Challenges in Developing a Wireless Sensor Network for an Agricultural Monitoring and Decision System

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IHP – Leibniz-Institut für innovative Mikroelektronik

Leibniz Association

Agenda

- Introduction
- WSN in Agriculture Monitoring and Decision Systems
- Requirements and Constrains
- Challenges
- Proposed Approach
- Outlook

Introduction

Today, agricultural systems are torn between

- the increasing demand for agricultural products,
- the scarcity of resources,
- the reduction of biodiversity and
- climate change (Wolters et al. 2014)

Need for a *sustainable and resource-efficient increase in agricultural production*

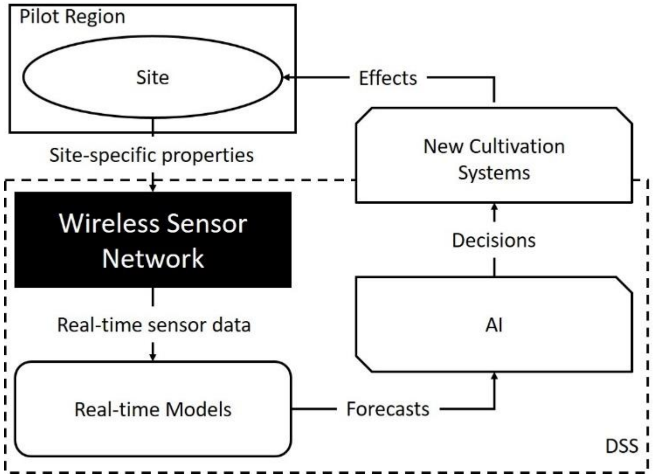
Smart farming — use of modern information and communication technologies for the *digitalization of agriculture*

Wireless Sensor Networks (**WSNs**) in an agriculture context

- data from the field can be retrieved from the sensors at any time without the physical presence of a farmer
- wired networks are often impossible or impractical due to the special circumstances of the agricultural sector

Introduction

- Digital Agricultural Knowledge and Information System (DAKIS) project*
- Use of advancing digitalization to integrate Ecosystem Services (ESS) and biodiversity into modern planning, production and marketing processes
- Development of a WSN on experimental fields in four pilot regions in order to **capture site-specific parameters in real time on a small scale**
- laying the foundation for adapting agricultural management strategies based on a **Decision Support System (DSS)** at any time using real-time information (Fig. 1)



WSN as part of a DSS

* https://adz-dakis.com/

WSN in Agriculture Monitoring and Decision Systems

Numerous publications have already recognized
the value of **WSNs** in **precision agriculture** and **environmental monitoring**

- "using heterogeneous sensor installations, **agricultural issues can be mapped onto the sensor networks** and targeted data acquisition can be carried out" (Wark et al. 2007)
- "important tool to **measure and understand the complex coupled dynamics** of biological systems" (Wark et al. 2007)
- "to **increase efficiency, productivity and profitability** while at the same time minimizing unintended effects on the environment" (Ruiz-Garcia et al. 2009)
- "distribution thanks to their low energy consumption, small dimensions and simple, high-density communication protocols, which **enables precise and fine-grained measurement of parameters in the monitored area**" (Stamenkovic et al. 2016)

WSN in Agriculture Monitoring and Decision Systems

WSNs are used, for example, for monitoring…

- crop condition
- soil moisture for irrigation and efficient use of water resources
- water quality
- water distribution for leak detection
- greenhouses and greenhouse gases

WSNs in Smart Farming — new opportunities are offered, for example, by incorporating newer technical concepts such as sensor cloud computing, big data, AI and the Internet of Things (IoT)

Requirements and Constrains

Project goals and partners
- > 10 years of operation
- 100 battery driven Wireless Sensor Nodes
- High spatio-temporal resolution
- High availability/ reliability
- High extensibility/ scalability (4 test sites)
- Low price per unit and production

Internal
- Reusability
- Recycling and Sustainability
- Security
- No (less) maintenance

Practical
- Simple manufacturing
- Easy deployment
- Mechanical and thermal properties
- Harsh environmental conditions

Technical
- Robustness
- Conformity RF, Rohs, etc.
- Low response time
- Temporal resolution

Protection against wild life and agricultural machinery

Site and partners
- Measurement of
  - UVA/B
  - Light and Sunshine duration
  - Air temperature
  - Relative humidity
  - Atmospheric pressure
  - Wind speed
  - Wind direction
  - Precipitation amount
- Transport of additional data
- Security

WMO
- Measurement range, resolution and uncertainty

Challenges

- Requirements + Constrains **+ Real world** → Challenges
- Energy management
  - System operating time
  - Overall consumption
  - Sensor selection, measurement intervals
  - Energy harvesting strategy and battery recharge cycles
- Spatial resolution, number of nodes in the field
- Overall system design and WSN construction, including the backbone network
- Financial framework
- Acceptance of farmers
- (Corona) electronic parts not available or canceled

Challenges

- Impossible to find sensors for all properties to be measured
  - Requirements
  - Power consumption
  - Handling, interfacing, maintenance, drift over time
  - Size, Price, Availability
- Adjustment of WMO* requirements necessary according to local realistic conditions at test sites
  - Example -80°C – 60°C air temperature is very unlikely in Brandenburg, Germany
    -40°C – 60°C is sufficient
  - Example 0 m/s – 75 m/s (270 km/h)
    0 m/s to 50 m/s (180 km/h) is sufficient

* World Meteorological Organization (WMO)

Proposed Approach

Parameter	Sensor	Adjusted Range	Required Range/Precision	Precision	Resolution
Air temperature	SHT35	-40°C – 125°C	-80°C to 60°C at ±0,1 K for -40°C to 40°C, else ±0,3 K	±0,1°C	0,01
	BME280	-40°C – 85°C		±1,5°C	0,01
	HS3001	**-40°C – 125°C**		**±0,2°C**	**0,015**
Air humidity	SHT35	0% – 100% RH	0% to 100% RH at ±1% RH	±1,5% RH	0,01
	BME280	0% – 100% RH		±3,0% RH	0,008
	HS3001	**0% – 100% RH**		**±3,0% RH**	**0,01**
Atmospheric pressure	**LPS25HBTR**	**260 hPa to 1260 hPa**	500 hPa to 1080 hPa at ±0,1 hPa	**±0,2hPa**	**0,01**
	BME280	300 hPa to 1100 hPa		±1,7hPa	0,18
Sunshine duration	**ADPS-9300**	**640 nm to 940 nm**	**-**	**-**	**-**
UVA and UV Index	**VEML6070**	**320 nm to 410 nm**		**5µW/cm²**	**0,05mW/cm²**
	GUVA-S12SD	240 nm to 370 nm		Dep. on OpAmp	Dep. on OpAmp
Soil Moisture	**SMT100**	**0% – 100%**	**0% – 100% at ±3%**	**±3,0%**	**0,1**
Soil Temperature	**SMT100**	**-50°C – 50°C**	**-25°C – 40°C at ±0,3**	**±0,2°C**	**0,01**

Some of the pre-selected sensors for evaluation

Proposed Approach

Sensor selection

- Select and test suitable sensors
- Implement and test drivers in parallel to our hardware development task
- Datasheet research based on requirements
- Take care also on WMO requirements
- Building a sensor test board
- Evaluate
  - Interfaces, accessibility, configurability
  - Sleep modes and wake up time
  - Power consumption
  - Calibration

Test board with pre-selected sensors

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Proposed Approach

Sensor calibration by calibrated stations

- DWD* stations
- Wind tunnel
- Climate chamber

Annually calibration and check

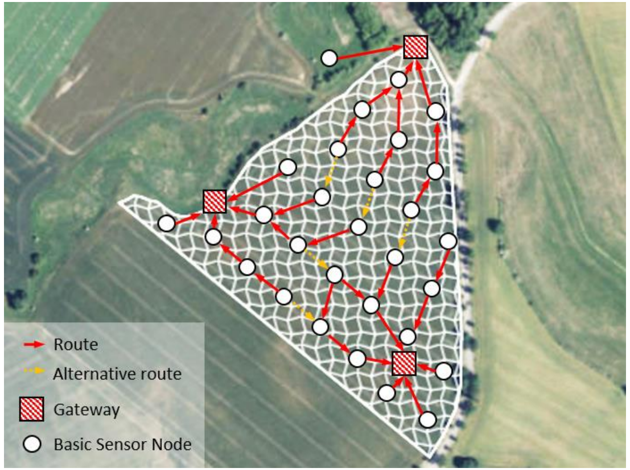
- Repeat calibration annually in laboratory
- take some WSNs out of all test site
- recognize and compensate drift if required/possible

* Ger: Deutscher Wetterdienst (DWD), Engl.: German Weather Service

Proposed Approach

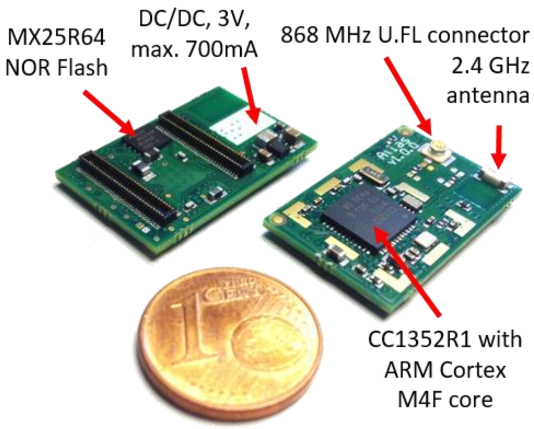
Sensor Node Concept

- Two sensor node types with different tasks
- 100x Basic Sensor Nodes (BSN) (~25 per test site)
  - Fine granular measurements
  - Low power operation, energy harvesting
  - Route measurements to ExtSN via 868MHz/2,4GHz radio
- 12x Extended Sensor Nodes (ExtSN) (~3 per test site)
  - Operating as gateway, collect sensor data of BSNs
  - Connected via modem to mobile network (3G/LTE)
  - Extended by weather station (wind direction and speed, precipitation)
  - Control BSNs and network maintenance
- Using the same core module (reusability) named *ATLAS*

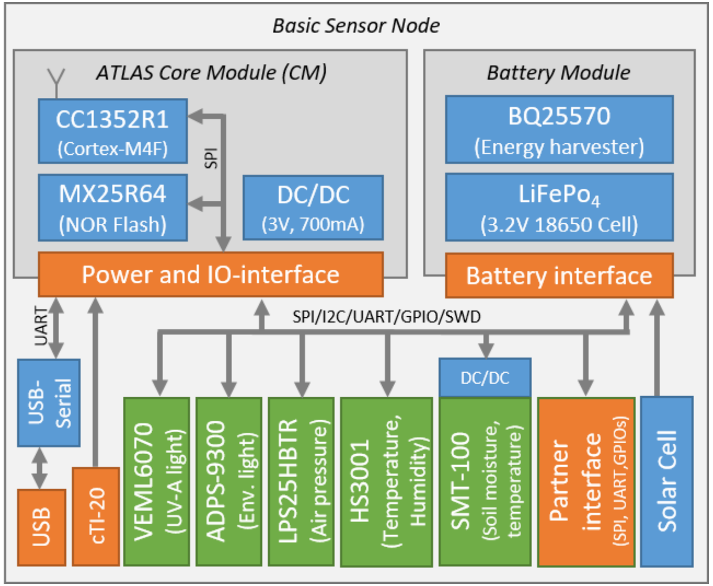


Test site in the north of Brandenburg, Germany, using protective stipes existing at the field.

Proposed Approach



ATLAS core module, 16x25mm in size, can be reused after end of project



BSN architecture, using ATLAS and modular battery charging module (energy harvester) powered by small solar panel

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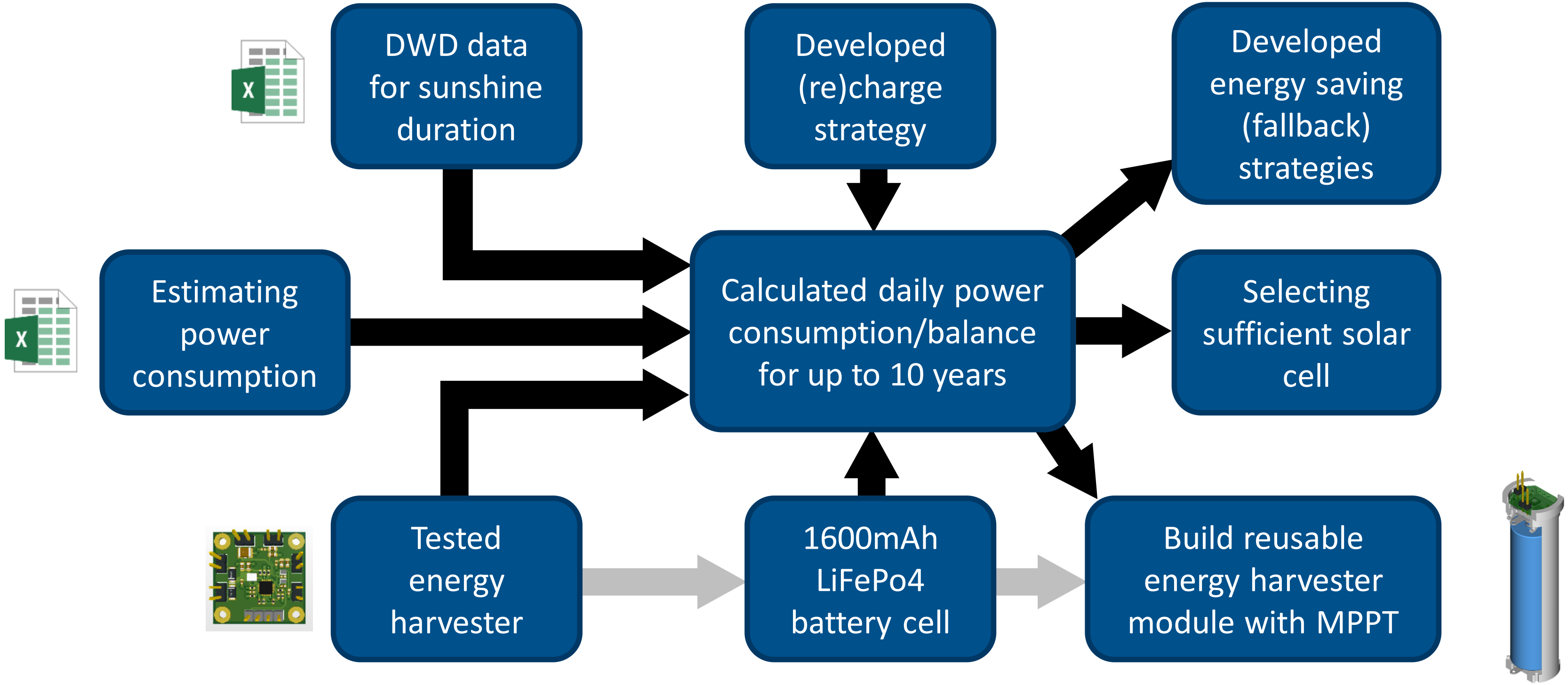
Proposed Approach



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Proposed Approach

Power estimation

- Not known in detail yet
- Estimation was required
  - By datasheet and measurements
  - Based on usage per minute derived from WMO requirements
  - Sleep and active current, self discharge
- BSN directly operated by 1600 mAh $LiFePo_4$ battery cell (3,2V nominal)
- Calculated power consumption
  - Peak current of 32 mA
  - Average current of 1,503 mA
  - Daily discharge of ~36 mAh
- In case of battery running low, reduce sampling, measurement period and radio communication stepwise to keep service online

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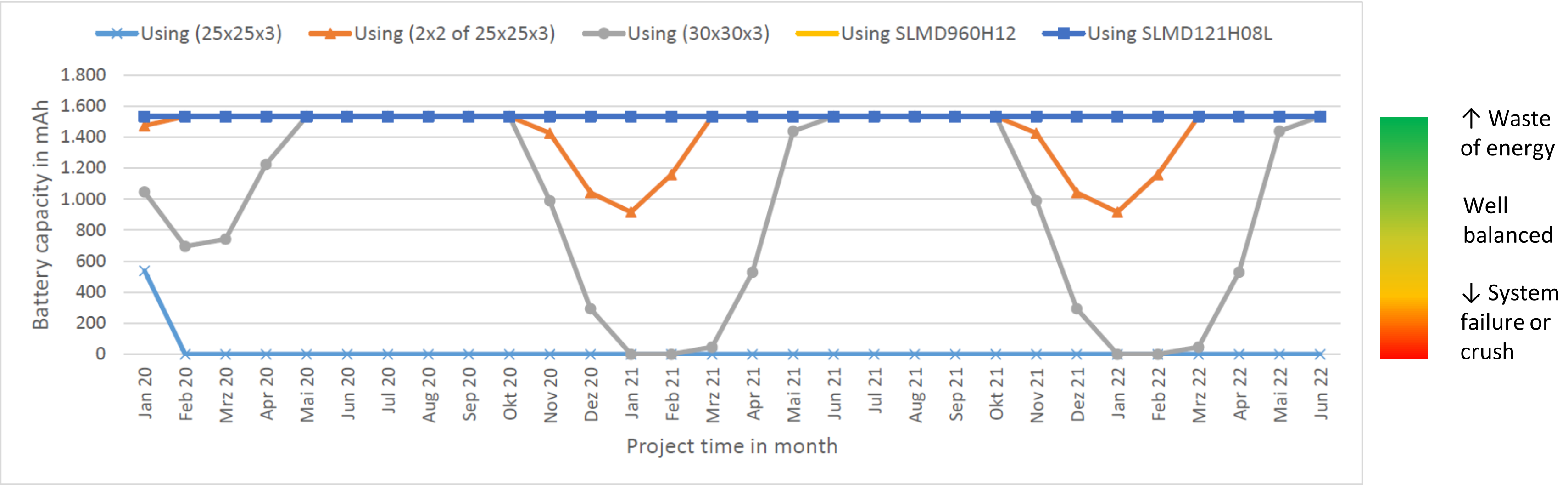
Proposed Approach

Solar cell selection

- Using energy harvesting methods
  - Suitable would be wind or **solar**
- Well balanced power resource with small safety buffer
  - Too much -> waste of money
  - Not enough -> system will crush finally
- Tested 5 different cells and combinations
  - Created charging strategy, balanced to charge in summer, consume in winter
  - Used average DWD data for sunshine duration from 1981 – 2010 (from test site region)
  - Calculated min. and max. charging current based on average hours of sunshine
  - Simulated daily battery charge level for time of project
- Made final choice by solar cell charging current, simulation results, price and availability

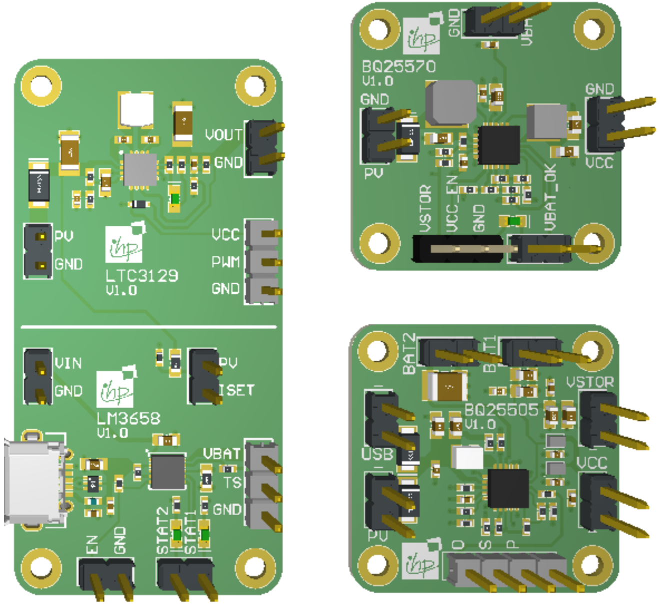
Proposed Approach



Proposed Approach

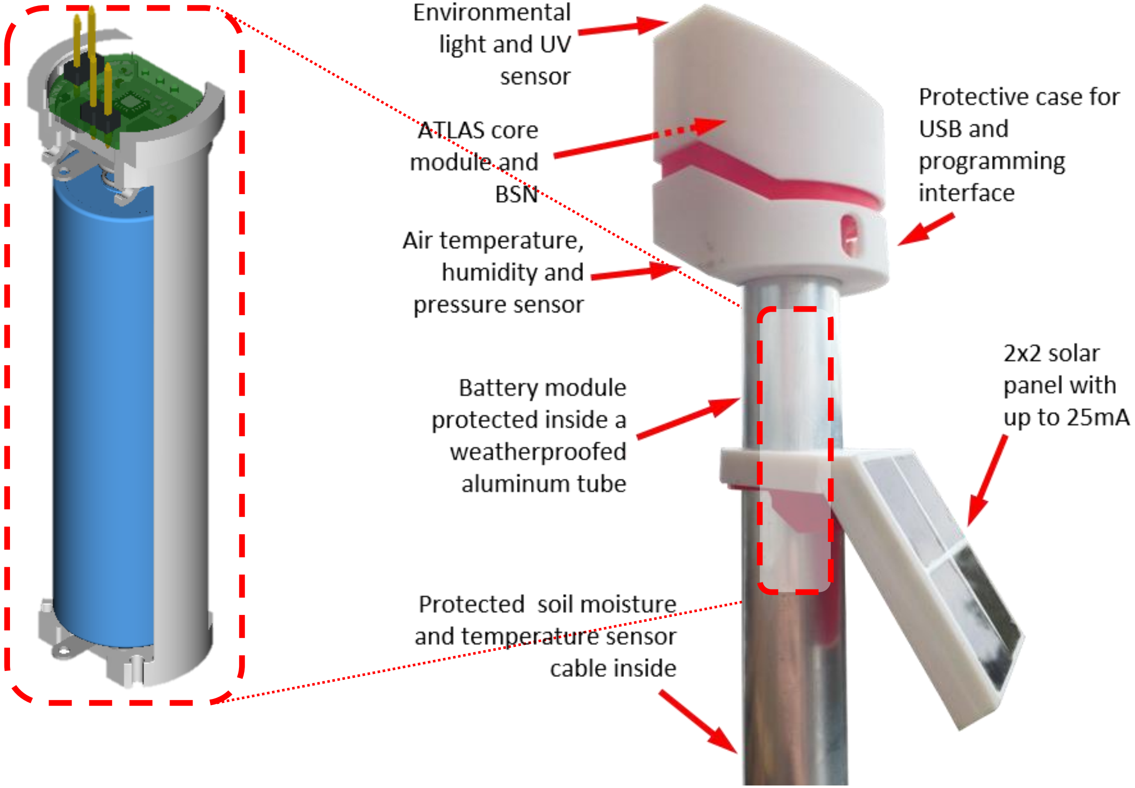
Energy harvester Selection

- Research for MPPT charger and micro harvester
- Selected 4 different charger/circuits
- Build boards for all of them for evaluation
- All performed as expected
- Selected 500mW BQ25570
  - Internal DC/DC for further projects at 3V (disabled for this one)
  - Less parts required
- Build as a module with 3D-printed parts for battery enclosure

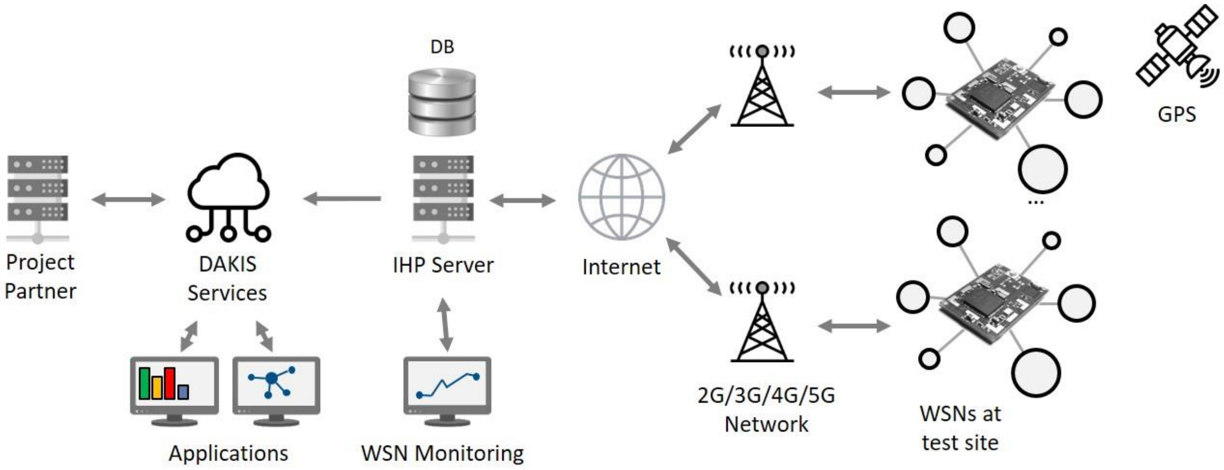


Evaluation boards for energy harvester and charger circuits.

Proposed Approach



Proposed Approach



Outlook

- Finishing BSN and ExtSN
- Local deployment for test and evaluation
- Deployment end of 2020/beginning of 2021 at first test site
- Developing nodes with acoustic sensors (MicSN)
  for biodiversity detection using AI and voice recognition
- Providing answers to the DAKIS research questions
  - Does this enable small-scale management at the optimal time?
  - Does this provide continuous feedback on the success of agricultural measures?
  - Scalability and acceptance of the users (farmer)?
  - Minimal required data for maximum of output
  - Biodiversity detection with low power devices at long time operation

Thank you for your attention!

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