



# Design and energy optimization of a multifunctional IoT solution for connected bikes

Ivan Minakov, Roberto Passerone and Maurizio Rossi

University of Trento, Italy

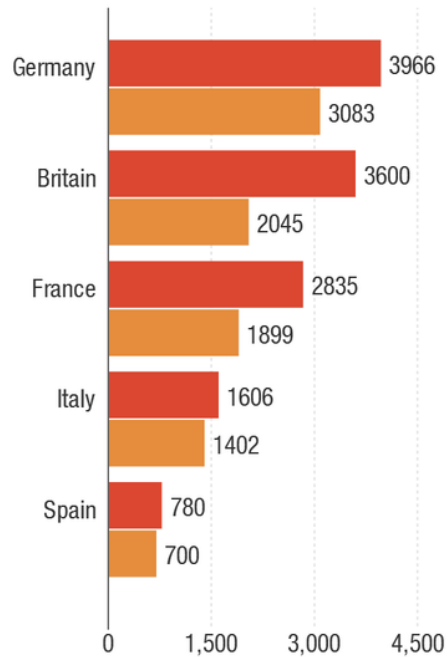
*maurizio.rossi@unitn.it*

# Motivation

## Electro mobility market trend

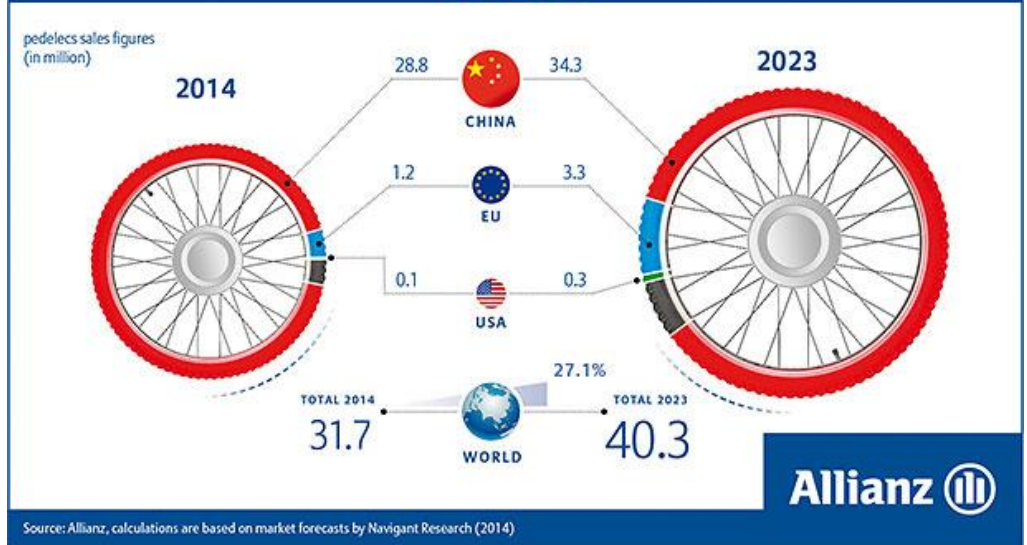
New Passenger Car And Bicycle Sales (2012)

■ Bicycles ('000) ■ Passenger cars ('000)



source: npr.org

Market forecasts for pedelecs (<25 km/h)  
2014–2023



source: Allianz.com

# Motivation

Many bike tracking and cycling analysis tools hit the market in the last years



## Features

[Sign Up for Free](#)

Velo Hero is free to use! Log your workouts and track your progress at no cost. Upgrade to a [Pro Membership](#) to find even more features like the ability to set heart rate and power zones. Here is a brief overview of our features:

### Mobile First



With Velo Hero you have access to your health and training information at any time. Whether on your smartphone, tablet or desktop. Whether at home, from work or on the go. All you need is an internet connection.

Cloud-based fitness tracking  
<https://www.velohero.com/>



[Garmin Chirp Per D2, Fenix, Fenix 2 E Tactix](#)

**17,90 €** proposto da oltre 10 negozi

Resistente, impermeabile ideale per le tue avventure di geocaching negli spazi aperti, il sensore Garmin



[Garmin eTrex 10 - Navigazione personale Navigatore GPS - 2.2 pollici...](#)

**122,90 €** proposto da oltre 20 negozi

★★★★☆ 232 recensioni prodotto

142 g - 5.4 cm x 3.3 cm x 10.3 cm - Antenna: Incorporato - 1000 punti prefisati - 10

Solo Garmin è in grado di migliorare eTrex. L'eTrex 10 conserva le funzionalità principali, la struttura rot



[Tracker Localizzatore Gprs Gsm Antifurto Realtime Per Moto Scooter ...](#)

**15,28 €** da it.EachBuyer.com

Caratteristica: 1. Monitoraggio in tempo reale, supporta la ricerca della posizione mediante messaggi e



[Dispositivo di monitoraggio antifurto Spot Trace Tracking Satellite](#)

**125,00 €** proposto da oltre 5 negozi

★★★★☆ 194 recensioni prodotto

Il dispositivo di monitoraggio Spot Trace Tracking Satellite permette di rintracciare qualunque attivo, do

“Wearable” GPS trackers  
source google shopping

# Motivation

## Bike security systems



<http://bitlock.co/>

<http://www.spybike.com/>



### Anti-theft GPS tracking devices for Bicycles

Arm your bicycle with the latest tracking technology. Covert and secure, our innovative devices provide you with the peace of mind that your bicycle can be traced should it be stolen.



<https://noke.com/pages/ulock>

### Tech Specs

- Bluetooth:** 4.0
- Accelerometer**
- Water Resistant**
- Alarm:** 120db
- Rechargeable battery**
- Battery Life:** 5 years standard, 6 months with alarm enabled
- Device Compatibility**
- iOS:** iPhone 4s or newer
- Android:** Devices with BT 4.0 or higher running Android (4.4) or higher
- Windows Phone:** Devices with BT 4.0 and Windows 10 or higher
- Security:** PKI technology and cryptographic key exchange protocol

Over one year of battery life

Bluetooth 4.0

Boron hardened steel shackles

# Motivation



**However Millions of  
bicycles are stolen every  
year**



- Stress
- Personal monetary losses
- Market losses (**≈150M** only in Italy)

**We seek a compromise between security, reliability, portability,  
efficiency, ease of installation/customization...**

# Challenge

**Electronic device for  
enhanced security and  
monitoring**

*Invisible*

*Charge-less*

*Effective*



**Cloud infrastructure**

Data Management

Efficient

Affordable

**Mobile application**

User assistance

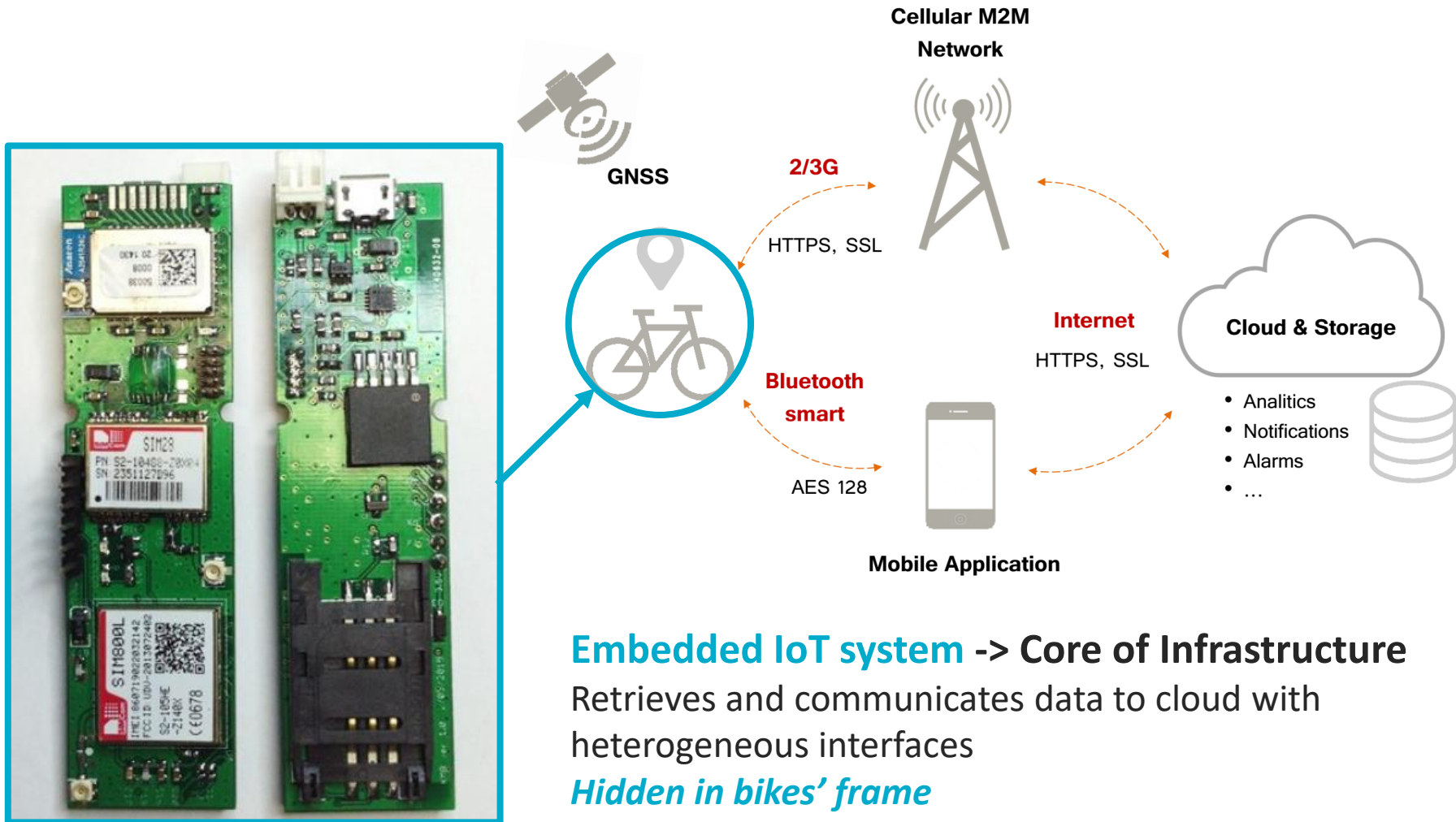
Parking recommendations

Legal retrieval assistance

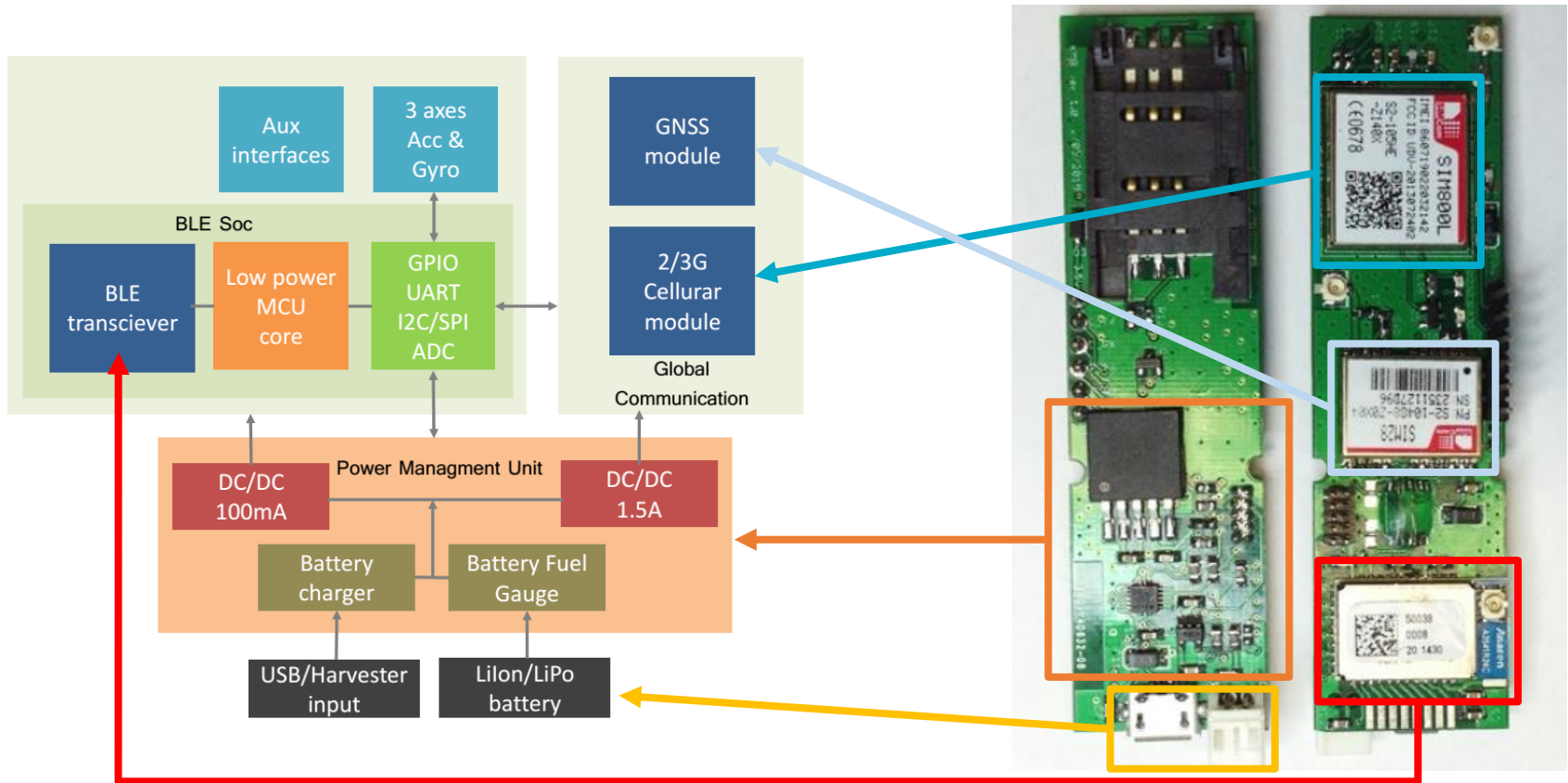




# System Infrastructure



# Embedded IoT System

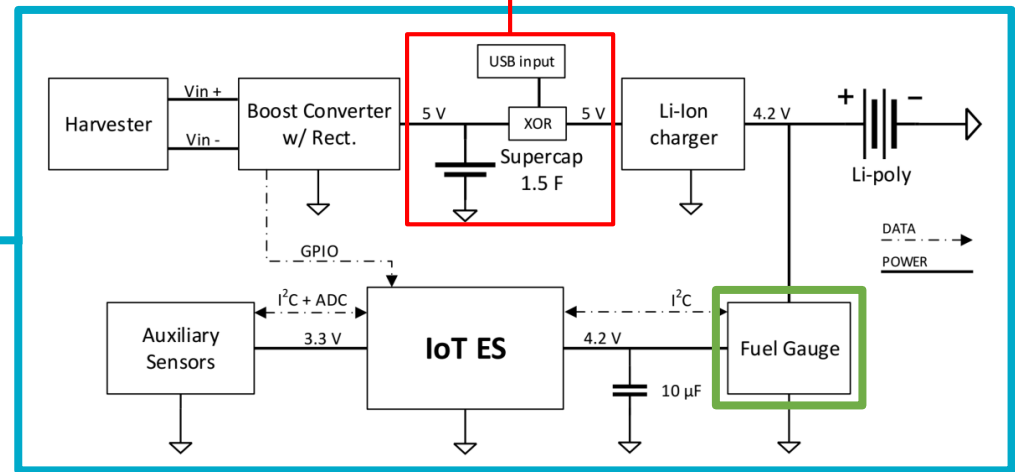
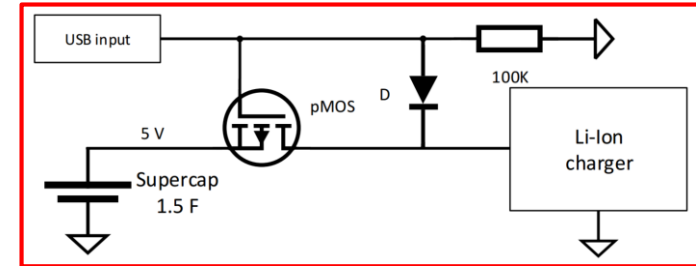
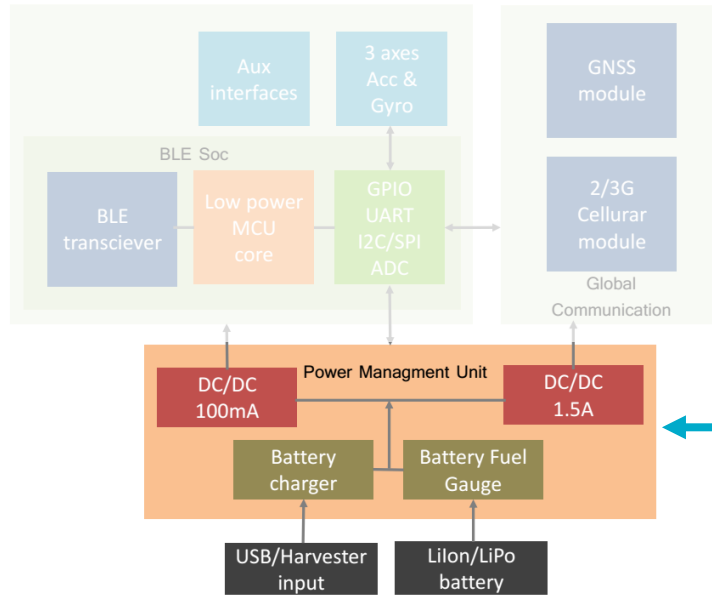


## HW Optimized for energy efficiency

Low-power BLE SoC as main MCU controlling sensors and communication peripherals  
Dedicated DC converters for energy hungry sub-systems



# Power Management Unit

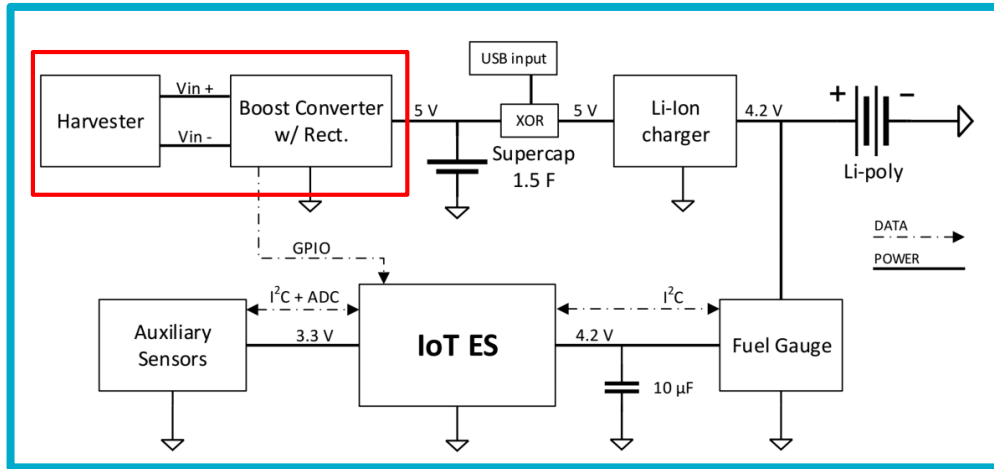


## Multi-source Power Supply and Management

Automatic switching between USB and Harvesting + Supercapacitors by means of HW XOR

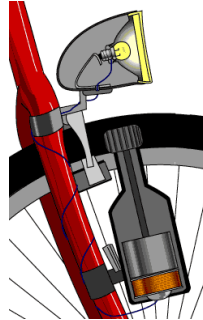
Fuel Gauge -> precise battery charge/discharge/state control

# Energy Harvesting Configuration and Tests



## Kinetic Energy Harvesters

- (i) Bottle Dynamo
- (ii – iii) Contactless single-/double-coil transformers



## Energy Transformers

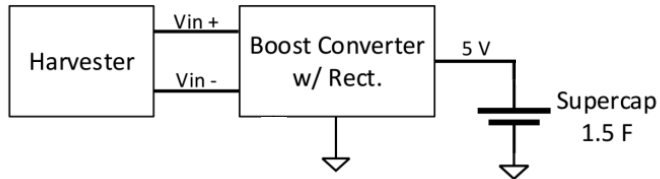
- (i) TI BQ-25570



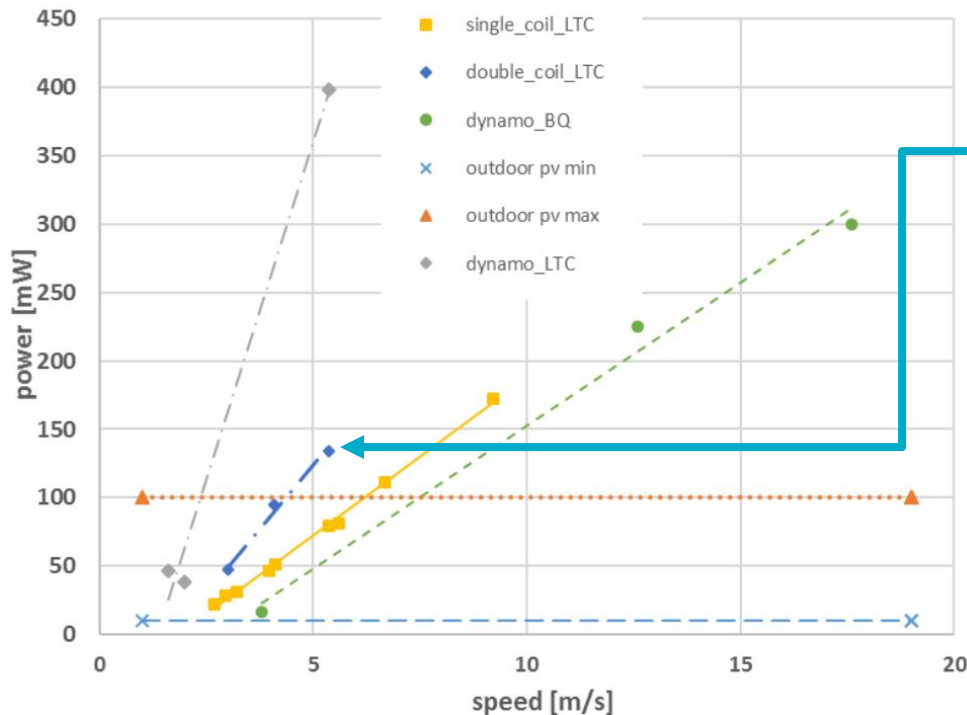
- (ii) Linear LTC-3588-1



# Energy Harvesting Performance



## Experimental Data



## Results

Solar PV panel as reference

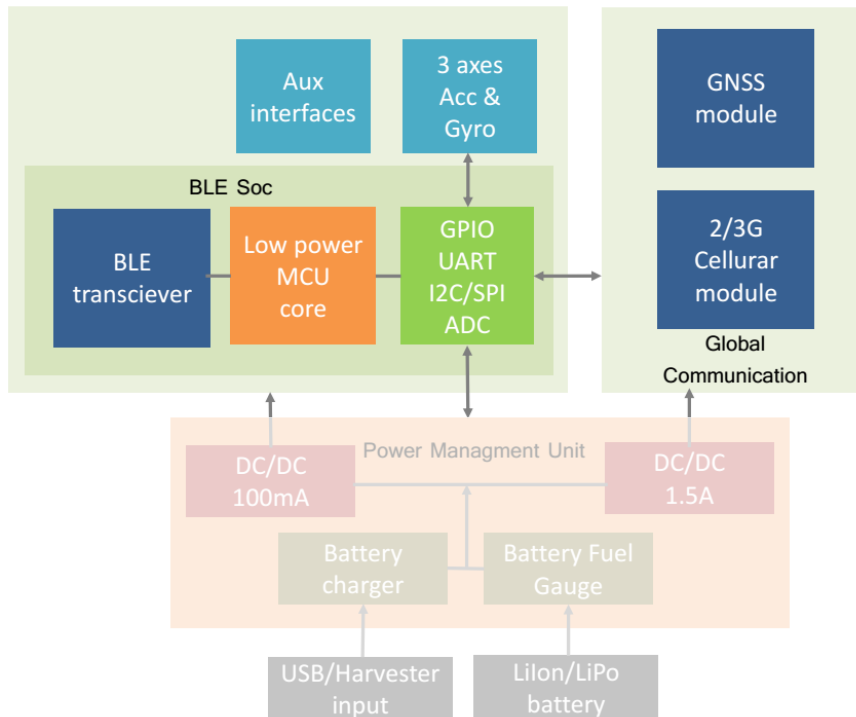
(i) Dynamo + LTC can sustain very large electronic loads

*DRAWBACK – can't be hidden*

(ii) Double inductive coil can provide more than 125 mW at 5 m/s travelling speed

(iii) LTC3588-1 with internal rectifier outperforms in efficiency BQ + external diode bridge solution

# SW Optimization



Component	Current Consumption	Power Consumption
<b>BLE SoC</b>		
Tx/Rx peak	14/12 mA	29.4/25 mW
BLE connection	100 $\mu$ A	210 $\mu$ W
Sleep	8 $\mu$ A	16 $\mu$ W
<b>IMU sensors</b>		
Active 100Hz	20 $\mu$ A	42 $\mu$ W
Off	2 $\mu$ A	4 $\mu$ W
<b>Cellular 2G</b>		
Tx/Rx peak	120 - 1000mA	450 - 3700mW
Active	13mA	50mW
Idle	1.1mA	4mW
<b>GNSS</b>		
Tracking mode	14mA	52mW
Idle	20 $\mu$ A	74 $\mu$ W
<b>PMU</b>		
Active	150 $\mu$ A	560 $\mu$ W
Idle	10 $\mu$ A	38 $\mu$ W

**Security and Fitness Tracking Tasks** have different performance requirements

- Reliability and long lasting autonomy
- High resolution spatial data, one day of autonomy

Power Consumption characterization of *any sub-system* is crucial to optimize performance focusing efforts on power hungry components

# SW Optimization – Adaptive Tracking

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**Algorithm 1:** Time based tracking algorithm

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```
Input: currentTime, lastSamplingInstant, targetTime  
while Forever do  
    updateCurrentTime();  
    elapsedTime = currentTime - lastSamplingInstant;  
    if elapsedTime == targetTime then  
        lastSamplingInstant = currentTime;  
        samplePositionWithGNSS();  
        storePositionInLocationsBuffer();  
    end  
    if getLocationsBufferState() == FULL then  
        sendLocationsBufferWithGPRS();  
        clearLocationsBuffer();  
    end  
    waitInLowPowerState(seconds);  
end
```

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**Algorithm 2:** Distance based tracking algorithm

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```
Input: speed, lastSamplingD, targetD  
while Forever do  
    updateDistanceTraveled(speed);  
    distanceTraveled = currentDistance -  
        lastSamplingD;  
    if distanceTraveled == targetD then  
        lastSamplingD = currentDistance;  
        samplePositionWithGNSS();  
        storePositionInLocationsBuffer();  
    end  
    if getLocationsBufferState() == FULL then  
        sendLocationsBufferWithGPRS();  
        clearLocationsBuffer();  
    end  
    waitInLowPowerState(seconds);  
end
```

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## Time-Based Tracking

Periodic sampling of GPS location  
Embedded in modern GPS modems  
Simple yet effective

## Distance-Based Tracking

External sensors to measure speed  
Minimal GPS utilization

These realize the **Adaptive Tracking**

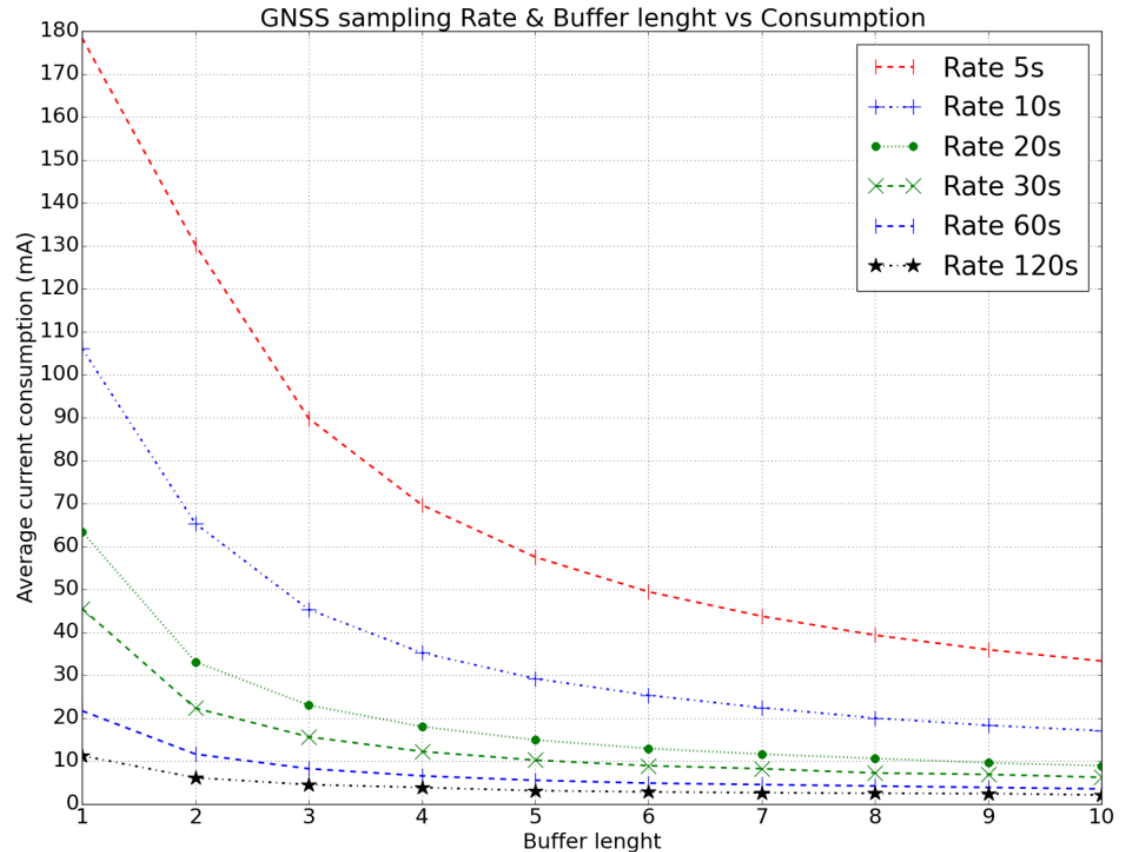
- > user selects its preferred tracking mode
- > Cloud post-processing to optimize tracking depending on activity and user habits/preferences

# SW Optimization – Power Consumption

## Simulated Power Profiles

Power consumption of Time-based tracking as function of GPS sampling rate and buffering (delayed transmission of data to cloud)

Independently from the rate, buffering severely increases performance, reducing current consumption down to 10 mA introducing a delay of 180 seconds, considering 20s rate and a buffer of size 9 packets





# SW Optimization – Battery Autonomy

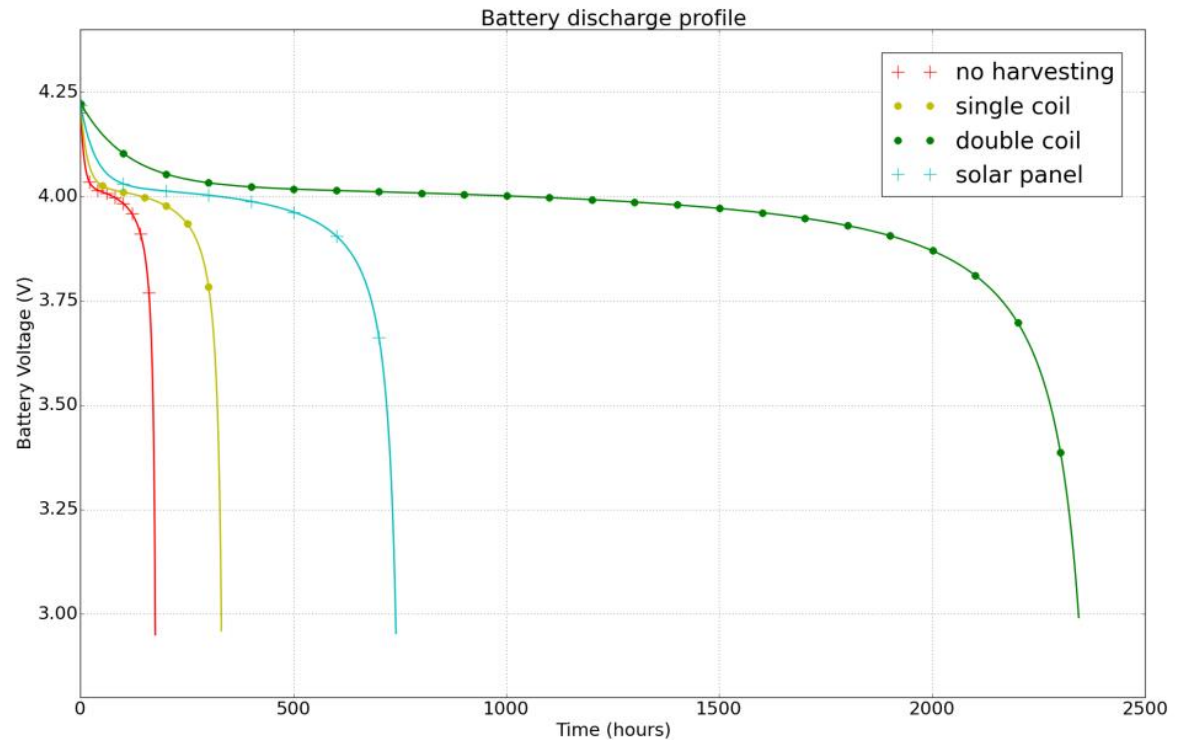
## Simulated Battery Discharge

One GNSS sampling per minute  
Direct data streaming (cellular)  
Constant 10 km/h speed

Theoretically, with harvesting,  
we expect up to 2400 hours of  
Autonomy

Reasonably, more than 1000  
hours of autonomy are expected  
in a real scenario

Even more implementing data  
buffering and adaptive tracking



# Conclusion

We presented an Embedded System and IoT based Infrastructure for bicycle tracking and enhanced security

We analysed the HW design of the power management subsystem and presented different energy harvesting solution for extending system autonomy and battery self recharge

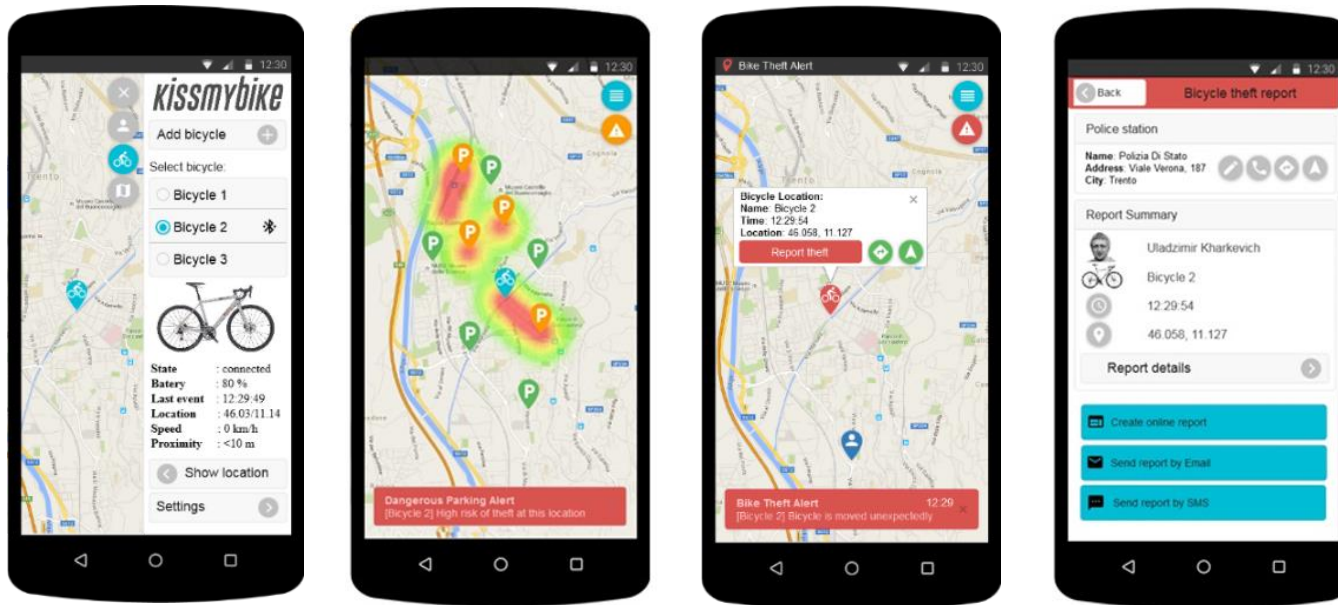
We investigated SW improvements for minimization of power consumption of the tracking task and data synchronization with cloud



*thank you very much for the kind attention*

*maurizio.rossi@unitn.it*

# Service



- ✓ Bicycle identification
- ✓ Parking recommendations and security maps
- ✓ Tracking service with global coverage
- ✓ Legal retrieval assistance

# E-bike installation





# Plain seatpost

