ASEAN IVO FORUM 2022

PROJECT REPORT
ASEAN IVO PROJECT 2020

Project Leader: Prof. Xuan-Nam Tran
Presenter: Van –Trung Nguyen
Le Quy Don Technical University, Hanoi, Vietnam

Project Final Report

Project Title: An Energy Efficient, Self-Sustainable, and Long Range IoT System for Drought Monitoring and Early Warning

Background:

Due to the characteristics of drought, real-time measuring and monitoring of full impacts of drought is complicated; hence, it requires research, extensive data and experiential evidences for decision making processes. This leads to the requirement of an efficient real-time drought monitoring and early warning system.

Targets:

This project aims to develop a real-time, energy efficient, self-sustainable and long range drought monitoring and early warning system based on IoT for river basin regions to adapt against this hazard. The specific objectives are as follows:

- Design & implement a real-time IoT based drought monitoring and early warning system to provide a continuous assessment and support decision making process;
- Investigate the efficiency of using innovative Beat sensors, different energy harvesting techniques and LoRa communication protocol for the proposed system.

Project Duration: From June 01, 2020 to March 31, 2022

Leader: Prof. Xuan Nam Tran (LQDTU, Vietnam)

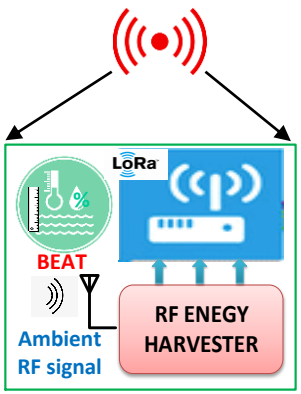
Presenter: Dr. Nguyen Van Trung (LQDTU, Vietnam)

Project Members

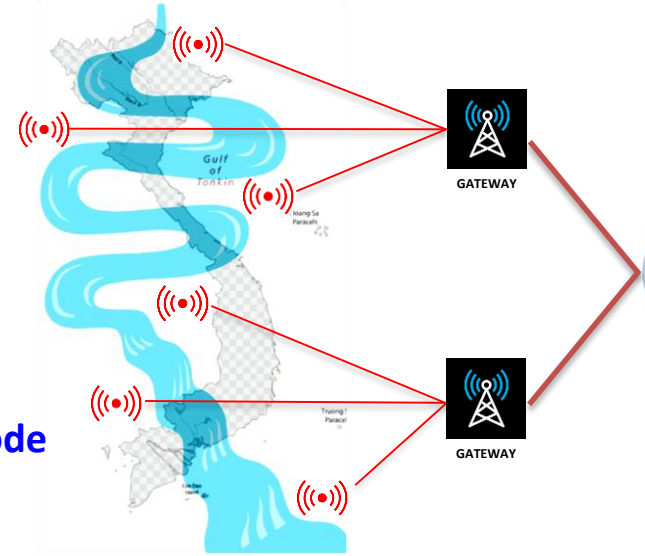
Xuan Nam Tran (LQDTU, Vietnam)
Hoang Van Phuc (LQDTU, Vietnam)
Koichiro Ishibashi (UEC, Japan)
Jiro Ida (KIT, Japan)
Kosin Chamnongthai (KMUTT, Thailand)
Taworn Benjanarasuth (KMITL, Thailand)
Luong Duy Manh (LQDTU, Vietnam)

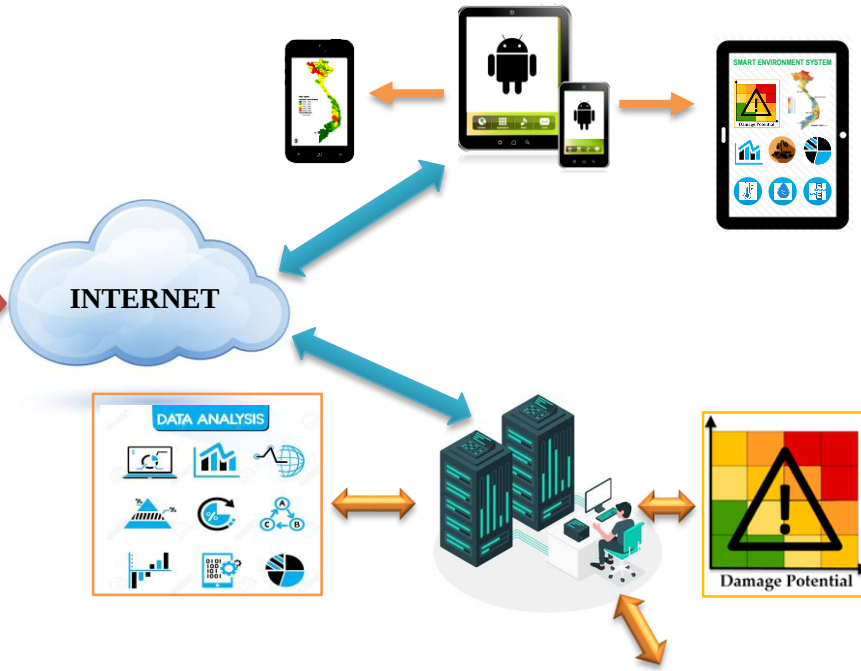
Nguyen Van Trung (LQDTU, Vietnam)
Nguyen Quoc Dinh (LQDTU, Vietnam)
Nguyen Thuy Linh (LQDTU, Vietnam)
Bui Du Duong (NAWAPI, Vietnam)
Dao Van Lan (Malardalen Uni., Sweden)
Dao Thanh Toan (UTC, Vietnam)
Truong Trung Kien (FUV, Vietnam)

General IoT System in the Project



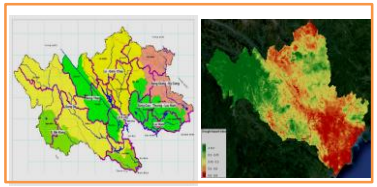
RFEH Beat sensor node





Project activities:

1. Scientific contributions
2. Technological development
3. Experiments including field testing
4. Workshops



Drought hazard map

Research Activities and Results

1. Theoretical evaluation and system design

- Performance evaluation of the proposed system under different conditions: LoRa system using energy harvesting and diversity cooperation

2. Technical meeting and workshops

- Project kick-off meeting between all collaborated partners: Online meeting, 11 participants
- Technical workshops to discuss about research activities and findings
  - October 2020: 2-day workshop in Nha Trang, Khanh Hoa province with 10-presentation session and field investigation.
  - March 2021: 2-day workshop in Hanoi with 12-presentation session and field investigation.
  - August 2021: 2-day workshop in Hanoi with 10-presentation session and field investigation.
  - December 2021: 2-day workshop in Hanoi with 12-presentation session and training.

3. System development

- Design low-power consumption sensors for energy saving.
- Design a concurrent triple-band RF energy harvesting circuit for IoT sensor networks.
- Other system components.

4. Application development

Activity #1: Theoretical Evaluation and System Design

- A LoRa system using energy harvesting and diversity cooperation
  - Sensors (S) have single antenna
  - *K* gateways (G_1-G_K) with multiple antennas
  - A power beacon (B) station with multiple antennas for wireless power transmission
- Transmission includes 2 phases: energy harvesting and information transmission.
- Sensors harvest energy transmitted from beacon to support their limited-capacity battery.

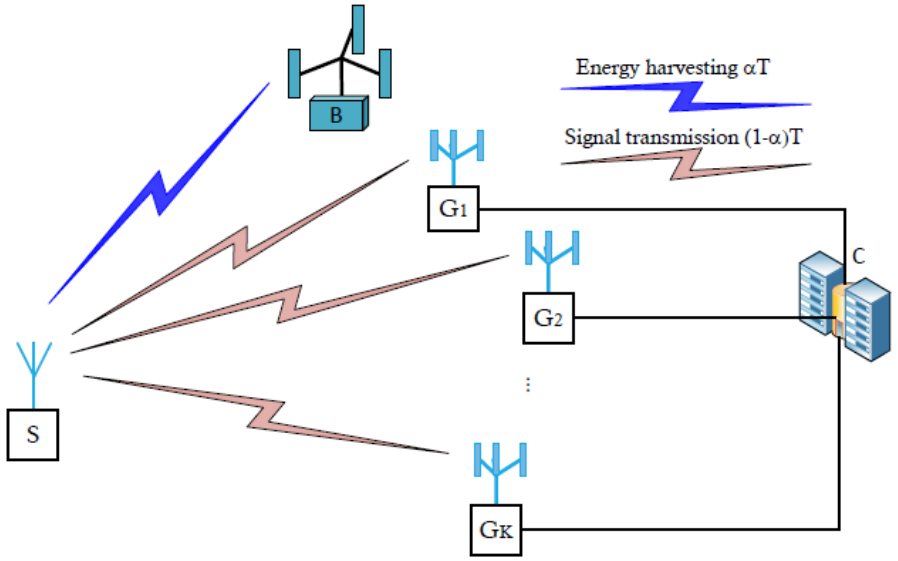


Fig. 1: Illustration of the considered LPWA system.

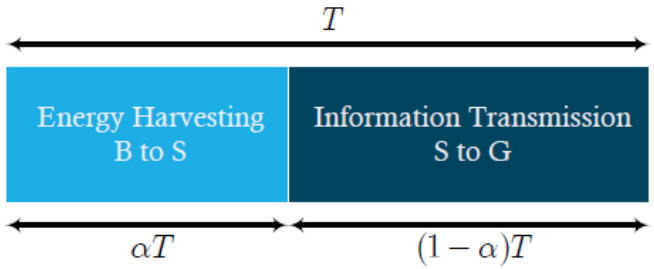


Fig. 2: TS protocol for the considered LPWA system.

Paper #1: **Xuan Nam Tran, Van-Phuc Hoang**, *Ba Cao Nguyen, "Combining RF energy harvesting and cooperative communications for low-power wide-area systems," AEU International Journal of Electronics and Communications, ISSN 1434-8411, vol.139, Sept. 2021.*

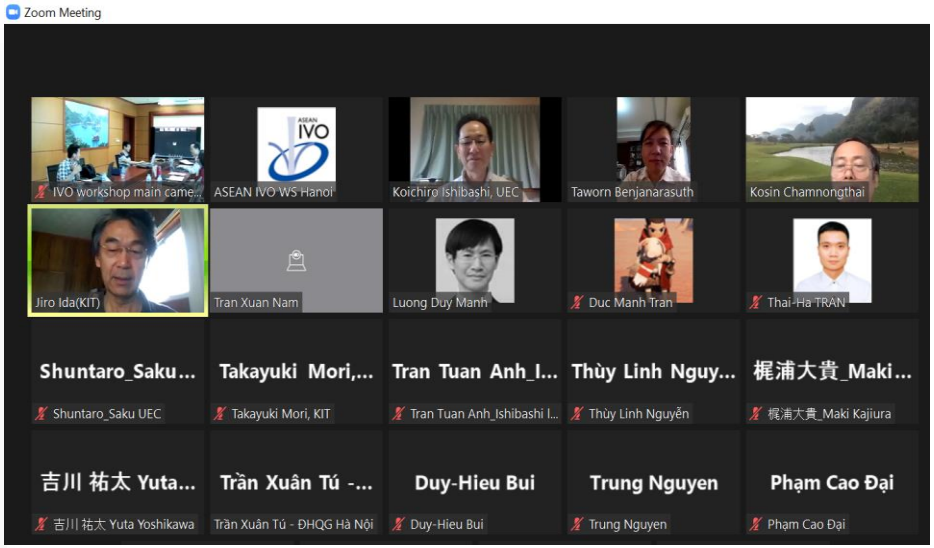
Activity #2: Technical Meetings and Workshops

- Project kick-off meeting: Online meeting, 11 participants.
- Open technical workshop (hybrid) entitled *"IoT and Wireless Communications for Smart Environment Monitoring"* organized in Nha Trang, Khanh Hoa province, Vietnam: 10-presentation session and field investigation.

- Open technical workshop (hybrid) entitled *"Advanced Wireless Communications, Energy Harvesting and IoT Sensors for Smart Monitoring Systems"* organized in Hanoi, Vietnam: 12-presentation session and field investigation.

- Open technical workshop (hybrid) entitled *"Energy Efficient Sensors and RF Energy Harvesting for IoT Based Smart Monitoring Systems"* organized in Hanoi, Vietnam: 14-presentation session and field investigation.

Activity #2: Technical Meetings and Workshops (cont.)

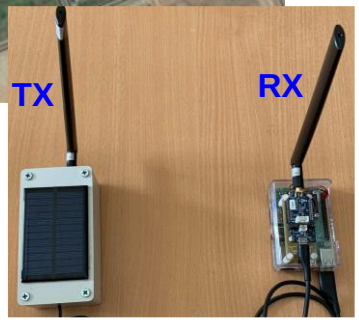


Activity #3: System Hardware Development

- **Activity 3.1: Develop energy-efficient sensors for LoRa communications**
  - Using Beat sensor for LoRa band (933MHz)
  - Communication range: 600 m tested in Tokyo; 1.7 km and 10 km tested in Hanoi.
- Participated members: Hoang Van Phuc, Xuan Nam Tran, Nguyen Van Trung, Dang Van Binh (LQDTU), Dao Van Lan (MU), Koichiro Ishibashi (UEC)

Field test in Tokyo

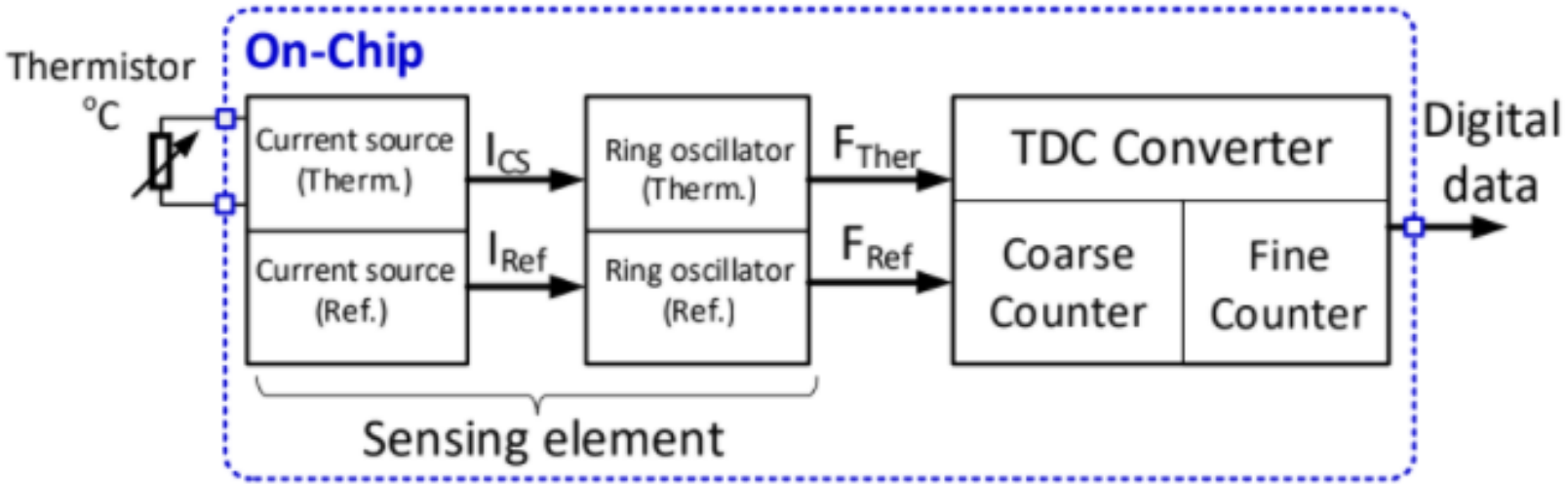
Field test in Hanoi



Paper#2: Van-Binh Dang, Van-Phuc Hoang, and Van-Trung Nguyen, Energy Efficient Temperature Beat Sensor for IoT Based Drought Monitoring Systems, *2nd ASEAN-UEC Workshop on Energy and AI*, Nov. 2020.

Activity #3: System Hardware Development (Cont.)

- **Activity 3.2: Temperature Sensor for IoT Using Thermistor-Defined TDC**
  - 0.07mm^2, 446nW power temperature sensor in 180nm CMOS technology
  - Operation range: -20^{o}C to 80^{o}C
  - Resolution: 0.06^{o}C
- Participated members: Nguyen Van Trung, Hoang Van Phuc (LQDTU), Nguyen Trong Hung, Koichiro Ishibashi (UEC)



Paper #3: Hung-Nguyen Trong, **Van-Trung Nguyen,** and **Koichiro Ishibashi**, *"A Sub-uW and 14bit Resolution Temperature Sensor for IoT Using Thermistor-Defined TDC," デザインガイア 2021 VLSIの設計/検証/テスト, Dec.* 2021.

Activity #3: System Hardware Development (Cont.)

- **Activity 3.2: Temperature Sensor for IoT Using Thermistor-Defined TDC**

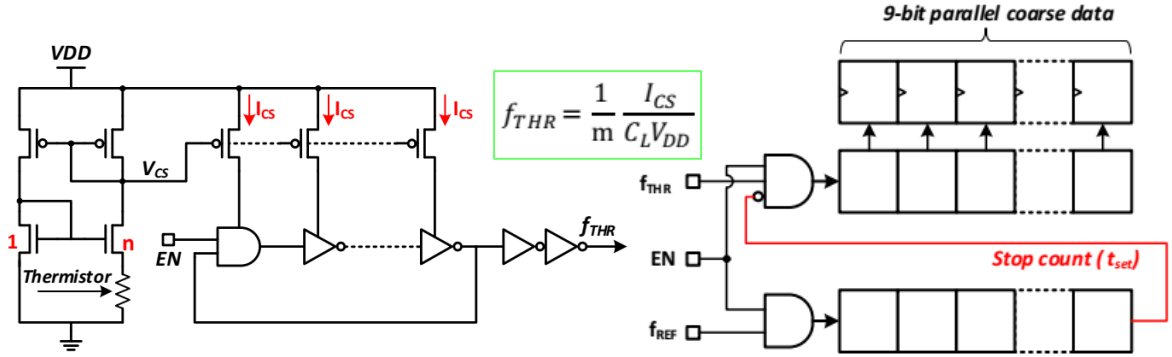
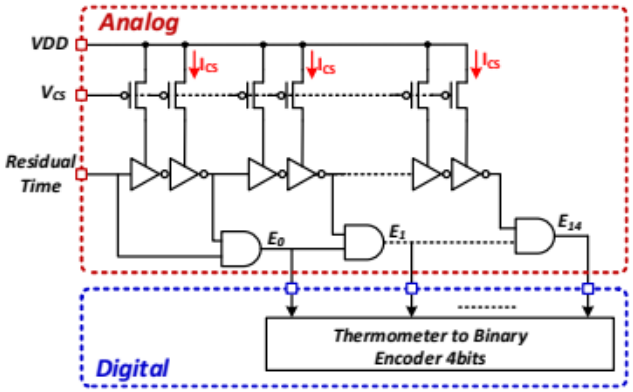
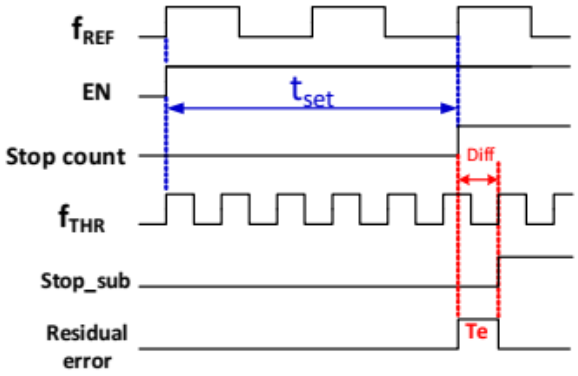


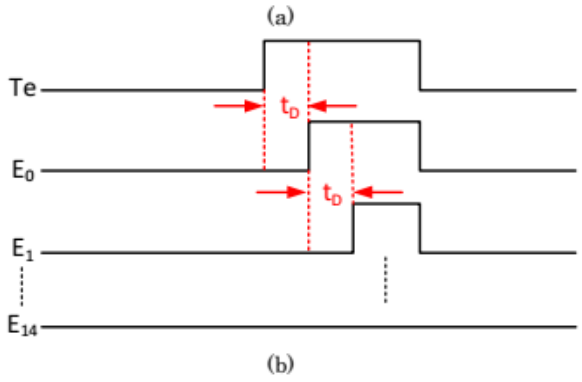
Fig. 2. Schematic of the temperature sensing element



- By substracting f_{ref}, global effect of temperature is removed;
- TDC help improving accuracy of temperature conversion



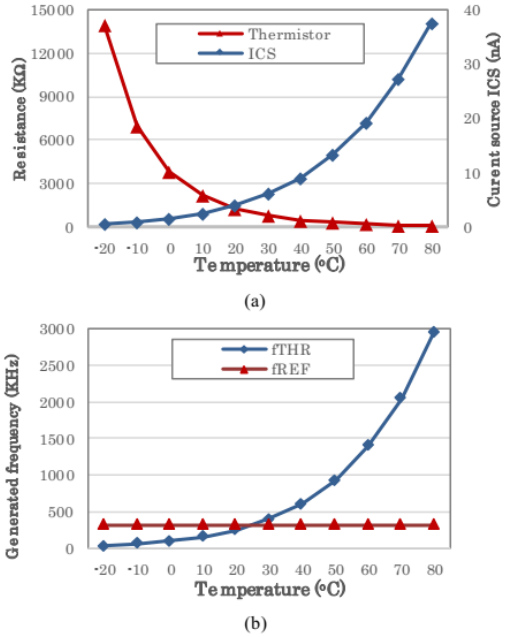
TDC - Coarse Counter



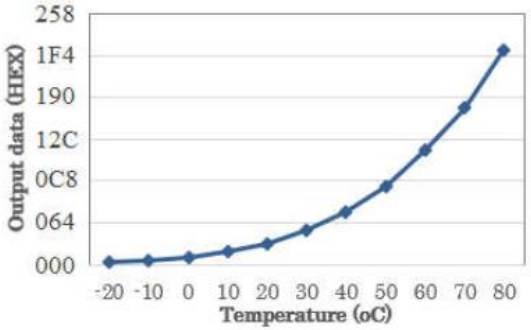
TDC - Fine Counter

Activity #3: System Hardware Development (Cont.)

- **Activity 3.2: Temperature Sensor for IoT Using Thermistor-Defined TDC**



(a) Res. vs Temp.
(b) f_{THR}, f_{REF} vs. temp.



Digital Sensor Output vs. temperature

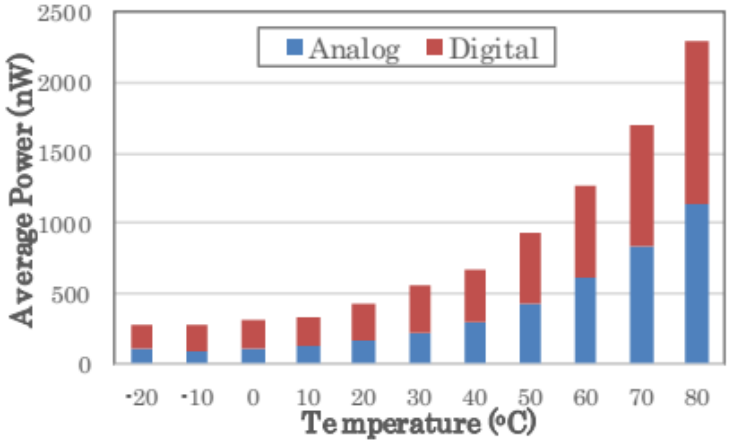


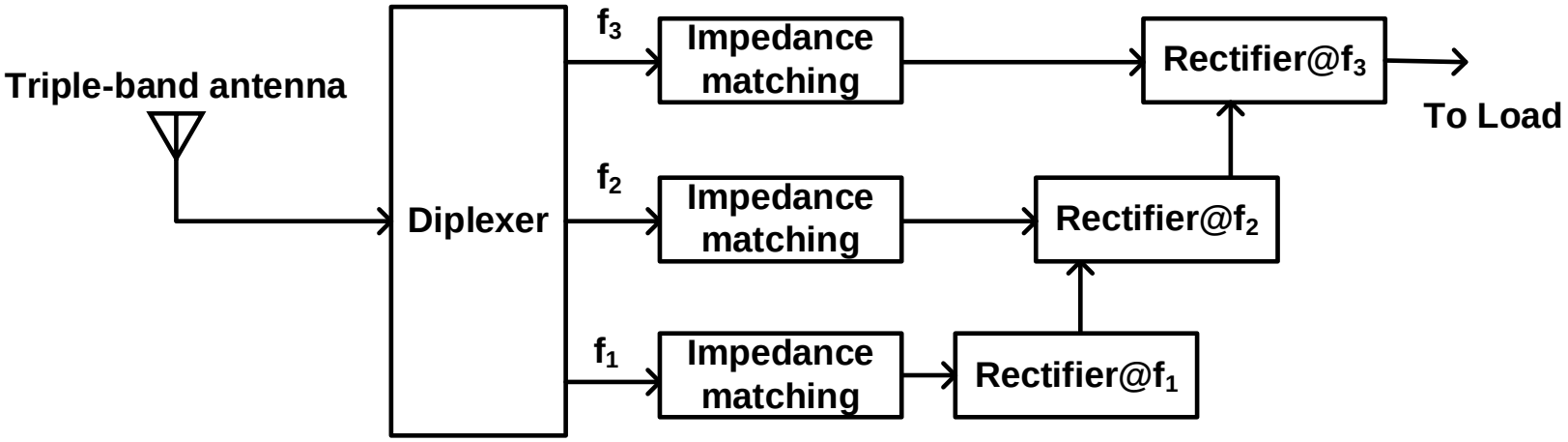
Fig. 8. The power average with the changing of temperature.

TABLE I. PERFORMANCE COMPARISON

	[3]	[4]	[5]	[8]	[9]	This work
Technology [nm]	180	65	130	65	65	**180**
Area [mm^2]	0.074	0.63	0.086	0.0084	0.058	**0.07**
Sensing type	MOS.	MOS.	BJT.	RES.	THR.	**THR.**
Supply voltage [V]	0.8	0.5	1.2/3.3	1.0~1.2	0.75	**1.0**
Temperature range [°C]	-20 ÷ 80	0 ÷ 100	-40 ÷ 125	-30 ÷ 100	-50 ÷ 50	**-20 ÷ 80**
Resolution	-	0.3	0.06	0.38	0.04	**0.06**
Conversion time [s]	0.839	0.3	1.3	2.5u	280u	**160u**
Power [nW]	11	0.763	39.7	35.2	531	**446**
Energy/Conversion [nJ]	8.9	0.23	51.6	0.088	0.148	**0.071**

Activity #3: System Hardware Development (Cont.)

- **Activity 3.3: Design a Concurent Triple-band RF Energy Harvesting Circuit for IoT Sensors**
  - Operating frequency: GSM-900, GSM-1800 and 2.45 GHz
  - Measured DC output level: 643mV
- Participated members: Luong Duy Manh, Nguyen Thuy Linh, Hoang Van Phuc, Xuan Nam Tran, Nguyen Van Trung (LQDTU), Koichiro Ishibashi (UEC)

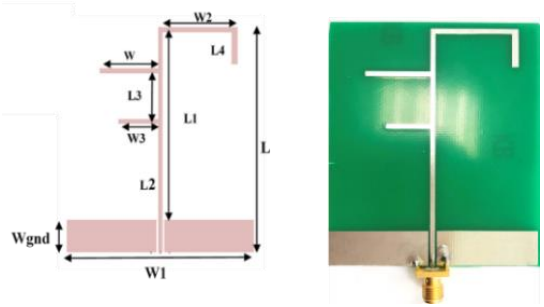


Schematic diagram of the proposed RFEH circuit.

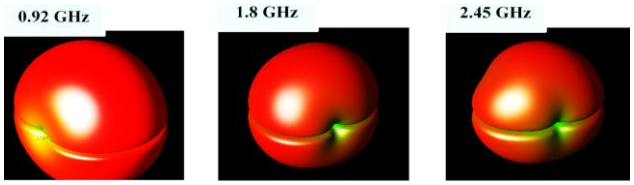
Paper #4: Luong Duy Manh, Phan Thi Bich, **Nguyen Thuy Linh**, Nguyen Huy Hoang, **Xuan Nam Tran** and **Koichiro Ishibashi**, *"A Concurrent Triple-band RF Energy Harvesting Circuit for IoT Sensor Networks ," IEEK Transactions on Smart Processing and Computing, vol.10, no.20, April* 2021.

Activity #3: System Hardware Development (Cont.)

- **Activity 3.3: Design a Concurent Triple-band RF Energy Harvesting Circuit for IoT Sensors → Antenna design**



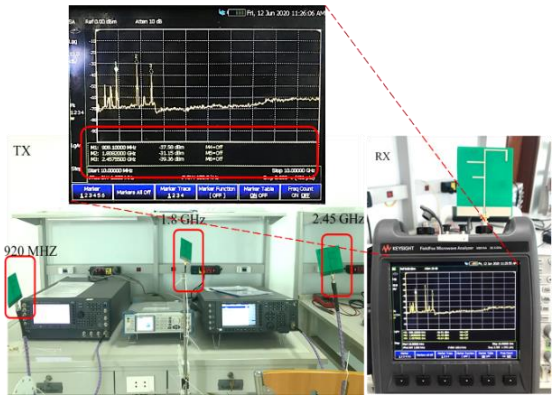
Triple-band antenna: Layout in ADS (left) and fabricated prototype (right).



Simulated radiation pattern of the triple-band antenna.

Antenna dimensions

Dimension	Value (mm)	Dimension	Value (mm)
L	90	Wgnd	10
L1	78.5	W	1.5
L2	30	W1	62.4
L3	14.3	S	0.5
L4	10	W2	26.5
W3	13.25	W4	19.5

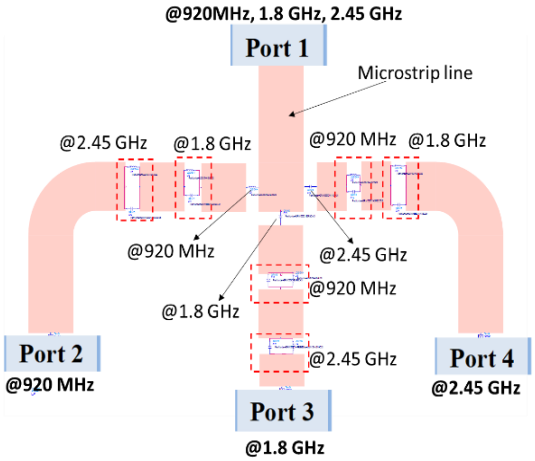


Realistic experiment for testing antenna

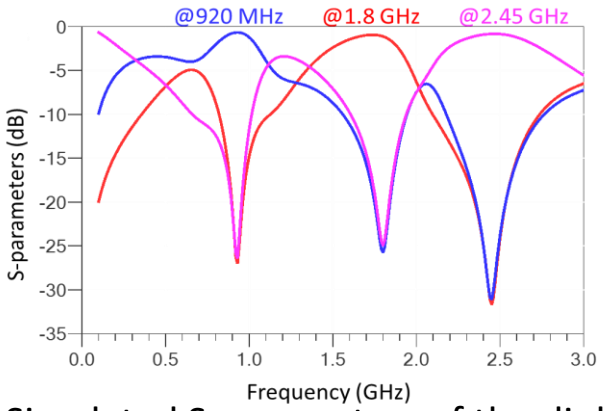
Paper #4: Luong Duy Manh, Phan Thi Bich, **Nguyen Thuy Linh**, Nguyen Huy Hoang, **Xuan Nam Tran** and **Koichiro Ishibashi**, *"A Concurrent Triple-band RF Energy Harvesting Circuit for IoT Sensor Networks ," IEEK Transactions on Smart Processing and Computing, vol.10, no.20, April* 2021.

Activity #3: System Hardware Development (Cont.)

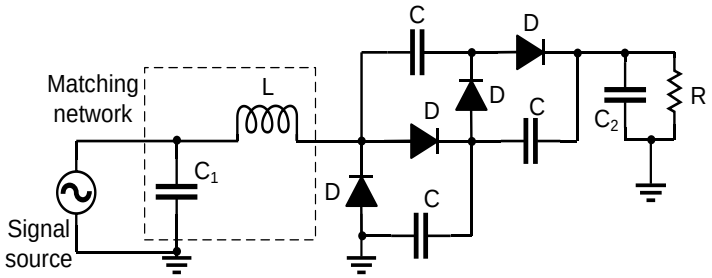
- **Activity 3.3: Design a Concurent Triple-band RF Energy Harvesting Circuit for IoT Sensors → Diplexer and rectifier design**



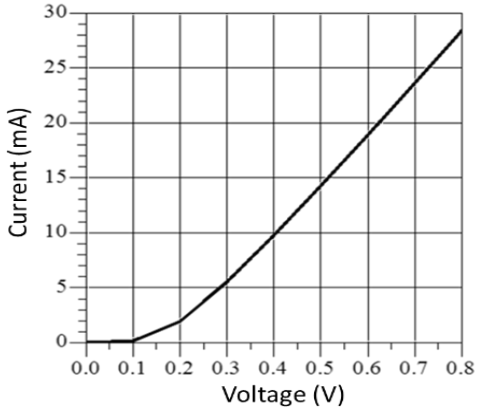
Co-simulation model for the designed diplexer. Total size of this circuit is 1.8 cm × 2 cm



Simulated S-parameters of the diplexer



Schematic of a rectifier consisting of a matching network and a two-stage voltage doubler circuit using two zero-bias SBD diodes (SMS7630)

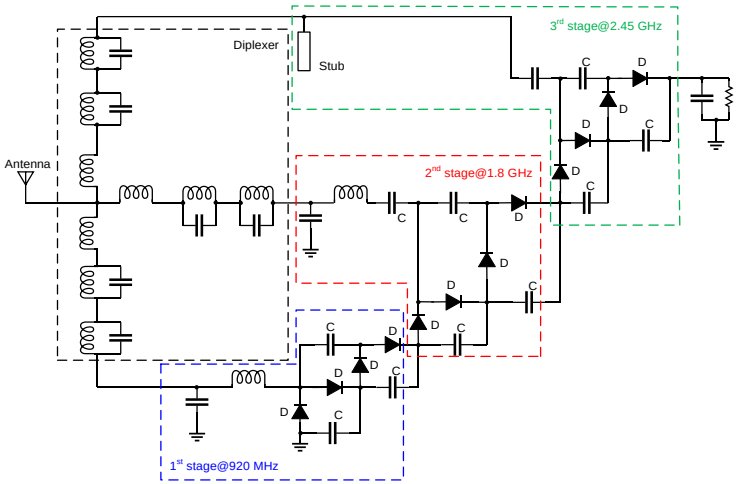


I-V characteristic of the SMS7630 diode

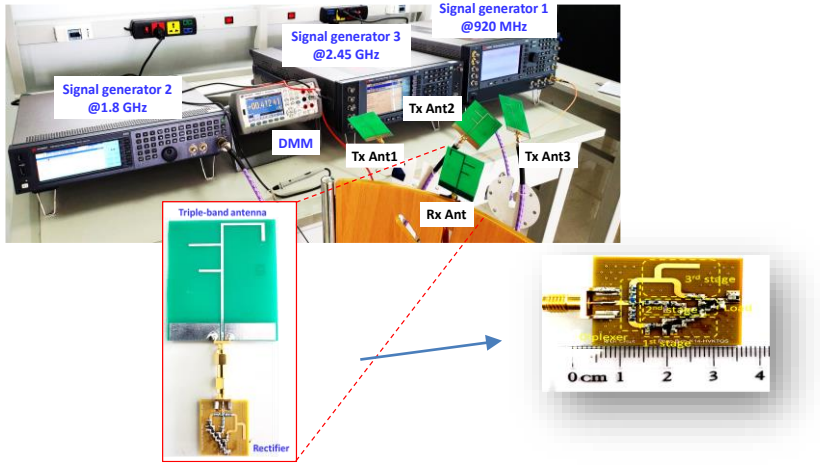
Activity #3: System Hardware Development (Cont.)

- **Activity 3.3: Design a Concurent Triple-band RF Energy Harvesting Circuit for IoT Sensors → Experiments**

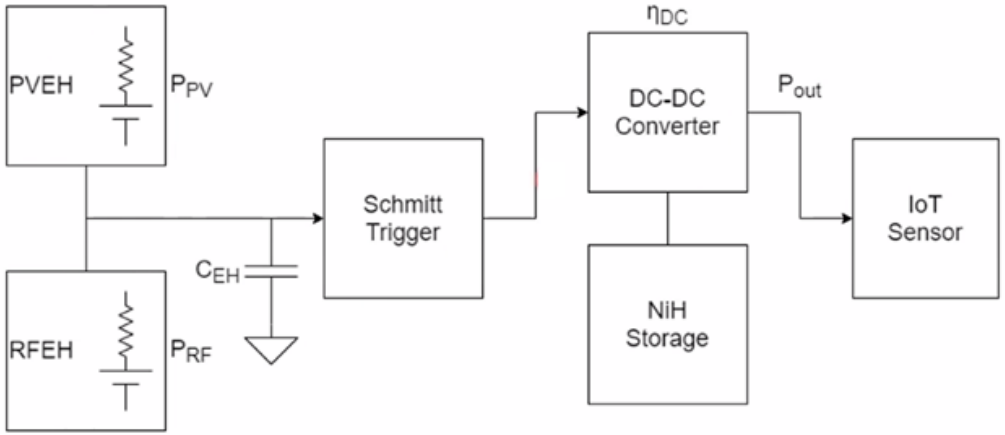
Schematic of the entire RF-EH circuit.



Experimental setup for output DC voltage measurement

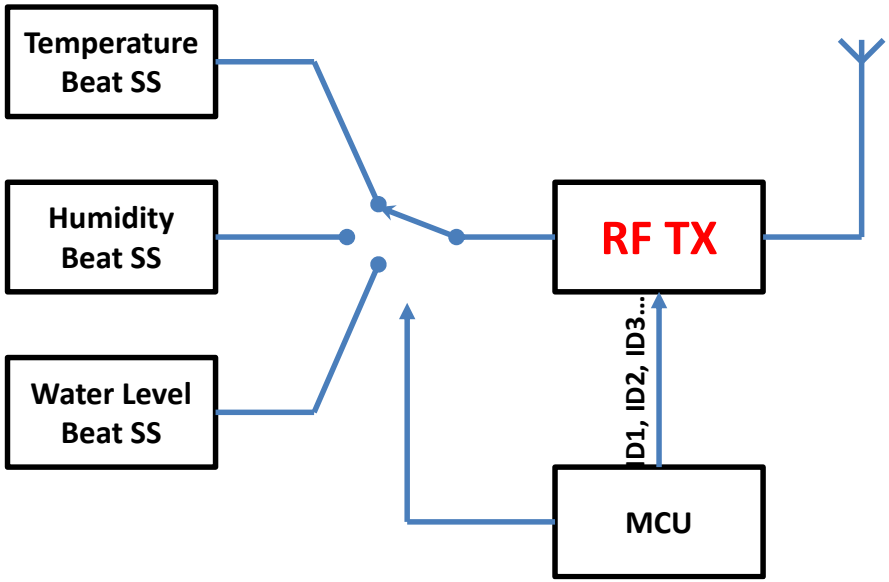


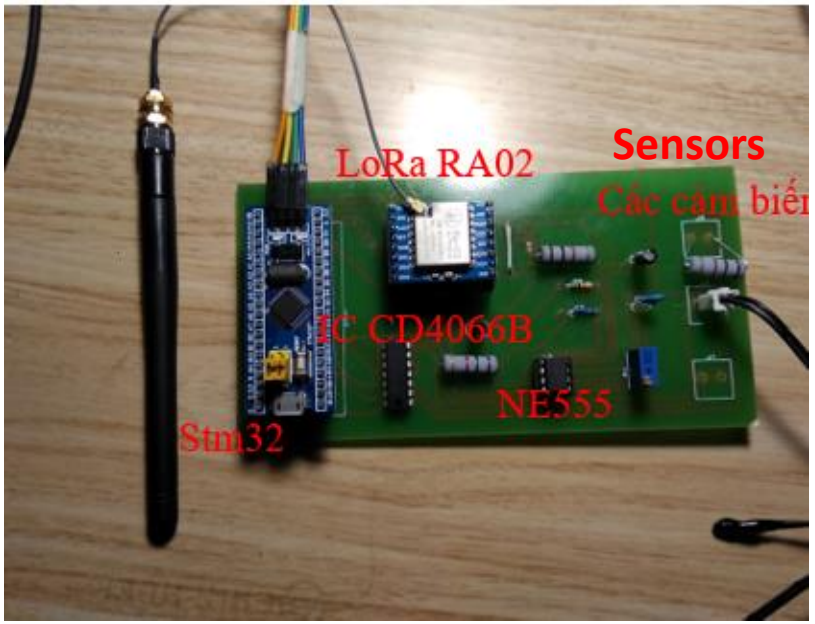
- **Currently: Developing hybrid EH power supply:**

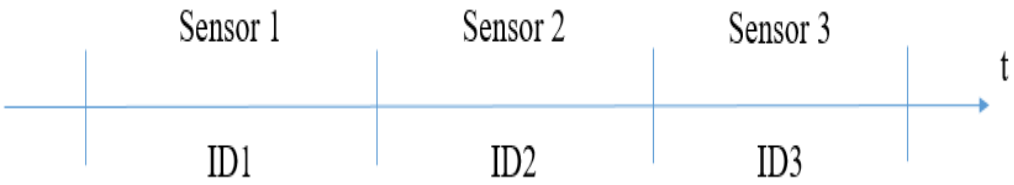


Activity #3: System Hardware Development (Cont.)

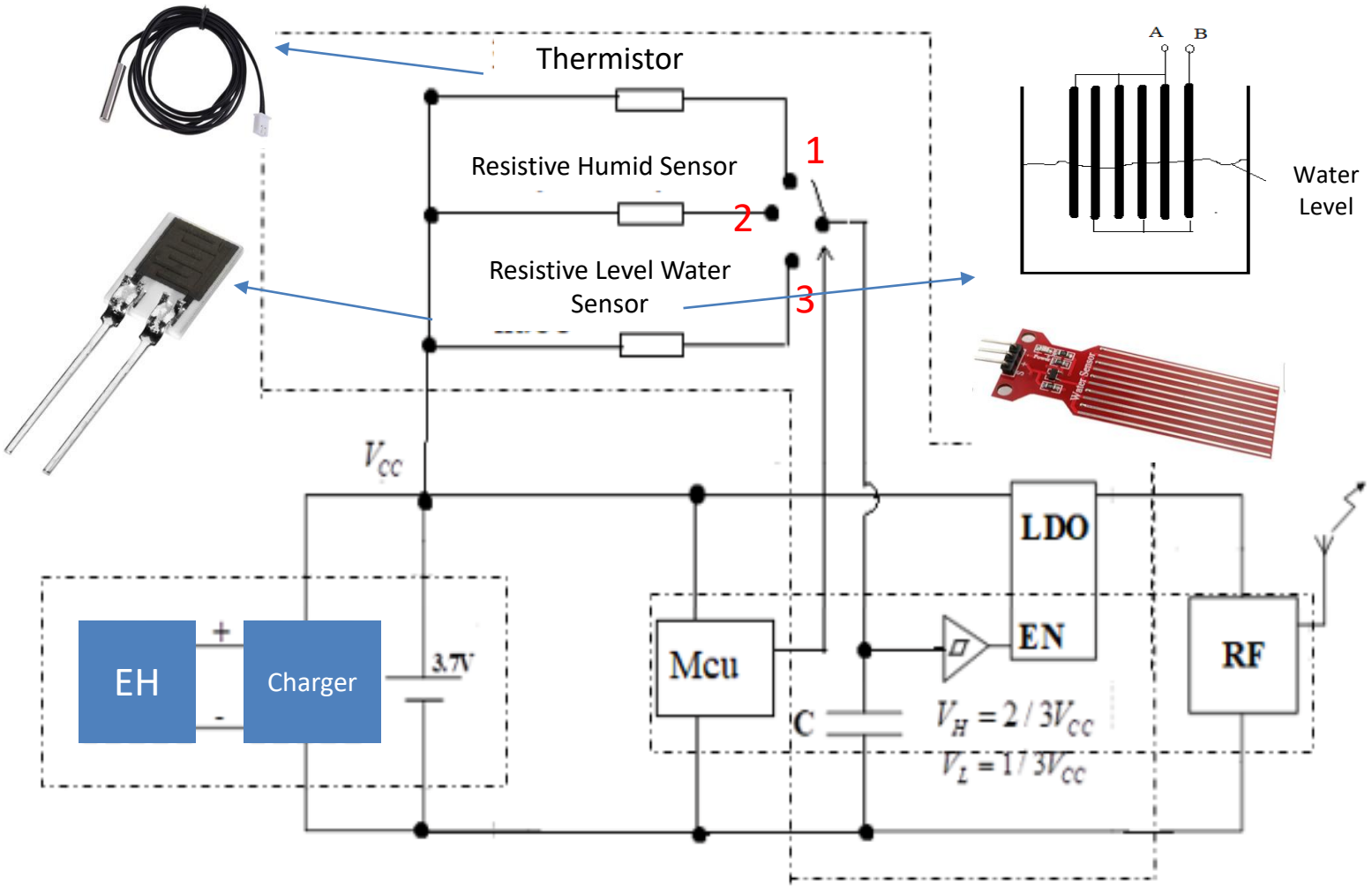
- **Activity 3.4: Multi-Beat Sensor Node with LoRa Powered by RF Energy Harvesting**





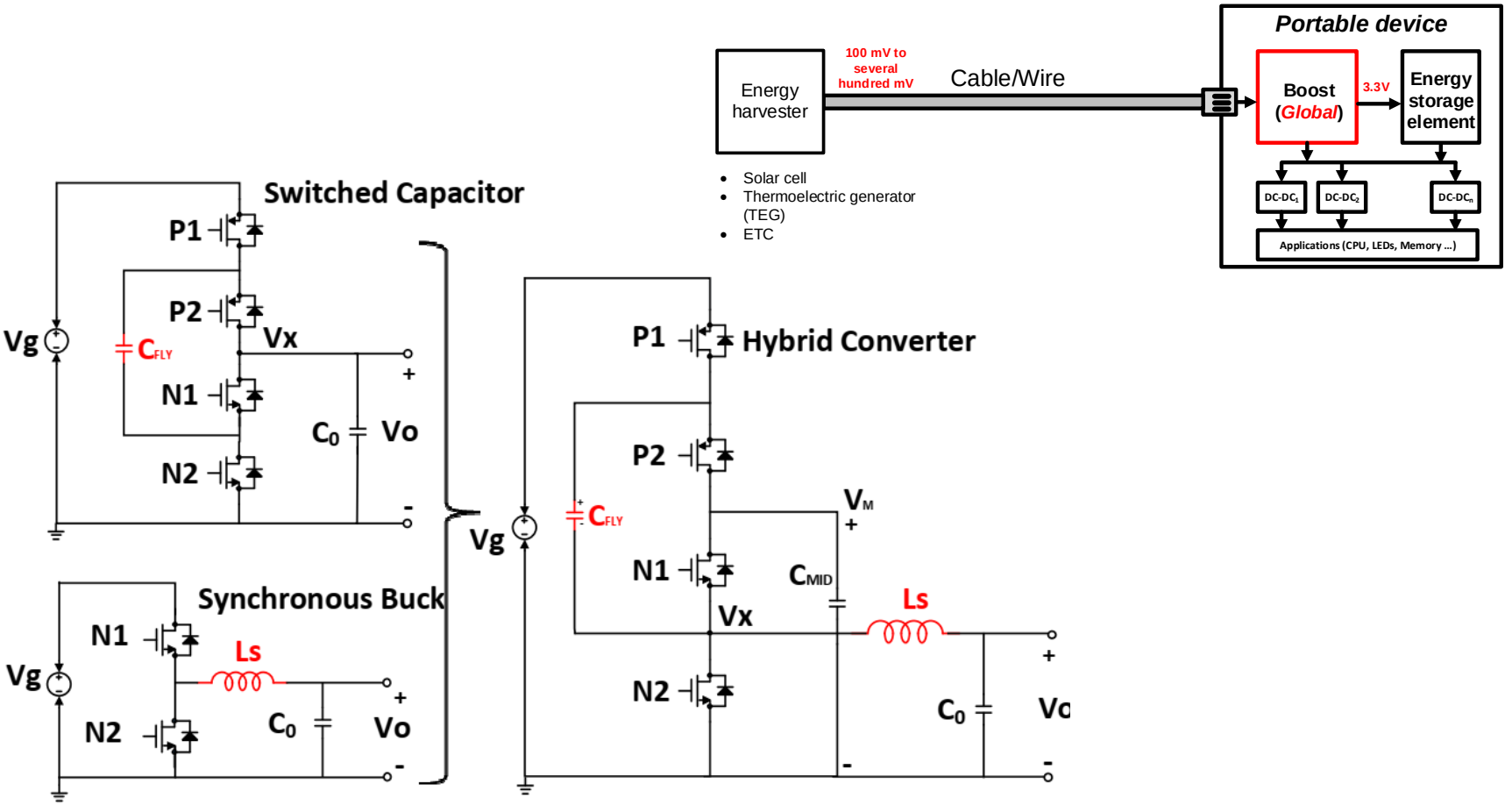


- **Activity 3.4: Multi-Beat Sensor with LoRa Powered by RF Energy Harvesting**



Activity #3: System Hardware Development (Cont.)

- **Activity 3.5: High-efficient DC-DC converter based on hybrid SI-SC topology for portable devices in IoT systems**



Paper #5: Van-Trung Nguyen *et al.*, "High-Efficient DC-DC Converter Based on Hybrid SI-SC Topology for Portable Devices," *2022 International Conference on IC Design and Technology (ICICDT)*, 2022, pp. 36-39.

Activity #3: System Hardware Development (Cont.)

- **Activity 3.5: High-efficient DC-DC converter based on hybrid SI-SC topology for portable devices in IoT systems (cont.)**

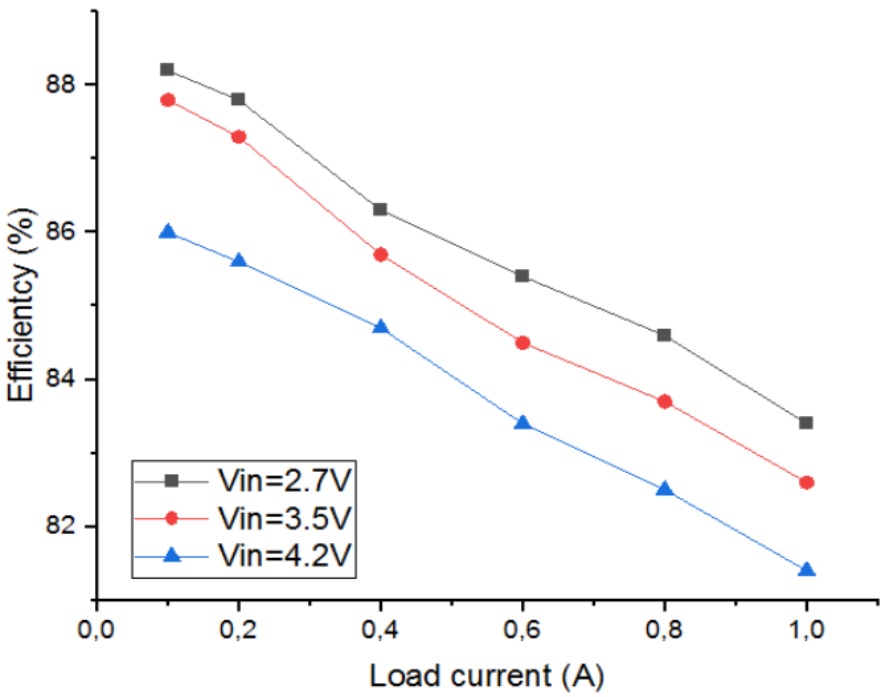


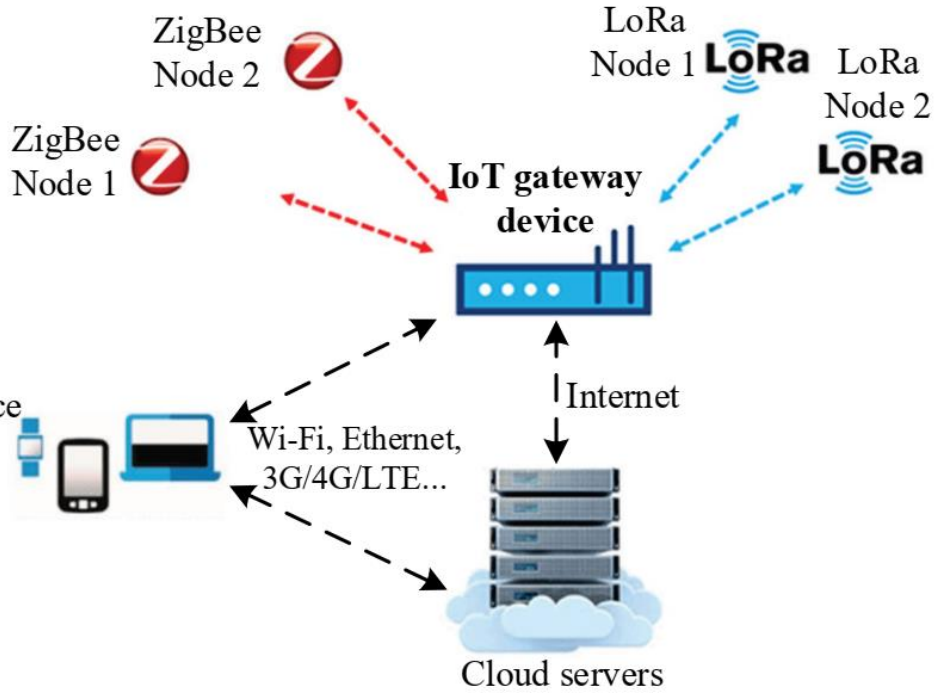
Table 1. Performance comparison to other the state-of-arts

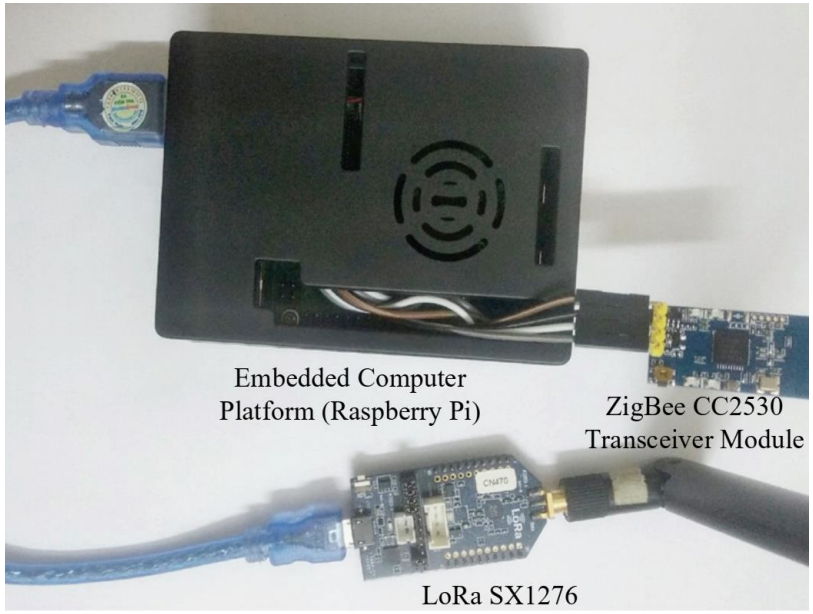
	This work	[9]	[2]	[5]	[3]
Structure	Hybrid SI-SC	3-Level Buck	Soft-Switching Hybrid	Traditional Buck	SC
Process	180nm	65 nm	65 nm	130 nm	28 nm
V_{IN} [V]	2,7÷4,2	5	2.0–2.4	1.2	3.2
V_{OUT} [V]	1÷2	1÷4	0.4–1.2	0.45–1.05	0.95
I_{MAX} [A]	0.1 ÷ 1	0.7	0.25	0.07	0.1
L [nH]	47	100	0.8	11.8	--
C_{FLY} [nF]	20(×2)	6	2	-	1.5
F_{SW} [MHz]	100	50	340	125/250	1600
Peak efficiency [%]	88	-	79.5	71	82
Verification	Simulated	Simulated	Simulated	Measured	Measured

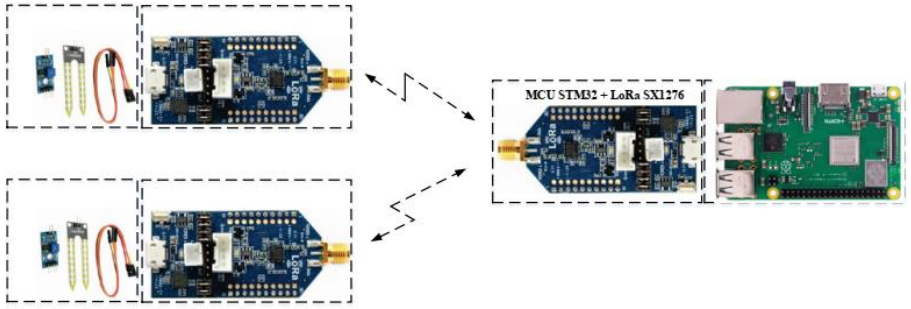
- **Conversion Efficiency: 81.4% - 88.2%**
- **High efficiency at lower V_{in} → suitable for output from energy harvester**

Activity #3: System Hardware Development (Cont'd)

- **Activity 3.5: Build IoT gateway for environment monitoring by combining multiple communication protocols (LoRa, Wi-Fi, Zigbee, 4G/LTE)**

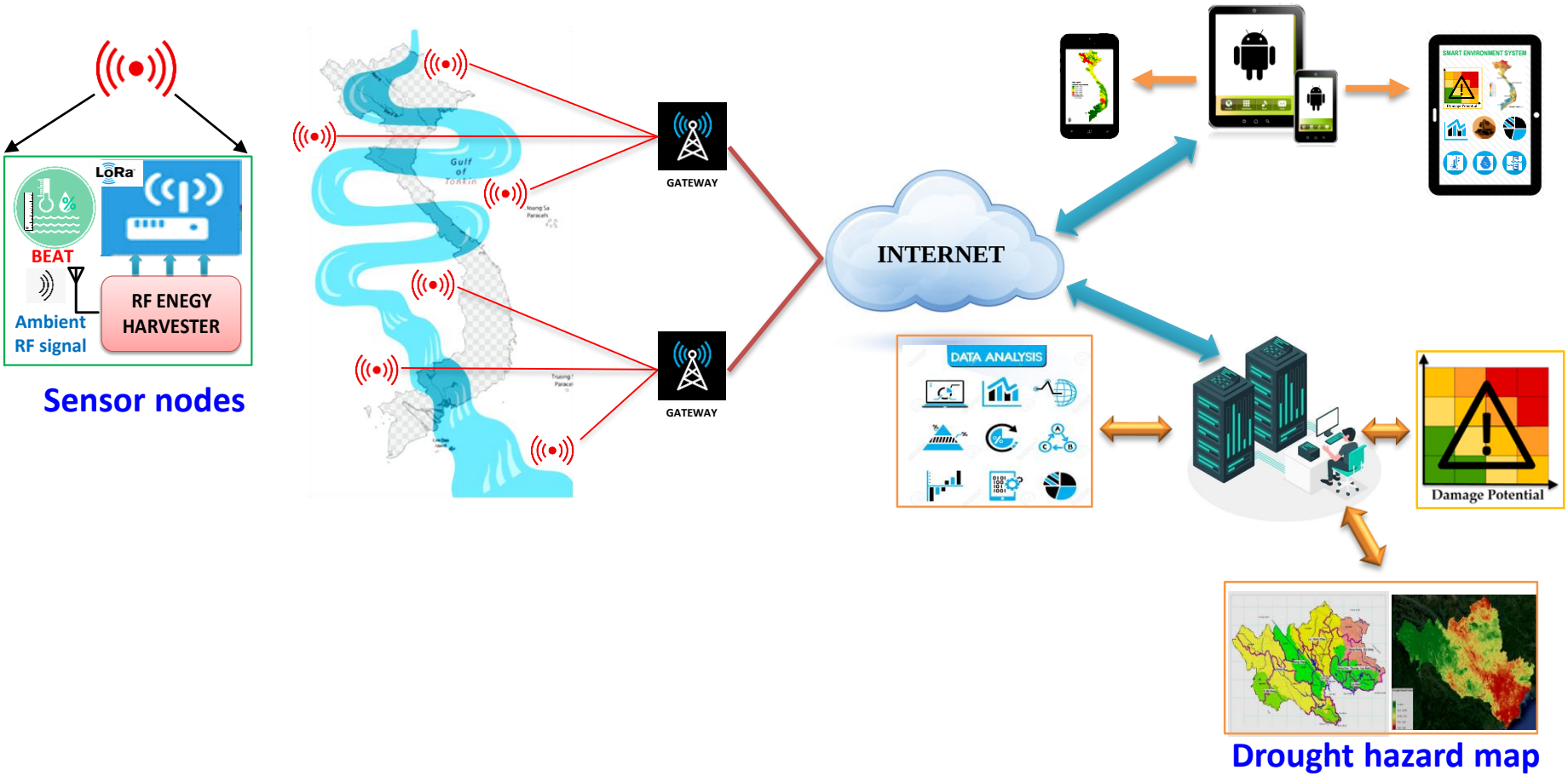






Activity #4: Application Development

- A prototype system with web interface was completed



Paper #6: VP. Hoang, VL. Dao, VT. Nguyen, X.N. Tran, K. Ishibashi, "An Energy Efficient, Long Range Sensor System for Real-Time Environment Monitoring," Lecture Notes on Data Engineering and Communications Technologies, vol. 141, Springer, 2022.

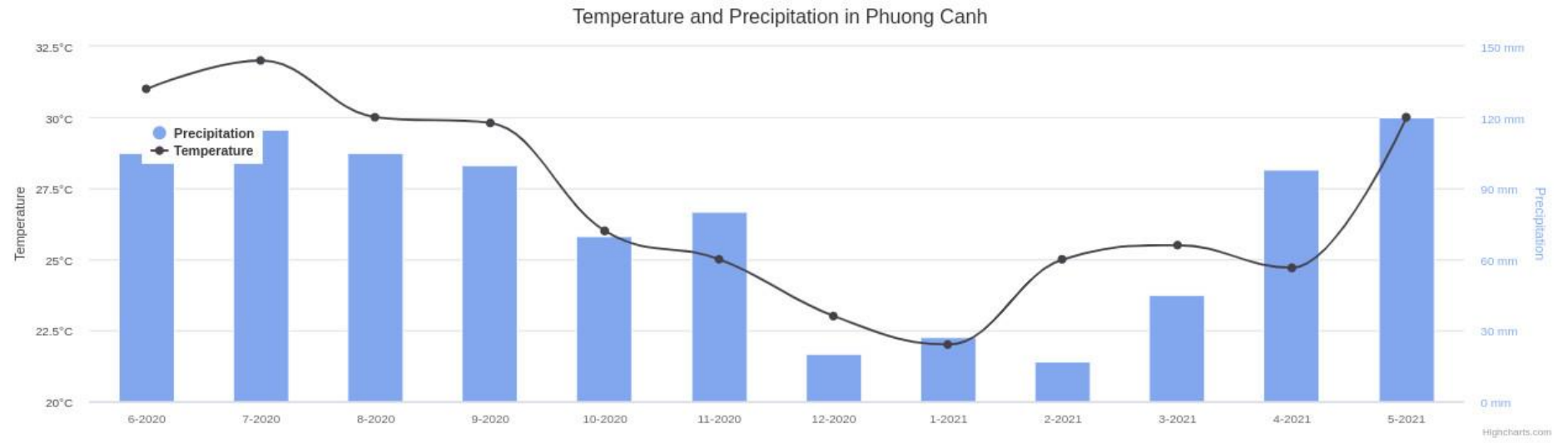
Activity #4: Application Development

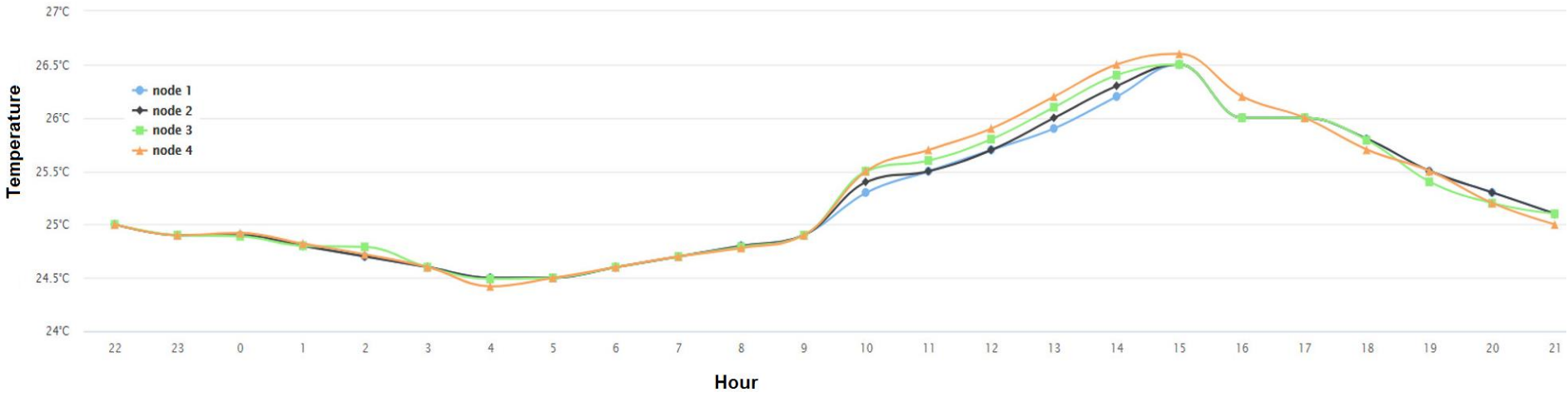
DROUGHT WARNING SYSTEM

Paper #6: VP. Hoang, VL. Dao, VT. Nguyen, X.N. Tran, K. Ishibashi, "An Energy Efficient, Long Range Sensor System for Real-Time Environment Monitoring," Lecture Notes on Data Engineering and Communications Technologies, vol. 141, Springer, 2022.

Activity #4: Application Development

- Some results from the web interface





Publication List

- **[J1] Xuan Nam Tran, Van-Phuc Hoang**, *Ba Cao Nguyen, "Combining RF energy harvesting and cooperative communications for low-power wide-area systems," AEU International Journal of Electronics and Communications, ISSN 1434-8411, vol.139, Sept. 2021.*
- **[J2] Luong Duy Manh**, Phan Thi Bich, **Nguyen Thuy Linh**, Nguyen Huy Hoang, **Xuan Nam Tran** and **Koichiro Ishibashi**, *"A Concurrent Triple-band RF Energy Harvesting Circuit for IoT Sensor Networks," IEEK Transactions on Smart Processing and Computing, vol.10, no.20, April* 2021.
- **[C1]** Van-Binh Dang, Van-Phuc Hoang, and Van-Trung Nguyen, Energy Efficient Temperature Beat Sensor for IoT Based Drought Monitoring Systems, *2nd ASEAN-UEC Workshop on Energy and AI*, Nov. 2020.
- **[C2]** Hung-Nguyen Trong, **Van-Trung Nguyen,** and **Koichiro Ishibashi**, *"A Sub-uW and 14bit Resolution Temperature Sensor for IoT Using Thermistor-Defined TDC," デザインガイア 2021 VLSIの設計/検証/テスト Dec.* 2021.
- **[C3]** Van-Trung Nguyen, Truong Pham, Thu-Hong Luu, Thuy-Linh Nguyen, Huu-Tho Nguyen, Van-Phuc Hoang, Xuan-Nam Tran, Van-Huan Nguyen, and Van-Ha Nguyen, "High-Efficient DC-DC Converter Based on Hybrid SI-SC Topology for Portable Devices," *2022 International Conference on IC Design and Technology (ICICDT)*, 2022, pp. 36-39.
- **[C4]** VP. Hoang, VL. Dao, VT. Nguyen, X.N. Tran, K. Ishibashi, "An Energy Efficient, Long Range Sensor System for Real-Time Environment Monitoring," Lecture Notes on Data Engineering and Communications Technologies, vol. 141, Springer, 2022.

Societal Impact

- For the community, thanks to this proposed water resources monitoring system, the water usage efficiency can be improved when all people understand the current state of water resources.
- For the government organizations, the developed system will provide an efficient tool for water resources management and decision making processes.
- Since the system is designed for low power consumption and using RF energy harvesting, it is environmental friendly.

Conclusions and Future Works

- **Conclusions of key findings:**
  - Novel theoretical evaluation and overall system design.
  - Design low-power consumption sensors.
  - Higher efficiency RFEH and hybrid EH power supply for IoT.
  - High-efficient DC-DC converter for IoT devices.
  - Build IoT gateway for smart monitoring.
  - A prototype system was completed for drought monitoring.

- **Future works:**
  - Build larger scale IoT network for longer range.
  - Higher efficiency RFEH and hybrid EH power supply.
  - Build an application on smart phone for drought monitoring and water resource management database (collaborating with NAWAPI, Vietnam).

Thank you for your attention!