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STELLENBOSCH UNIVERSITY

AGRINET
A system for smart agriculture
Present status and results

Nathalie Mitton, Riaan Wolhuter, Brandon Foubert

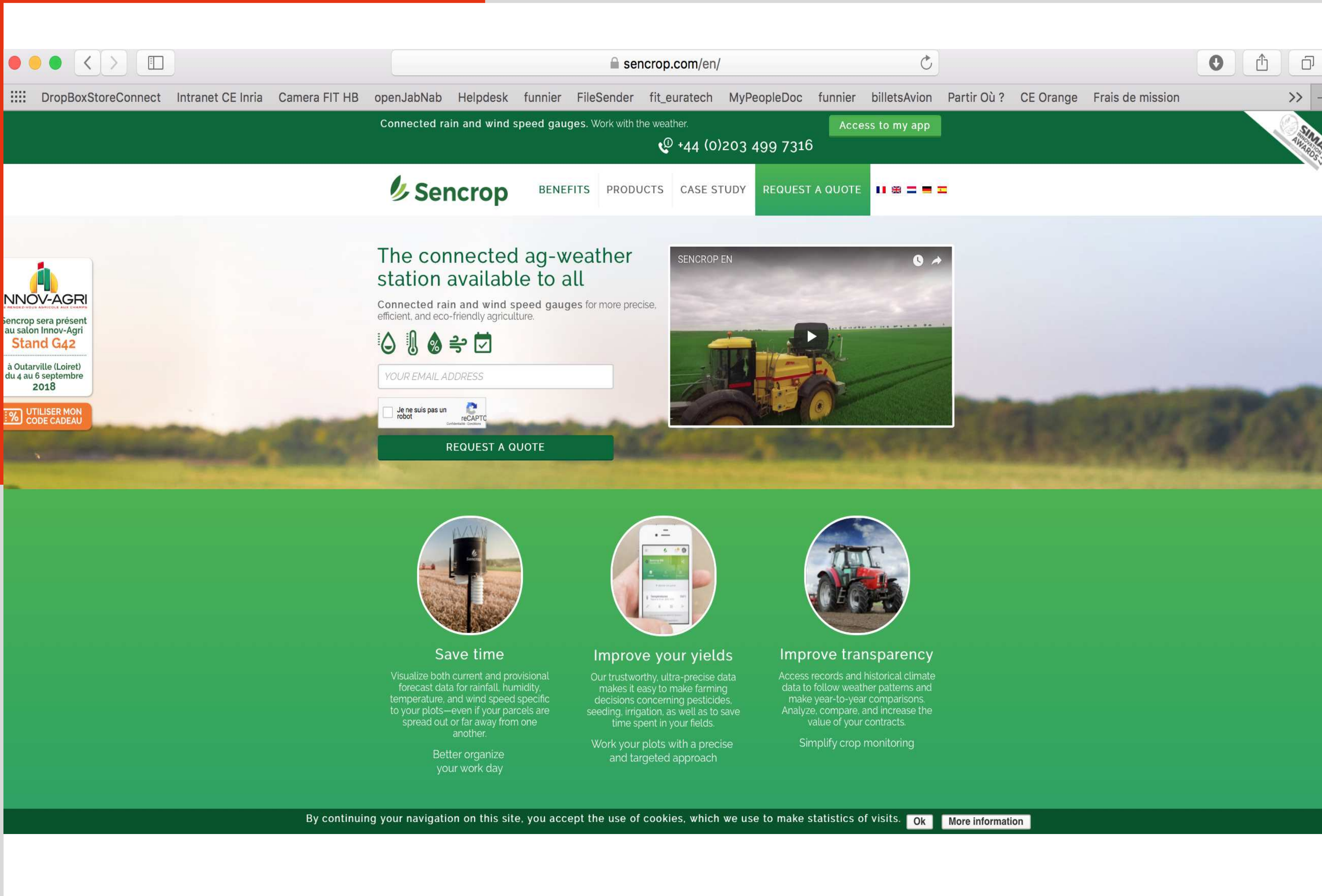
Context and motivations

- In France, South Africa and Africa in general, agriculture makes a huge economic contribution
- The current drought and limited water resources in many parts of Southern Africa and beyond, already have a significant impact on agriculture and hence, food production.
- Sustainable food security depends upon proper plant and crop management respectful of soils and natural resources, such as water.
- **→ The Agrinet initiative entails:**
- **Development of a WSN-based platform for intelligent data acquisition**
- **Development of innovative sensors for the actual measurement inputs**
- **Machine learning based algorithms for better data extraction and interpretation**
- **Purpose is development towards more sustainable farming and resource utilisation**

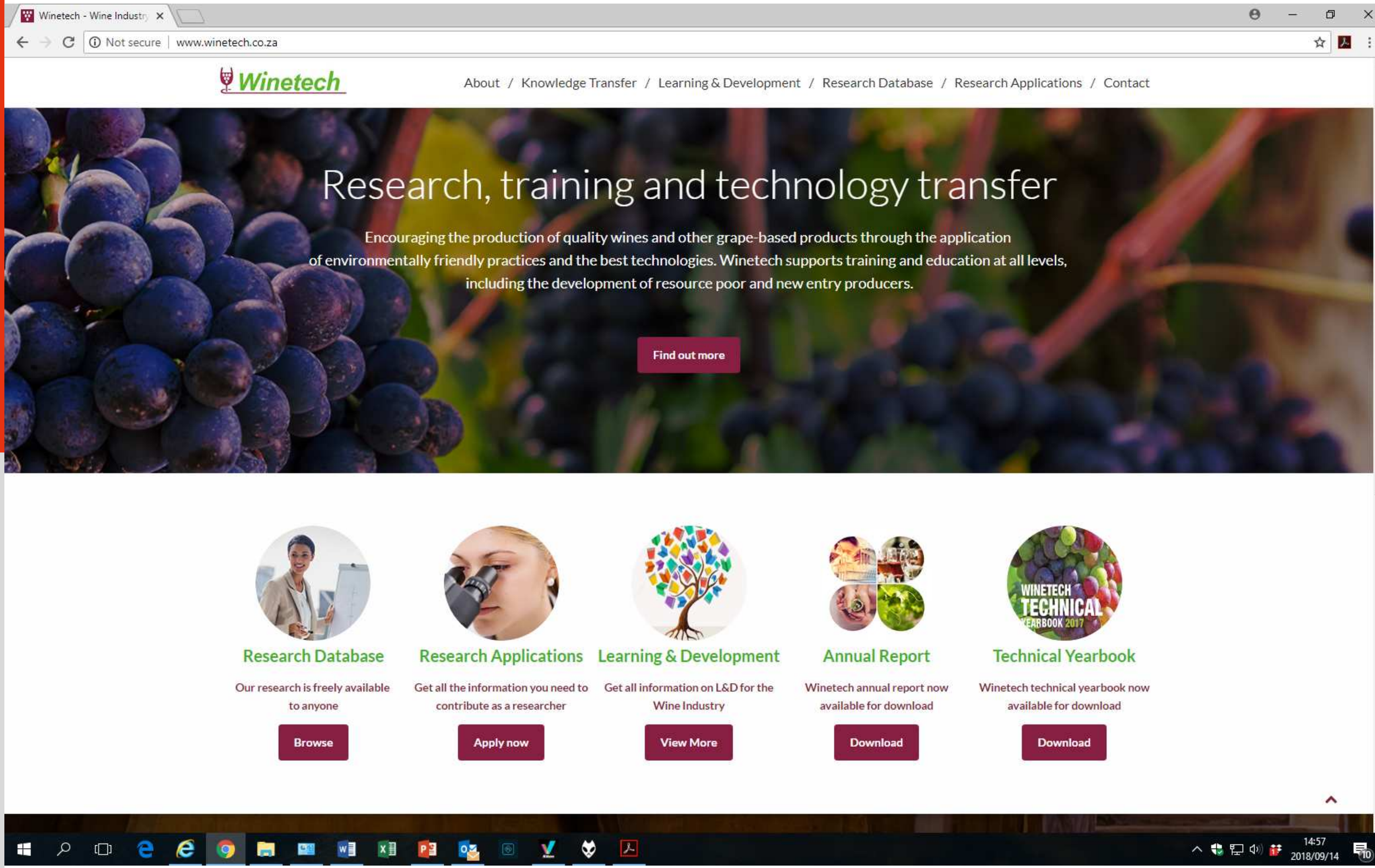
AGRINET project – Outline and partners

- A LIRIMA project since January 2017
  Participants:
  - FUN team at Inria Lille
    - Nathalie Mitton and Valeria Loscri
    - Students: V. Toldov, A. Mbacke, C. Razafimandimby, B. Foubert
  - Stellenbosch University, South Africa : Dept of Electrical & Electronic Engineering
    - R. Wolhuter and T. Niesler
    - Students: R Lùttich, J. Wotherspoon, D. Christians, S Vanasbroek, M. O'Kennedy, N. Nell, PC de Waal
    - Department of Agrisciences
      - A. Strever, C Poblete
  - With the participation of:
    Sencrop company (www.sencrop.com) (France)
    Winetech Industry Research Organisation (www.wintech.co.za) (South Africa)
- Supported by the PHC PROTEA 2017 – 2018 program

Sencrop France



Winetech South Africa



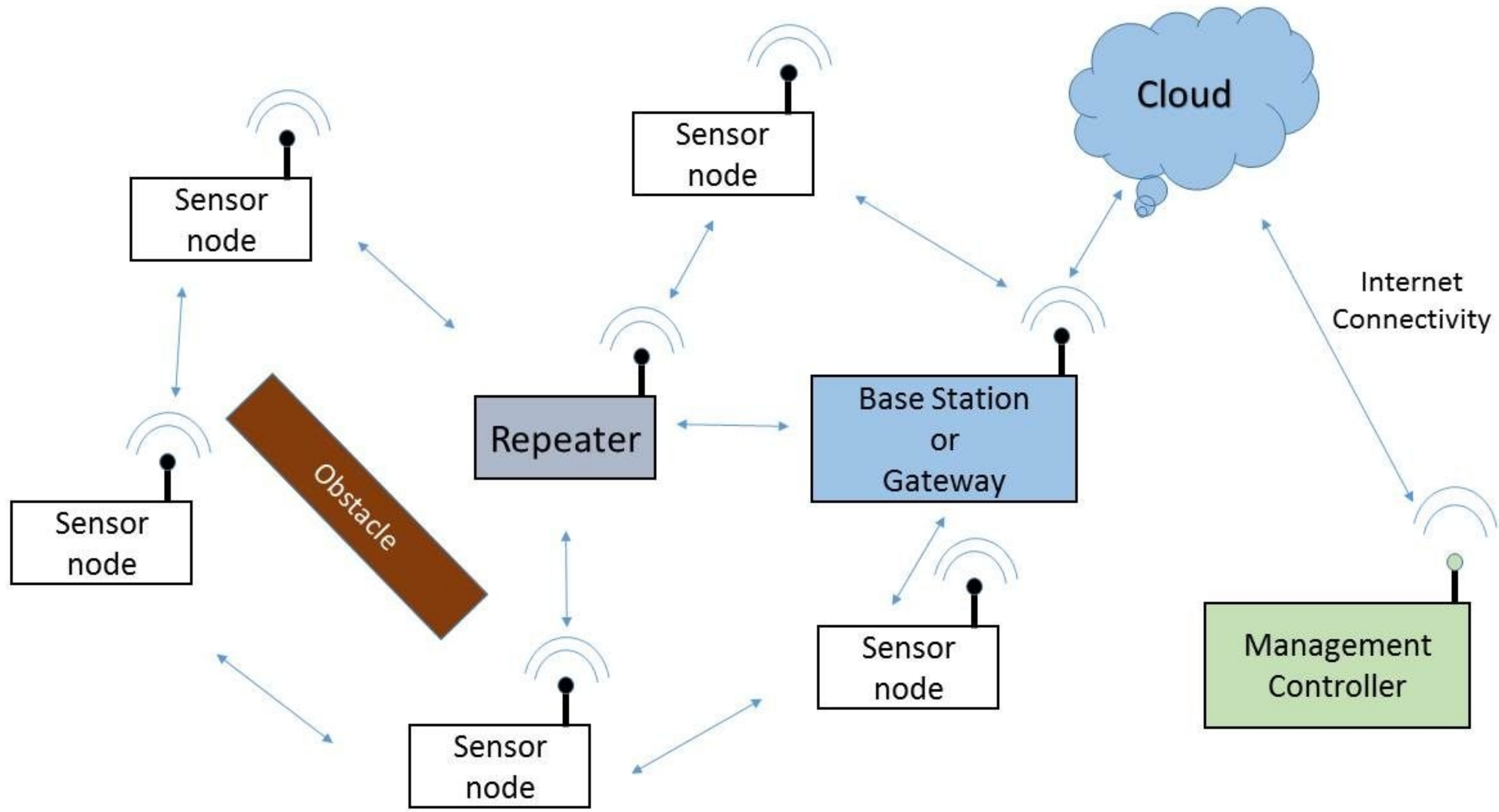
Methodology

- Develop efficient WSN for crop deployment
- Adaptive Machine Learning based tools for data extraction
- Continuous deep view of crop, soil and climatic status
- Identify different factors that impact on crops towards smarter crop management
- Understand and utilise the correlation between these different factors together with their time and space variability
- Anticipate crop disease and stress conditions

- **Realisation of two pilots (vineyards and potatoes)**

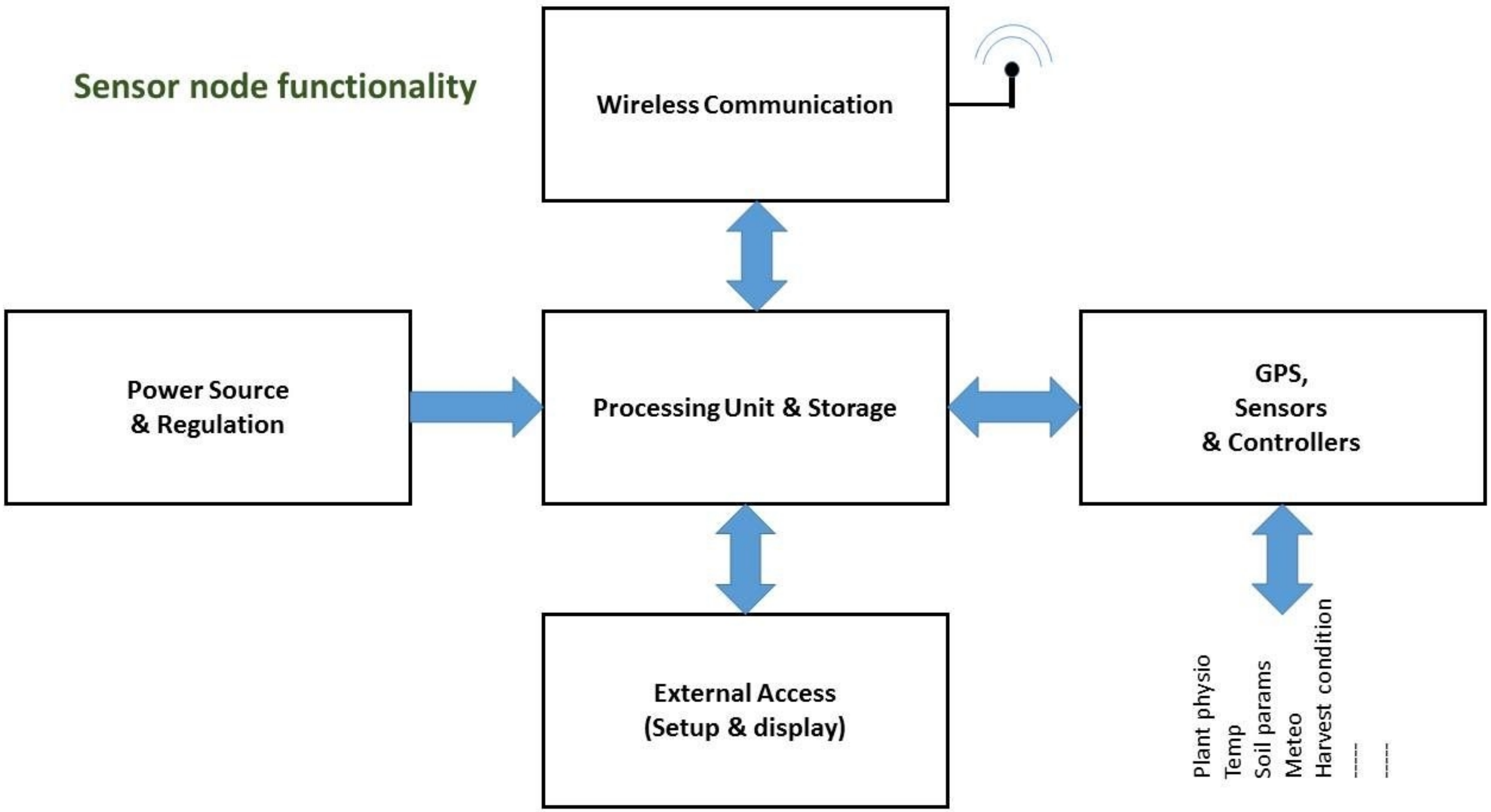
System Design

Typical WSN configuration:



Sensor network architecture

WSN Block Diagram



Hardware and Software

- Wireless sensor design : (SU)
  - Small, low cost, robust, wireless @ 868 MHz
  - Several embedded sensors (temperature, humidity, canopy moisture)
- Wireless communication protocols (Inria + SU)
  - Adaptive , energy-efficient, reliable, multihop, multipath, multi-technology
  - IoT MAC layer development
- Gateway node design with Internet connection (Inria + SU)
- Machine-learning based algorithmic tools for decision-assistance (SU)
- Low cost soil moisture sensor
- Remote canopy moisture sensing system

Vineyard WSN Prototype

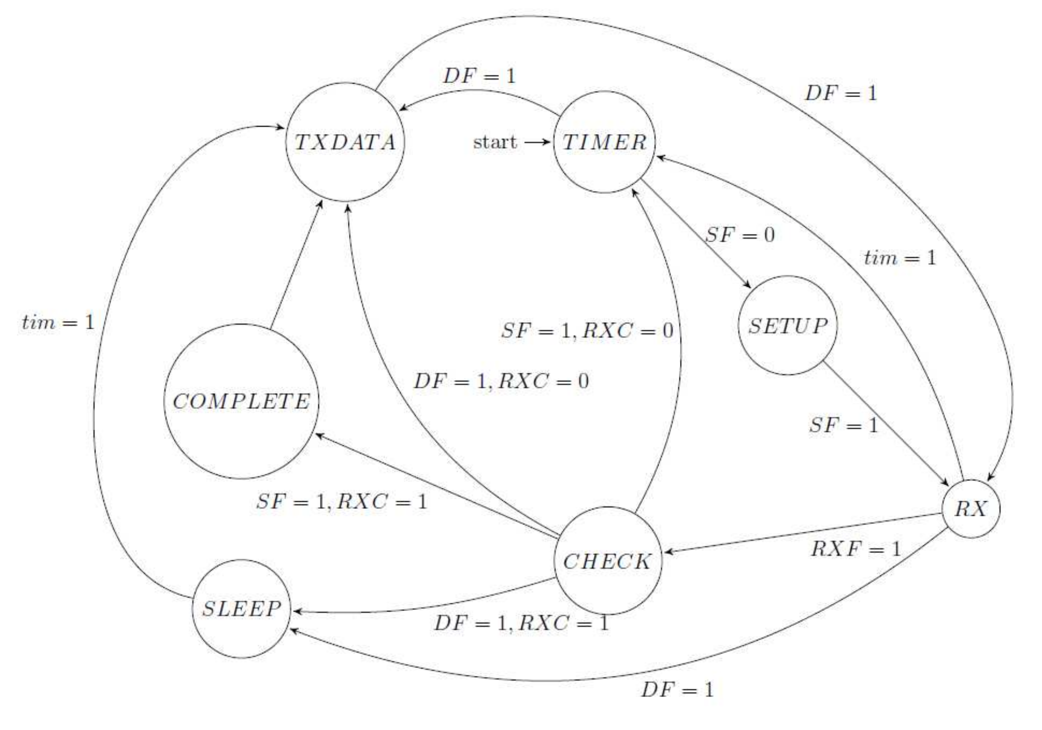
Project Objectives

Final year project: Nicholas Nell

- Develop a Working Sensor Network
- Multiple Nodes (Expandability)
- Long Range and Low Power
- Operate in a Vineyard Environment
- Working Database

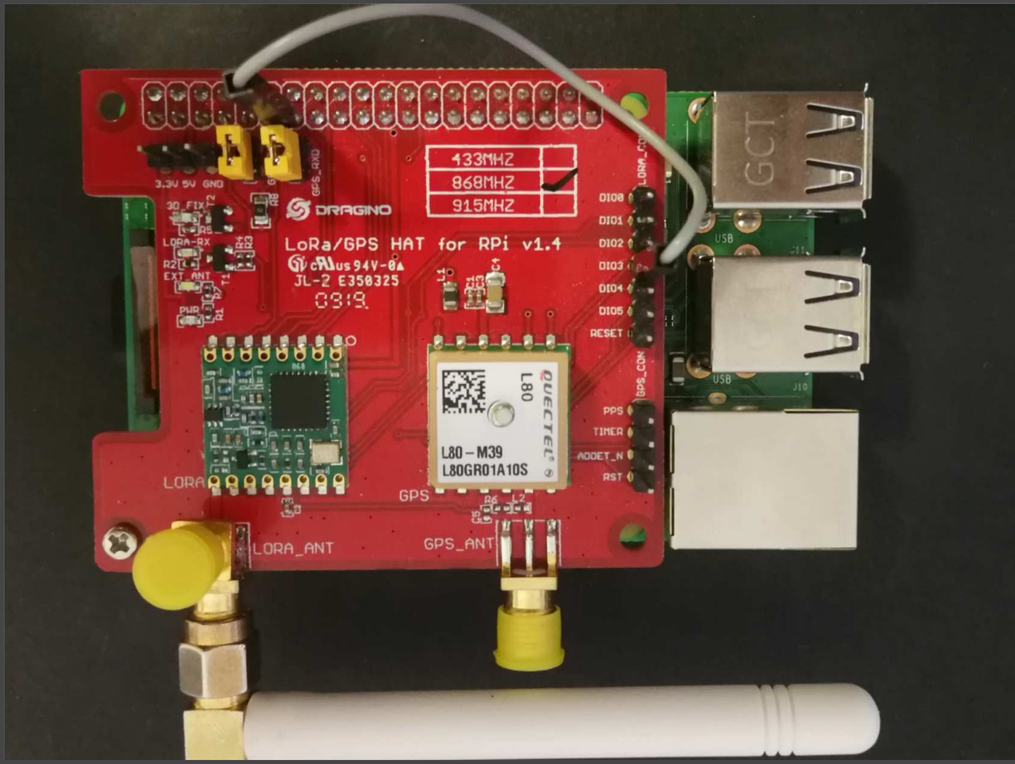
Sensor Node

- Arduino Pro Mini
- RFM95W Lora Chip
- Sensors
  - Temperature
  - Relative Humidity
  - Light Intensity
  - Soil Moisture
- 3D Printed Case



Gateway

- Raspberry Pi 3B+
- Dragino Lora Hat
- Running Python Script
- Operates on an Interrupt Basis
- Receives Data from Nodes
- Sends Data to Database Via GSM



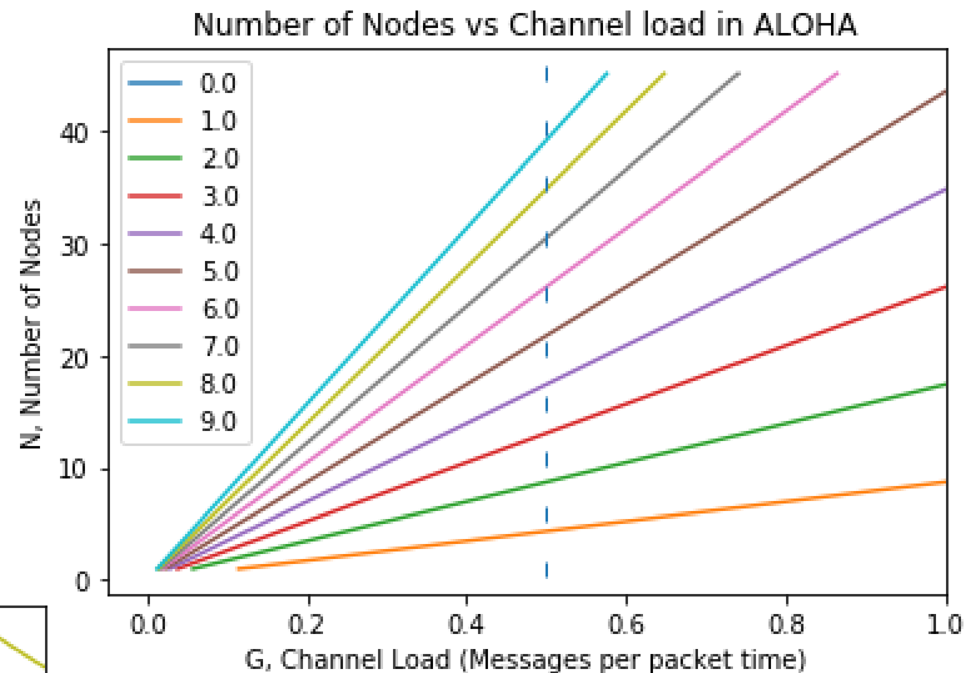
Database

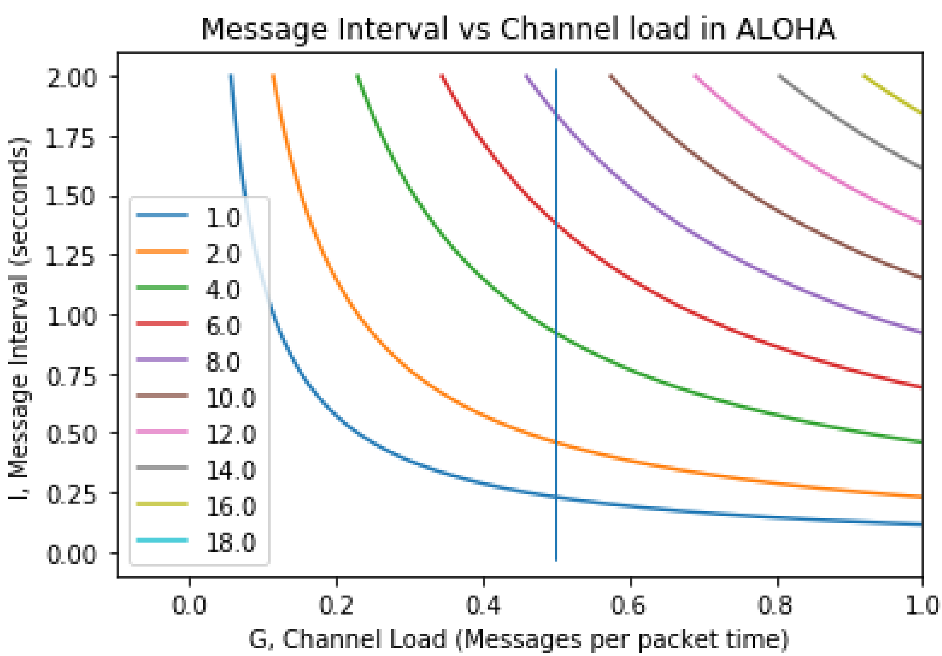
- Google's Firebase
- Telemetry Data is Stored For Each Node
- Makes it Easy to Retrieve Data for Analysis

Theoretical Analysis

Analysis was done using Python

Compared various message intervals and number of nodes

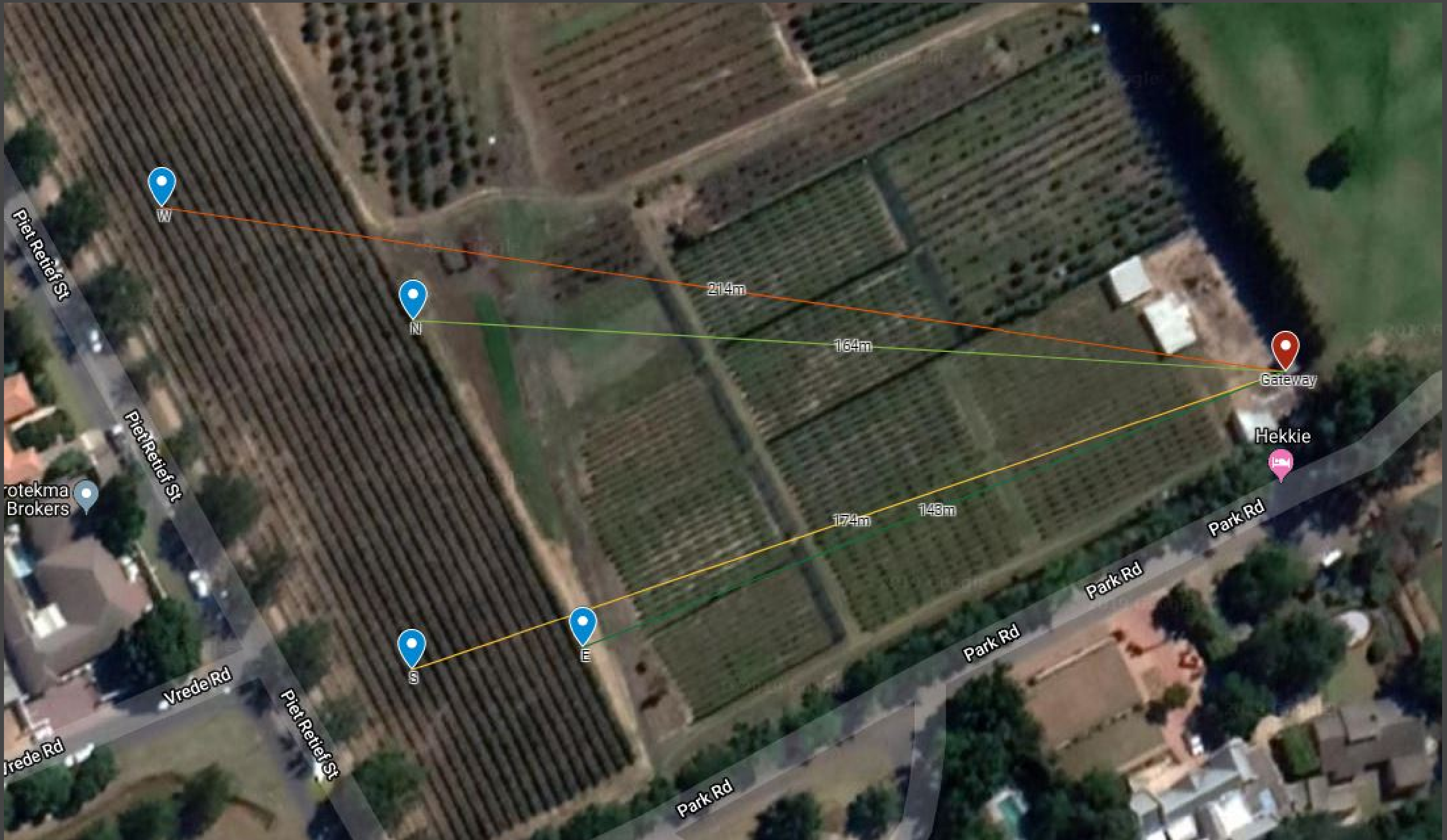




The optimal message interval for a four node system is 0,9 seconds

Installation and Testing

- *Installed at Welgevallen Vineyards, Stellenbosch*
- *Sensors Placed at Varying Distances*
- *Gateway Placed Inside Security Hut*



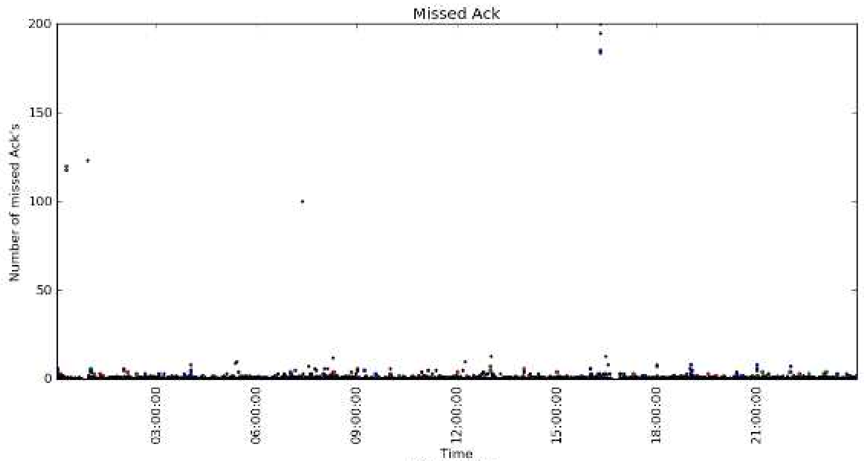
Test Results:

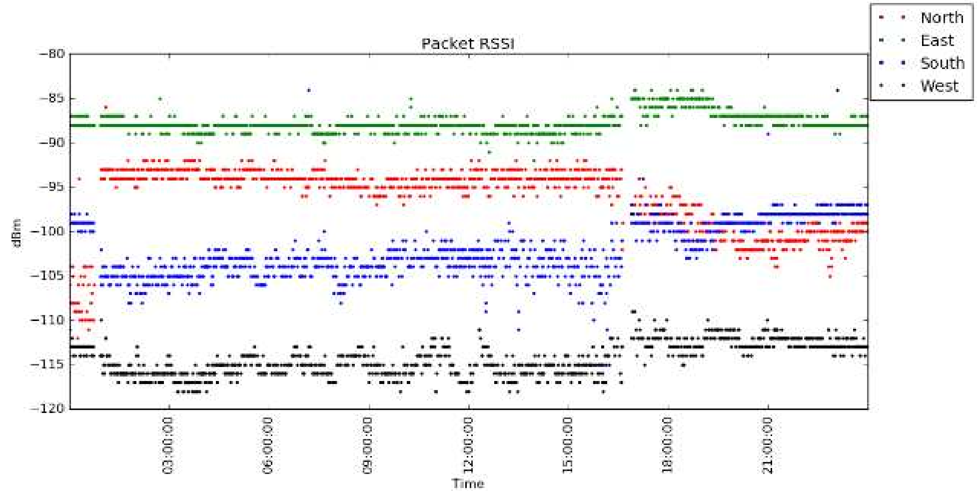
No noticeable gaps in comms

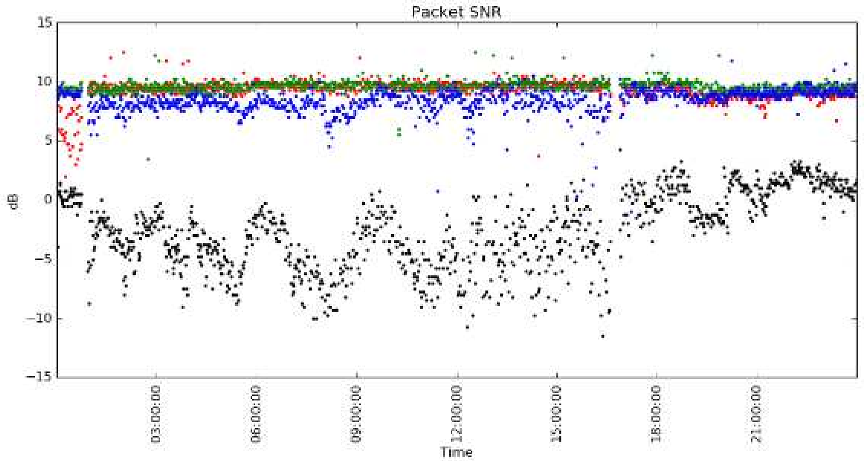
Fully functional and reliable

6 Day Battery Life

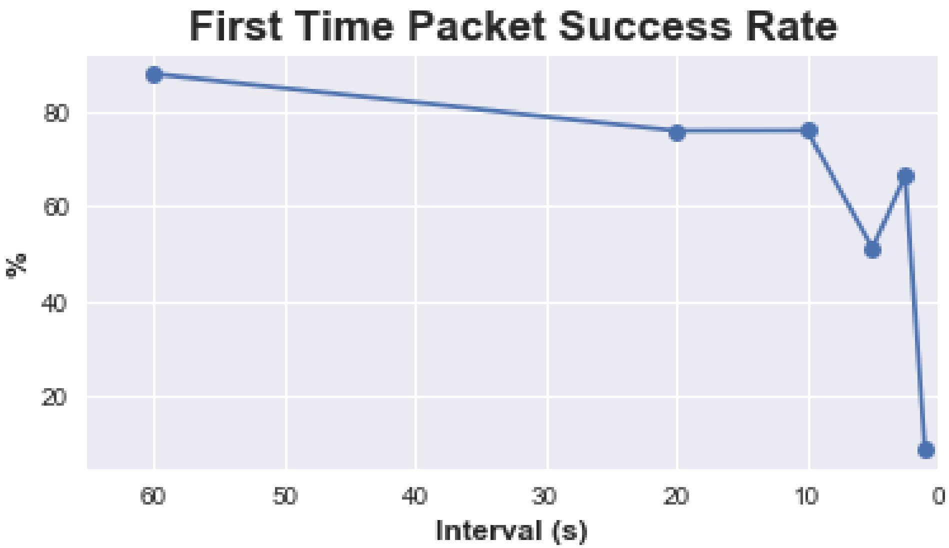
Very good platform for further developments







Test Results: Stress Test

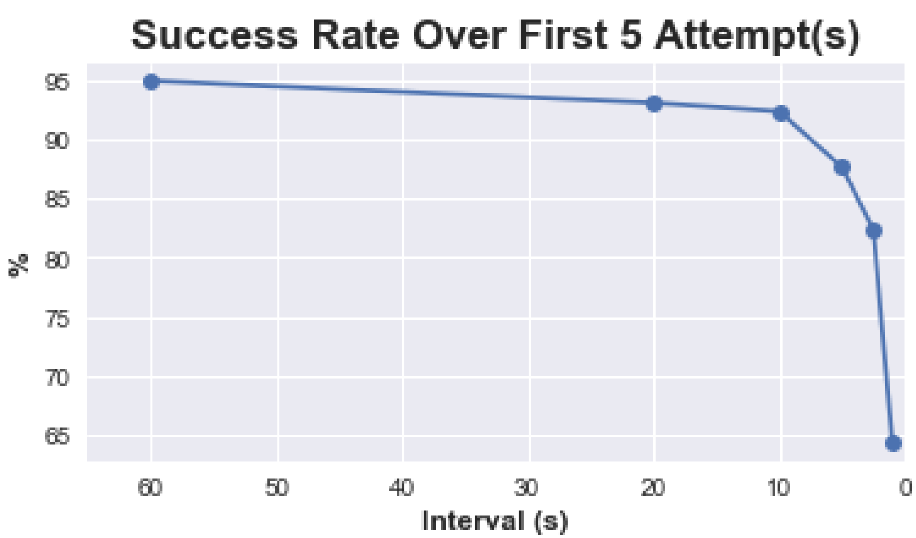


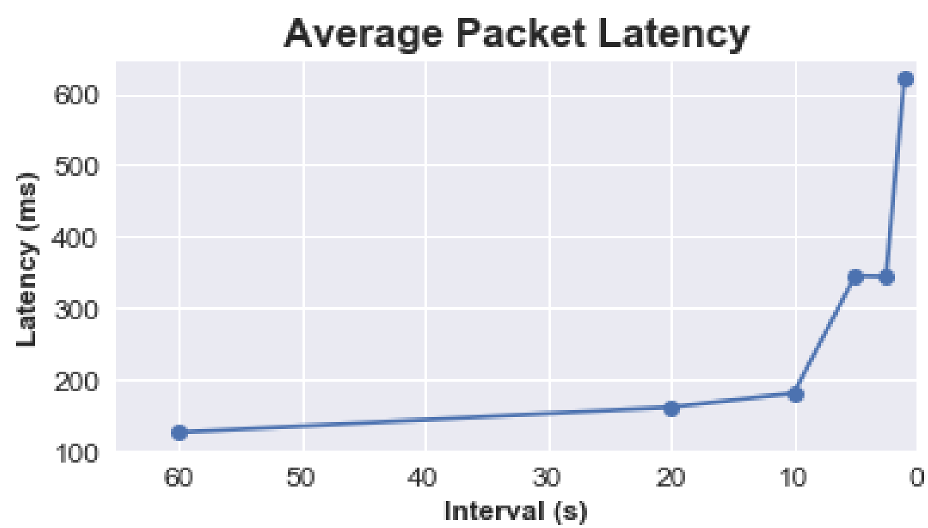
Tested the Limits of the Four Node System

Used Constant Packet Length

Bypassed Sensor's Polling Rate Limitations

Increase Packet Interval Until the System Performance Degraded Severely





Conclusion

- The System Successfully Collected and Transmitted Telemetry Data
- Distances of Over 200m Through the Vineyard
- Data was Immediately Retrievable From the Database
- The LoRa Modulation Technique Proved Suitable for Use in Vineyards
- Very good basis for next generation in 2020

Prototype Soil Humidity Sensor

Final year project: Charl de Waal

Scope:

- Investigate different methods of measuring soil moisture
- Develop a suitable soil moisture sensor at reasonable cost
- Develop a soil moisture sensor with economical hardware
- Test the developed system in vineyard soil

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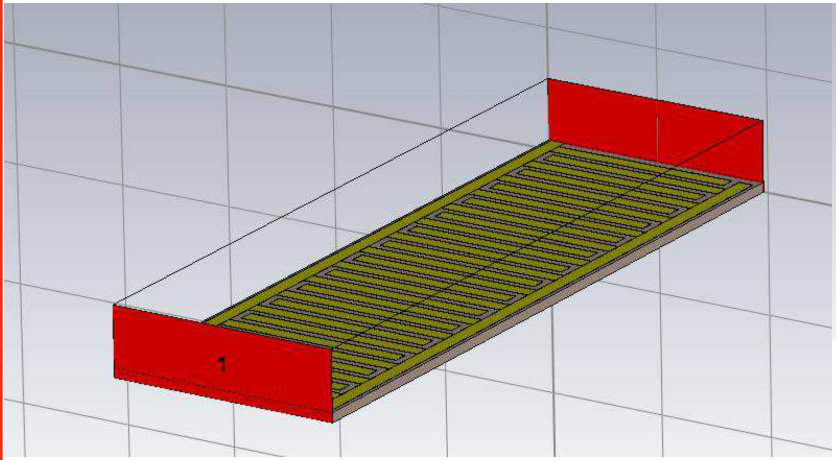
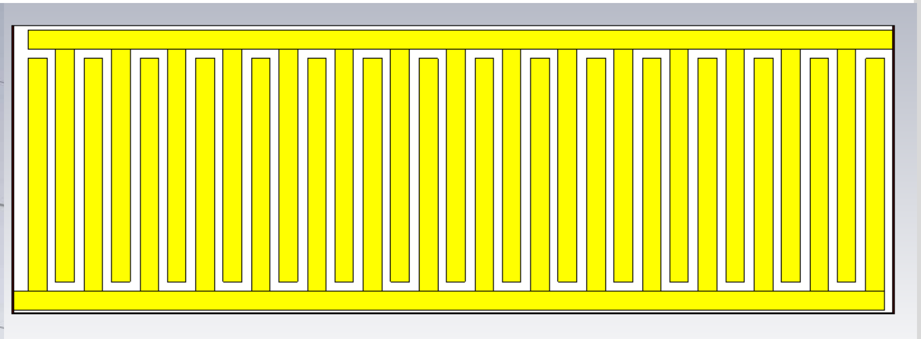
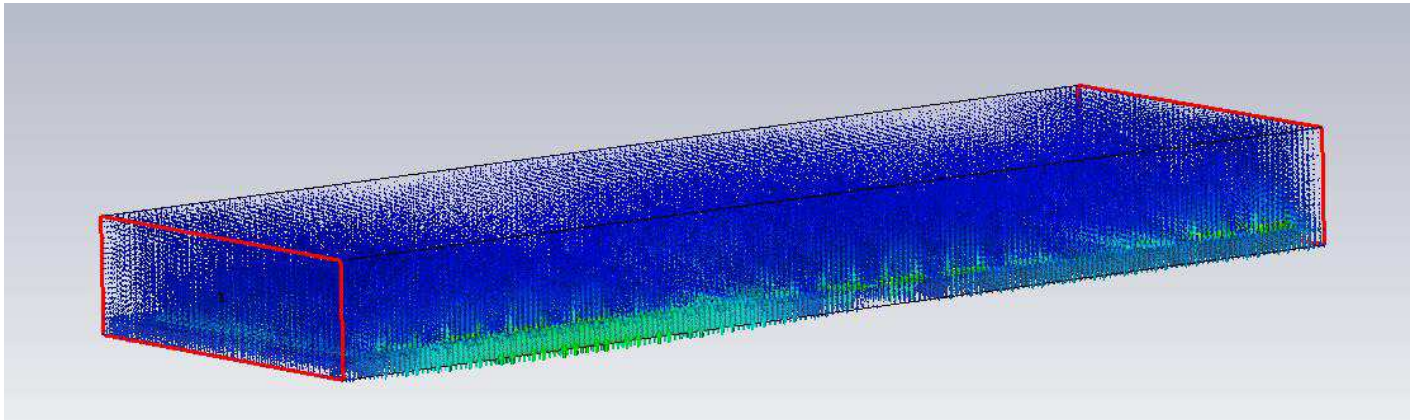
Capacitive type sensor developed





Interdigital sensor model in CST



Interdigital sensor e-field CST simulation

Final prototype

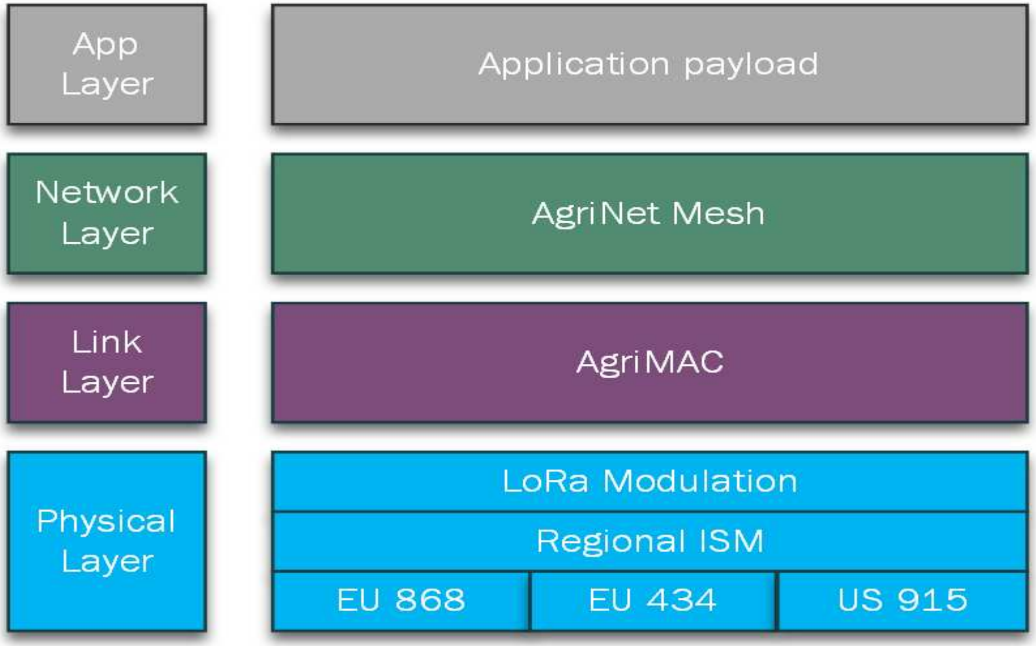
Sensor worked well and accurately

Advanced CSMA IoT MAC layer

Masters project: Morgan O'Kennedy

Objectives:

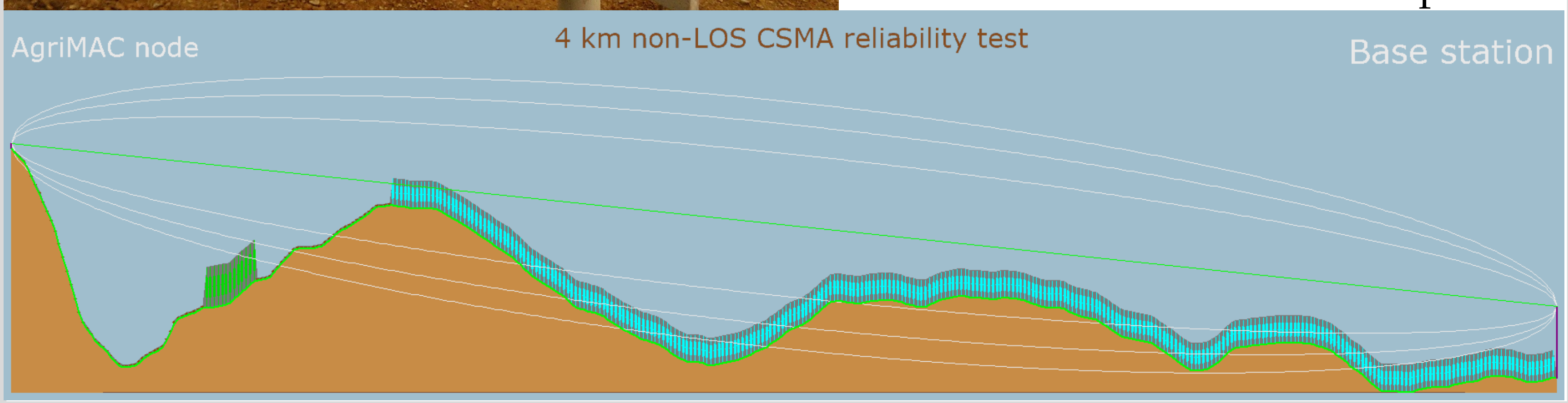
- To evaluate current LORaWAN performance limits
- To investigate possible performance improvement by developing a new LoRaWAN MAC layer
- To construct a prototype network and evaluate the proposed strategy practically

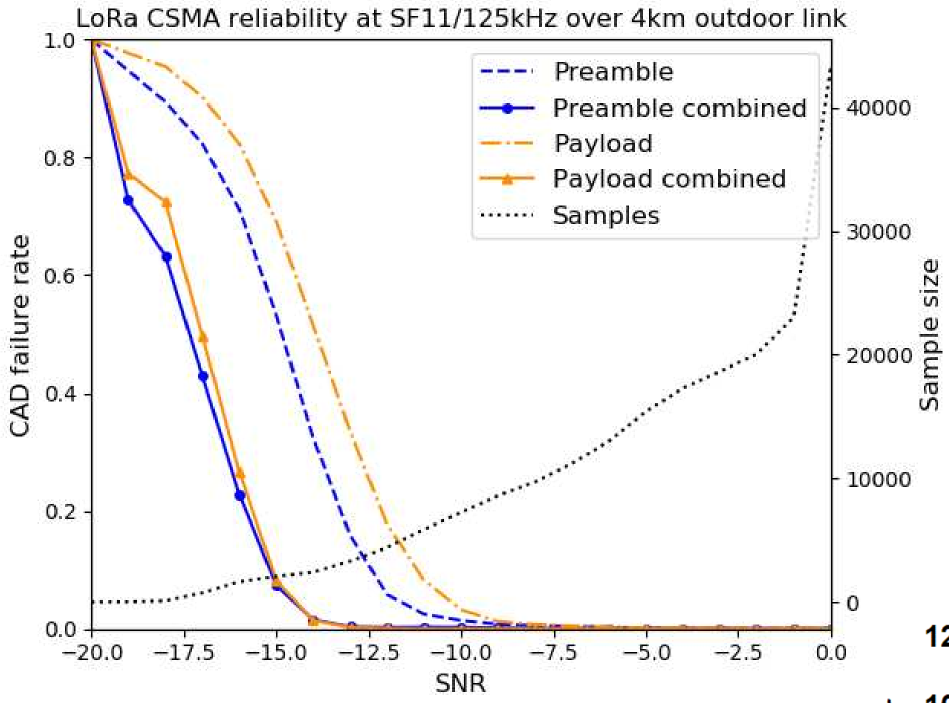


Agrinet OSI diagram

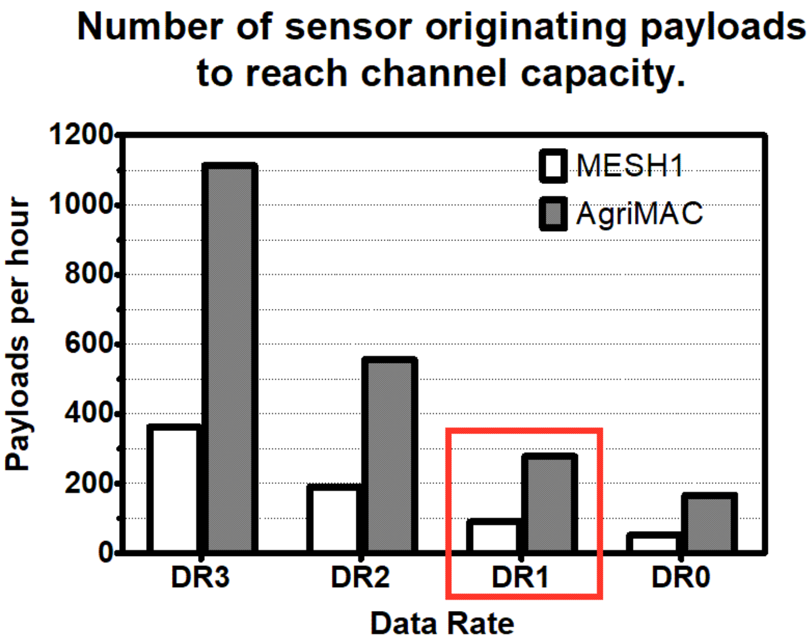
AgriMAC sensor node

LOS test profile

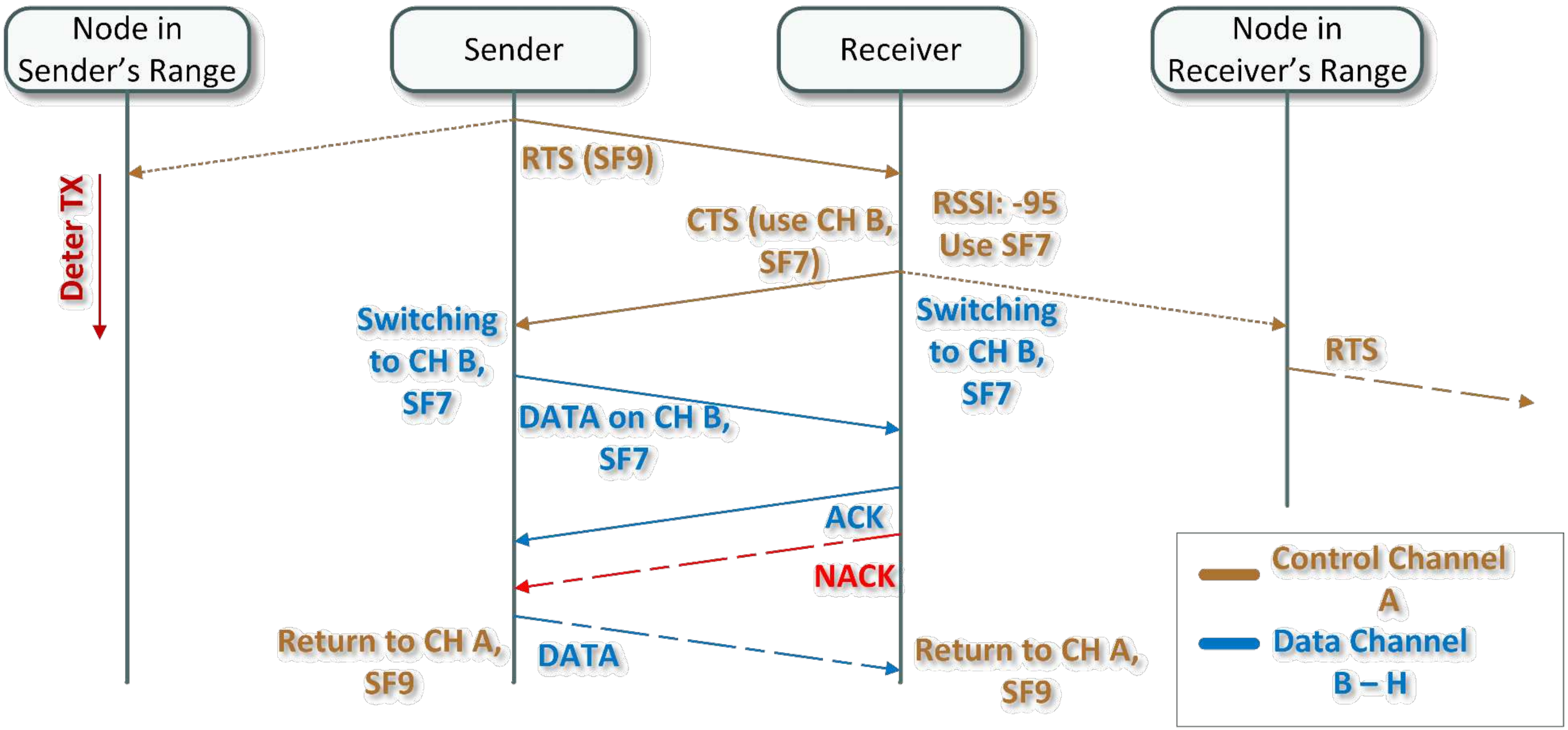




AgriMAC CSMA reliability results



Capacity modelling of AgriMAC vs Mesh



AgriMAC automatic rate adjustment

M-L Algorithms for vineyard temperature prediction and extraction

Master's project:
Reinhard Luttich

- A predictive model created to estimate soil temperatures, given weather data.
- With a modified linear regression method, the prediction error was 5.56%
- An improved neural network model currently provides an error of 4.8%
- Very promising results and next step to use data from Agrinet WSN

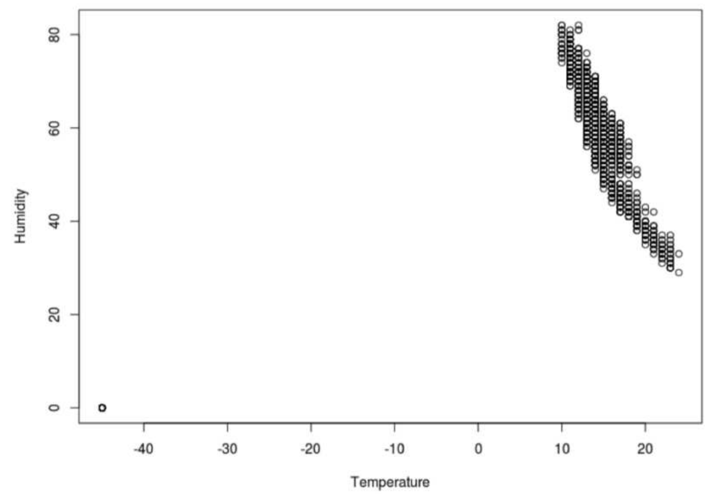


Figure 4: Relationship between humidity and temperature data.

Scenario	*#Transmitted data* [Byte]	*EC* [kJ]	*MSE*	*ER*
s_1	8408	1634.5152	-	-
s_2	4204	817.2576	0.62	0.295
s_3	4260	828.144	0.022	0.0066

Table I: Results obtained during eighteen hours of readings for different scenarios.

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Experimentation vineyards where soil and environmental conditions are measured and studied

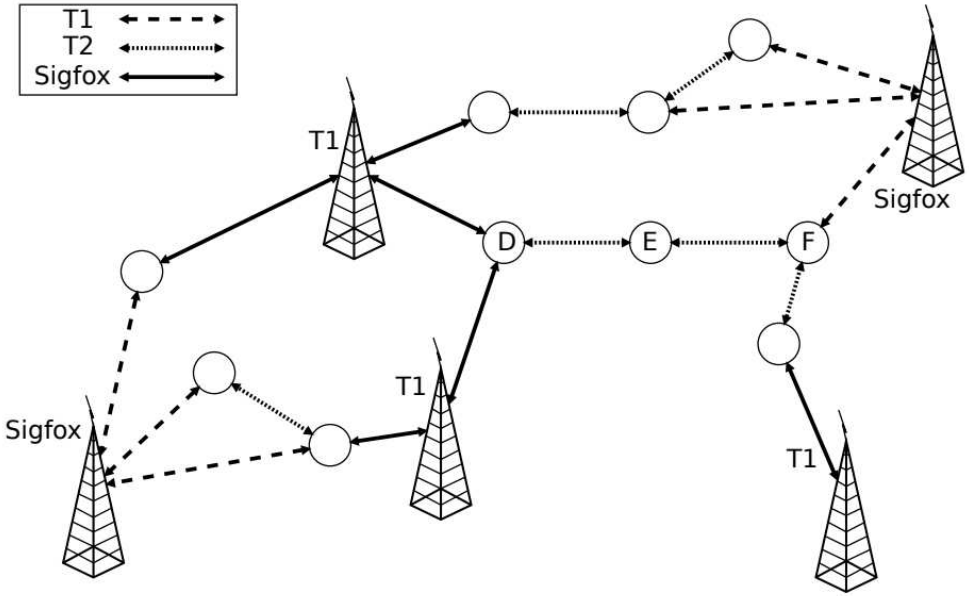
Rustenberg wines vineyard. Communications tests with LoRA modules

inventors for the digital world

Polymorphical wireless communication for connected agriculture

PhD thesis: Brandon Foubert

Scope:
- Multi long range technology devices
- Autonomous selection of best technology and path for data
- Test developed pilot in vineyard and potato fields



01

Sencrop

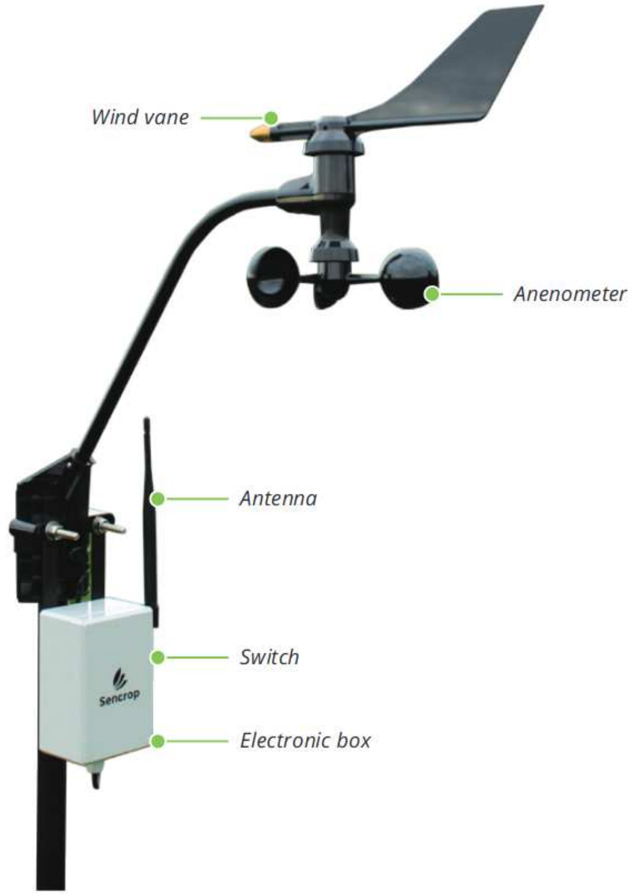
Provide help to agricultural workers

- Automate the collection of information
- Records climate data
- Ultra-precise data

https://www.terre-net.fr/actualite-agricole/economie-social/article/revenus-agricoles-2017-en-hausse-202-133225.html

Raincrop

- Rain gauge
- Temperature
- Air humidity



Windcrop

- Wind speed
- Gusts
- Wind direction

https://sencrop.com/

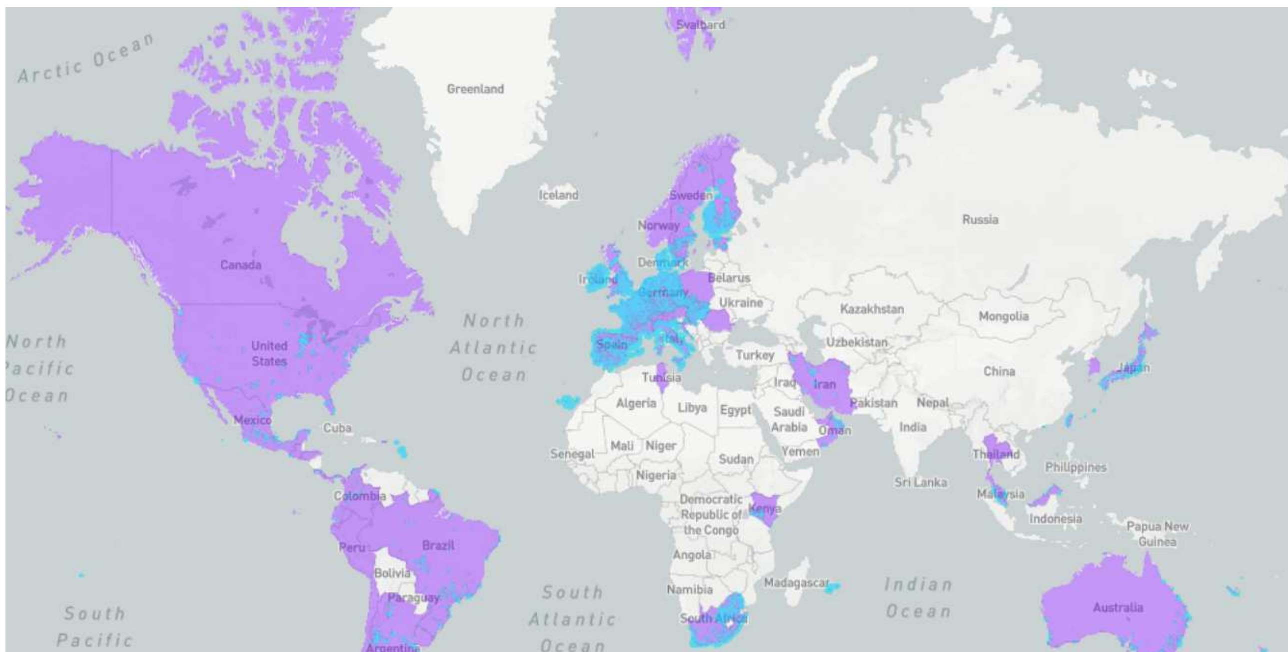
Leafcrop

- Temperature
- Humidity
- Dew point
- Wet bulb temperature

sigfox

Current Sencrop use

- 12 bytes payload
- Every 15 minutes



https://www.sigfox.com/en/coverage

Sencrop’s objectives

Extend geographical range of operation

Firmware over the air updates

- Multiple radio technologies
- Multi-hop networks

02

Long range technologies

Cellular networks

Enhanced Machine Type Communication (eMTC a.k.a. LTE-M)

- Based on 4G (LTE)
- 1 Mbps bit-rate
- 1,4 MHz bandwidth
- eDRX & PSM

Narrow-band IoT (NB-IoT)

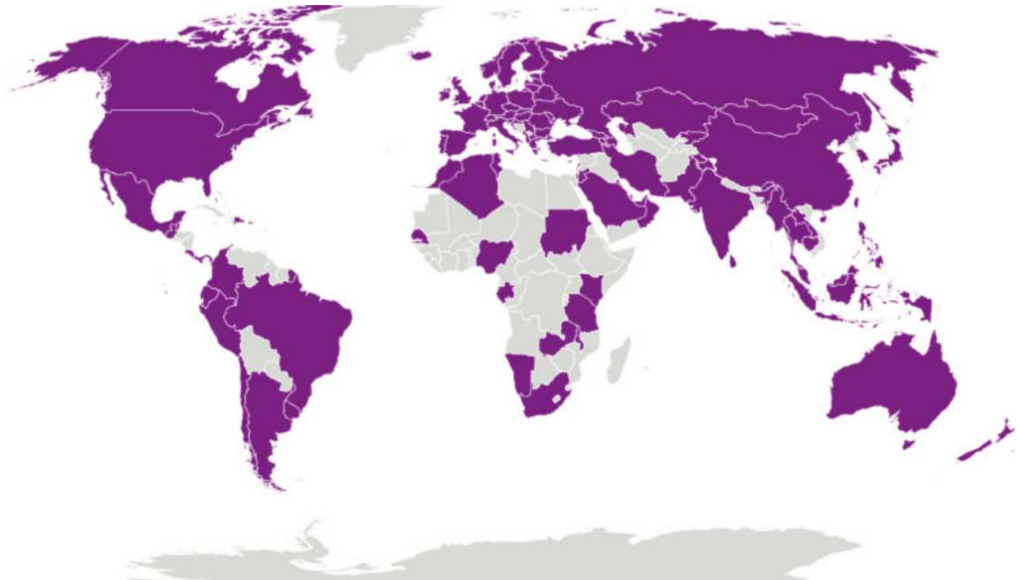
- Also based on 4G
- 250 kbps down & 20 kbps up bit-rate
- 180 kHz bandwidth
- No handover

Extended Coverage GSM IoT (EC-GSM-IoT)

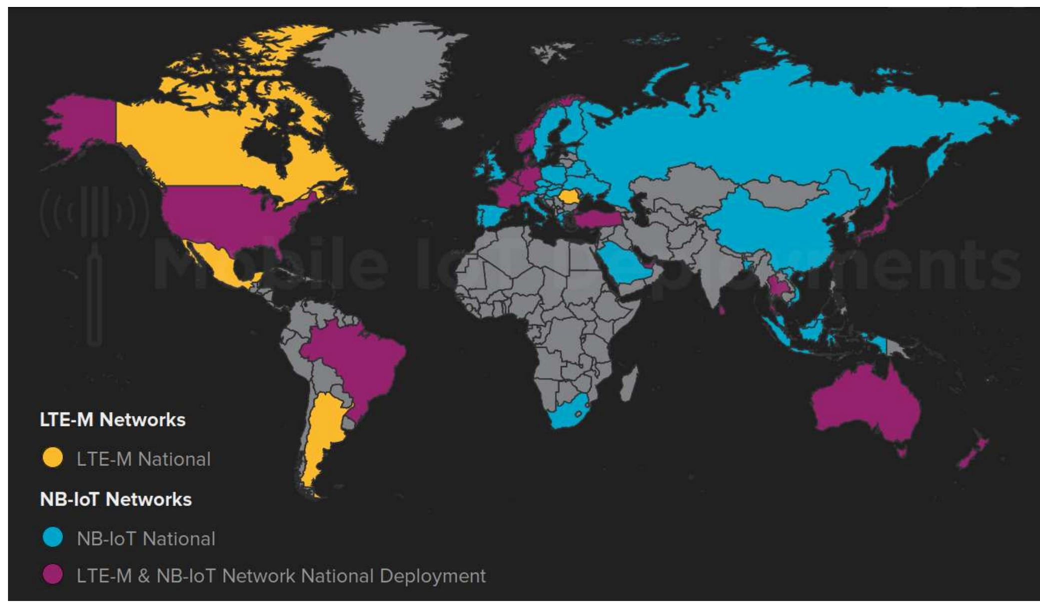
- Based on 2,75G (eGPRS)
- 70-240 kbps bit-rate
- 200 kHz bandwidth
- **GSM decommission**

5G

- Nothing for the IoT



Global mobile Suppliers Association (GSA). Evolution from LTE to 5G: Global Market Status



https://www.gsma.com/iot/deployment-map/

Low power wide area network

Sigfox

- 100 bps bit-rate
- 140 x 12 B / day up
- 4 x 8 B / day down

LoRa

- 0,3-50 kbps bit-rate
- 3 classes of device

Ingenu

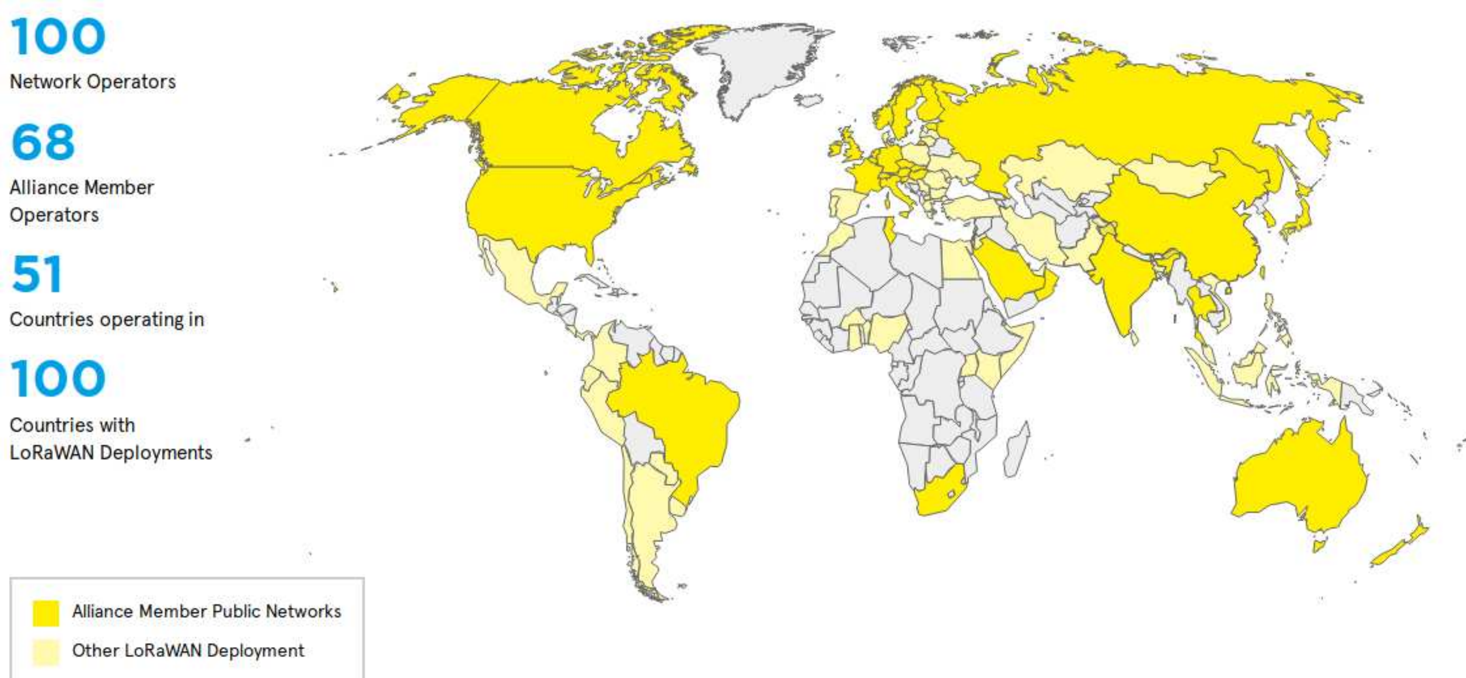
- 2,4 GHz ISM band
- 78 kbps up
- 19,5 kbps down

Weightless

- 3 standards: W/**P**/N
- 0,2-100 kbps
- Ack & FotA

Many more

- Telensa
- DASH7
- Qowisio
- WAVIoT
- ...



https://lora-alliance.org/

Which one wins ?

Energy consumption

- Dependent on hardware
- Based on datasheets: UNB < LoRa < Weightless-P < Cellular < Ingenu
- Ratio bit-rate / energy ?

Coverage

- Highly dependent on the environment
- UNB > LoRa > Weightless-P >Cellular > Ingenu
- Penetration of natural environment ?

Usage of the spectrum

- Many LPWANs on the sub-GHz ISM unlicensed band
- Cellular use licensed bands, but partly LTE bands

Deployment

- Cellular is by far the largest deployment
- LoRa can be deployed as a private network / not cellular
- Evolution in the future ?

Financial cost

- Highly dependent on countries, operators and so on
- Cellular « brokers » e.g. Hologram (1$/month +40¢/MB)

	Module	Connectivity	Infrastructure
LTE-M	$10-15	$3-5 / mo for 1MB	
NB-IOT	$7-12	<$1 /mo for 100kb	
Sigfox	$5-10	<$1 / mo	
Ingenu	$10-15	?	
LoRaWAN Public	$9-12	$1-2 / mo	
LoRaWAN Private	$9-12	$0.25 / mo	$500
Symphony Link	$15	$0.25 / mo	$500

https://www.link-labs.com/blog/costs-in-iot-lte-m-vs.-nb-iot-vs.-sigfox-vs.-lora.

https://lora-alliance.org/

Push it to the limit

Combine cellular technologies

- EC-GSM-IoT & 5G out of the game
- EMTC & NB-IoT are complementary, both in capabilities and deployment
- Several chips already integrates both technologies

Extend the network even further

- Multi-hop networks between stations to communicate in uncovered areas
- Unlicensed band technology is mandatory
- LoRa and Weightless-P are the best candidates as of now (FotA PoC for both)

03

Network Interface Selection (NIS) for the IoT

Goal: select the best technology to communicate with low overhead

Assume a station with N different network technologies

How do we choose which technology do we use to communicate ?

Many different tools

- Integer Linear Programming (ILP)
- Utility / cost function
- Game theory
- Multi Attribute Decision Making (MADM)
- Markov chain
- Fuzzy logic

Multi Attribute Decision Making (MADM)

MADM problem

- A = {Ai, for i=1,2,...,n} the set of candidates
- C = {Cj, for j=1,2,...,m} the set of attributes
- w1, w2, ..., wm the weights of each attribute

Many algorithms

- Simple Additive Weighting (SAW)
- Weighting Product (WP)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)
- Analytical Hierarchy Process (AHP)
- Gray Relationnal Analysis (GRA)

	C1 (w1)	C2 (w2)	.	.	Cm (wm)
A1	a11	a21	.	.	am1
A2	a12	a22	.	.	am2
.	.	.	.	.	.
.	.	.	.	.	.
An	a1n	a2n	.	.	amn

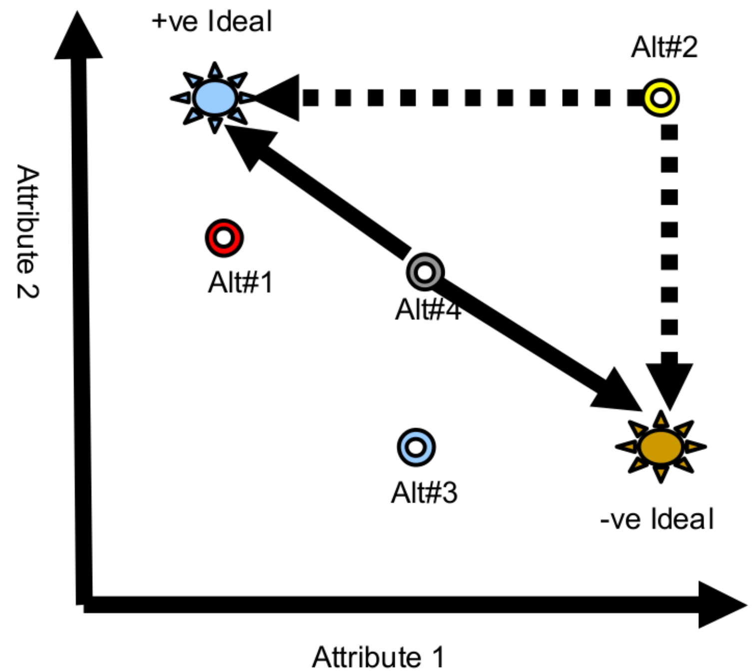
F. Bari and V. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access," 2007 4th IEEE Consumer Communications and Networking Conference, Las Vegas, NV, 2007, pp. 808-812

Inria

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

Algorithms steps

- Normalization
- Weighting
- Determination of positive and negative ideal solutions
- Determination of best and worst values for each attribute
- Measurement of distance from the positive and negative ideal solution for each candidate
- Calculation of the relative closeness to the ideal solution
- Selection of best candidate



F. Bari and V. Leung, "Multi-Attribute Network Selection by Iterative TOPSIS for Heterogeneous Wireless Access," 2007 4th IEEE Consumer Communications and Networking Conference, Las Vegas, NV, 2007, pp. 808-812

Inria

Complexity and ranking abnormalities

Heavy calculations for IoT

- Euclidean normalization:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{N} a_{ij}^2}}$$

- Distance from ideal position:

$$S_i^+ = \sqrt{\sum_{j=1}^{m} \left(v_j^+ - v_{ij}\right)^2}$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} \left(v_j^- - v_{ij}\right)^2}$$

Ranking instability

- Alteration of the final ranking when removing worst candidates
- Caused by euclidean normalization
- Using alternative normalization methods can reduce the effect but not neutralize it

Light TOPSIS for IoT

Simple and stable normalization

- Reduce complexity and eliminate rank reversal
- Use fixed bounds for each attribute

Algorithm 1 Lightweight normalization

Require: a_{ij} the raw value of each attribute j for each candidate i

for each attribute C_j **do**
  if C_j is an upward attribute **then**
    B_j^+ is the upper bound of C_j
    $r_{ij} = \frac{a_{ij}}{B_j^+}$
  else if C_j is a downward attribute **then**
    B_j^- is the lower bound of C_j
    $r_{ij} = \frac{B_j^-}{a_{ij}}$
  end if
end for
return r_{ij} the normalized value of a_{ij}

Application layer

- Express needs in term of bounds and weights

Performance assessment

Network Interface Selection for IoT

- Hardware: Pycom Fipy
- Algorithm implementation: MicroPython
- Experimentation to compare with TOPSIS
- Preliminary results: 50% time improvement

https://pycom.io/product/fipy/

Planning for 2020

- New M student to continue with next gen Agrinet WSN (N Nell)
- M. O'Kennedy to complete M by end 2019 and joint paper with N Mitton
- New M student to develop new soil humidity and related sensors (C de Waal)
- PhD student from Inria to visit Stellenbosch
- M student(s) from Stellenbosch to visit Inria

Thank you for your attention!
Any questions?

brandon.foubert@inria.fr