

# Device Adaptive Control Method Considering Power Consumption for Pedestrian-to-Infrastructure Communications

Noriyuki Oki<sup>†</sup>, Atsuki Mukoda<sup>†</sup>, Ayumu Ueda<sup>†</sup> and Takeo Fujii<sup>†</sup>

<sup>†</sup> Advanced Wireless and Communication Research Center (AWCC), The University of Electro-Communications  
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan  
Email: {oki, mukoda, ueda, fujii}@awcc.uec.ac.jp

**Abstract**—The current pedestrian recognition technology used for autonomous driving of automated vehicles faces a problem in that it is difficult for the vehicle to recognize pedestrians in response to changes in the surrounding environment, such as bad weather or structures. Therefore, to share location data between the pedestrian device and the vehicle using wireless communications technology can improve pedestrian recognition ability. There is a need for technology that enables mutual recognition without being affected by influence of the surrounding environment. The pedestrian device used for location data sharing must acquire location data by global positioning system (GPS) and transmit the information using wireless communication technologies such as wireless LAN (WLAN). However, although the small size and long battery life are desirable for pedestrian devices, the power consumption of the GPS and WLAN modules is large. Therefore, the increase in the power consumption of pedestrian devices has become a problem. This paper proposes a method for pedestrian devices to adaptively determine when to start using GPS and when to start communicating with roadside units (RSUs), to reduce the power consumption of pedestrian devices.

**Index Terms**—Energy Consumption, LoRaWAN, Wireless LAN, Pedestrian-to-Infrastructure communications

## I. INTRODUCTION

In automated driving, which has been the focus of much attention in recent years, there is active discussion of fully automated driving, not just safe driving support for the driver. In order to realize fully automated driving, safety must be sufficiently guaranteed, and in particular, the prevention of traffic accidents involving pedestrians is required. For this reason, technologies that enable vehicles to recognize surrounding pedestrians are being actively researched. Automatic driving can be broadly divided into "autonomous" and "cooperative" systems. Autonomous systems use the vehicle's built-in sensors to recognize their surrounding environments. On the other hand, cooperative systems use wireless communications to recognize their surrounding environments by sharing information with surrounding vehicles and roadside units (RSUs). When autonomous systems recognize pedestrians, they are easily affected by the surrounding environment and may not be able to recognize their surroundings accurately. If we use a cooperative system, we may obtain information on blind spots through wireless communications, which enables prior recognition of pedestrians. Therefore, the study of pedestrian

recognition using wireless communications has been focused [1].

Many pedestrians acquire their location information by global positioning system (GPS) and share it through wireless communications technology. The device built-in GPS and wireless LAN (WLAN) modules are becoming smaller and smaller, and compact devices specialized for location sharing are also being developed [2]. Such devices should have a low battery replacement interval. However, it has been reported that the power consumption of the wireless LAN and GPS modules is large, and the increase in the power consumption becomes an issue during constant use [3], [4].

This paper proposes the method by which the pedestrian device adaptively determines when to start using GPS and when to start communicating with RSUs to reduce the power consumption of the pedestrian device. In this method, a pedestrian device periodically sends beacons using LoRaWAN, and a RSU that receives beacons sends packets back to the pedestrian device. The RSU sends information necessary for WLAN communications to the pedestrian device. In this case, by controlling the operation of the device's built-in LoRaWAN module, GPS module, and WLAN module based on the positional relationship between the pedestrian and the RSU, the system can be used for location data sharing. We confirmed that the power consumption of the pedestrian device during location data sharing can be reduced.

This paper is organized as follows. Sect. II describes the proposed method. Sect. III explains the details of the measurement campaign. Then, the simulation result of the proposed method using measurement data is shown in Sect. IV. Finally, we conclude this paper in Sect. V.

## II. PROPOSED METHOD

### A. System model

Fig. 1 presents the overview of vehicle-to-pedestrian (V2P) communications via a RSU. V2P communications can be approximated by having a RSU and a vehicle, and a RSU and a pedestrian communicate with each other and share the information received by a RSU. A RSU refers to the communications device installed in infrastructure such as traffic signals. A Pedestrian holds a communication device (e.g., smartphone) and move into the intersection from a non-line-of-sight point

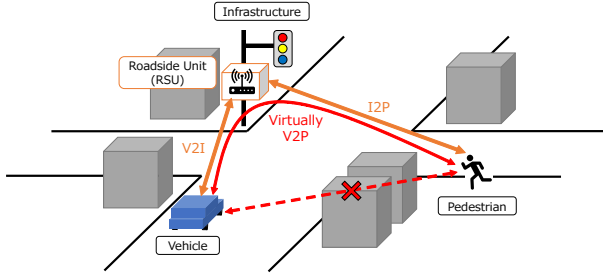


Fig. 1. An overview of V2P communications via RSU.

for a vehicle. It is assumed that there are structures between a vehicle and a pedestrian and that direct communication is not possible. In this case, we would like to discuss that the location of a vehicle and a pedestrian is shared via a RSU in order to avoid collisions with each other. This paper considers the situation in which pedestrian locations are provided to vehicles in order to prevent collisions. The details of the roadside unit and the pedestrian are summarized below.

1) *Roadside Unit*: The RSU is possible that communications via WLAN and LoRaWAN. It functions as an access point (AP) for WLAN and as a gateway (GW) for LoRaWAN. It is connected to the backbone network and can determine the location of vehicles in the vicinity.

2) *Pedestrian*: The device held by a pedestrian is possible that communicate via WLAN and LoRaWAN. It functions as an end device for WLAN and LoRaWAN. It obtains the location data using the device's built-in GPS. By the way, the measurement error of GPS is not taken into account.

### B. Operation of RSU and pedestrian device

This paper focuses on communications between a pedestrian and a RSU. Communications between a pedestrian and a RSU provide a RSU with the pedestrian location data. However, constant communications, communications via WLAN, and location data acquisition via GPS consumes large amounts of power. Therefore, the device held by a pedestrian should be controlled appropriately for the place, and information should be transmitted when a pedestrian approaches a RSU.

Fig. 2 shows the concept of the proposed method and Fig. 3 shows the algorithm of the proposed method. In this method, LoRaWAN is used when a pedestrian and a RSU are far apart in order to achieve power savings. The pedestrian device periodically sends a request beacon over LoRaWAN to the surrounding RSUs; when a RSU receives a beacon from the pedestrian device, it sends information about itself to the pedestrian device. This information includes the latitude and longitude of the RSU, SSID, channel, and coverage of the RSU's built-in WLAN AP; the amount of information that can be transmitted over LoRaWAN is discussed in the next subsection. Once the pedestrian device receives a response from the RSU, the pedestrian device activates the GPS module and deactivates the LoRaWAN module. If the pedestrian device detects its approach to the RSU using the RSU information and GPS data, it activates the WLAN module when it enters the

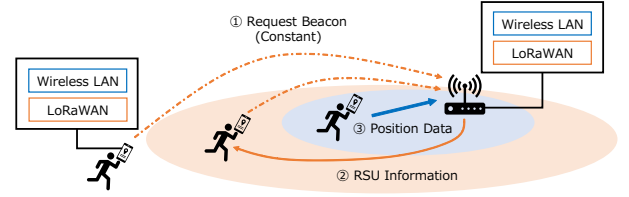


Fig. 2. The concept of proposed method.

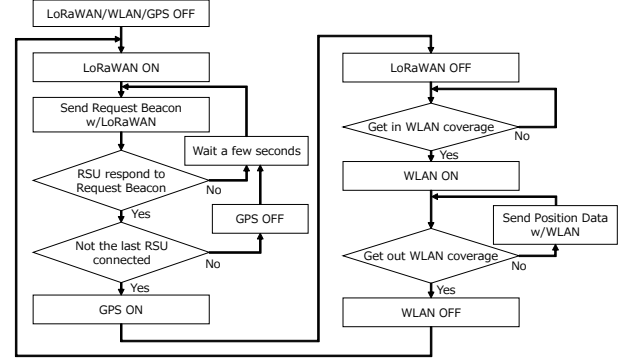


Fig. 3. The algorithm of proposed method.

coverage of the WLAN, and transmits its location data. When it leaves the coverage of the WLAN, the WLAN module shall be deactivated and the LoRaWAN module shall be activated again. If the RSU that responded to the request beacon of the pedestrian device is different from the last connected RSU, the approach to the RSU shall be detected in the order described earlier. If not, the GPS module is deactivated and periodic request beacons are sent until a connection can be made with a different RSU. As described above, power saving is achieved by using different internal modules depending on the proximity to the RSU.

### C. Data transmitted by LoRaWAN

This method assumes that the RSU's built-in LoRaWAN GW transmits its information to a pedestrian device when a RSU received a request beacon with LoRaWAN from a pedestrian. Then, we should consider data size with LoRaWAN. The RSU provides a pedestrian device with the latitude  $R_{lan}$  [byte] and longitude  $R_{log}$  [byte] of the RSU, SSID  $W_{ssid}$  [byte] and channel  $W_{ch}$  [byte] of the RSU's built-in WLAN AP, and WLAN coverage on the  $i$ th road  $W_{cover}^i$  [byte]. The data size  $D$  [byte] transmitted to the pedestrian device is represented by the following equation:

$$D = R_{lan} + R_{log} + W_{ssid} + W_{ch} + \sum_{i=1}^{N_{road}} W_{cover}^i \text{ [byte]}, \quad (1)$$

where  $N_{road}$  is the number of road.

Assuming that latitude and longitude are provided in decimal degrees, location information can be provided with an accuracy of approximately 1 [m] on the equator if provided to the fifth decimal place, and with an accuracy of approximately 10 m on the equator if provided to the fourth decimal place.

TABLE I  
MAXIMUM DOWNLINK PAYLOAD SIZE IN AS923  
(REPEATER COMPATIBLE) [9]

SF	Payload size [byte] (No limit)	Payload size [byte] (Dwelltime)
12	59	N/A
11	59	N/A
10	123	19
9	123	61
8	230	133
7	230	230

Since the earth is a rotating ellipsoid, the accuracy of position information increases as it approaches the poles. RSUs are fixed and are not densely installed in the vicinity. Therefore, if a RSU can provide  $R_{\text{lan}}$  and  $R_{\text{log}}$  with an accuracy of at most 10 [m] (i.e., to the fourth decimal place), a pedestrian device can uniquely identify a RSU. In this case,  $R_{\text{lan}}$  and  $R_{\text{log}}$  can be expressed with 7 [byte] each. On the other hand,  $W_{\text{cover}}^i$  needs to be determined empirically, considering the radio propagation characteristic due to the influence of surrounding structures.

For this determination, it is effective to utilize a radio environment database, which has been attracting attention as a high-precision radio propagation estimation method [8]. The radio environment database is constructed from radio environment information observed by mobile devices equipped with observation functions at surrounding points. Statistical processing using the observed data in the database can be used to determine the location of the reception limit. If a more precise WLAN coverage can be provided at this time, pedestrian devices can activate the module at the appropriate location, and power saving can be expected. Therefore, it is desirable to provide location information for each road with an accuracy of approximately 1 [m] (i.e., to the fifth decimal place). Each  $W_{\text{cover}}^i$  is represented by 8 [byte], with the data size increasing with the number of roads present.  $W_{\text{ch}}$  can be represented by 3 [byte].  $W_{\text{ssid}}$  varies depending on the length of the string. Based on the above, depending on the number of roads supported by a RSU and the length of the SSID, the data size may be too large to be transmitted over LoRaWAN.

The data size that can be transmitted over LoRaWAN depends on the spread factor (SF) [9]. Table I summarizes the maximum downlink MAC payload size that can be transmitted by each SF. Here, this paper summarizes the contents of the AS923 ISM (Industry, Science, Medical) band (915–928 [MHz]), which is allowed to be used in Japan. Note that the data size that can be transmitted differs depending on the presence or absence of transmission constraints. The table shows that SF 7 can transmit 230 [byte] even with transmission constraints. Even if the SSID is represented by 8 characters, we will consider using SF 7 in this paper because it can transmit  $W_{\text{cover}}^i$  for more than 10 roads.

### III. LORAWAN MEASUREMENT CAMPAIGN

We measured the transmission characteristics of LoRaWAN to evaluate the proposed method by simulation considering a

TABLE II  
MEASUREMENT PARAMETERS

Communication standard	ARIB STD-T108 [6]
Center frequency [MHz]	920
Bandwidth [kHz]	125
Transmission power [dBm]	13
Modulation format	LoRa
Spread factor (SF)	7
Transmission interval [s]	10
Transmitter height [m]	3

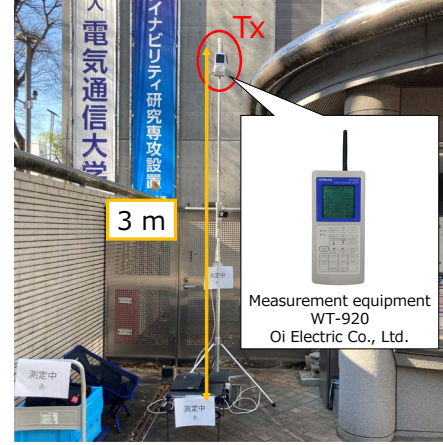


Fig. 4. The installation of transmitter.

real environment. The measurement was performed in Chofu City, a typical suburban area in Tokyo, Japan on December 24, 2021. Two pieces of equipment for 920 [MHz] band were prepared, one as a transmitter and the other as a receiver. The transmitter was mounted on a pole so that the antenna height was 3 [m] shown in Fig.4 and located at the yellow point shown in Fig.5. The receiver was mounted on a backpack. We carried the backpack and walked on the red line shown in Fig.5 to measure the signal from the transmitter. In the measurement, the received signal strength indicator (RSSI), reception point, and packet delivery rate (PDR) were observed in each location. The measurement equipment is WT-920 from Oi Electric Co., Ltd. The communication standard is IEEE 802.15.4-based method called ARIB STD-T108, which is developed for 920 [MHz] band telemeter, telecontrol, and data transmission radio equipment by the Association of Radio Industries and Businesses (ARIB) [6]. Table II is the measurement parameters.

Fig. 6 presents the radio map in the measurement area. The radio map is the two-dimensional mesh map by statistically processes the observed data for each mesh. Here, the mesh size is 10 [m]. Fig. 6(a) expresses that the average RSSI when the transmitter is located in the black mesh corresponds to the yellow point shown in Fig. 5. Fig.6(b) expresses the PDR when the transmitter is located in the transmission mesh. In this result, it was confirmed that it is difficult to receive the signal from the transmitter in a non-line-of-sight environment. On the

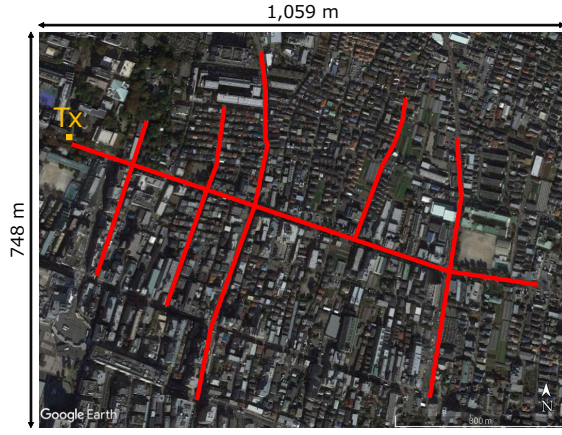


Fig. 5. The measurement route.

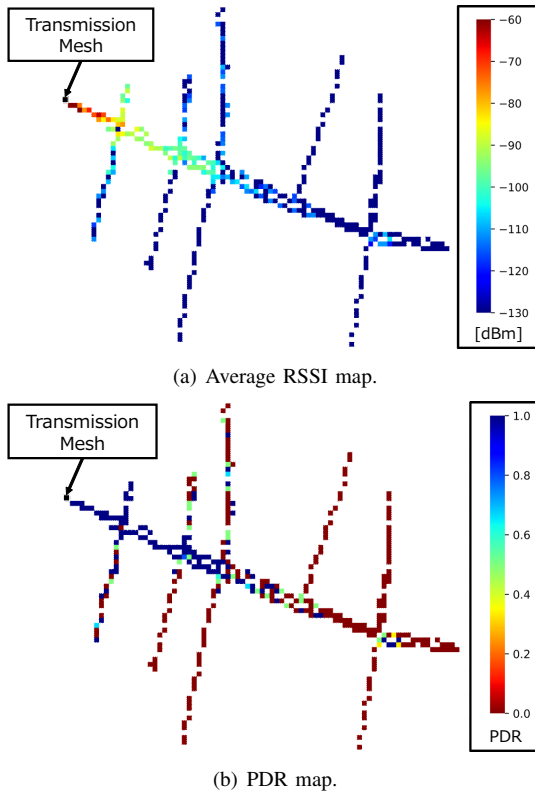


Fig. 6. The radio map using observed data.

other hand, as shown in Fig. 7, in a line-of-sight environment, the PDR was generally 50 % or higher at a distance of approximately 500 [m] from the transmitter. The results were smaller than the expected coverage due to the heavy traffic and tree-lined streets in the measurement environment.

#### IV. SIMULATION

##### A. Setup

Fig. 8 shows the simulation model. This paper assumes the one-dimensional environment as the initial study and calculates the cumulative power consumption of the pedestrian

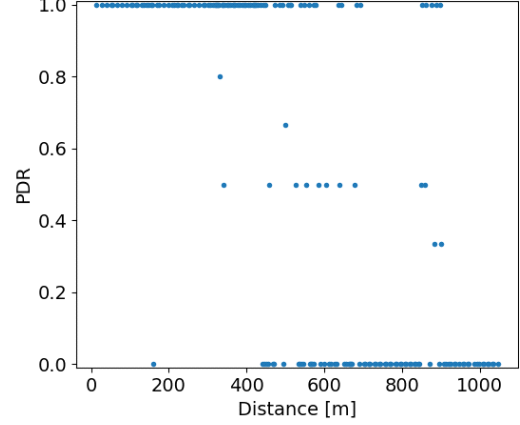


Fig. 7. The relation between distance and PDR in line-of-sight environment.

device as the pedestrian moves. The distance that the pedestrian walks is  $L$  [m], and the RSU is located at  $L/2$  [m]. The communication distance of the RSU's built-in LoRaWAN is  $l$  [m] and the coverage of the RSU's built-in WLAN is  $w$  [m]. It is assumed that when the pedestrian enters the coverage of the various communication scheme, the pedestrian device can activate the corresponding communication module and communicate with the RSU.

Table III shows the simulation parameters. Based on the measurement results, three different LoRaWAN coverage  $l$  (200, 500, 800 m) are used to understand the change in the cumulative power consumption at each value. However, packet errors are not considered in this paper. The power consumption for each communication module is calculated based on the author's actual measurements. The coverage of the WLAN  $w$  is also calculated based on the author's actual measurements in the same way, and this is included in the transmission content when the RSU's built-in LoRaWAN responds to the pedestrian request beacon.

As a comparison method, we consider the case where the pedestrian device is not equipped with a LoRaWAN module. Since the RSU information is not available in advance and it is not possible to figure out when to activate the various modules, it is assumed that the GPS and WLAN modules are activated throughout.

##### B. Results

Fig. 9 shows that the cumulative power consumption of the proposed method is smaller than that of the comparison method. The proposed method has a slower increase in the cumulative power consumption, especially when only the GPS module is activated (i.e., before and after entering the coverage of the WLAN). Since the power consumption of the GPS and WLAN modules is larger than that of the LoRaWAN module, we were able to significantly reduce the power consumption by setting them to sleep outside the LoRaWAN coverage. On the other hand, in the situation when communicating via WLAN (i.e., within the WLAN coverage), the proposed



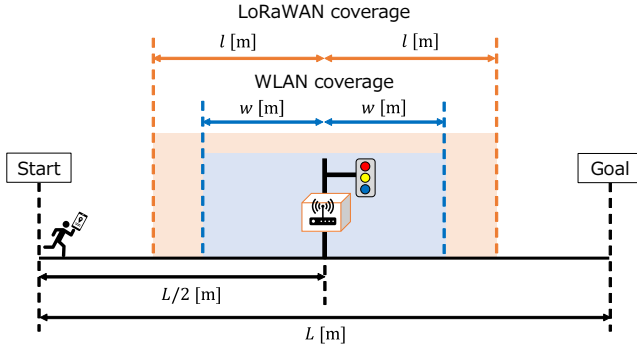


Fig. 8. The simulation model.

TABLE III  
SIMULATION PARAMETERS

(a) LoRaWAN	
Coverage $l$ [m]	200, 500, 800
Center frequency [MHz]	920
Bandwidth [kHz]	125
Transmission power [dBm]	13
Modulation format	LoRa
Spread factor (SF)	7
Power consumption (sleep) [mW]	107.5
Power consumption (transmit) [mW]	107.5
Power consumption (receive) [mW]	161.0
Beacon Interval [s]	150
(b) WLAN	
Coverage $w$ [m]	86
Center frequency [MHz]	2400
Bandwidth [MHz]	20
Transmission power [dBm]	10
Modulation format	OFDM
Power consumption (sleep) [mW]	0.45162
Power consumption (transmit) [mW]	476.10
Power consumption (listen/receive) [mW]	526.89
(c) Others	
Walking distance $L$ [m]	5000
Walking speed [m/s]	1.33
Power consumption (GPS) [mW]	230.8

method showed a greater tendency to increase the power consumption. This is simply because the LoRaWAN module is also in the sleep state in the proposed method while the WLAN and GPS modules are on in the comparison method. The cumulative power consumption of the proposed method at the end of walking in each LoRaWAN coverage was 533.4, 637.3, and 741.1 [mWs], respectively. The cumulative power consumption of the comparison method was 2834.9 [mWs], which is about 78 % less than that of the LoRaWAN with a coverage of 500 [m].

## V. CONCLUSION

In this study, we proposed the device control method using LoRaWAN to reduce the power consumption of devices in location data sharing. Using computer simulations based on actual measurements of LoRaWAN communications and the power consumption of each module, we confirmed that the

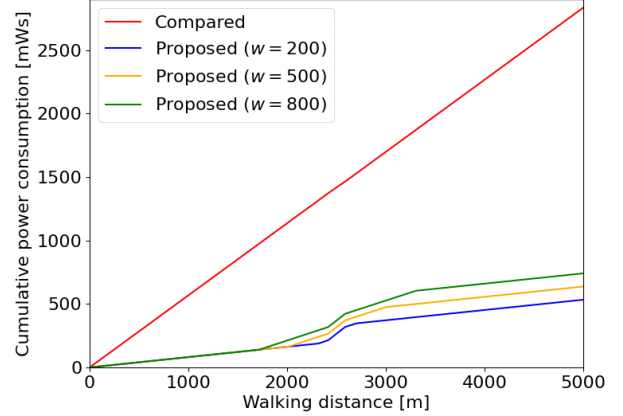


Fig. 9. The simulation results.

power consumption of pedestrian devices can be reduced through adaptive device control based on the location between pedestrians and RSUs.

If this method will be implemented in small goods (e.g., key fobs), it is possible to prevent traffic accidents at intersections involving the elderly and children at low cost and for a long time. However, in real-world situations, such as when RSUs are far apart from each other, there are likely to be situations in which responses from the RSUs cannot be received for long periods. Therefore, it is necessary to consider when to stop sending response request beacons when responses from RSUs cannot be received.

## ACKNOWLEDGMENT

This work was supported by JSPS KAKENHI Grant Numbers 18KK0109, 21H01322.

## REFERENCES

- [1] P. Ho et al., "WiSafe: Wi-Fi pedestrian collision avoidance system," *IEEE Trans. on Vehicular Technology*, vol. 66, no. 6, pp. 4564–4578, Jun. 2017.
- [2] A. Bahillo, I. Angulo, E. Onieva, A. Perallos and P. Fernández, "Low-cost Bluetooth foot-mounted IMU for pedestrian tracking in industrial environments," in *Proc. 2015 IEEE ICIT*, 2015, pp. 3430–3434.
- [3] P. K. D. Pramanik et al., "Power consumption analysis, measurement, management, and issues: A state-of-the-art review of smartphone battery and energy usage," *IEEE Access*, vol. 7, pp. 182113–182172, Dec. 2019.
- [4] X. Li et al., "Measurement and analysis of energy consumption on Android smartphones," in *Proc. 2014 4th IEEE ICIST*, Shenzhen, China, Oct. 2014, pp. 242–245.
- [5] S. E. Efimov et al., "Research LoRaWAN Collide Signals with Used SDR", in *Proc. 2021 WECONF*, St. Petersburg, Russia, 7 July 2021.
- [6] ARIB STD-T108: 2021. 920MHz-band telemeter, telecontrol, and data transmission radio equipment version 1.4. Association of Radio Industries and Businesses.
- [7] LoRa Alliance, "LoRaWAN® Specification v1.1," Oct. 2017, [online] Available: [https://loro-alliance.org/resource\\_hub/lorawan-specification-v1-1](https://loro-alliance.org/resource_hub/lorawan-specification-v1-1).
- [8] S. Bi, J. Lyu, Z. Ding, and R. Zhang, "Engineering radio maps for wireless resource management," *IEEE Wireless Communications*, vol. 26, no. 2, pp. 133–141, Feb. 2019.
- [9] LoRa Alliance, "RP2-1.0.1 LoRaWAN® Regional Parameters," Feb. 2020, [online] Available: [https://loro-alliance.org/resource\\_hub/rp2-101-lorawan-regional-parameters-2/](https://loro-alliance.org/resource_hub/rp2-101-lorawan-regional-parameters-2/).