CONNECTED OBJECTS FOR A GREEN WORLD ?

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IIoT Department, fortiss , 1st August (Münich, Germany)

Before we start, one word on my team

Future ubiquitous networks fun

Research interests:

- Internet of Things
- Wireless sensor networks, RFID, wireless robots networks
- Communications (MAC layer, routing, etc), Network security

7-9 PhD students, 3 Post-Doc, 2 Engineers, 1-2 VisitingPhD

https://team.inria.fr/fun/

Inria

Content

01. Context

02. IoT paths to a greener world
- *Application 1*
- *Application 2*

03. Proposed directions

01

Context

World orientation must change!

- Climate changes: All the fields and domains are concerned

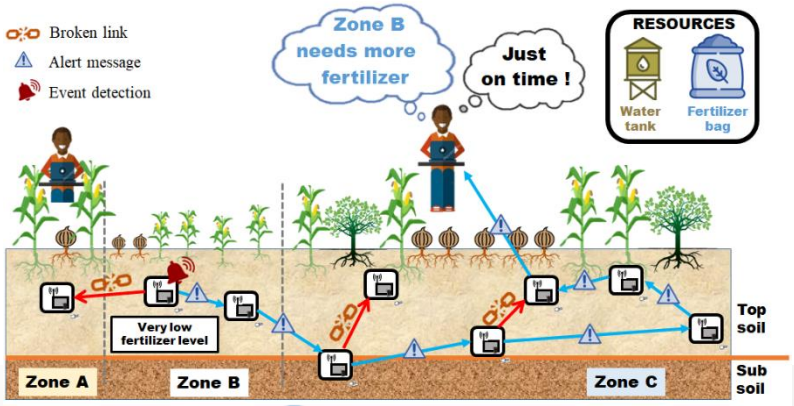
⇒ **Even for the young IoT**

02

IoT paths to a greener world

Connected objects for a green world !

Connected objects for a green world !



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What about the Agriculture ?

Agriculture ⇔ source of livelihood

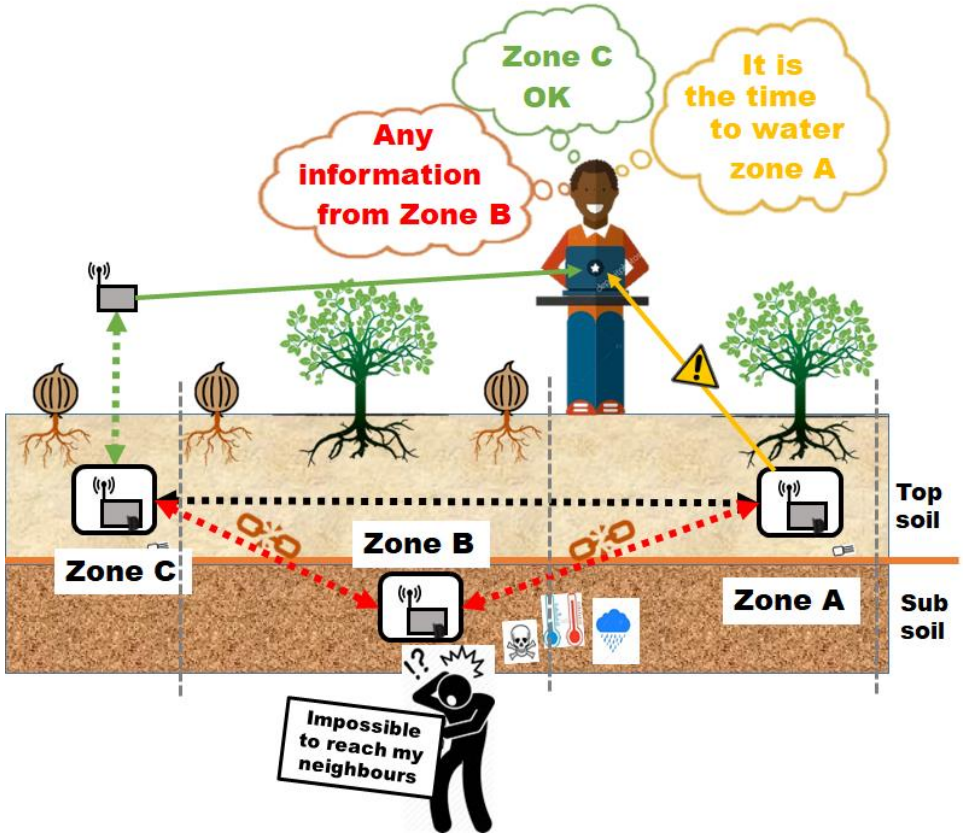
- Agriculture as
  - Source of food supply;
  - Country development index;
- Lack of production ⇒ local food shortages;
- Africa spent $64.5 Billions on importing foods (AfDB, 2017);
- Food import will increase to over $110 Billions by 2025;

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

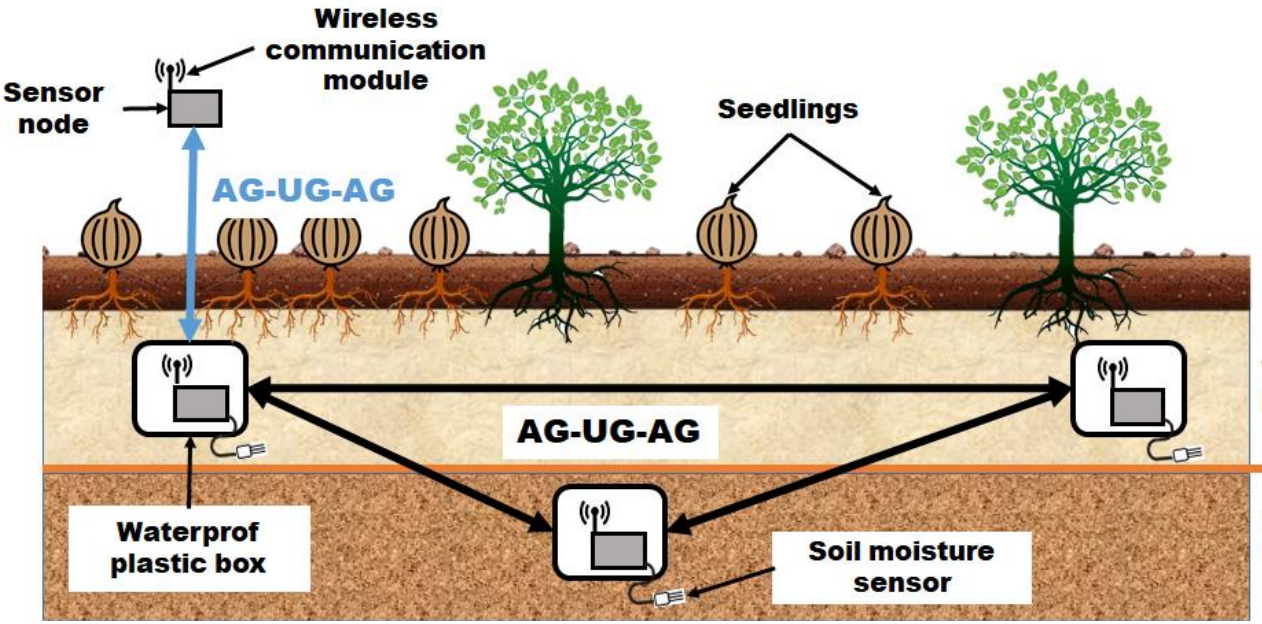
Challenges of WUSNs in agriculture

- 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**

A model adapted to agriculture in Africa!



- UG2UG, UG2AG et AG2UG AG2UG2AG;

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

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

[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.

Experimental setup to collect data

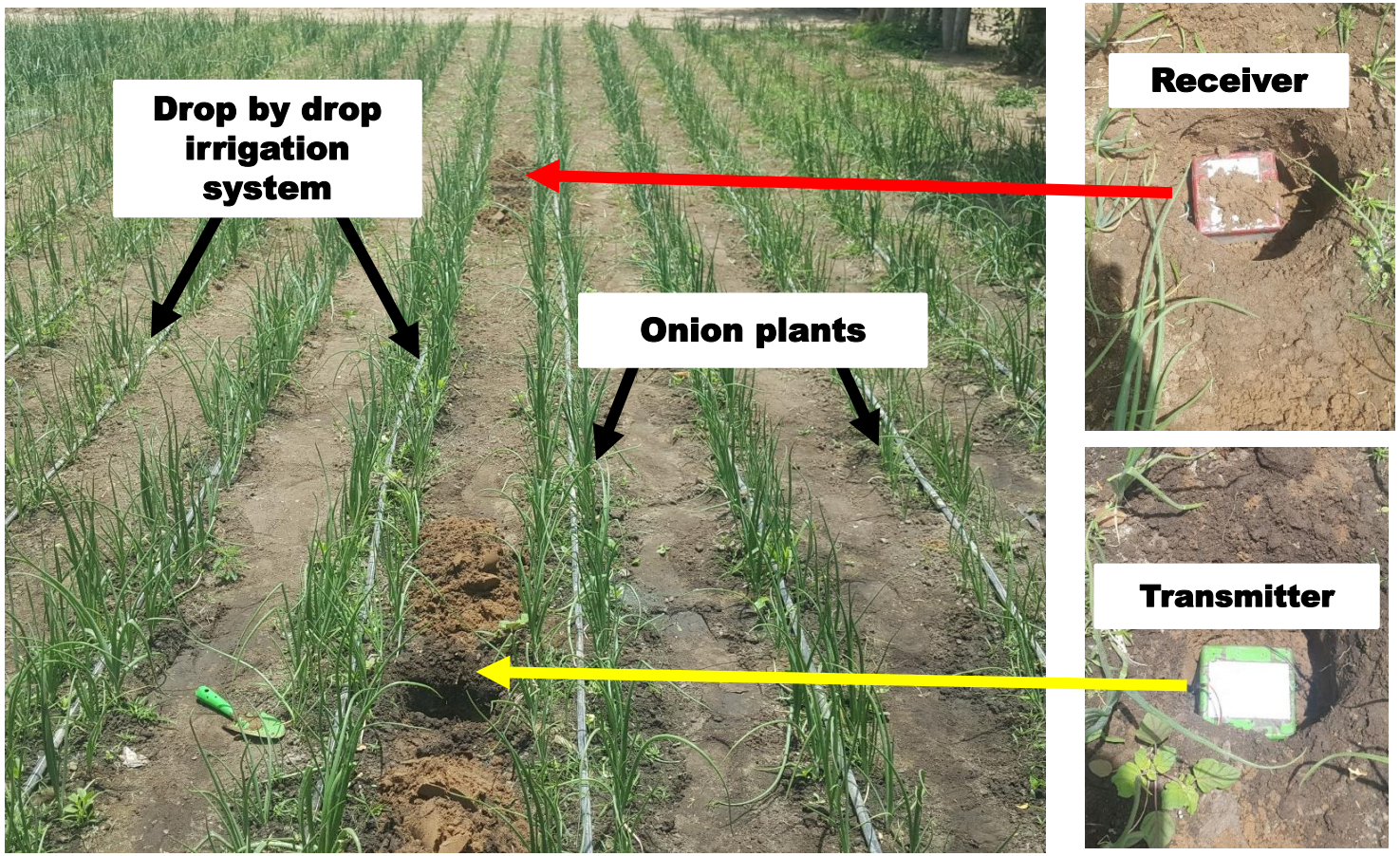


Fig. Experimental onion field for the collection of data at the botanical garden of the Cheikh Anta Diop University in Dakar

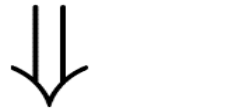
[DAB2020]. **D. Wohwe Sambo**, A. Förster, B. O. Yenke, I. Sarr, B. Gueye and P. Dayang "*Wireless Underground Sensor Networks Path Loss Model for Precision Agriculture (WUSN-PLM)*", IEEE Sensors Journal, vol. 20, no. 10, pp. 5298-5313, 2020.

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

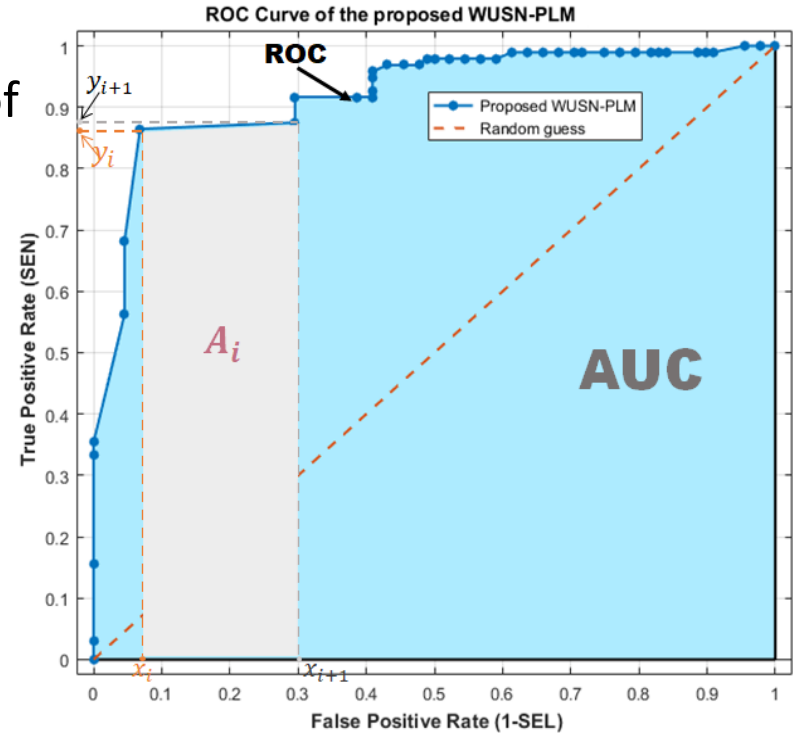


Fig. ROC curve and AUC

[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 … !

Q: Can I reach a recipient or not?

- Need of a decision-making tool:

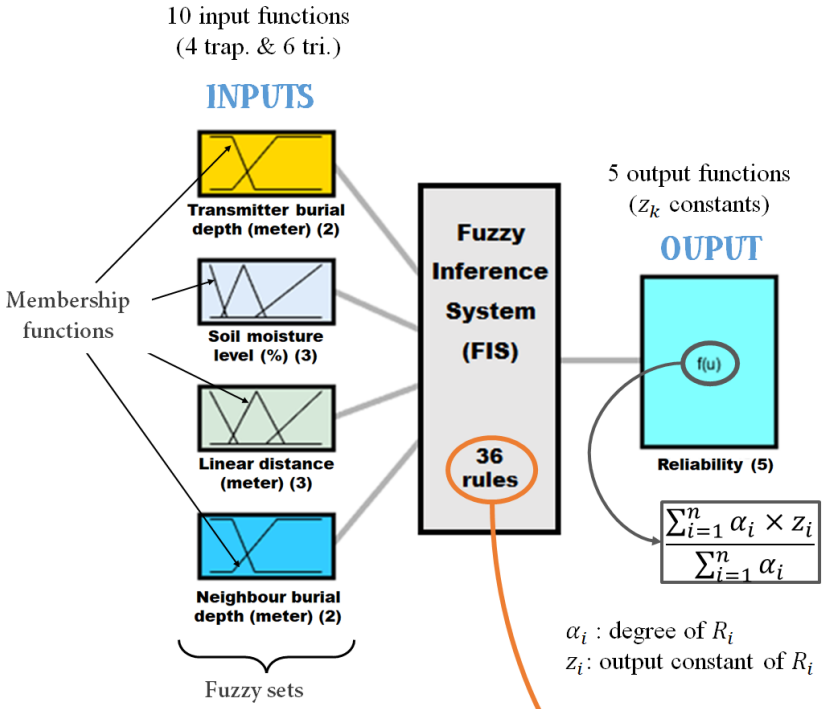
SEND or NOT ?

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) & (LL h)
$R14$. (BD=close) & (MST=high) & (LD=close) & (NB
$R15$. (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 ility=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.

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**

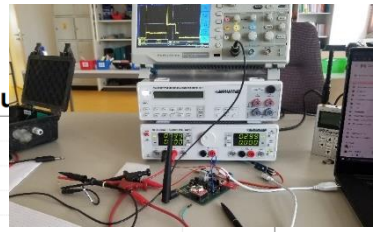
- MCC = 0.798 ➔ strong correlation between the obervation and the prediction;
- AUC = 0.92 ⇔ 92% chance to do the difference between the reception and not reception of a data.

[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.

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



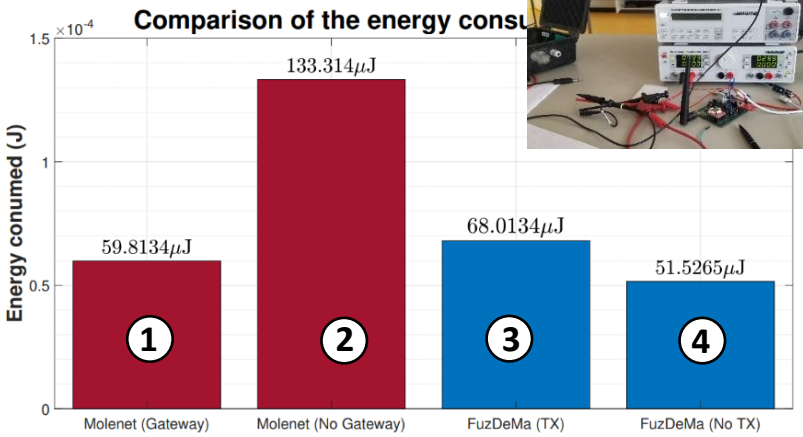


Table 3 : Evaluation of the energy saved by FuzDeMa according to the data statement

	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

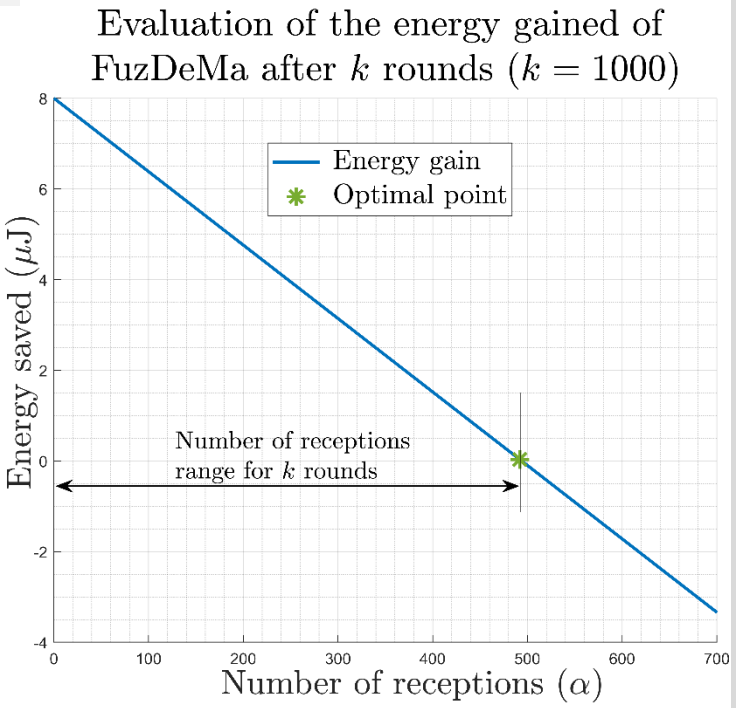
[DJN2023]. **D. Wohwe Sambo**, J. Dede, N. Mitton and A. Förster, "*FuzDeMa: A portable Fuzzy based Decision-Making tool for reliable communication in Wireless Underground Sensor Networks*", ITU Jounal – Future and evolving technologies, *in press,* 2023.

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

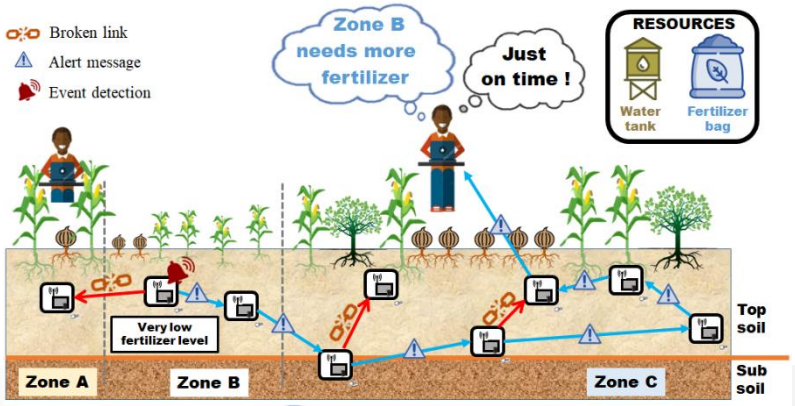
$$E_i = P_{comp} + tx_{cost}$$

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



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

Connected objects for a green world !



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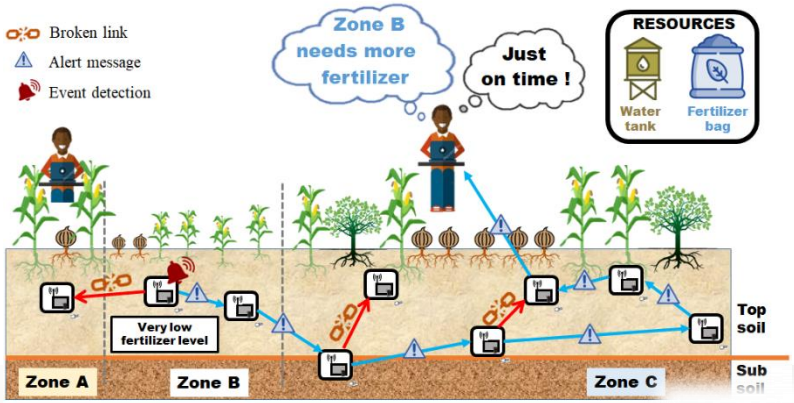
A wireless underground sensor network for agriculture

Connected objects for a green world !



1 **A wireless underground sensor network for agriculture**

2 **The industry could be more interesting!**

Today's supply chain

- Take - Make - Waste ;
- **50%** of waste is packaging

Reusable packaging

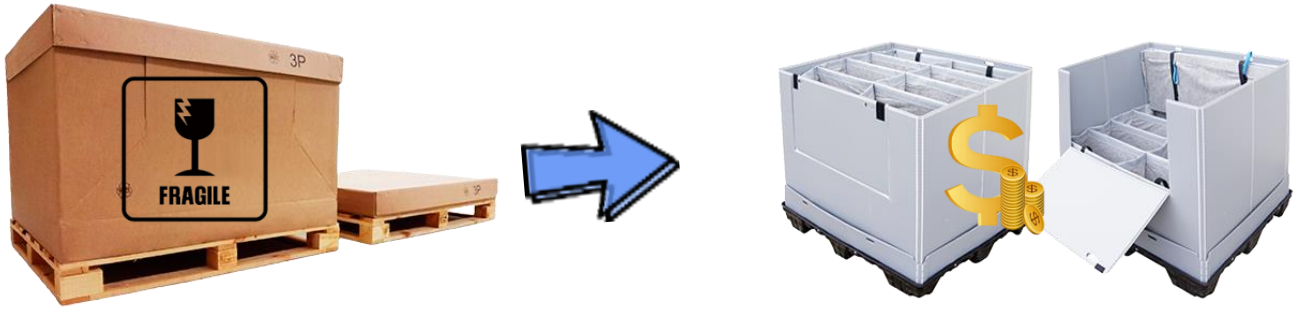
Reduction of wastes

Productivity

Profitability

Reusable packaging challenges

E.g. RENAULT AIRBUS



- Difficulty in managing the conditions of reusable packaging;

Who was the responsible ?

Who will pay ?

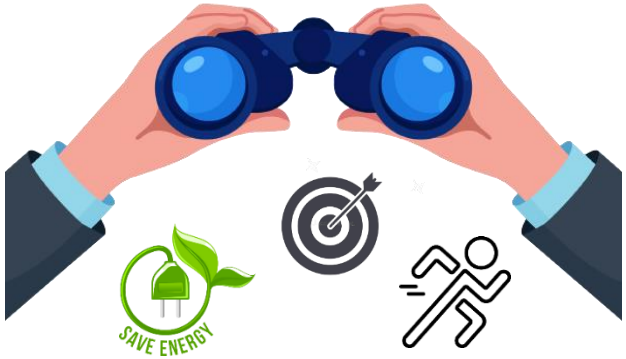
Can you confirm that ?

When ? ….

- Issues in assigning responsibility;

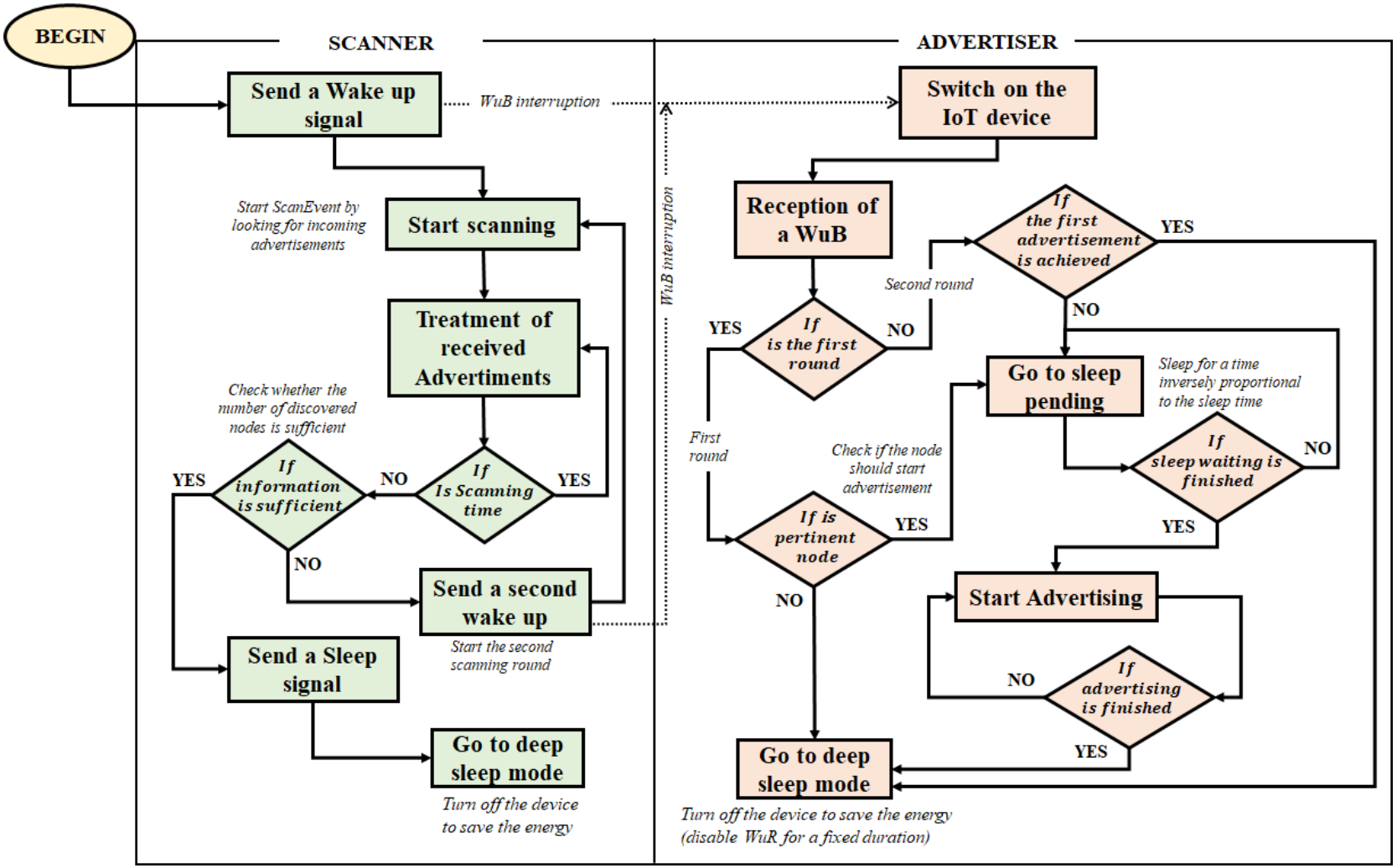
Responsability assignation through NDP

- NDP : Neighbour Discovery Process
- Assigning responsibility for a reusable package using its neighborhood;
- Embedded devices are multi-wireless communication technologies;
- Synchronisation of communication: ***Listening when others are speaking***;
- IoT must stay alive longer than a reusable packing (7 years);

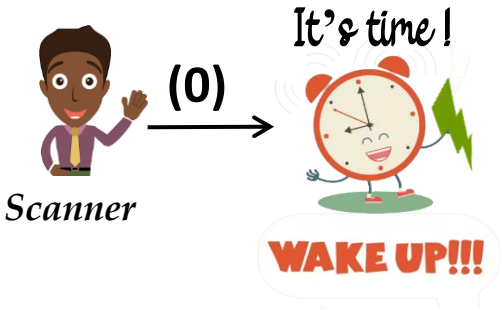


- Find out as quickly as possible which nodes are most relevant;
- **WuR** for synchro. , **BLE** for the NDP and **LoRa** to send.

2 rounds NDP

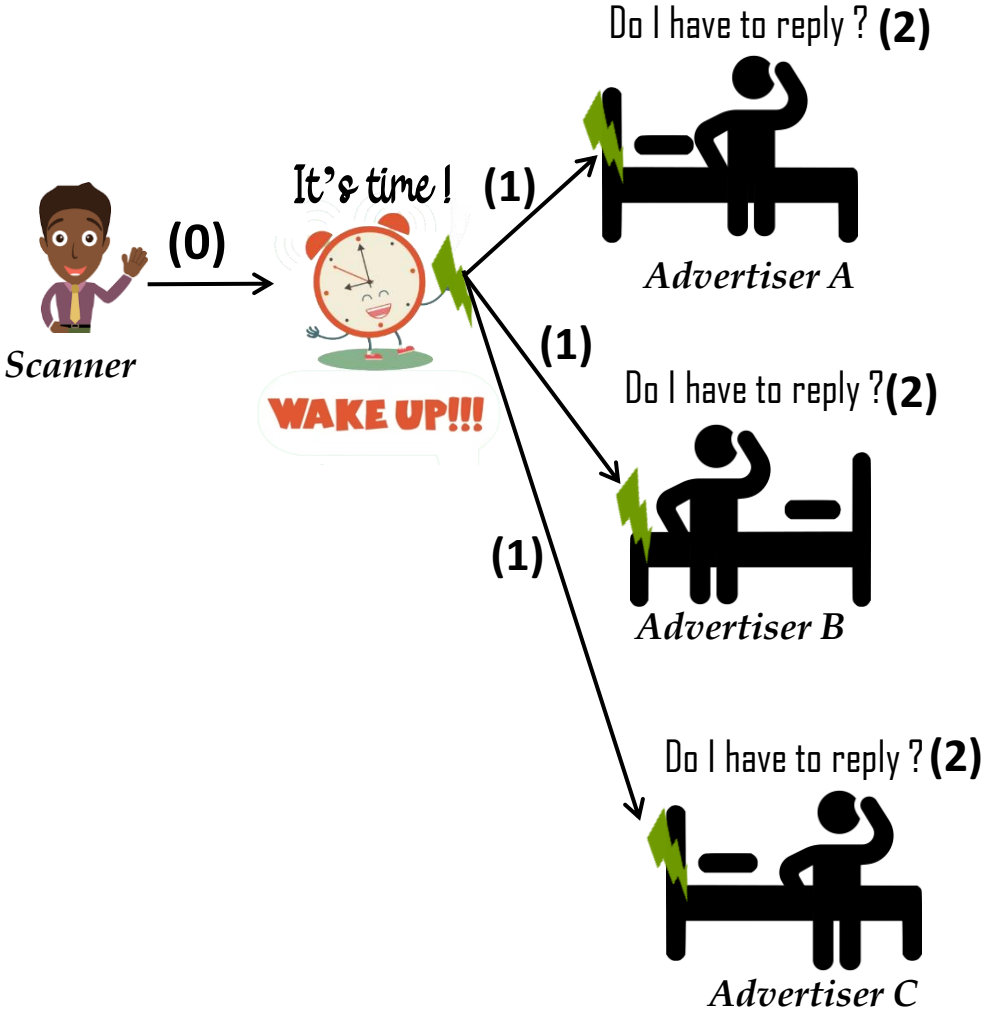

BEGIN
SCANNER
ADVERTISER
Send a Wake up signal
WuB interruption
Switch on the IoT device
Start ScanEvent by looking for incoming advertisements
Start scanning
Reception of a WuB
If the first advertisement is achieved
YES
NO
Second round
Treatment of received Advertiments
If is the first round
YES
NO
Go to sleep pending
Sleep for a time inversely proportional to the sleep time
Check whether the number of discovered nodes is sufficient
If information is sufficient
YES
NO
If Is Scanning time
YES
First round
Check if the node should start advertisement
If sleep waiting is finished
NO
YES
If is pertinent node
YES
NO
Start Advertising
Send a second wake up
Start the second scanning round
If advertising is finished
NO
YES
Send a Sleep signal
Go to deep sleep mode
Turn off the device to save the energy
Go to deep sleep mode
Turn off the device to save the energy (disable WuR for a fixed duration)
WuB interruption

Proposed discovery process – 1st round



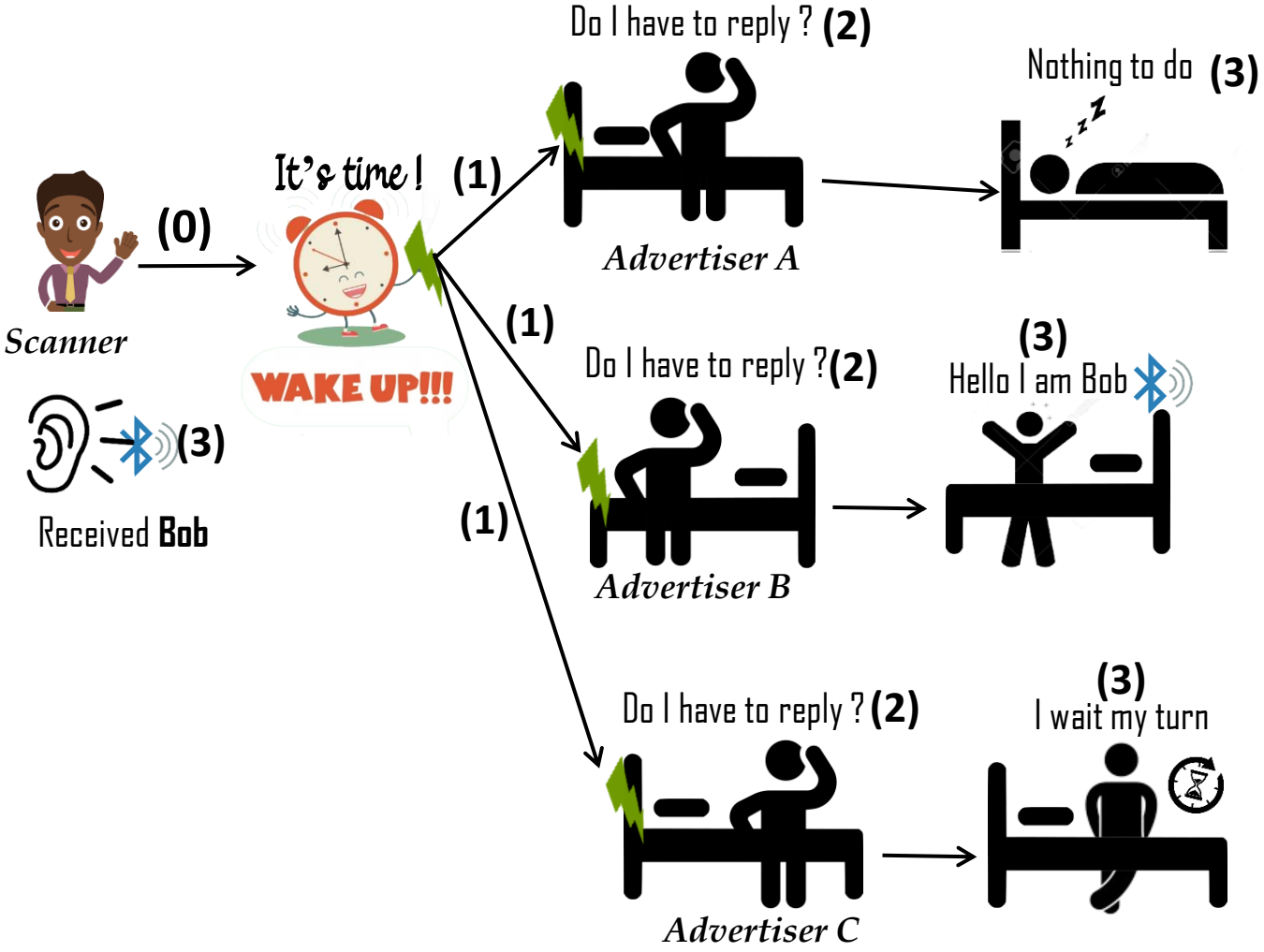
Scanner: A node that needs to discover its neighborhoods and start the neighbor discovery process

Proposed discovery process – 1st round

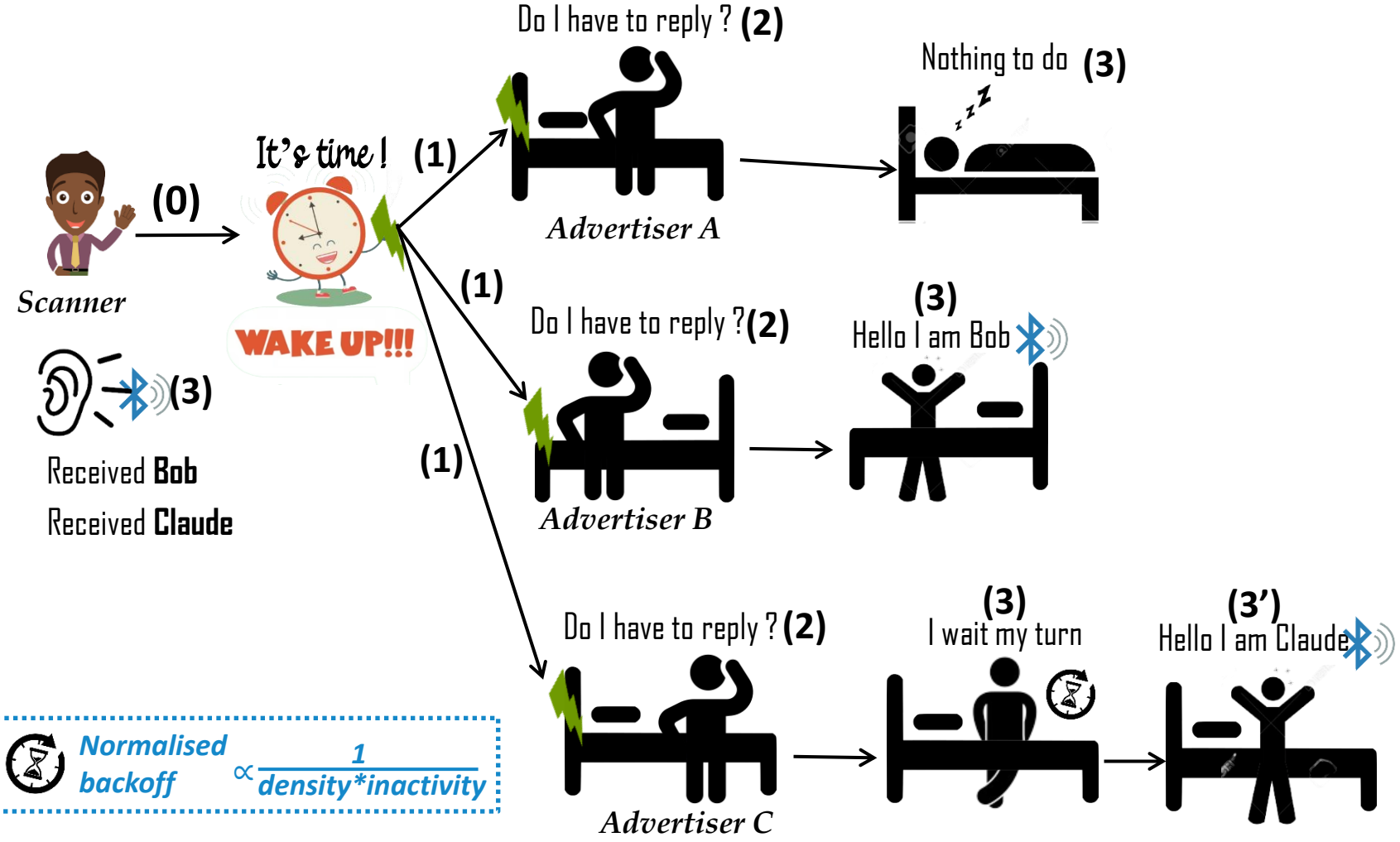


Advertiser: A node that replies to a neighbor discovery request

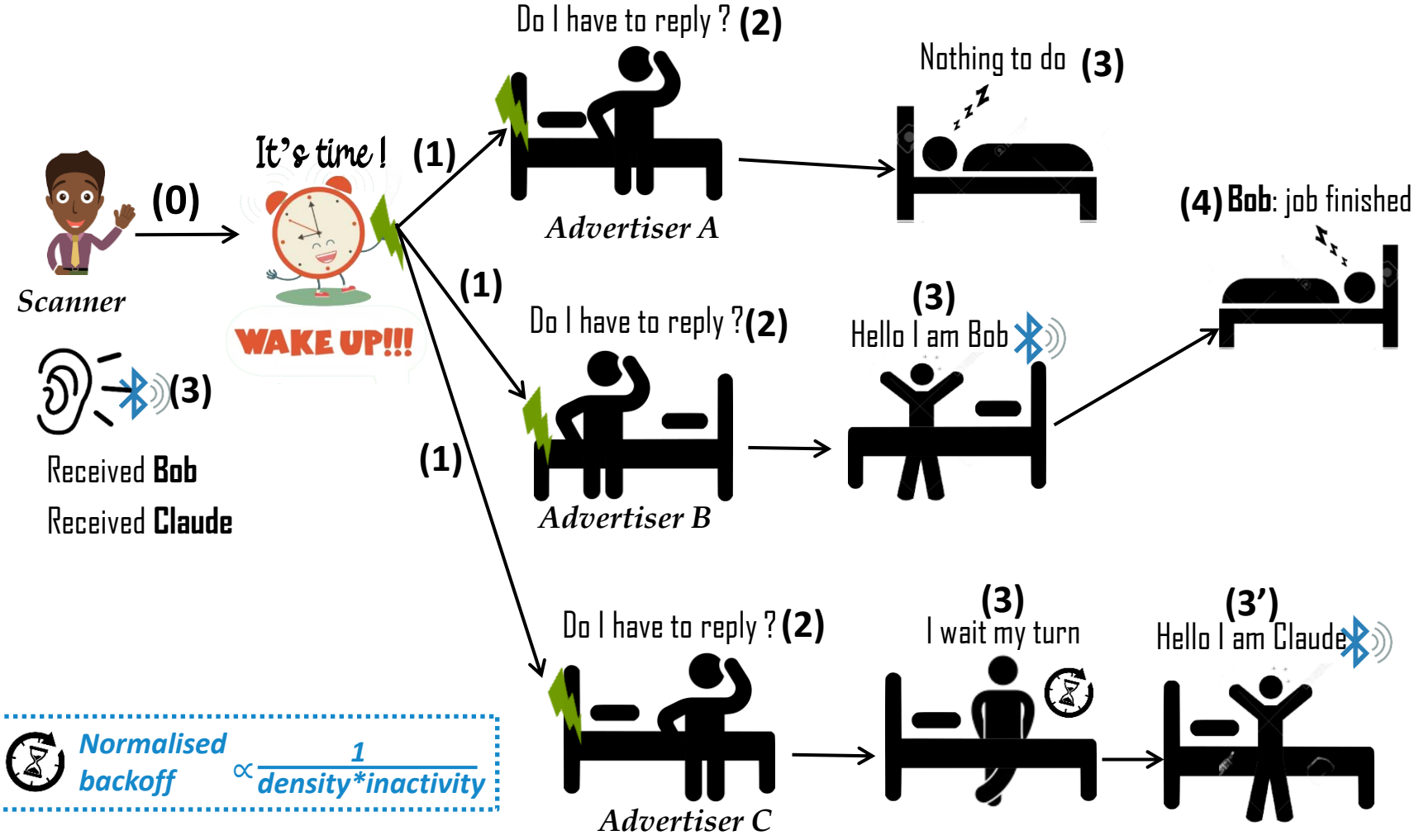
Proposed discovery process – 1st round



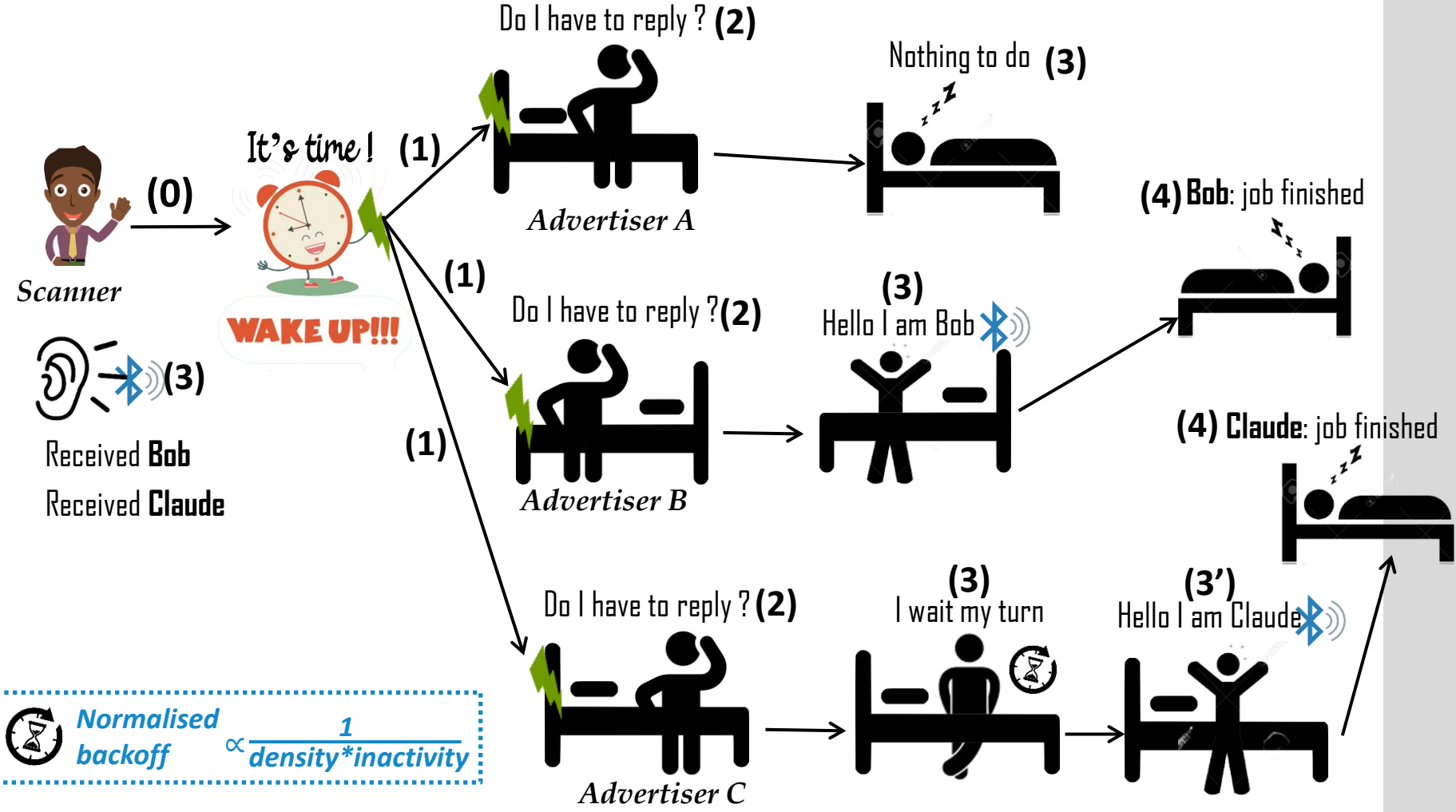
Proposed discovery process – 1st round



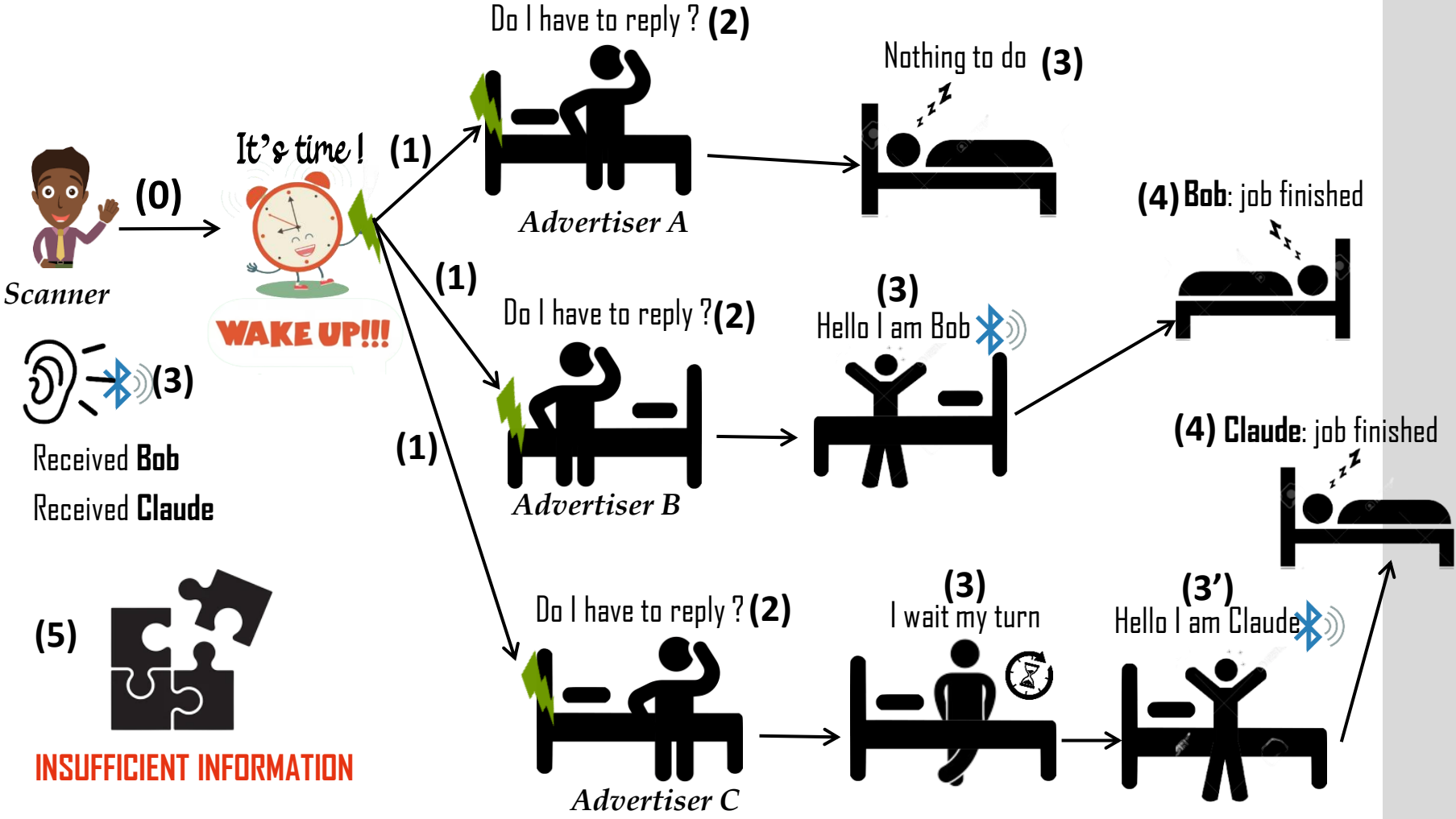
Proposed discovery process – 1st round



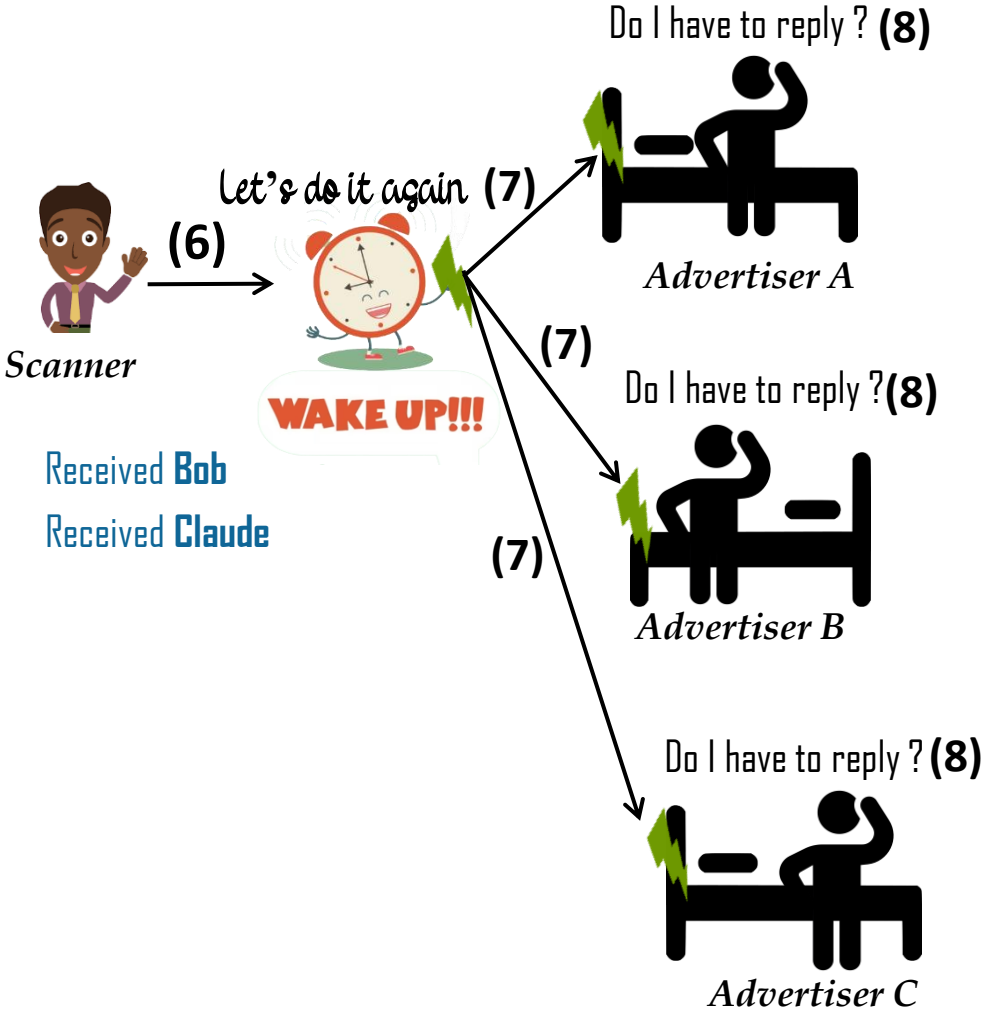
Proposed discovery process – 1st round



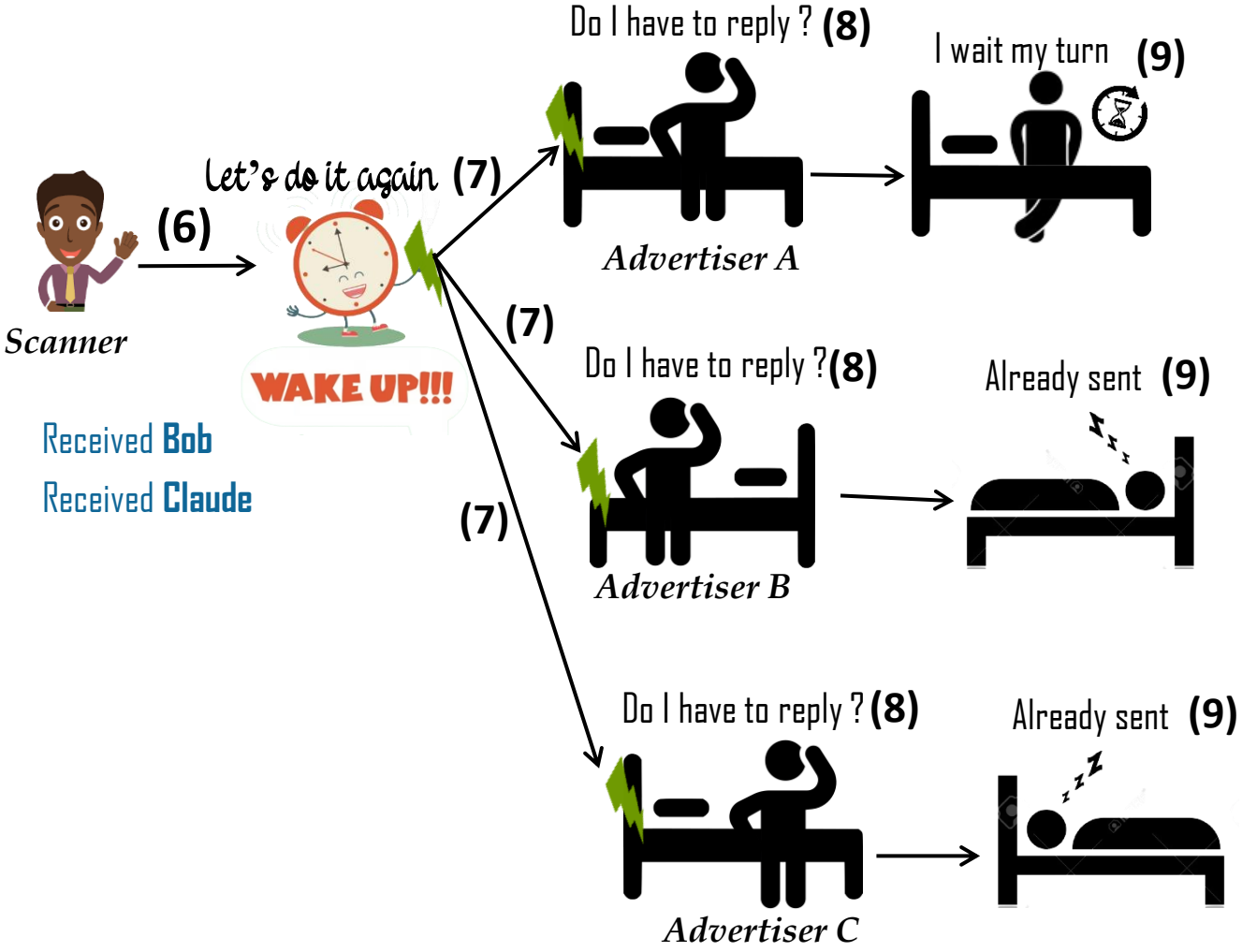
Proposed discovery process – 1st round



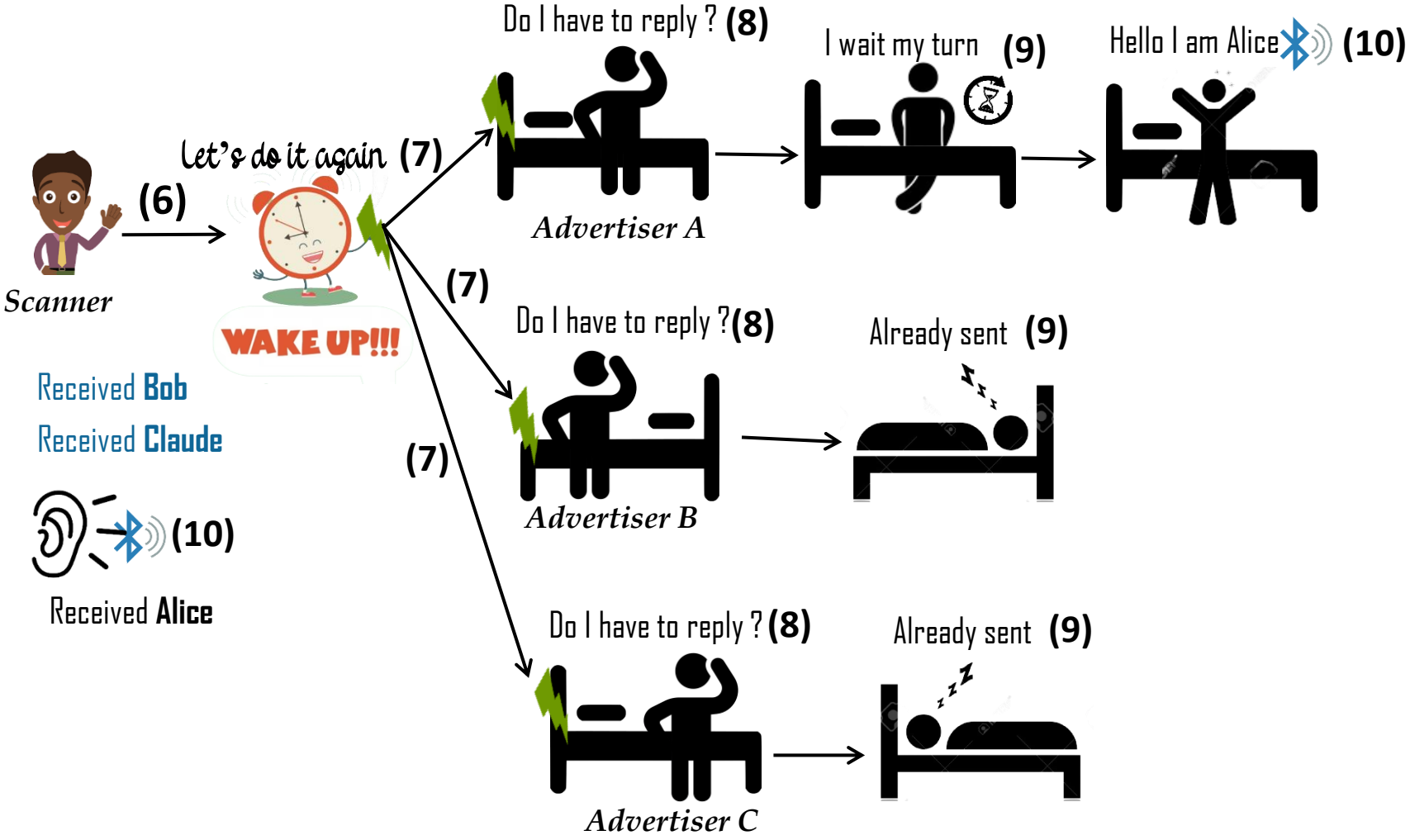
Proposed discovery process – 2nd round



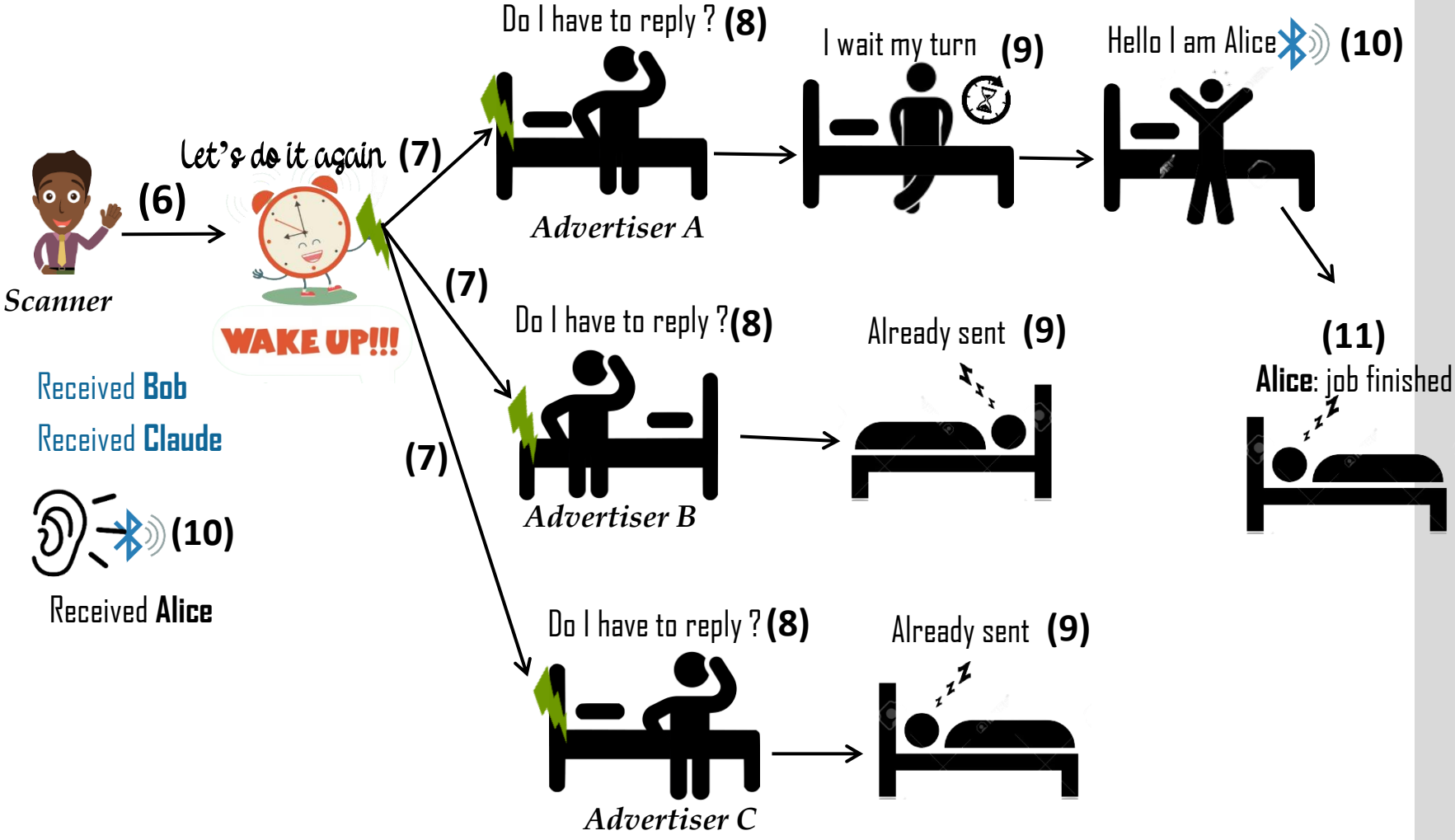
Proposed discovery process – 2nd round



Proposed discovery process – 2nd round



Proposed discovery process – 2nd round



Synchronisation and reduction of collisions

Area Under the Curve (AUC)

Adv_old : 32.9580 mA

Adv_new : 33.7660 mA

Scanner : 78.9803 mA

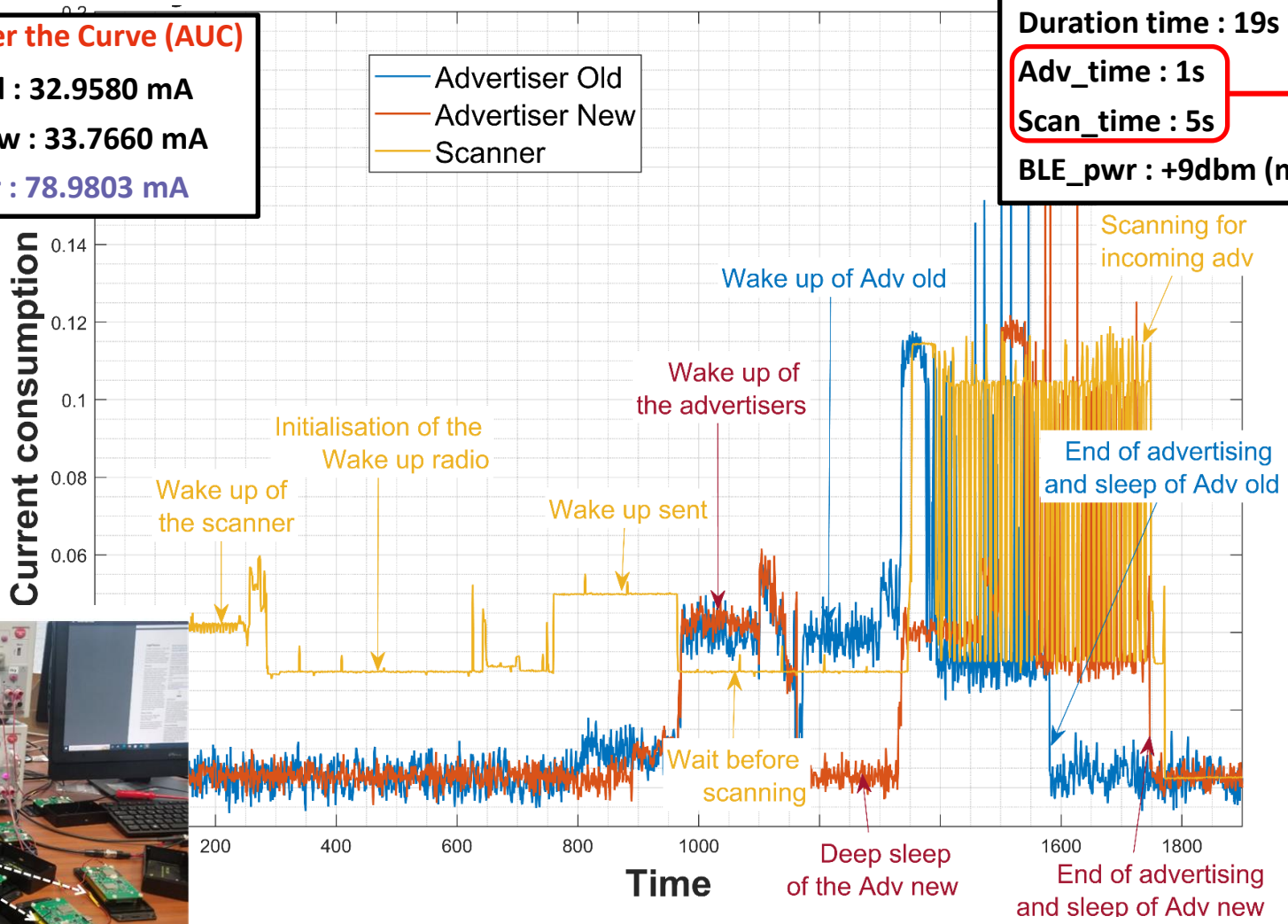
Duration time : 19s

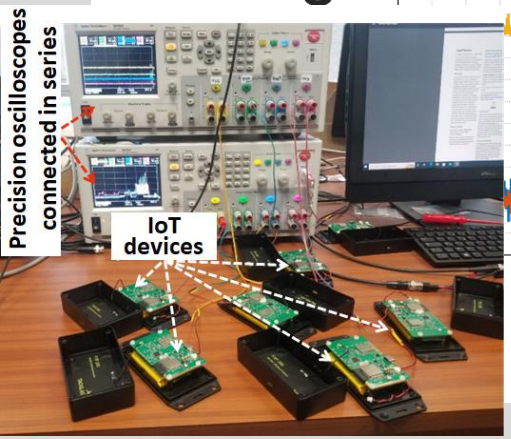
Adv_time : 1s

Scan_time : 5s

→ **Fixed time**

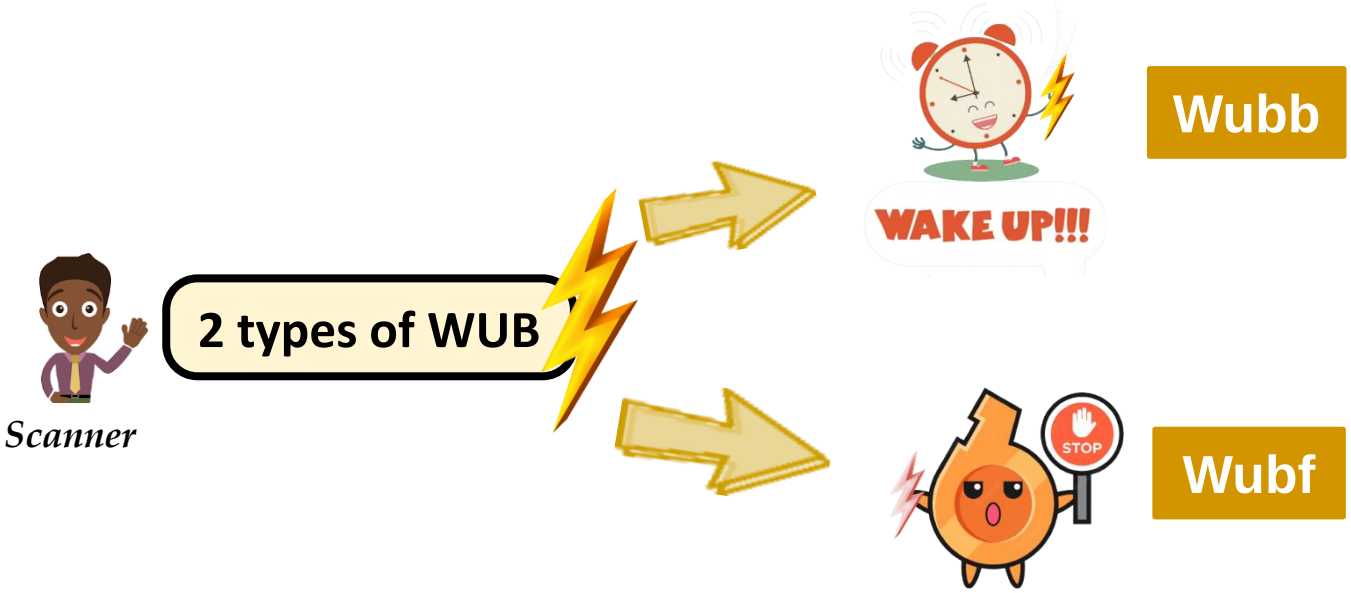
BLE_pwr : +9dbm (max)





Enhance the neighbour discovery : WUBBLE

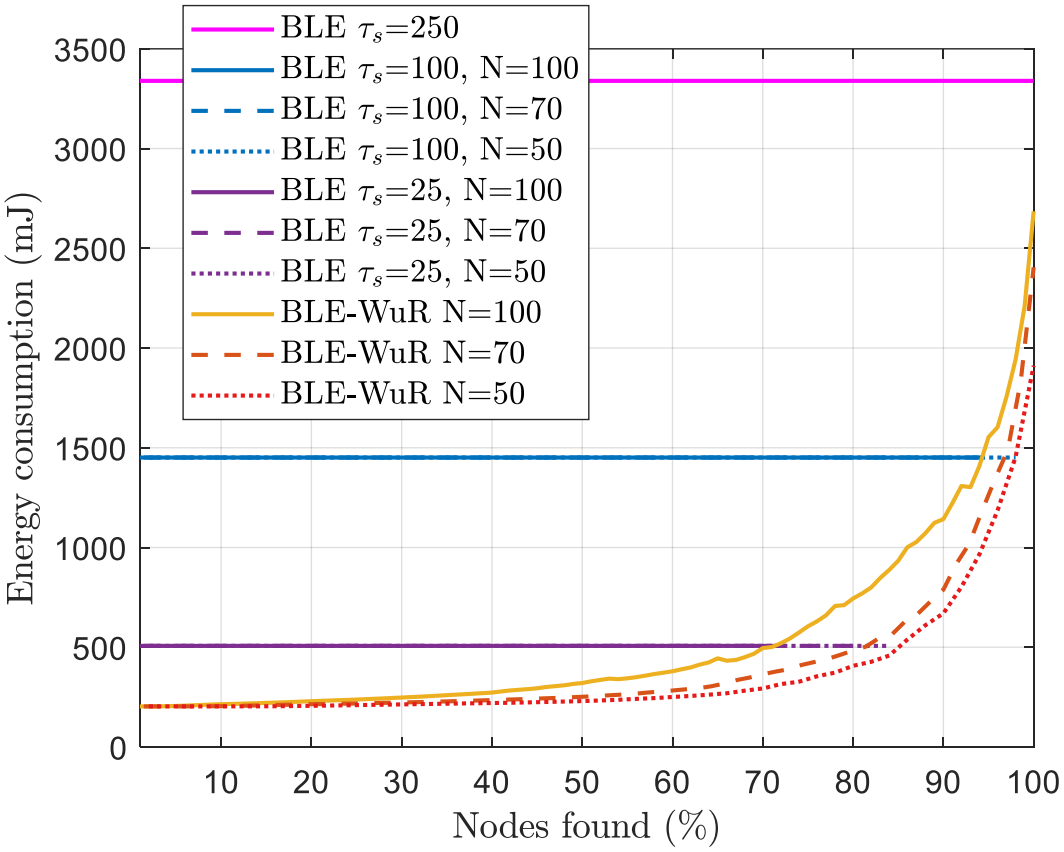
- Discovering K nodes is enough, why discover more?
- A scanner needs to discover K nodes from the N available ($K \leq N$);

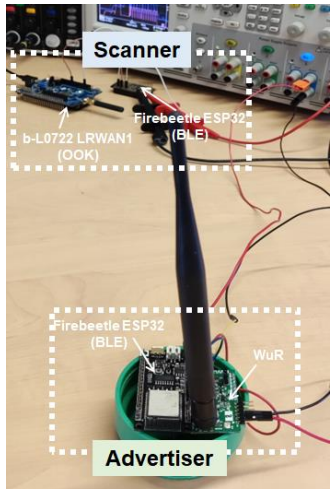


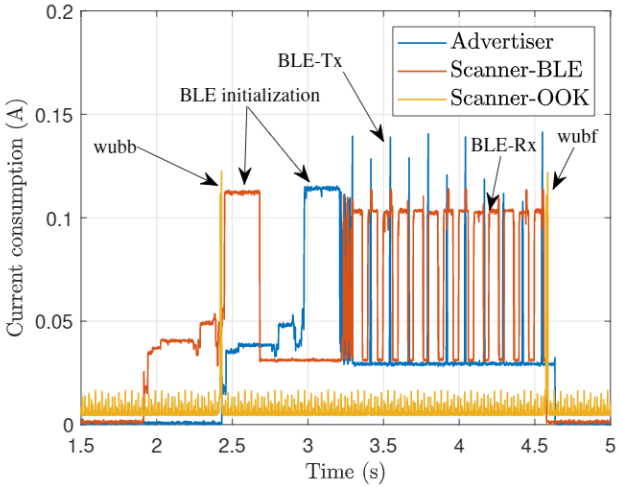
- The scanner stops the advertisers when it has found the K nodes;

[*]. N. E. Hoda Djidi, ***D. Wohwe Sambo***, M. Gautier, O. Berder and N. Mitton, "*WUBBLE: Energy Efficient BLE Neighborhood Discovery Leveraging Wake-up Radio*", *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (Submitted in ALGOWIN 2023).*

Energy conso. w.r.t number of nodes found





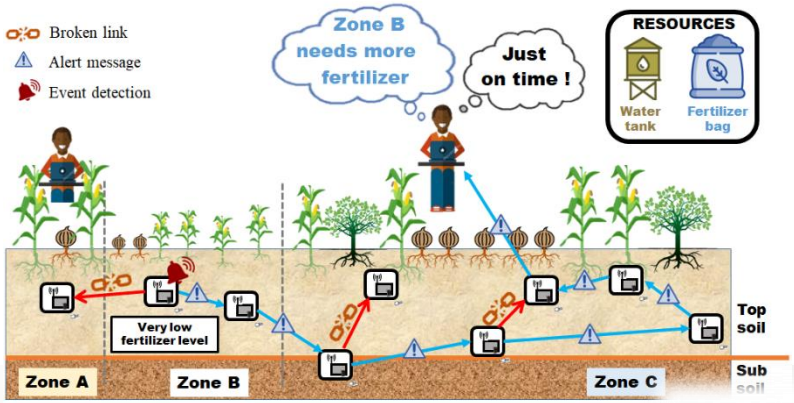


Micro-benchmark

- τ_s = scanning duration (in time slots)

[*]. N. E. Hoda Djidi, ***D. Wohwe Sambo***, M. Gautier, O. Berder and N. Mitton, "*WUBBLE: Energy Efficient BLE Neighborhood Discovery Leveraging Wake-up Radio*", *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (Submitted in ALGOWIN 2023).*

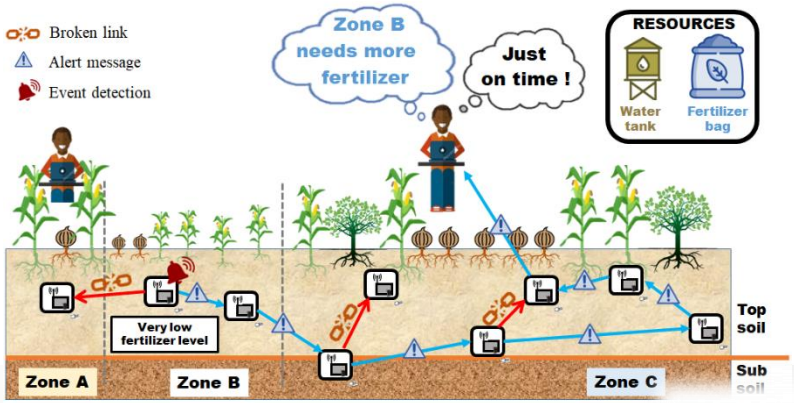
Connected objects for a green world !



1 **A wireless underground sensor network for agriculture**

2 **Reducing packaging waste for a green industry**

Use existing systems for new applications?



1 **A wireless underground sensor network for agriculture**

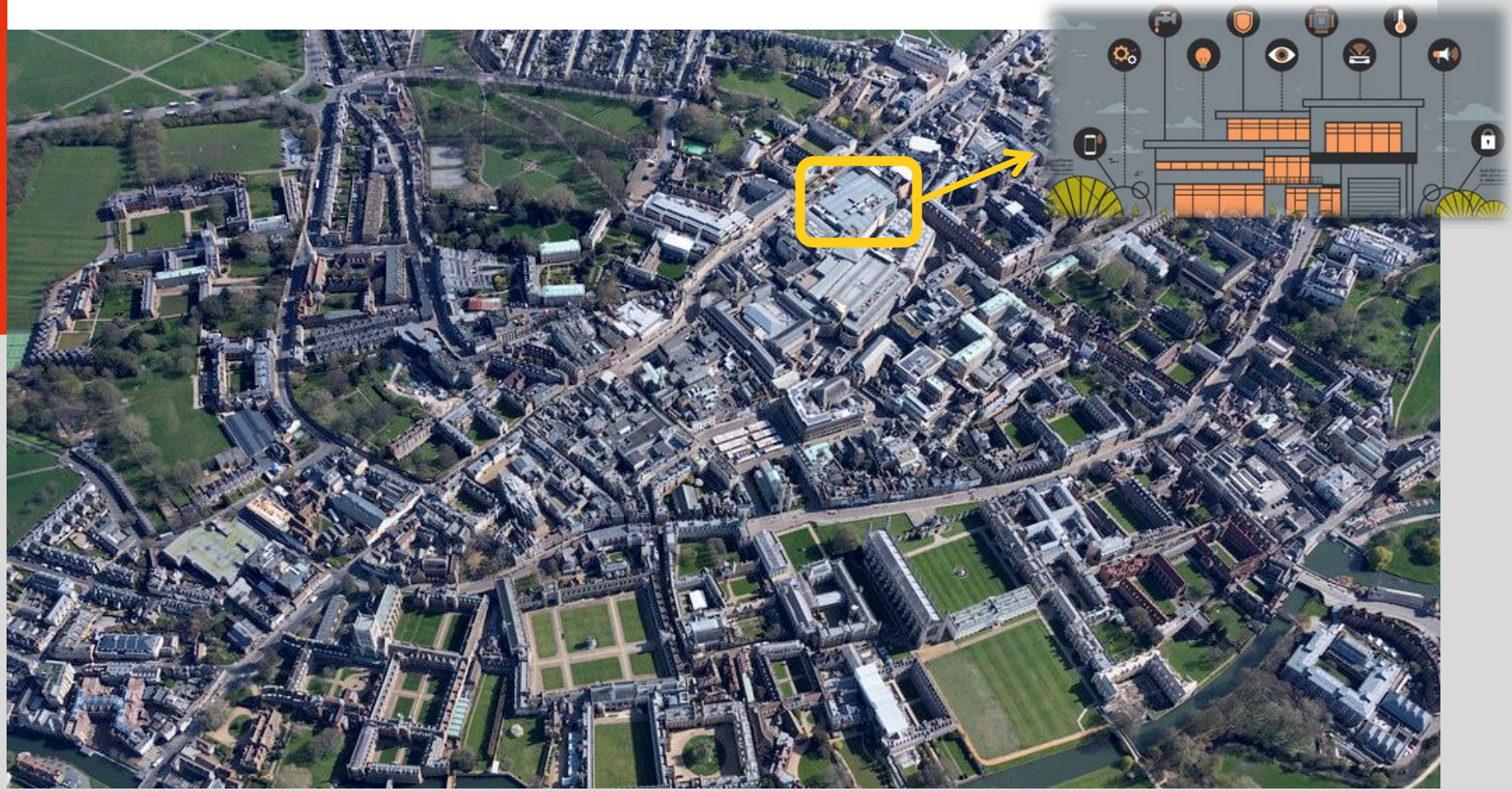
2 **Reducing packaging waste for a green industry**

03

Proposed directions

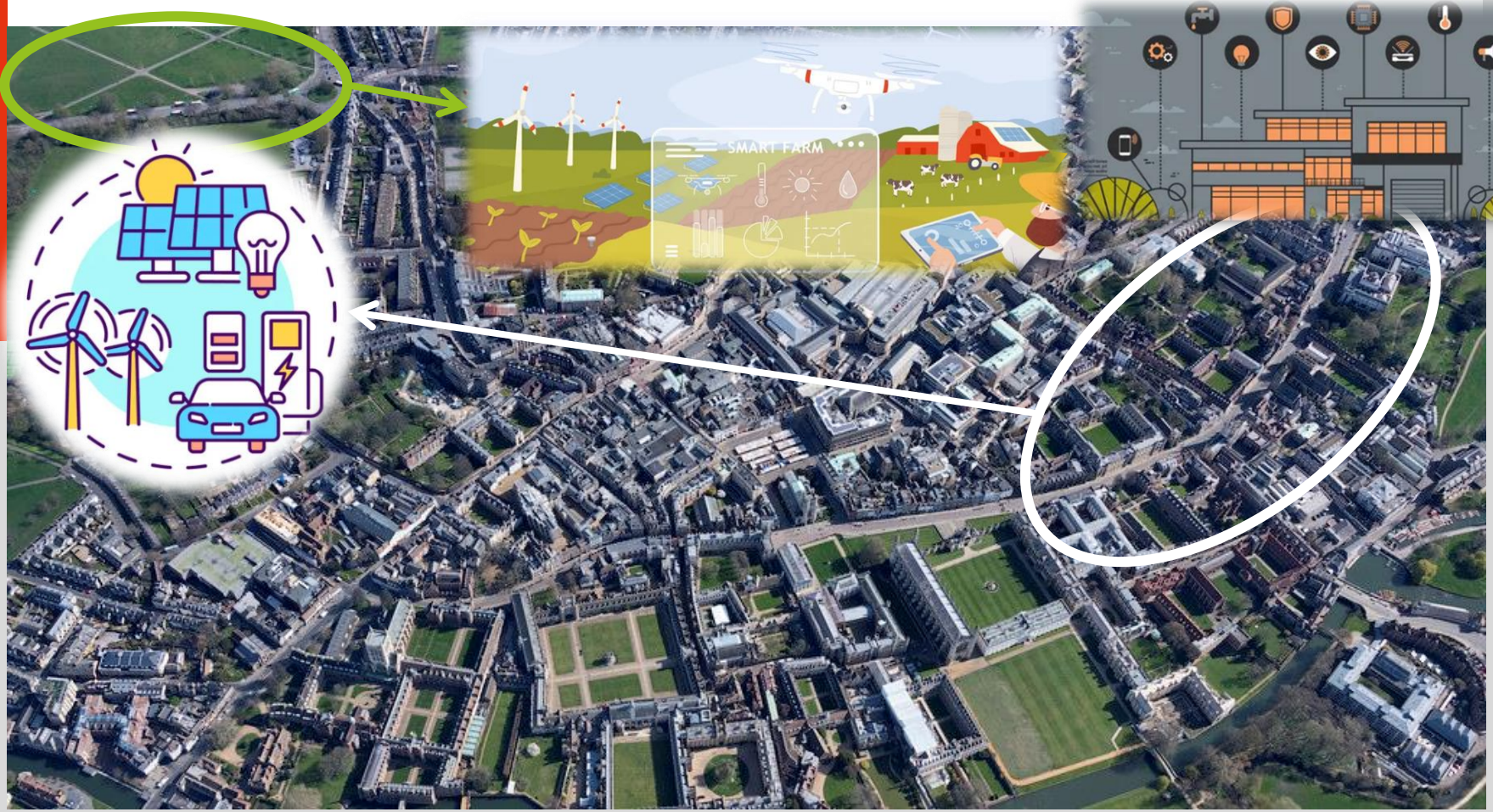
Proliferation of connected object systems

Proliferation of connected object systems

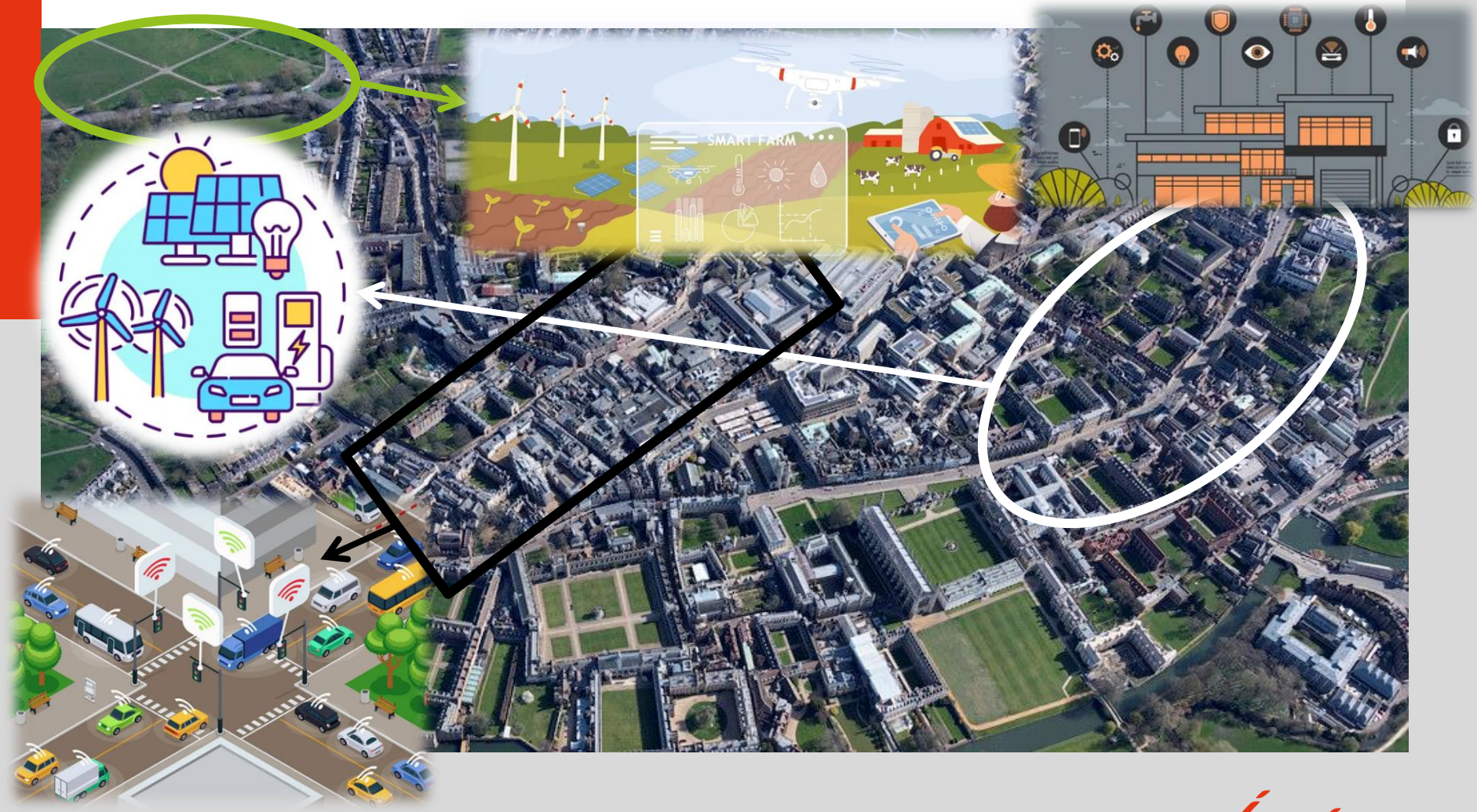


Proliferation of connected object systems

Proliferation of connected object systems



Proliferation of connected object systems



Proliferation of connected object systems

Proliferation of connected object systems

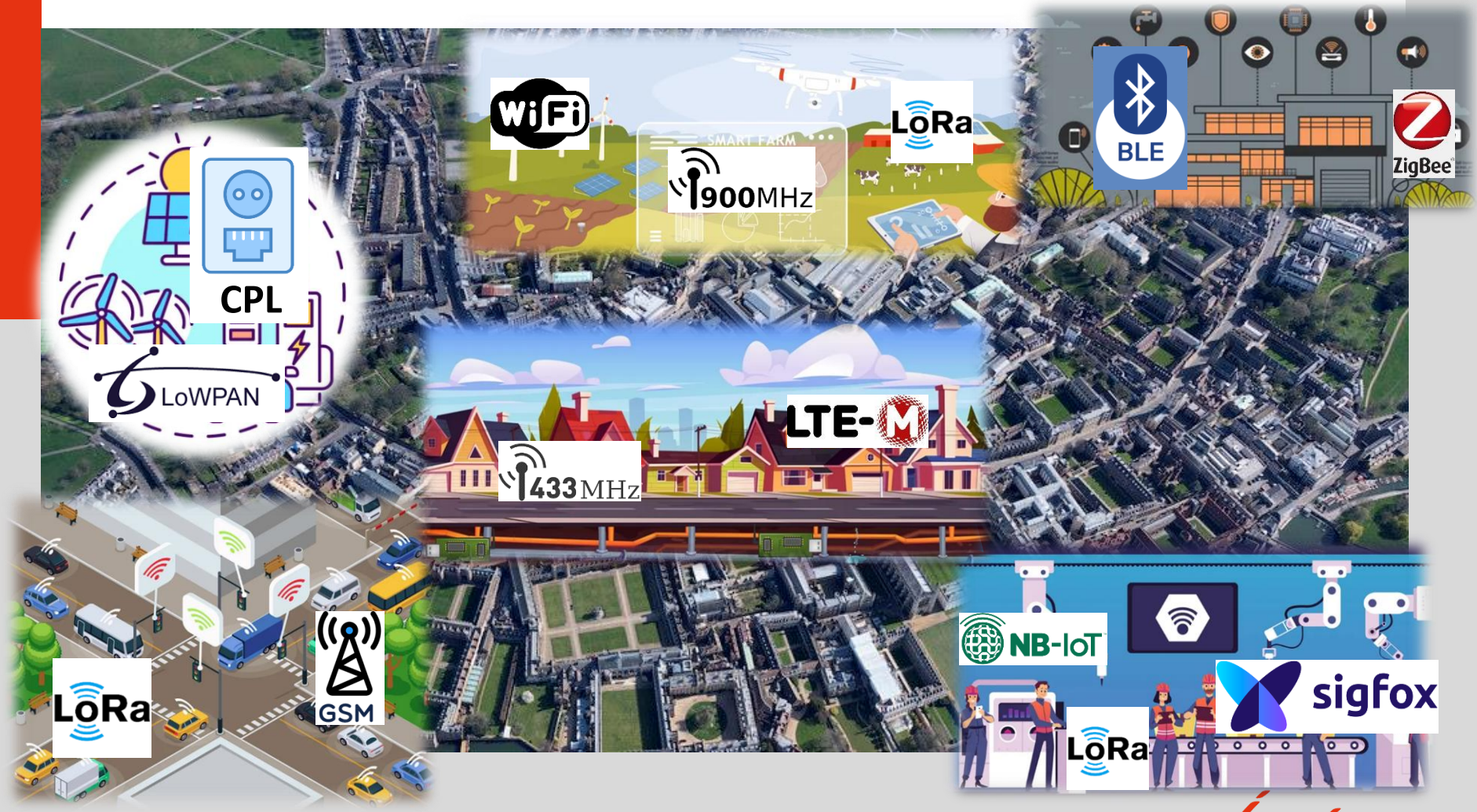
Proliferation of connected object systems

Independent connected object systems

Independent connected object systems

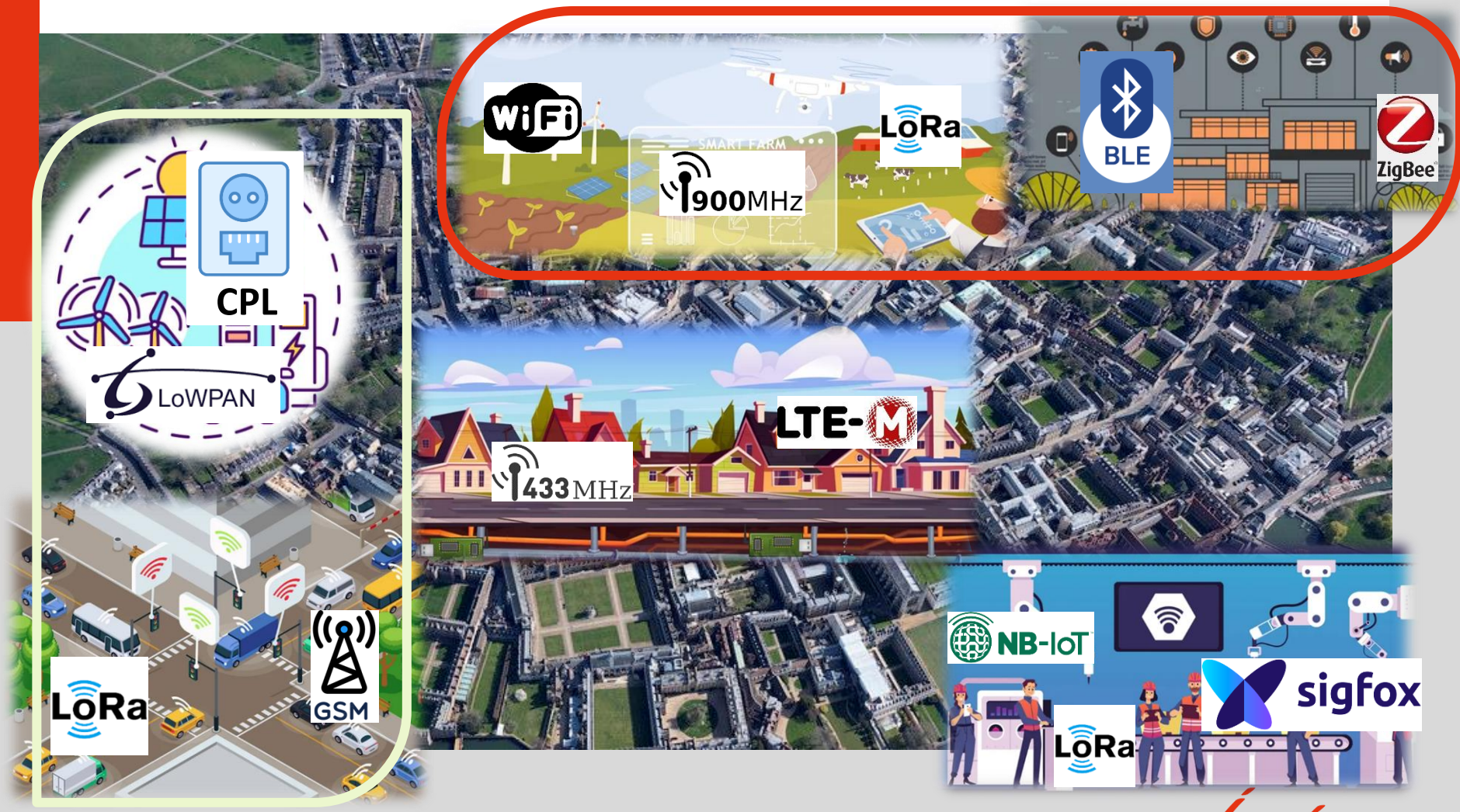
Reuse of connected object systems ?

New applications with existing systems



Reuse of connected object systems ?

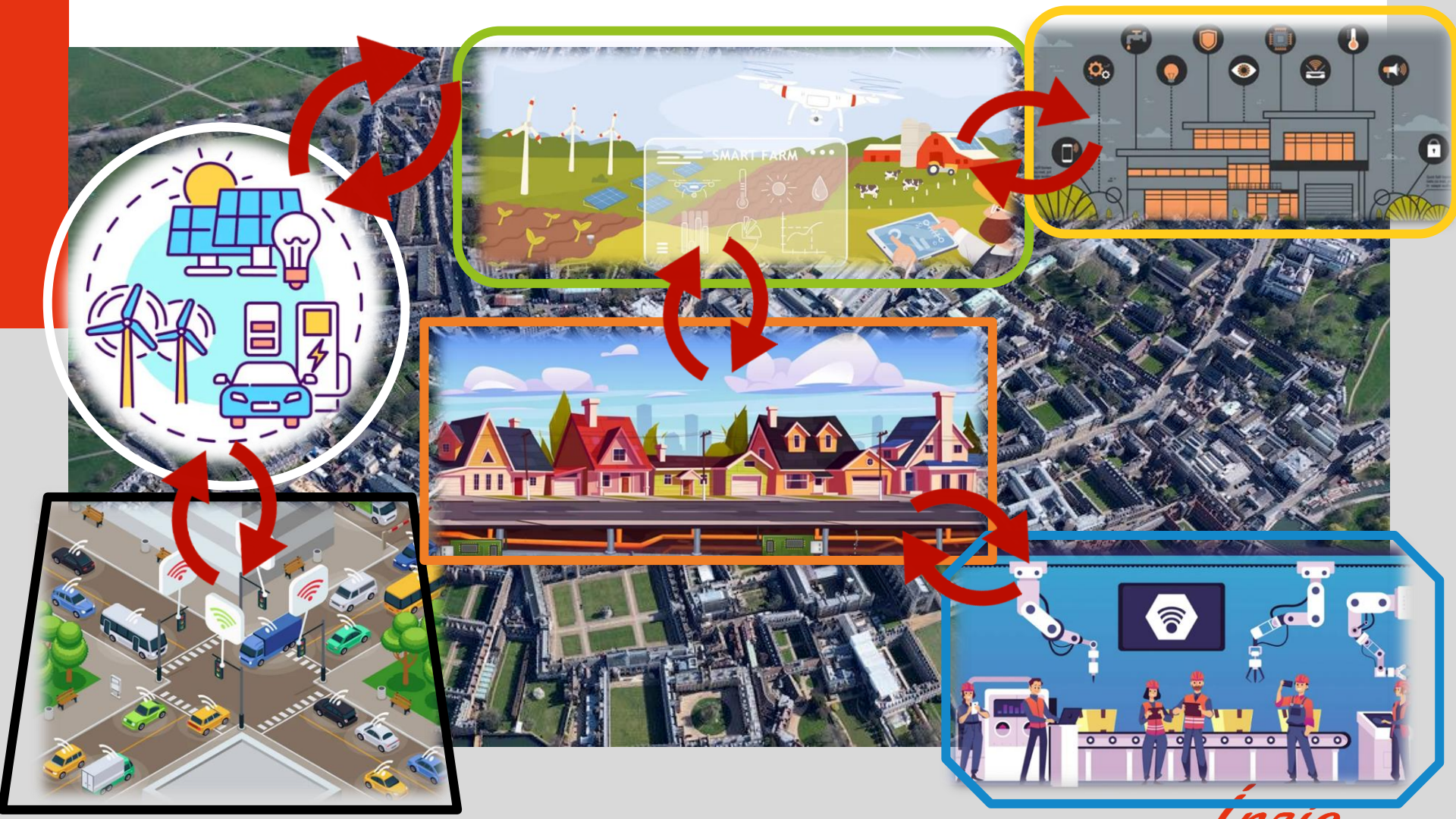
New applications with existing systems



Reuse of connected object systems ?

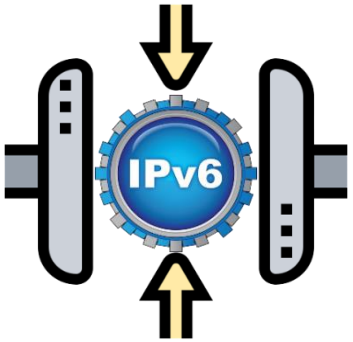
New applications with existing systems

Reuse what exist to avoid proliferation



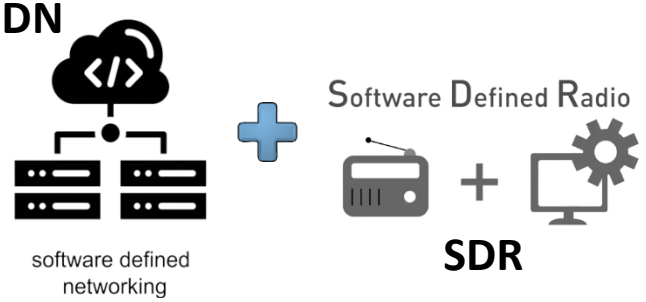
Possible approaches

- **Compression and fragmentation of packets**

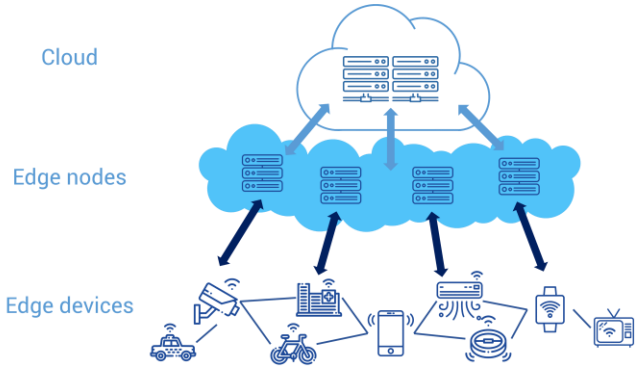


SCHC

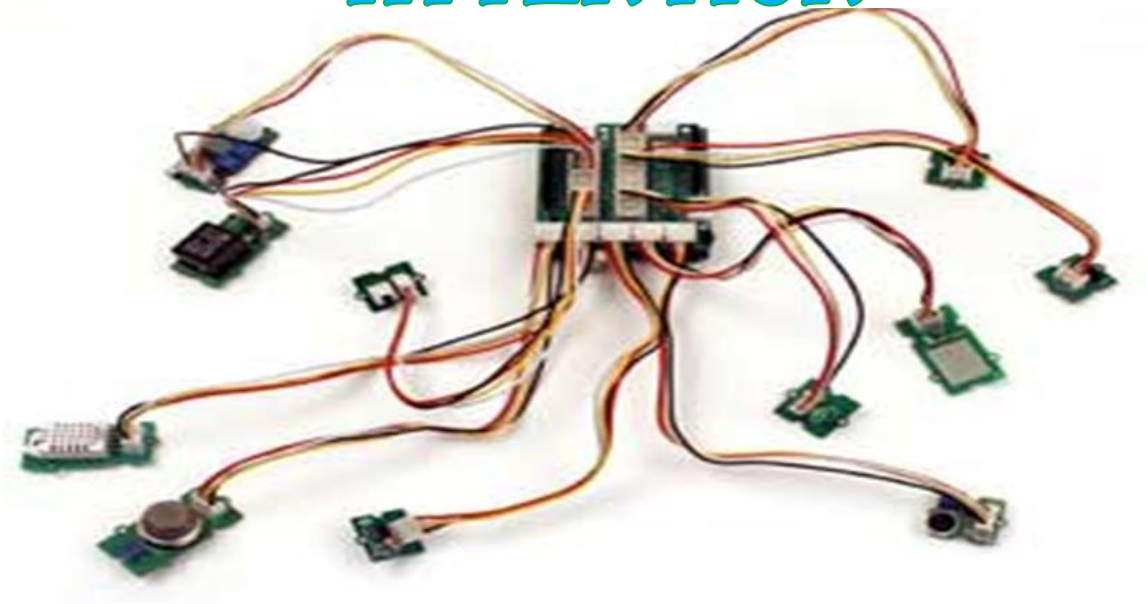
- **Reprogramming of the connected devices**



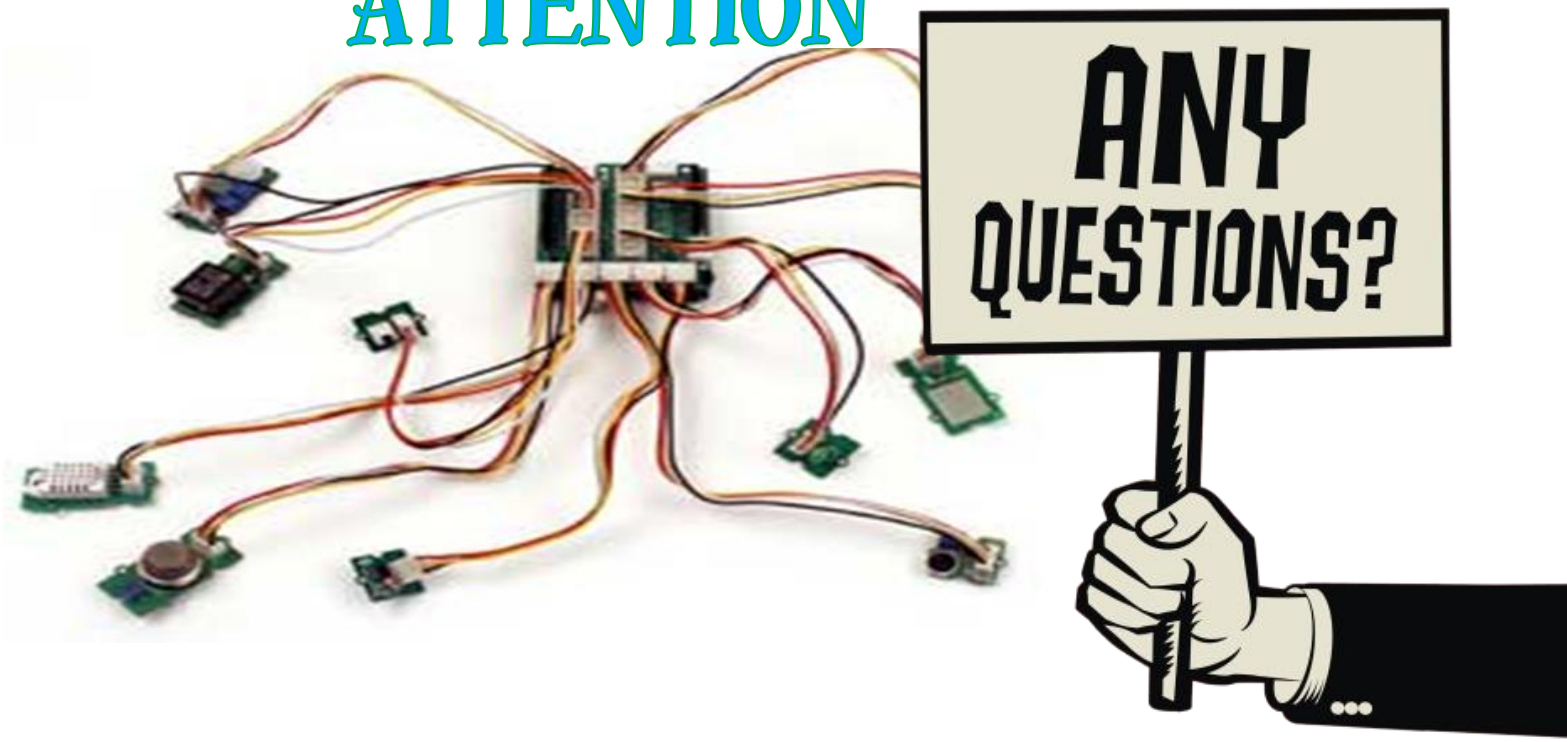
- **Close and edge intelligence**



THANK YOU FOR YOUR ATTENTION



THANK YOU FOR YOUR ATTENTION



Thank you !
Get in touch with me

damien.wohwe-sambo@inria.fr
https://wsdamieno.github.io/Site_perso/#home

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About Me

Services to the scientific community

- **Co-organizing of an international workshop** : LS-NoT 2023 (with proceedings) co-located to IEEE-DCOSS 2023;
- **TPC member** : DCOSS 2024, ANT 2023, AlgoTel/CoRes 2023, CNRIA 2023.
- **Reviewer for high ranked scientific journal/conferences:**
  - **Journals:** IEEE Internet of things, IEEE sensors journal, EURASIP (Springer), Computer Communications (Elseviers), Applied soft computing (Elsevier), AEÜ (Elsevier), Optimal Control, Applications and Methods (Wiley), Peerj Computer Science, etc.
  - **Conferences**: IEEE GLOBECOM 2022, MSN 2022, PerCom 2023, IEEE ICC 2023, CNRIA 2023,etc.
- **Vulgarisation : scientific talks at conferences** :
  - IHAD 2023 (University of Luxembourg);
  - « *Journée LPWAN* » of **GDR RSD**;
  - Annual COPAIN research team seminar

Current position

Post doc INRIA (FUN team) in **IoT**

Teaching activities

Fundamentals and specialised units

In Universities : **Unv. of Lille** and **univ. of Ngaoundéré**

In Engineering schools : **Centrale** (**Centrale Lille** & **ITEEM**) and **IMT Lille-Nord**

Levels : From **L1** to **M2/ Ing. 3A**

594 h eq. TD in **CM**, **TP** and **TD;**

Research activities

Theories + Practices

Research field: **IoT**

Previous works: **Wireless Underground Sensor Network** and **Industry 4.0**

Publications: **6 journals, 2 Int. Conferences**, and **1 Nat. Conference**

Submitted: **1 journal (accepted), 2 Int. Conference**

Citations: 209*

*. Source: Google scholar : "Damien Sambo" (visited 23/04/2023)

Current position

- Since June 1st, 2022: Post-doc in IoT;
- Institution (team): INRIA – FUN research team
- Supervisor*: DR Nathalie Mitton*

  - Project: *GoodFloow (funded by ADEME);*
  - Collaboration between: IMT Lille-Europe, IRCICA, Inria, IMT Atlantique, Irisa.
  - Main purpose: *reduction of the carbon footprint in industry by optimising the supply chain*;

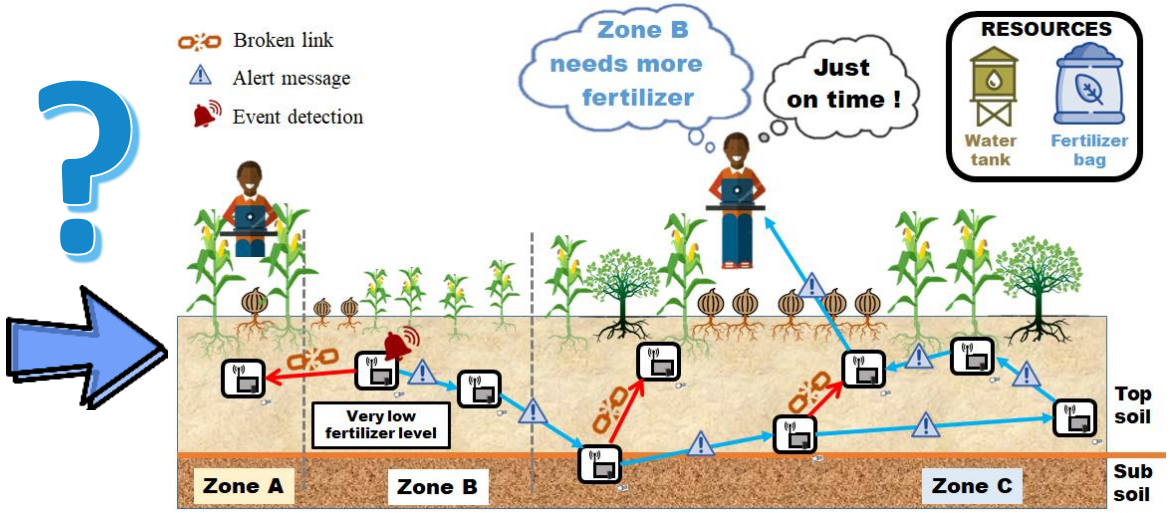
Use of reusable packing

Problems addressed: energy consumption, sychronisation of communications, quality of services, latency, collision reductions.

Application domains: Industry 4.0, ecology.

Education : Ph.D.

- **Ph.D. thesis**: « *Conception of a wireless underground sensor network for precision agriculture* »
  - Supervisors: Prof. –Dr. A. Förster (**Bremen**) & Profs. B. O. Yenke & P. Dayang (**Ngaoundéré**)
  - Defended on the 23rd July 2021 in Bremen;

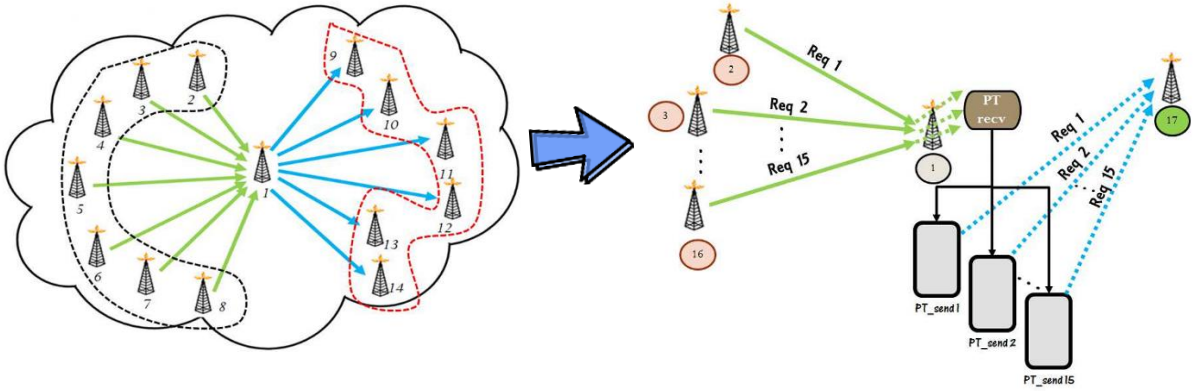


- **3 scholarships**: INTRA-ACP, ERASMUS + and AUF

Education : Master of Science (MSc.)

- **Master** :
  - Distributed systems;
  - Software engineering;
  - Etc.
  - **Beginning of the passion for the IoT**;
  - **Master thesis [BDA2016]** : « *Une approche efficace de multithreading dans les réseaux de capteurs sans fils* »

- Research area: Internet of Things.
- Problematics addressed: Energy consumption, quality of service, multi-tasking, etc.



- Decongestion of central nodes (e.g. CH);
- Based on protothreads;
- *Contiki (Cooja) – Telos B*;
- Better ratio performance/ energy consumption;

[BDA2016] - Blaise Omer Yenke, **Damien Wohwe Sambo**, Abba Ari Adamo Ado, and Abdelhak Gueroui, "MMEDD : Multithreading Model for an Efficient Data Delivery in wireless sensor networks", International Journal of Communication Networks and Information Security (IJCNIS), vol. 8, no. 3, pp. 179–186, 2016, ISSN: 2073-607X.

Stop proliferation of a new waste's types

- **Instead of endless deployments, if we reuse existing?**