country where smart gas meter installations began on a large scale.
The national Regulatory Authority for Electricity, Gas and Water has set a target that 60% of residential gas meters and 100% of industrial gas meters should be smart by 2018 and full coverage by 2020.
Installation in Trieste is currently taking place

# Smart gas metering

Gas distribution can also be extended to places not covered  by the buried infrastructure, For example,

Butano24,  http://www.b24iot.com/ a Spanish company that supplies services for bottled fuel products to energy and utility companies, developed a “Smart Bottle” which reports its state of fill across the LoRaWAN network with the addition of a self-powered, wireless sensor module.

I

f the bottle’s level is low, a request for a refill is automatically passed to the system’s scheduling and dispatch application, along with the customer’s address.

# WATER

## IoT can impact water resources in the following aspects:

- water distribution maintenance
- water saving
- waste water treatment, drainage and sanitation.

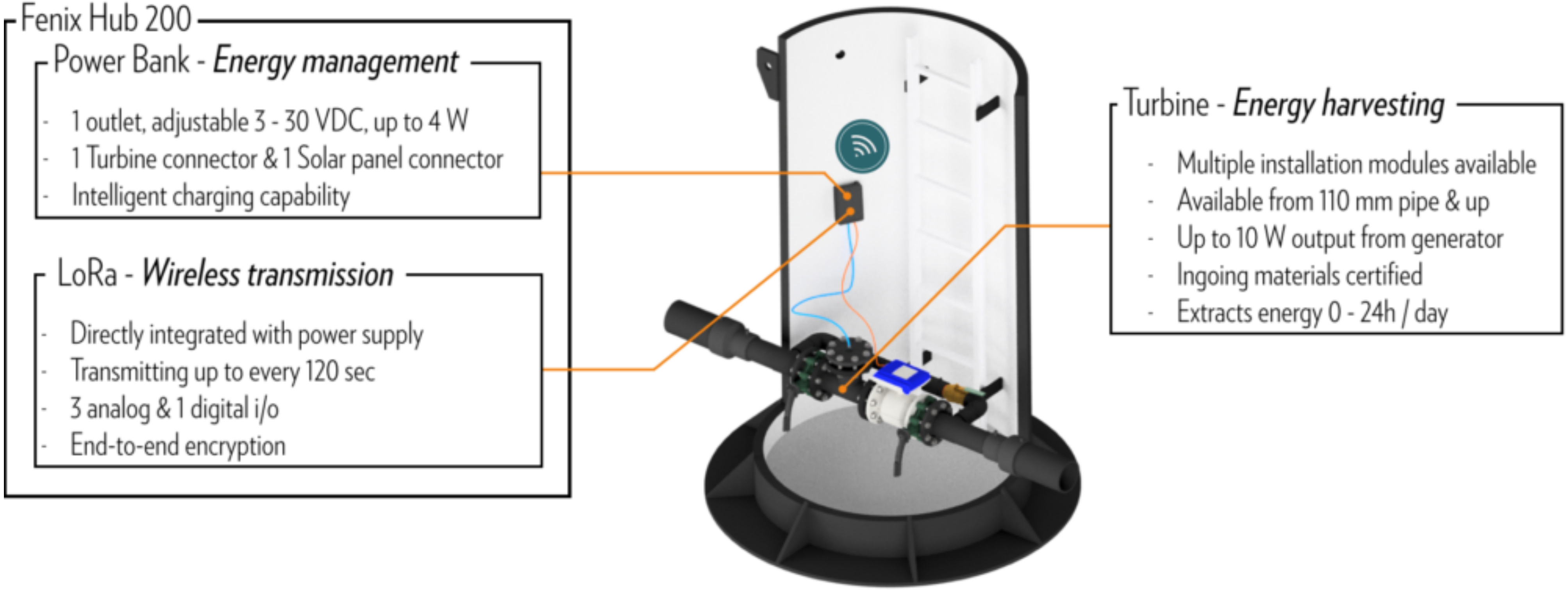
In most countries, 20-25% of the fresh water produced is lost due to leakages in the public water network.

Billions of Euros are wasted each year in Europe because pipelines cannot be effectively and efficiently monitored.

Besides economic aspects the need to conserve water resources is a major concern as the world population increases.

# WATER

## Hydropower harvester and wireless water consumption meter




https://www.aquarobur.se/?gclid=Cj0KCQiA2o_fBRC8ARIsAIOyQ-IdoFJ1ItkY4e_Q9HfkV6W5bZ23MYYEce6axU9k2Ccdx-Y6eUngS98aAmDUEALw_wcB

# Air Quality

One of the main concerns of city inhabitants is air pollution, which should be accurately monitored since it has been directly correlated to a number of premature deaths from respiratory and cardiovascular diseases.

The related data should be transparently made available to the public and authorities should permanently monitor them in order to impose limits to certain types of road traffic when dangerous thresholds are surpassed.

From https://news.itu.int/how-ai-and-big-data-are-tackling-the-health-impacts-of-urbanisation/

*Sao Paolo, Brazil, has developed a solution to estimate and predict air quality using AI and Big Data analytics. Aggregated, anonymized data is leveraged from the mobile network and layered with data from weather, traffic and pollution sensors. This helps calculate pollution levels 24 to 48 hours in advance, helping policy-makers, municipalities and governments to take action to prevent death and disease—for example, by redirecting traffic before air pollution hotspots strike*.

# Noise

Noise measurement is an important input to assess where the always limited funds noise absorbing structures should be allocated.

On going measurement in critical points might be necessary.

A simple microphone attached to an end-device can be used to measure the noise  and transmit it to the application server for visualization and record keeping, paving the way to appropriate mitigation measures.

# Insect and pest control

Aedes Aegypti is a kind of mosquito responsible for the transmission of several diseases including Malaria and Dengue.

Since insecticide spraying has many undesirable side effects and insecticide resistance has been growing, alternative methods to limit proliferation are being actively pursued.

One of these methods consists in capturing male insects, rendering them infertiles, and releasing them in the wild so that their mating with females on the wild will reduce the reproduction rate.

To implement this strategy, it is necessary to capture live male Aedes for sterilization and subsequent release. This is performed with a number of traps, with different kind of lures to attract the insects.

# Insect and pest control

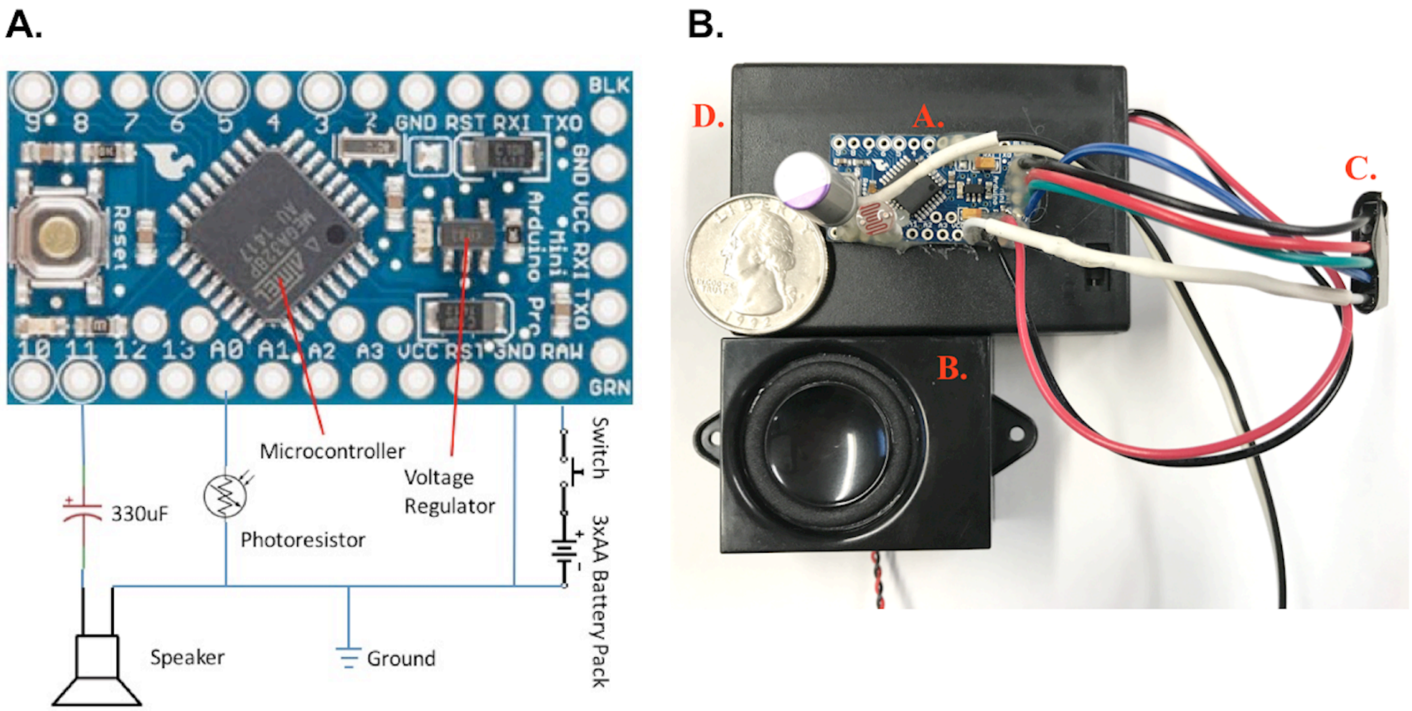
A recent work found that  to maximize surveillance effort, efforts should be made to combine the “sound lure” concept with an Internet of Things-based sentinel detection and reporting system, providing real-time information about the spatio-temporal population dynamics of the target population before and after release.

From: **A low-cost, battery-powered acoustic trap for surveilling male *Aedes aegypti* during rear-and-release operations**
https://doi.org/10.1371/journal.pone.0201709

# Insect and pest control

***A)*** *Detailed schematic of the Arduino-based sound lure (The lure is programmed to produce a pulse-width-modulated 484 Hz signal, applied to the speaker*

***(B)*** *Assembled sound lure composed of: (A) assembled Arduino board, (B) speaker, (C) wired TTL serial adapter to connect to FTDI USB to TTL serial adapter to enable programming of board and (D) battery pack.*



# Vehicle tracking

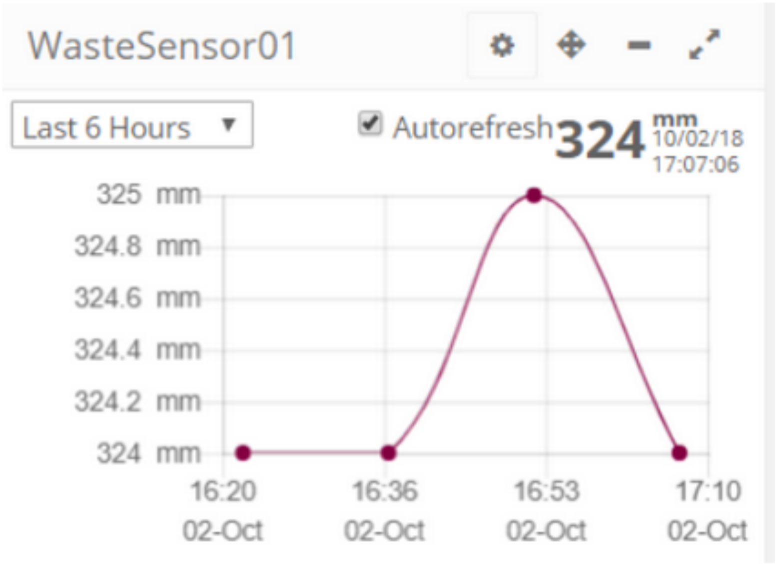
from: https://www.iotforall.com/smart-city-approaches-real-world/?utm_source=Newsletter&utm_campaign=IFA_Newsletter_Nov15_2018

*In order to improve bus service and further incentivize its use, NYC's Department of Transportation (DOT) and Metropolitan Transportation Authority (MTA) developed a system called Transit Signal Priority (TSP) to decrease the amount of time buses spend at red lights from the historic average of 20%. Since 2008, TSP has used GPS trackers built into public buses and data integration into the city's traffic lights either to trigger early green lights or to extend a green light when a bus nears an intersection. Since this entire system is digital, the city can continue to decrease bus commute times by tuning specific variables*

# Waste Management

Wireless reporting the level of garbage in city trash containers allows for a more efficient routing of the collection trucks.

from: https://mail.google.com/mail/u/0/#inbox/WhctKJVBFfnzgNFRFqkbCxcsgQzcxPQvhvBmJkFXkzJmvZgPghtVBXHGMqkxTljGjdTLHNb



# Security and Safety

**Security** concerns mainly **human-originated** threats, in particular crime and terrorism.

**Safety** refers to actions to mitigate the effects of **natural disasters** and accidents.

ICTs can improve effectiveness in handling both areas.

Smart-city applications could reduce fatalities from homicide, road traffic and fires by 10% , while assault, robbery, burglary and car theft could be lowered by 40 % , since smart systems can optimise call centres and field operations, and clear driving paths for emergency vehicles according to McKinsey Global Institute

# Example of IoT Traffic in a city

| Sensor Type | Num. of sensor | Average freq. of pkts/day | Average payload in bytes | Average time on air (ToA) seconds | Average Indicative packet rate in bit/s | Average Traffic in Mbit/s | Peak Traffic in Mbit/s |
|---|---|---|---|---|---|---|---|
| Electrical meter | 10000 | 96 | 17 | 0.040425 | 501.16 | 5.011 | 54.7 |
| Water meter | 8000 | 2 | 17 | 0.040425 | 501.16 | 4.009 | 43.76 |
| Vehicle tracking | 100 | 2880 | 22 | 0.09 | 2000 | 0.200 | 0.6 |
| | | | | | | | |
| | | | | | | | |
| Total traffic per day | | | | | | 9.221 | 99.06 |

# 3G Small Cell Planning for remote areas

Network properties

- Radio Link
  - Up and downlink frequencies
  - Polarization
  - Shadow margin
- UE Properties
  - Rf power
  - Receiver Noise Figure
  - Additional Losses due to non specific factors
- Antenna Properties
  - Gain and radiation pattern
  - Height and downtilt (inclination required to serve nearby users)

# 3G Small Cell Planning for remote areas

Traffic Profile:

- Voice
  - Number of voice users
  - Arrival calls rate
  - Call service time
  - Voice activity factor
- Data
  - Number of data users
  - Arrival packets rate, UL and DL
  - Packet service time, UL and DL
  - Data activity factor
- Distribution of traffic according to user location

# 3G Small Cell Planning for remote areas

3G Network:

- Rates and spreading factors for voice and data
- Link Quality requirements
- Target $E_b/N_o$ for voice and data

HNB (femto and small cells) properties:

- RF output power
- Maximum number of users
- Maximum distance
- Noise Figure
- Antenna Pattern, gain, height and downtilt

# 3G Small Cell Planning for remote areas

Power Consumption:

- Power consumption at zero RF output power ($P_o$)
- Slope of power consumption versus radiated power (sl)
- Number of RF transmission chains ($N_{TRX}$)

Total power consumption= $N_{TRX} ( P_o + sl \, P_{RF} )$

# 3G Small Cell Planning for remote areas

Power Supply: backup batteries will always be required and photovoltaic panels are recommended.

Photovoltaic parameters:

- Solar Irradiance in the site, $W/m^2$
- Photovoltaic panel peak power, W
- Losses due to inefficiencies of solar cells, %
- Percentage of harvested energy used for battery charging, %
- Days of autonomy
- Battery level at maximum discharge allowed, %
- Required battery capacity, Wh

# IoT Network Planning

For IoT applications, besides the previous procedure, it is also important to plan for data analytics, which nowadays are commonly performed in the cloud.

Although some users might want to set up their own data processing infrastructure, perhaps in a private cloud, there are a number of commercial cloud services providers that offer different types of capabilities that cater to most user needs.

# Commercial providers of cloud services

- Atlantic.net
- Amazon Web Services
- Microsoft Azure
- Google Cloud Platform
- IBM Cloud
- Rackspace
- GoDaddy
- Verizon Cloud
- Oracle Cloud
- Red Hat

People argue about vulnerability of hosting data in the cloud, but such vulnerability extends to any device connected to the Internet.

# IoT Network Planning Caveat

Keep in mind that in a complex field like IoT there is never a unique and perfect step-by-step procedure that can guarantee success: you will have to adapt your planning scheme to fit the local situation with its advantages and constraints.

# Conclusions

- Some of the consideration for planning an IoT network were presented.
- Planning is a very creative undertaking and different perspectives might lead to different results.
- Proper planning takes time. Remember to allocate a reasonable amount of time to do your planning in advance and to start doing it, right from the beginning of your project
- Examples presented show the wide variety of applications that can be addressed by IoT.