Contribution to the conception of a wireless underground sensors network for precision agriculture in Africa

FuzDeMa : a portable fuzzy-based decision-making tool for reliable communication in WUSN

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COPAIN research team seminar, 29th Juin (Clermont-Ferrand)

Content

01

Introduction

Agriculture ⇔ source of livelihood

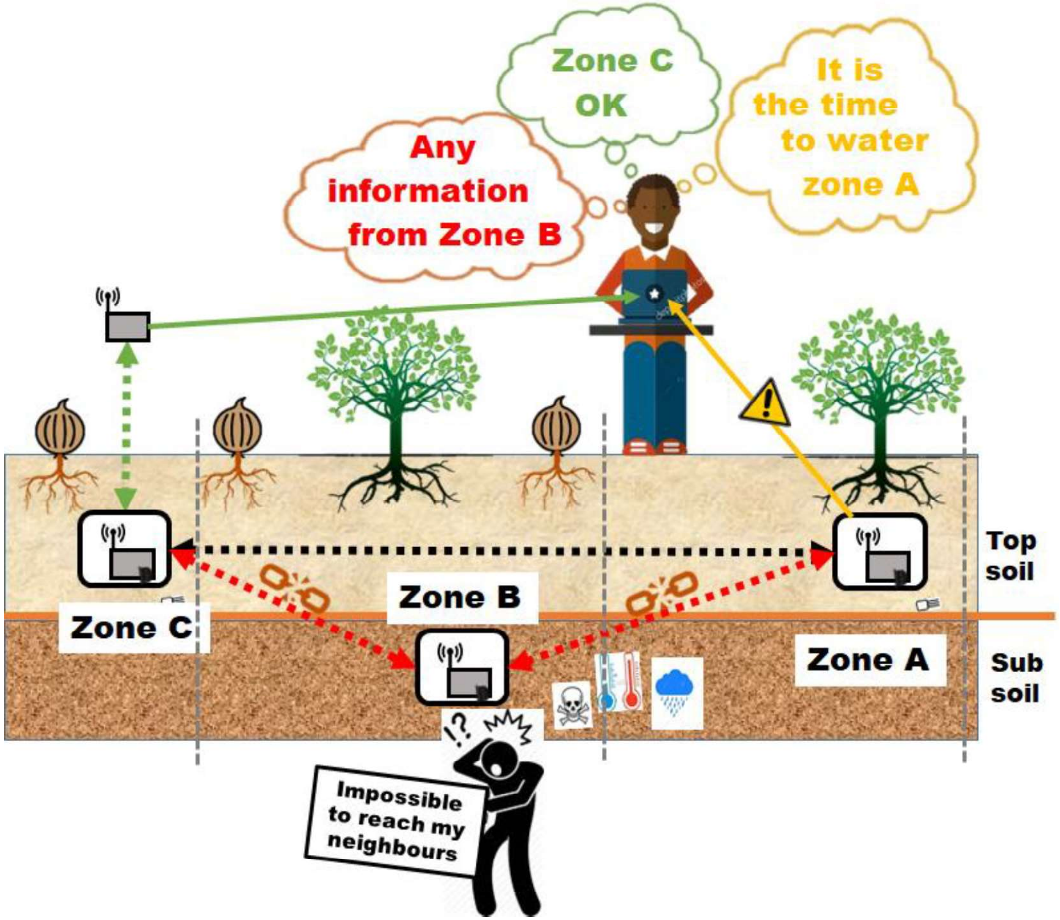
- Agriculture as
  - Source of food supply;
  - Country development index;
- Lack of production $\Longrightarrow$ local food shortages;
- Africa spent $64.5 Billions on importing foods (AfDB, 2017);
- Food import will increase to over $110 Billions by 2025;

PAMACC[1] : *"Agricultural production in Africa will explode if technologies are made available to producers"*

[1] Pan African Media Alliance for Climate Change (PAMACC) is an association of African journalists who report on climate change, environment, sustainable development and related subjects

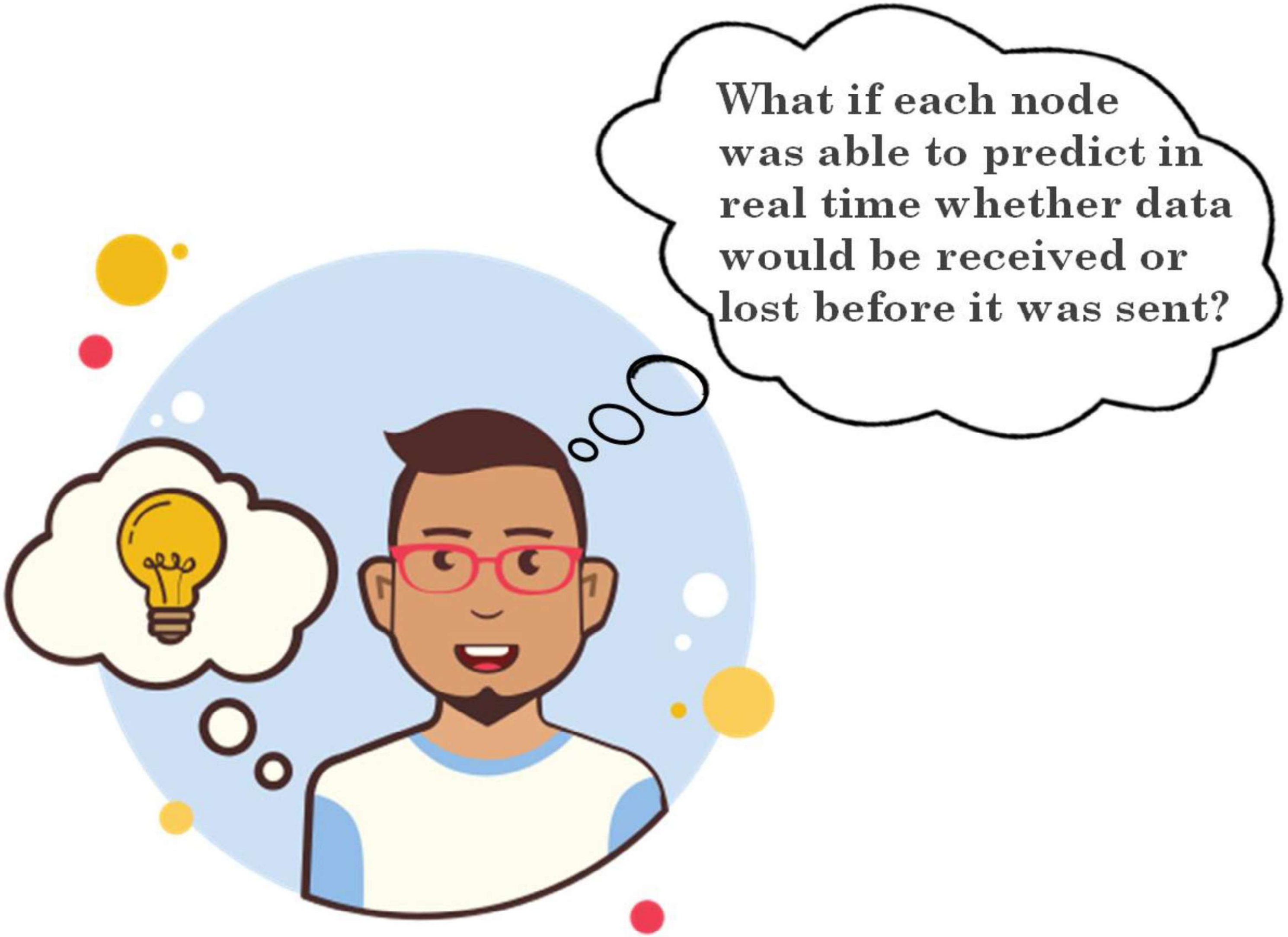
Challenges of WUSNs in agriculture

- Communication medium: **SOIL**;
- Mitigation of wireless communications
- Changes of soil properties ⇒ link qualities;
- Water presence ⇒ reflection, refraction, … of the EM waves (radio);
- e.g. Intelligent watering system ;



- **Waste of energy when sending data not received**

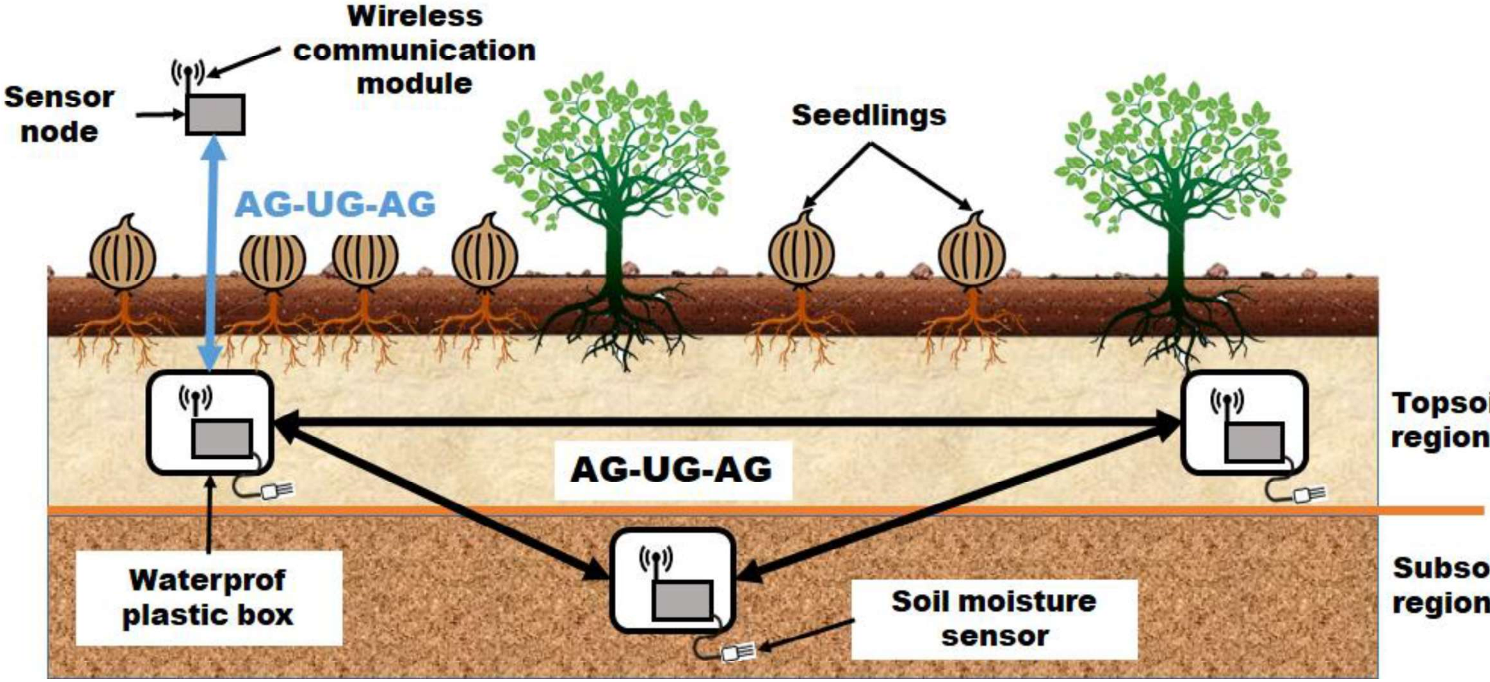
What if… ?


What if each node was able to predict in real time whether data would be received or lost before it was sent?

02

A new path loss model for Wireless underground communications

A model adapted to agriculture in Africa!



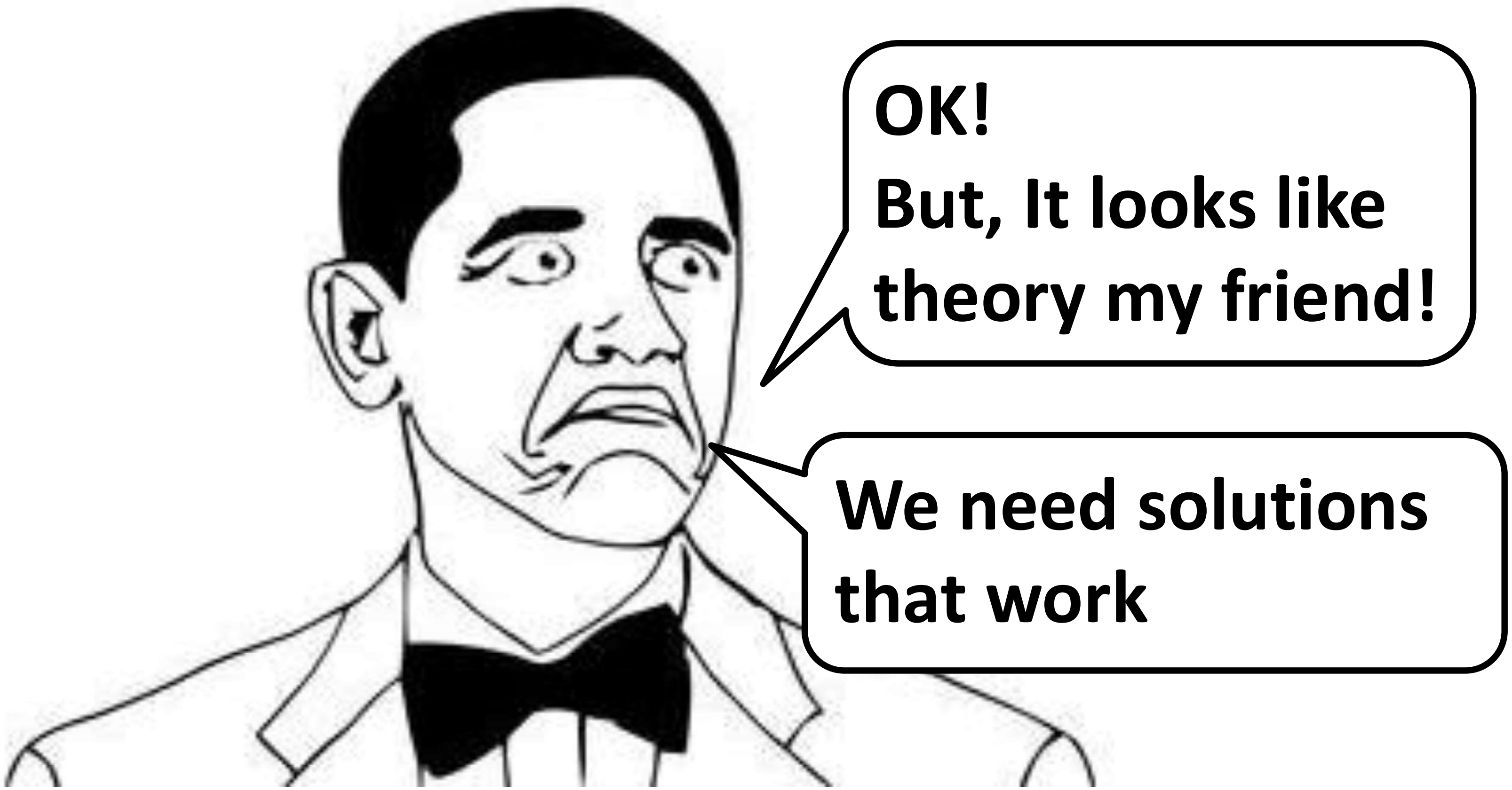
- UG2UG, UG2AG et AG2UG AG2UG2AG;

$$W_{\#1} = -288.8 + 20\log\left(d_1.d_2.d_{ug}.\beta.f^2.\sqrt{\frac{2R}{1+R}}\right) + 8.68\alpha d_{ug} \quad (4)$$

$$W_{\#2} = -288.8 + 20\log\left(d_1.d_2.d_{ug}.\beta.f^2\right) + 8.68\alpha d_{ug} \quad (5)$$

[DAB2020]. **D. Wohwe Sambo**, A. Förster, B. O. Yenke, I. Sarr, B. Gueye and P. Dayang "*Wireless Underground Sensor Networks Path Loss Model for Precision Agriculture (WUSN-PLM)*", IEEE Sensors Journal, vol. 20, no. 10, pp. 5298-5313, 2020.

Is this enough for agriculture application?



Experimental setup to collect data

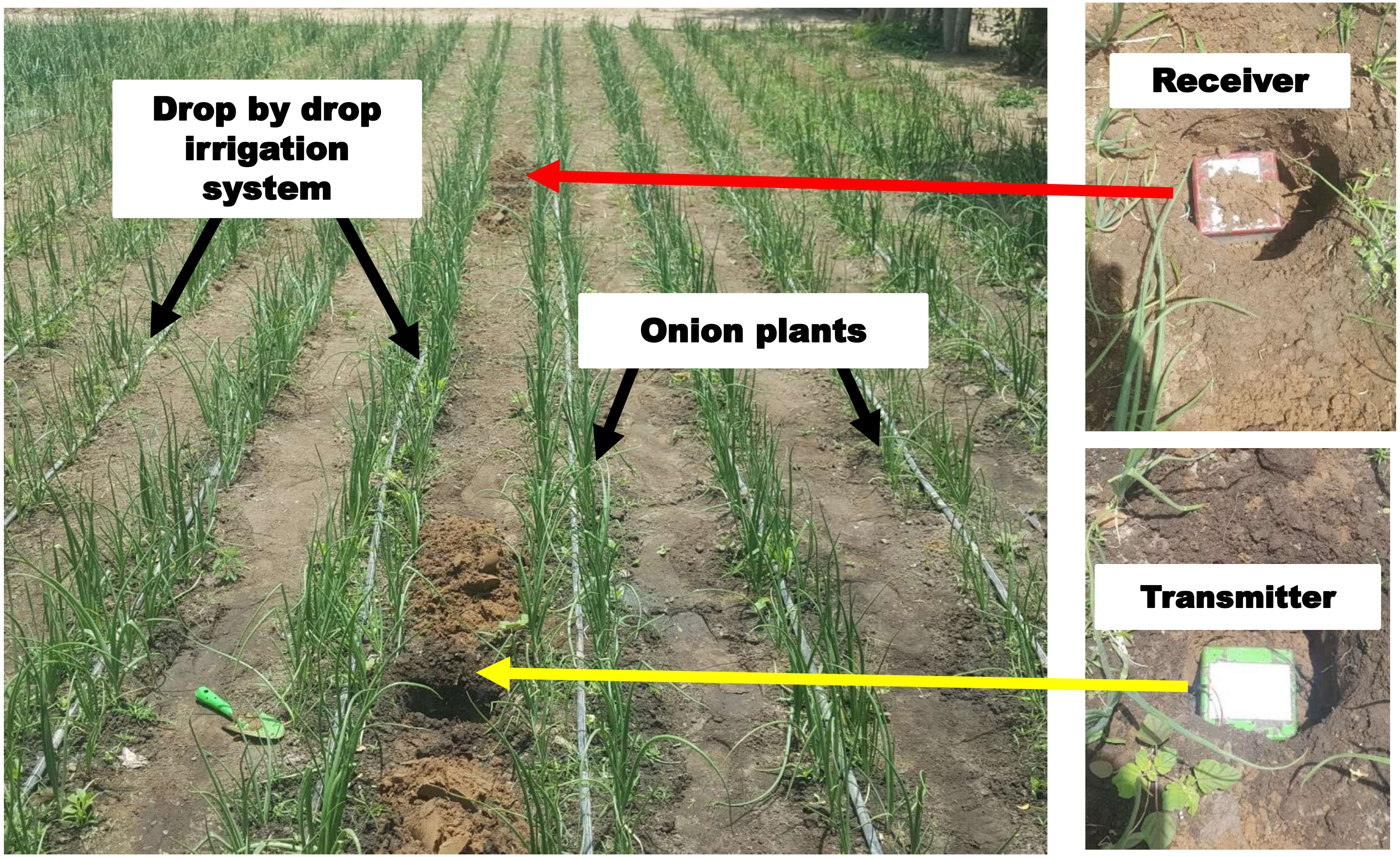


Fig. Experimental onion field for the collection of data at the botanical garden of the Cheikh Anta Diop University in Dakar

[DAB2020]. **D. Wohwe Sambo**, A. Förster, B. O. Yenke, I. Sarr, B. Gueye and P. Dayang "*Wireless Underground Sensor Networks Path Loss Model for Precision Agriculture (WUSN-PLM)*", IEEE Sensors Journal, vol. 20, no. 10, pp. 5298-5313, 2020.

Results and validation of WUSN-PLM

Table 1: Evaluation of performances

PRE	ACC	SEN	SEL	bACC	MCC	AUC
87,13 %	85 %	0.92	0.70	81.06 %	0.64	0.92

- Graphical metric: ROC Independent of PL_{max} ;
- Numerical evaluation AUC = 0.92

⇓

The proposed solution has a 92% chance of predicting the reception or the loss of a data

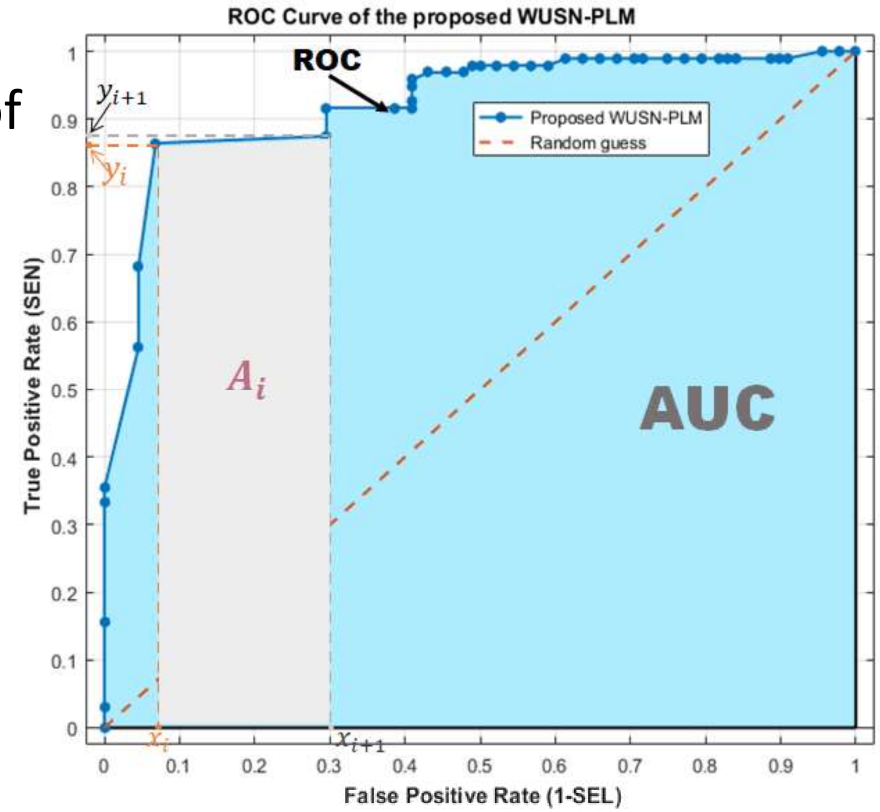


Fig. ROC curve and AUC

[DAB2020]. **D. Wohwe Sambo**, A. Förster, B. O. Yenke, I. Sarr, B. Gueye and P. Dayang "*Wireless Underground Sensor Networks Path Loss Model for Precision Agriculture (WUSN-PLM)*", IEEE Sensors Journal, vol. 20, no. 10, pp. 5298-5313, 2020.

Interesting but … !

03

Lightweight and portable model for transmission (FuzDeMa)

Q: Can I reach a recipient or not?

- Need of a decision-making tool:

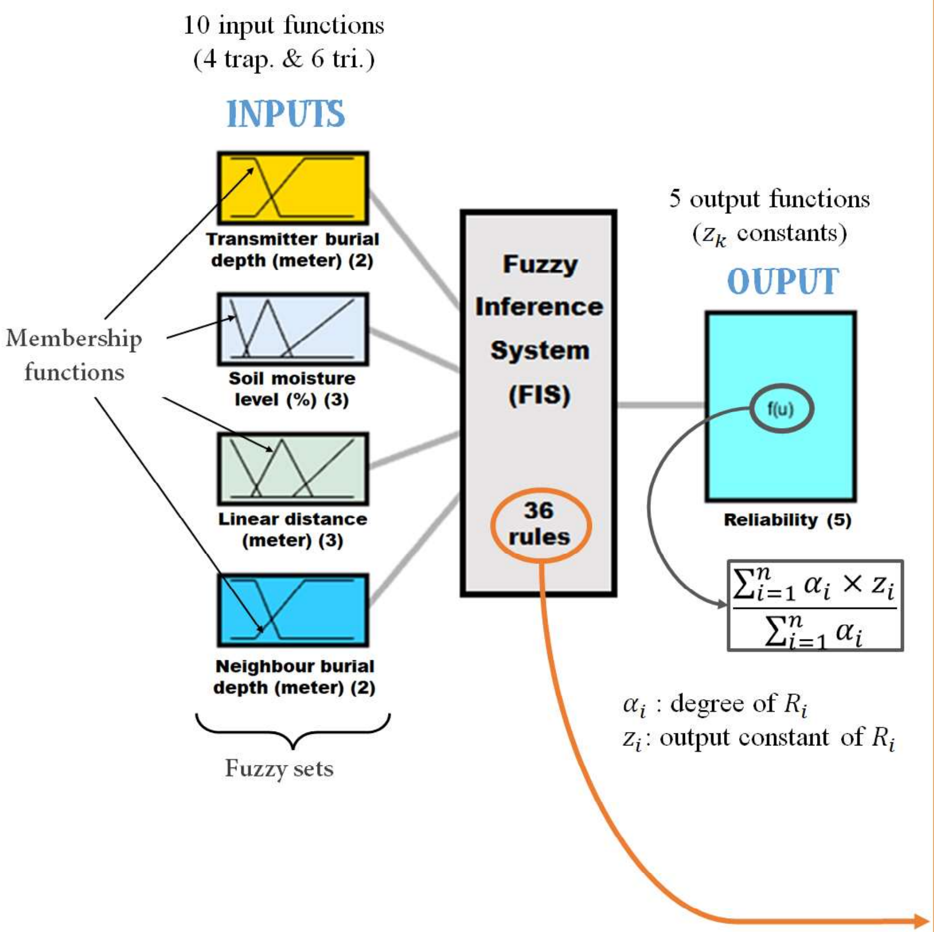
SEND or NOT ?

Need of a decision-making tool:

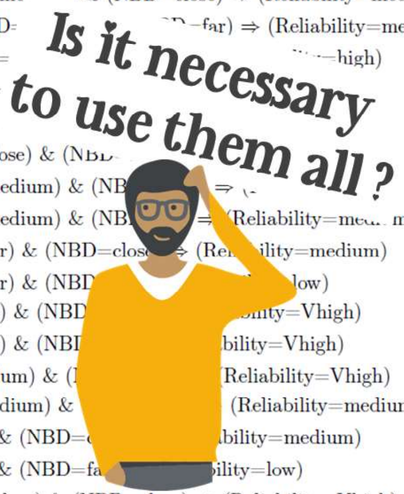
Based on **Sugeno** FIS**:**

- 4 inputs ;
- 36 rules ;
- 1 output (*probability of packet's reception*) ;

Quick overview of FuzDeMa



R1. (BD=close) & (MST=low) & (LD=close) & (NBD=close) ⇒ (Reliability=Vhigh)
R2. (BD=close) & (MST=low) & (LD=close) & (NBD=far) ⇒ (Reliability=Vhigh)
R3. (BD=close) & (MST==low) & (LD=medium) & (NBD=close) ⇒ (Reliability=Vhigh)
R4. (BD=close) & (MST=low) & (LD=medium) & (NBD=far) ⇒ (Reliability=high)
R5. (BD==close) & (MST=low) & (LD=far) & (NBD=close) ⇒ (Reliability=medium)
R6. (BD=close) & (MST=low) & (LD=far) & (NBD=far) ⇒ (Reliability=medium)
R7. (BD=close) & (MST=average) & (LD=close) & (NBD=close) ⇒ (Reliability=Vhigh)
R8. (BD=close) & (MST=average) & (LD=close) & (NBD=far) ⇒ (Reliability=high)
R9. (BD=close) & (MST=average) & (LD=me … & (NBD=close) ⇒ (Reliability=medium)
R10. (BD=close) & (MST==average) & (LD= … far) ⇒ (Reliability=medium)
R11. (BD=close) & (MST=average) & (LD= … high)
R12. (BD=close) & (MST=average) & (LD= …
R13. (BD==close) & (MST==high) & (LD … h)
R14. (BD=close) & (MST=high) & (LD=close) & (NBD …
R15. (BD=close) & (MST=high) & (LD=medium) & (NB …
R16. (BD=close) & (MST=high) & (LD=medium) & (NB … (Reliability=me… m)
R17. (BD=close) & (MST=high) & (LD=far) & (NBD=clos … (Re…ility=medium)
R18. (BD=close) & (MST=high) & (LD=far) & (NBD … low)
R19. (BD=far) & (MST=low) & (LD=close) & (NBD … ity=Vhigh)
R20. (BD=far) & (MST=low) & (LD=close) & (NBI … bility=Vhigh)
R21. (BD=far) & (MST=low) & (LD=medium) & (… Reliability=Vhigh)
R22. (BD=far) & (MST=low) & (LD==medium) & … (Reliability=medium)
R23. (BD=far) & (MST=low) & (LD=far) & (NBD= … bility=medium)
R24. (BD=far) & (MST=low) & (LD=far) & (NBD=fa … bility=low)
R25. (BD=far) & (MST=average) & (LD=close) & (NBD=close) ⇒ (Reliability=Vhigh)
R26. (BD=far) & (MST=average) & (LD=close) & (NBD=far) ⇒ (Reliability=medium)
R27. (BD=far) & (MST=average) & (LD=medium) & (NBD=close) ⇒ (Reliability=high)
R28. (BD=far) & (MST=average) & (LD=medium) & (NBD=far) ⇒ (Reliability=low)
R29. (BD=far) & (MST=average) & (LD=far) & (NBD=close) ⇒ (Reliability=medium)
R30. (BD=far) & (MST=average) & (LD=far) & (NBD=far) ⇒ (Reliability=low)
R31. (BD=far) & (MST=high) & (LD=close) & (NBD=close) ⇒ (Reliability=high)
R32. (BD=far) & (MST=high) & (LD=close) & (NBD=far) ⇒ (Reliability=medium)
R33. (BD==far) & (MST=high) & (LD=medium) & (NBD=close) ⇒ (Reliability=medium)
R34. (BD=far) & (MST=high) & (LD=medium) & (NBD=far) ⇒ (Reliability=low)
R35. (BD=far) & (MST=high) & (LD=far) & (NBD=close) ⇒ (Reliability=medium)
R36. (BD=far) & (MST=high) & (LD=far) & (NBD=far) ⇒ (Reliability=Vlow)

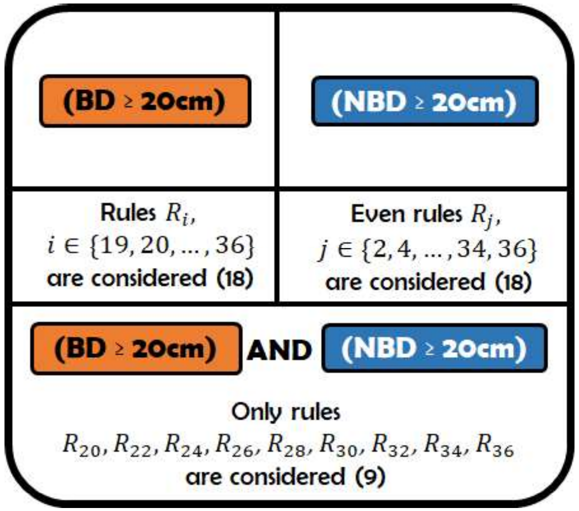


We need to reduce the energy consumption !

[DBA2022]. **D. Wohwe Sambo**, B. O. Yenke, A. Förster, I. Ndong, P. Dayang and I. Sarr, “*A New Fuzzy Logic Approach for Reliable Communications in Wireless Underground Sensor Networks*", Springer Nature – Wireless Networks, vol. 28, no. 7, pp. 3275-3292, 2022.

Reduction of rules before calculation!

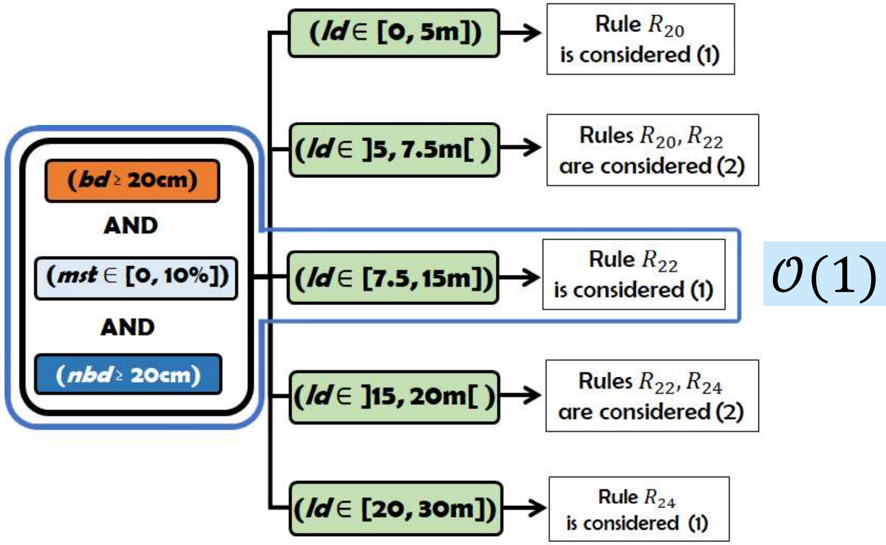
- **If buried transmitter :**
  - 18 rules needed;
- **For les comm. UG2UG:**
  - 9 rules needed;



- **Low humidity + comm. UG2UG + distance = 10m : 1 rule (R22)**

R22: (BD=far) & (MST=average) & (LD=medium) & (NBD=far))=>(Reliab=medium)

- ***Reliab(medium) = 0.5*** ⇔ ½ chance to receive a packet



Evaluation et validation

- Evaluation of the performances : **SEN, bACC, MCC & AUC**;

Table 2: Performance evaluation

	Sensibility (SEN)	**Balanced accuracy (bACC)**	**Phi coefficient (MCC)**	**Area Under the ROC Curve (AUC)**
Modified Friis	0.9	75.77%	0.52	0.83
NC Modified Friis	0.9	72.03%	0.35	0.87
WUSN-PLM	0.917	81.061 %	0.643	0.92
FuzDeMa	**0.969**	**88.21**	**0.798**	**0.92**

- MCC = 0.798 ➔ strong correlation between the obervation and the prediction;

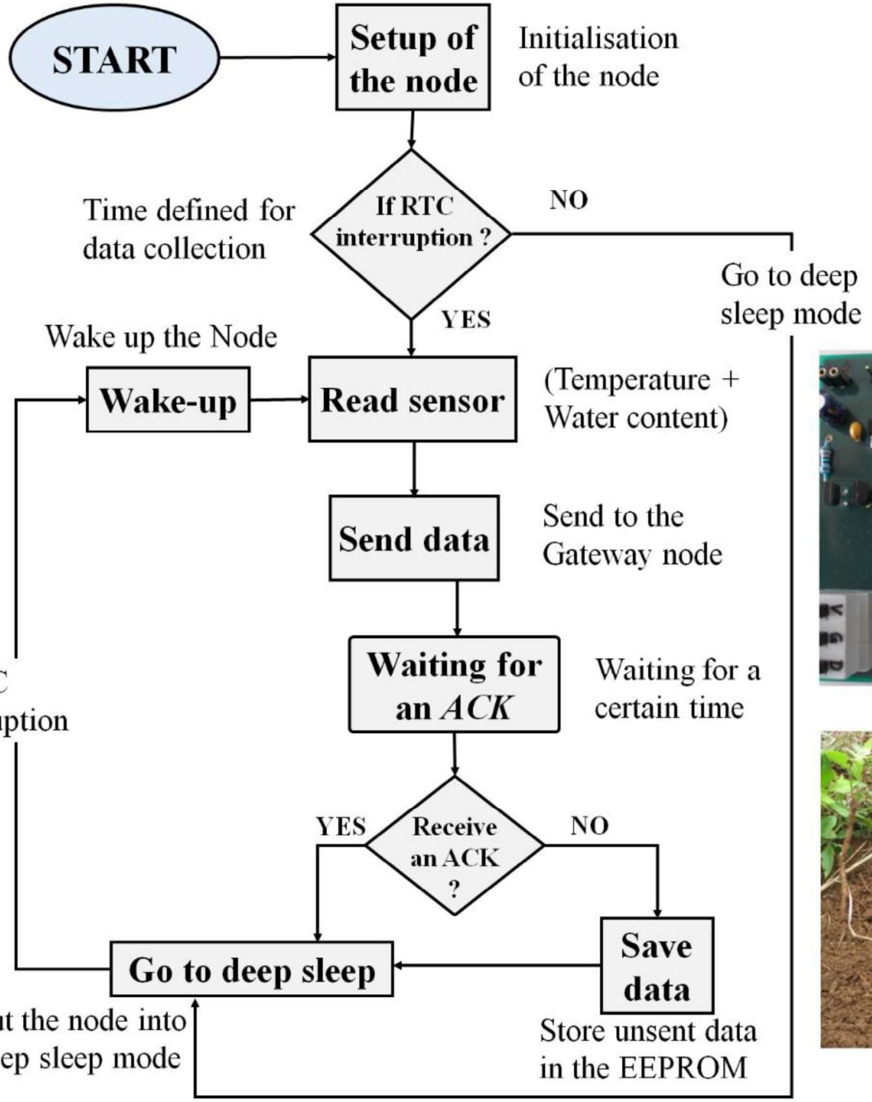
- AUC = 0.92 ⬄ 92% chance to do the difference between the reception and not reception of a data.

[DBA2022]. **D. Wohwe Sambo**, B. O. Yenke, A. Förster, I. Ndong, P. Dayang and I. Sarr, "*A New Fuzzy Logic Approach for Reliable Communications in Wireless Underground Sensor Networks*", Springer Nature – Wireless Networks, vol. 28, no. 7, pp. 3275-3292, 2022.

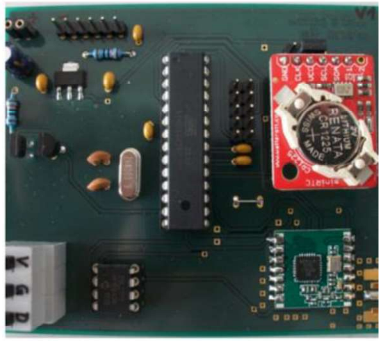
What's next ?

Good ...
Is it really possible to implement ?

We need a real dedicated node!



- What is **MoleNet**[1]?

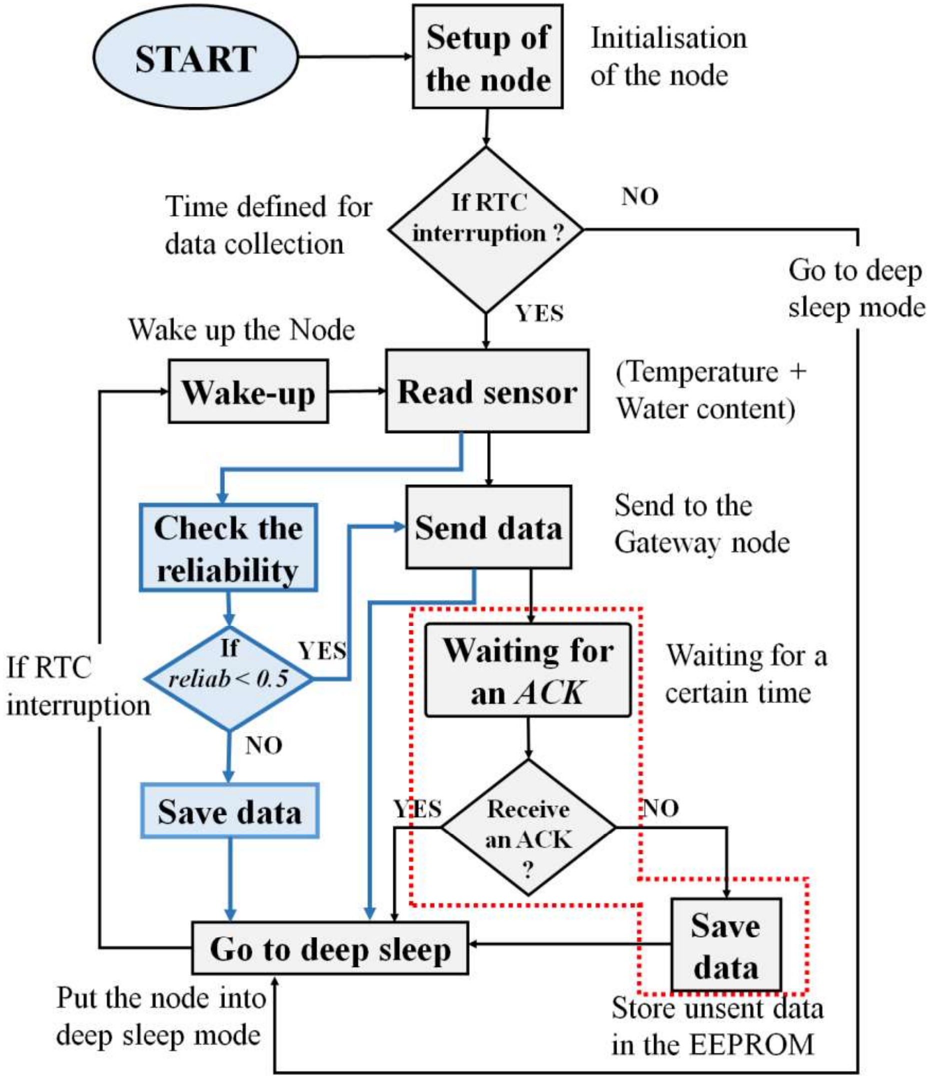


- Underground sensor node;
- From *ComNets* (Univ-Bremen)
- One-hop communication
  (node ➔ gateway)

[1] molenet.org

Integration of FuzDeMa within MoleNet

- Control before any transmission;
- According to the computed reliability:
  - ***Transmit*** *($reliab \geq 0.5$)*
  - ***No transmit*** *($reliab < 0.5$)*

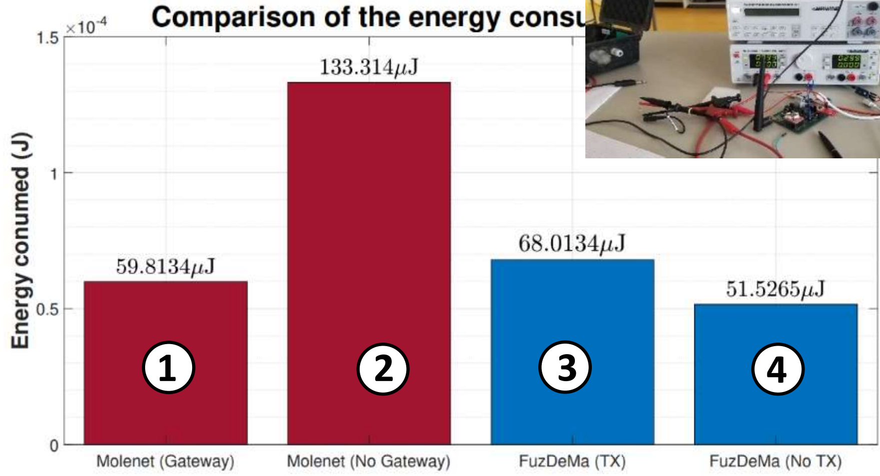


simple but effective!

Evaluation of the energy consumption

- 2 possibilities:
  - The gateway is reachable; ①
  - The gateway is not reachable; ②

- FuzDeMa:
  - With TX; ③
  - No TX; ④



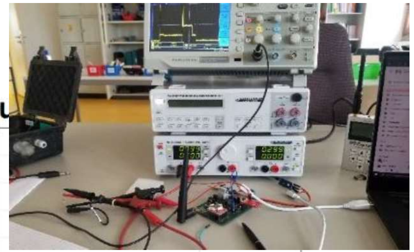
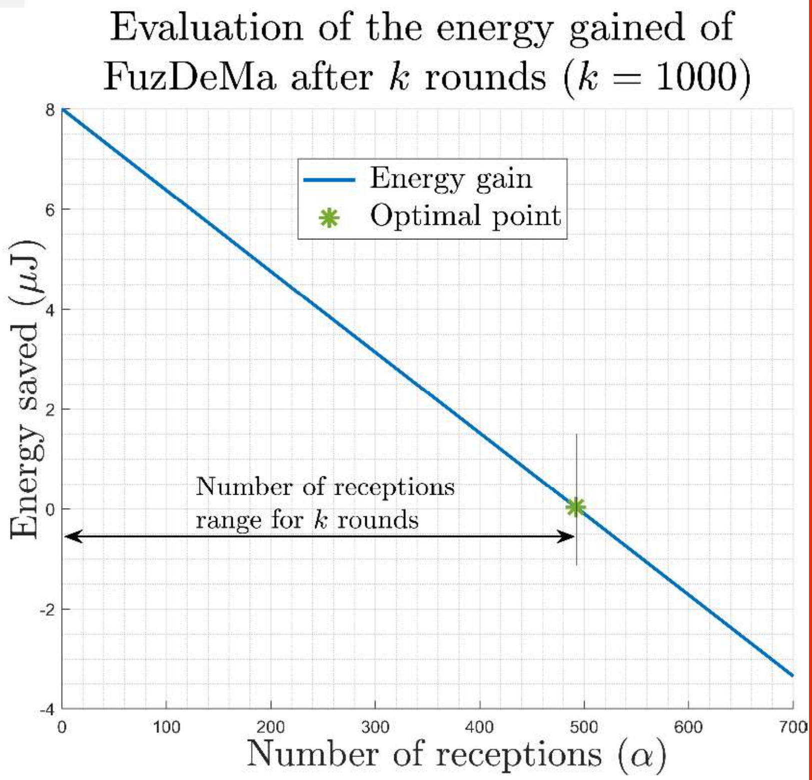


Table 3 : Evaluation of the energy saved by FuzDeMa according to the data statement

	Energy saved	Data	Observations
True Negative (TN)	$81.7876\ \mu J$	*Not send & not received*	No reception
False Negative (FN)	$8.287\ \mu J$	*Not send & not received*	Reception
False Positve (FP)	$65.3007\ \mu J$	*Send & not received*	No reception
True Positive (TP)	$-8.2\ \mu J$	*Send & received*	Reception

Generalization of FuzDeMa and validation

Parameters	Definitions
N	Number of nodes
E_i	Energy consumed/round of node i (without FuzDzMa)
E'_i	Energy consumed/round of node i with FuzDeMa
P_{comp}	Energy consumed/round due to MC computation
tx_{cost}	Energy consumed/round during transmission
fuz_{cost}	Addition energy cost/round of FuzDeMa
k	Random number of rounds
α	Number of reception
G_i	Energy saved by node i (FuzDeMa) after k random rounds



$$E_i = P_{comp} + tx_{cost}$$

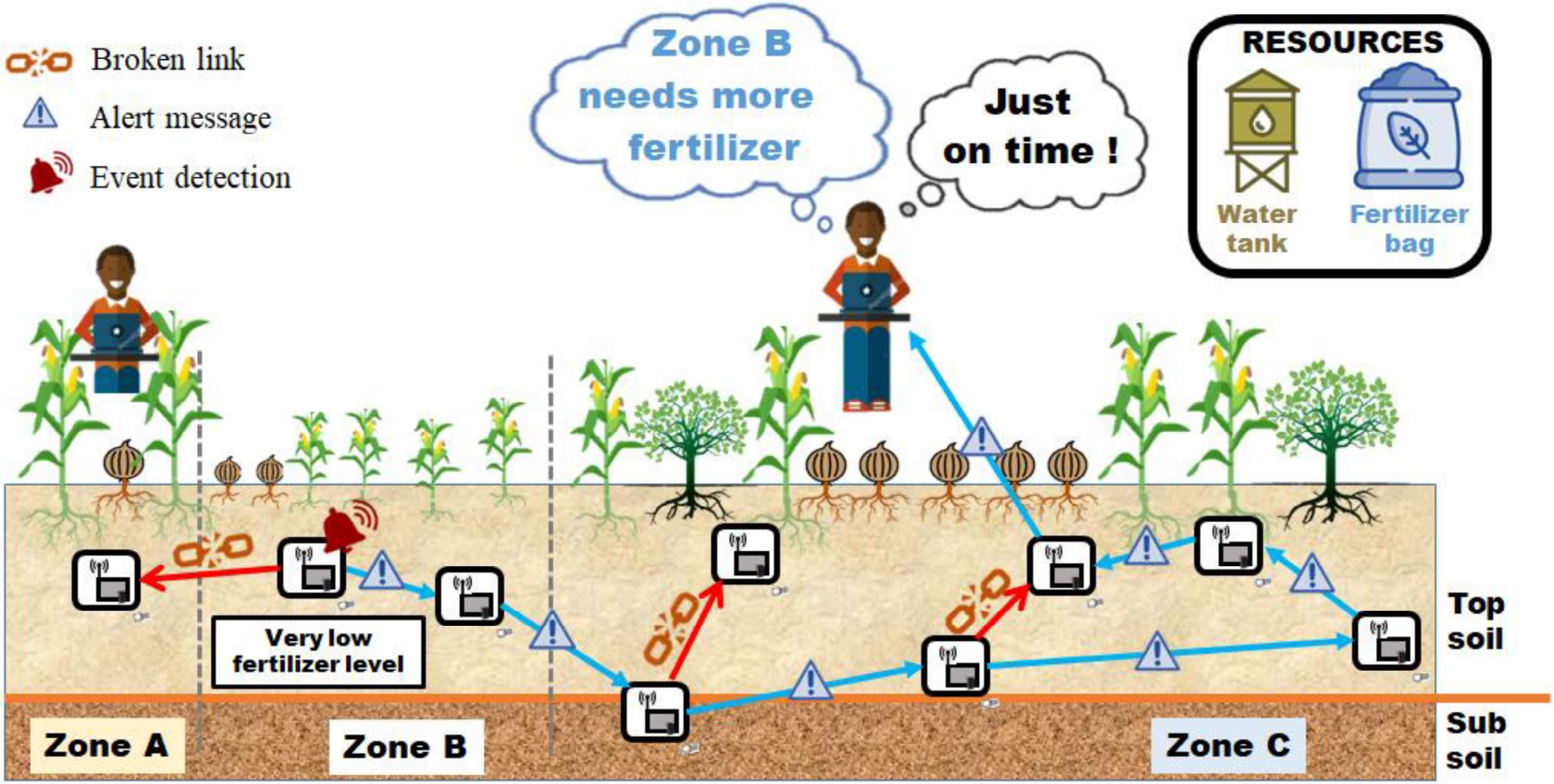
$$E'_i = \begin{cases} E_i + fuz_{cost} & \text{If transmission (TX)} \\ E_i + fuz_{cost} - tx_{cost} & \text{else} \end{cases} \Rightarrow$$

Since $tx_{cost} > fuz_{cost}$ **When** $\alpha \leq \left\lfloor \frac{k(tx_{cost} - fuz_{cost})}{tx_{cost}} \right\rfloor \Rightarrow \boxed{G_i = tx_{cost}(k - \alpha) - k fuz_{cost}}$

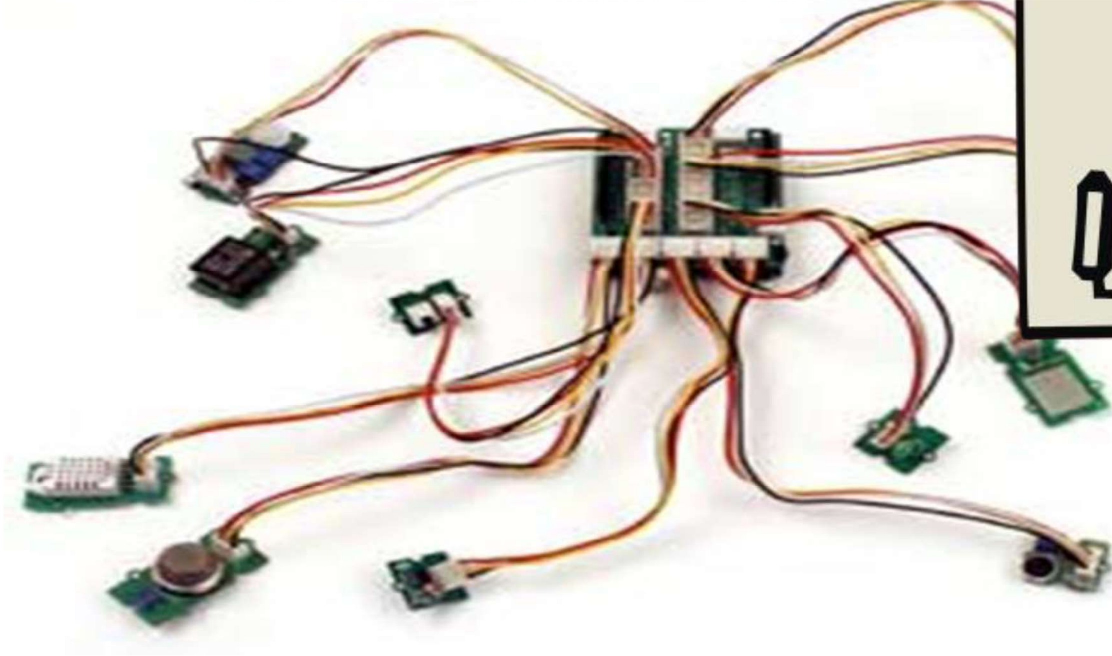
04

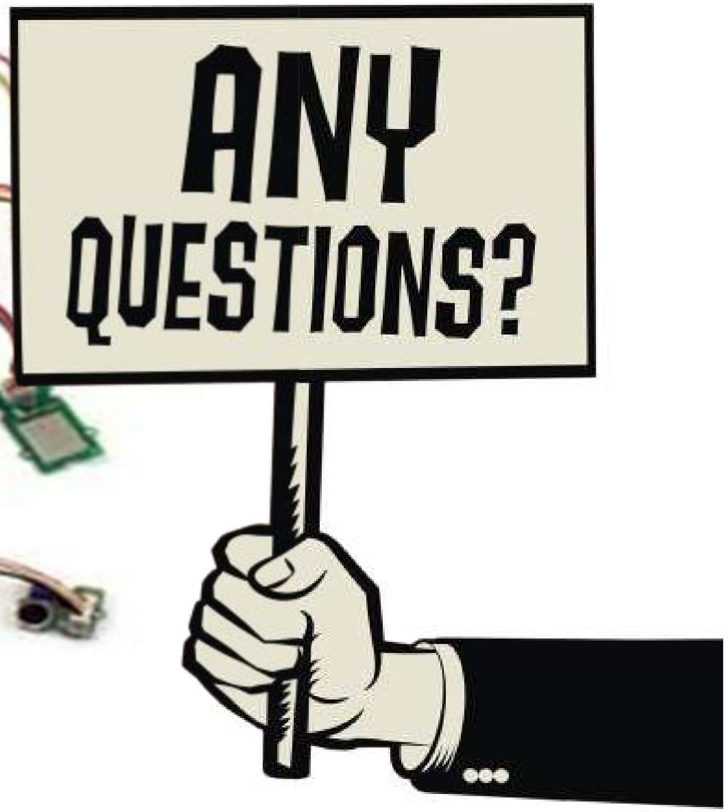
Conclusion

In Short!


Broken link
Alert message
Event detection
Zone B
needs more
fertilizer
Just
on time !
RESOURCES
Water
tank
Fertilizer
bag
Very low
fertilizer level
Zone A
Zone B
Zone C
Top
soil
Sub
soil

THANK YOU FOR YOUR ATTENTION





Thank you !

Get in touch with me

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