Extending IP connectivity to non-electrified areas by combining LPWA and autonomous vehicles

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Abstract: Japan is a country where forests cover 70% of the land. Although smart forestry using IoT devices is being implemented, but its diffusion is limited due to the poor availability of power sources and the lack of mobile network base stations. Cell phone base stations require licenses and government permits for installation, and the costs of installation, operation, and removal are expensive. Even tower-type mobile base stations installed in the suburbs have a coverage area of only about 10 km, so even though the population coverage rate has already reached over 99%, the area coverage rate is still less than 70% for all carriers. The purpose of this research is to establish a method to extend Internet Protocol (IP) connectivity to non-electrified areas by patrolling autonomous vehicles using Low Power Wide Area (LPWA) communication systems, especially IEEE802.11ah as the core. and standardize new communication methods.

1. Background and objective

A sustainable city or district is called a “smart city” if it is managed and optimized as a whole while utilizing new technologies such as ICT to address various urban issues. As a result of these efforts, urban areas become more convenient, while depopulated areas (rural areas) become relatively less convenient. This exacerbates the concentration of population in urban areas, which makes it difficult to sustain smooth economic activities, especially in the event of a major disaster. In order to alleviate the concentration of population in urban areas, measures to increase the convenience of rural areas are inevitably proposed. A sustainable city or district where the various problems faced by urban areas are managed and optimized as a whole through the use of new technologies such as ICT is called a ”smart rural” .

Japan is a country where forests cover 70% of the land, and smart forestry using IoT devices is being implemented, but its diffusion is limited due to the poor availability of power sources and the lack of mobile network base stations. This is partly due to the chicken-and-egg relationship between the use of mobile networks and the development of base stations in non-electrified areas. Cell phone base stations require licenses and government permits for installation, and the costs of installation, operation, and removal are expensive. Even tower-type mobile base stations installed in the suburbs have a coverage area of only about 10 km, so even though the population coverage rate has already reached over 99%, the area coverage rate is still less than 70% for all carriers.

IP connectivity is a prerequisite for achieving smart rural. However, as mentioned above, the installation, operation, and removal costs of mobile network base stations are expensive. Wireless LANs are less expensive in terms of these costs. Wireless LAN access points (APs) have the advantage of low cost in terms of both price and power consumption. However, the cost of manually installing, operating, and removing APs in forested or mountainous areas where mobile network signals do not reach is low compared to the cost of mobile network base stations, but is high enough in absolute terms. In addition, the coverage of a single AP in a wireless LAN is sufficiently narrow compared to that of a single base station in a mobile network that uses high power.

It is possible to expand coverage by constructing a mesh network with multiple APs. However, changes in environmental conditions between APs are expected to deteriorate communication quality. Although it is possible to cope with environmental changes by shortening the distance between APs or increasing the radio wave output of APs, it is difficult to do so in locations that are inaccessible and where the AP locations are fixed. In order to reduce operational costs, it is foreseeable that security vulnerabilities of APs will be left unaddressed. APs installed in difficult-to-reach locations may also be abandoned due to high removal costs, and there are concerns about the negative environmental impact of the large number of discarded APs.

The purpose of this research is to establish a method to extend Internet Protocol (IP) connectivity to non-electrified areas by patrolling autonomous vehicles using Low Power

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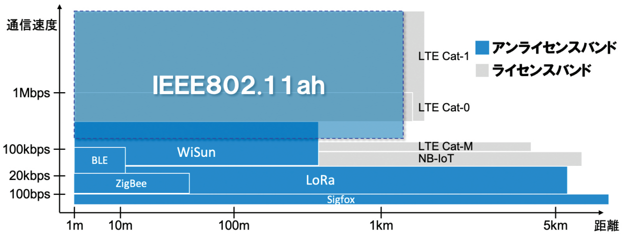

Fig. 1 Differences between communication standards for IoT devices and IEEE802.11ah.

Wide Area (LPWA) communication systems, especially IEEE802.11ah as the core. and standardize new communication methods.

2. Methodologies

The problems in extending IP connectivity to non-electrified areas described in the previous section can be summarized into the following three categories:

(1) High installation, operation, and removal costs

(2) Narrow wireless LAN coverage/low mesh network throughput

(3) Constraints associated with poor power supply

To solve these problems, the proponents of this research propose a model in which a portable node, consisting of a mobile part with autonomous mobility and a communication system part using LPWA, is designed, and the portable node travels in a closed path drawn in a single stroke to cover the area where the IP is to be extended. We also consider providing network services using the **Local Area Computing and Network Resources Group (LACNRG)** possessed by the portable nodes.

LPWA such as WiSun[*1], ZigBee[*2], LoRAWAN[*3], and Sigfox[*4] have already been widely used since the mid-2010s, and IEEE802.11ah is expected to be approved in 2022, and modules with a technical qualification mark will be available in 2023 (see Figure 1 below). Therefore, in this paper, communication technology that mixes and matches existing standards as LPWA and IEEE802.11ah in the right places is called **heterogeneous type and heterogeneous performance communication technology (H2CT)**.

In this paper, the method is classified into three major categories, and we attempt to solve the problem with an approach that has three sub-categories each as follows.

2.1 Design of the mobility with digital twin and LACNRG operation model

2.1.1 Mathematical modeling of the mobile part in response to dynamic changes in environmental conditions

In this research and development, the mobile units on which the AP will be mounted are assumed to be drones (unmanned aerial robots) and multi-legged robots. These robots have the ability to move autonomously at high speeds, and their distance from the user of the AP and their geographical characteristics fluctuate dynamically and significantly. Therefore, the network capabilities (throughput, RTT, reachability, etc.) and physical characteristics provided by the mobile units are to be mathematically modeled based on actual equipment measurements, so that they can be used as parameters for topology determination methods, especially in 3-a, described below. In addition, the model will be established as an operational model for LACNRG that can reduce the cost of installation, operation, and removal in non-electrified areas, taking into account IP connectivity and the operational period of the mobile unit.

2.1.2 communication middleware

To optimize the LACNRG operation model, not only information exchange with the service management server but also operation monitoring and control of each other's mobile units are essential. The network load for these data transfers must be minimized. Therefore, we are developing communication middleware technology for LACNRG, with communication between mobile devices and service management servers as specialized domains. The data formats exchanged in these communications will be elaborately designed to establish efficient data formats and communication schemes. The cornerstone of the communication middleware technology will be DDS (Data Distribution Service), which is used in ROS (Robot Operating System), the de facto robot development platform.

2.1.3 digital twin verification environment

Build a virtual verification environment that objectifies portable nodes, cloud servers, and network communications. In conjunction with network simulators and other evaluation tools, construct an evaluation infrastructure that enables highly accurate visualization of the physical location of mobile objects and associated network performance, which varies according to environmental conditions. The evaluation infrastructure will not only materialize the results of the topology determination method obtained in the virtual world in the physical world, but will also reflect the results to optimize the topology configuration. In other words, this will not only reduce the cost of verification in the demonstration field, but also create a digital twin environment that builds iterations of the physical and virtual worlds.

2.2 Multi-hop Networks Using H2CT

2.2.1 network configuration methods

Communication technologies have various communication characteristics, such as frequency, media control, and its parameters in the case of wireless communication, and physical movement conditions of nodes and radio waves during data transfer in the case of delay-tolerant communication such as DTN. We will construct a multi-hop network that can maximize the performance of heterogeneous communication technologies with different characteristics. The net-

*1 Wi-SUN Alliance `https://www.wi-sun.org`
*2 CSA-IOT Connectivity Standards Alliance `https://csa-iot.org/`
*3 Homepage - LoRa Alliance `https://lora-alliance.org/`
*4 `http://www.sigfox.com/`

work topology is specified using a digital twin-like simulation under the condition that each node has one or more available communication technologies, and in the case of two or more, the combination of the technologies is varied. For any given node location and environmental conditions, the construction of an appropriate topology for each communication technology and the optimization of the network topology by merging the topologies of all communication technologies are performed in a coordinated manner.

2.2.2 providing communication functions

In a multi-hop network composed of heterogeneous and heterogeneous performance communication technologies, the communication performance obtained by an application depends on the communication characteristics of the via hops. With routing control such as that used in the Internet, when an application performs data communication, the throughput, delay, etc. will vary depending on the route selected at that point in time. Since the application contexts vary and the communication technologies suitable for data transfer differ, this research will realize a routing method that takes into account the communication characteristics of each communication technology on the route, such as wideband, short-distance, low latency, narrowband, long-distance, high latency, wideband, long-distance, high latency, and so on. In addition, communication control is performed utilizing the characteristics of routing control. For example, since delay-tolerant communication such as DTN can move large amounts of data because data is transported as nodes move, it is possible to control communication such as intentionally delaying communication for applications that observe gradual changes, such as environmental monitoring. In order to allow such communication and routing functions to be selected according to the characteristics of the application, we abstract the specific control details and realize a method of providing network functions that can be used efficiently by the application.

2.2.3 evaluation of proposed communication functions

Based on the technologies described in a and b above, we will develop a technology to construct a network topology with a digital twin and verify the performance of the resulting topology using simulation. First, the potential communication performance that the constructed network topology can provide is evaluated. Based on that performance evaluation, we generate a variety of application communications and evaluate the performance of the routing control. At this time, the feasibility of appropriate communication control according to the application context is evaluated.

2.3 service model that utilizes the computing and network resources

2.3.1 topology determination methods for portable nodes

When a group of portable nodes patrol a closed path to form a mesh network coverage, the throughput in the mesh network changes depending on the shape of the closed path and the distance between the nodes. The environmental conditions between nodes also affect the throughput. Therefore, we will develop a method to determine the topology of the propagating nodes that can maximize the throughput by using the radio simulation system of the Ministry of Internal Affairs and Communications and the network simulator ns-3, based on the locations of mobile objects and the environmental conditions between mobile objects obtained in 1-a above.

2.3.2 distributed computation methods using LACNRG

The topology determination method described in 3-a can be outsourced to a cloud computing environment, but in order to ensure that the closed circuit patrol of a transportable node continues even when connectivity to the Internet is cut off, a calculation must be performed to determine the topology based on the ever-changing environmental conditions. The calculation must be performed to determine the topology based on the ever-changing environmental conditions. As a basis for this computation, we design and implement a method of distributed computation using the surplus computing and network resources of the propagating nodes, and in particular, evaluate the impact of this computation on the power consumption of the propagating nodes.

2.3.3 general-purpose service with LACNRG

The distributed computation infrastructure presented in 3-b can serve as an infrastructure for providing more general-purpose services, not only for computing topology decision methods. While it is difficult to maintain sufficient computing/network resources in non-electrified areas, data conversion, analysis, and distribution of diverse things are essential to realize smart rural areas. If small-scale web services could be provided, for example, it would be possible to monitor and track the situation through sufficiently small communications with mobile devices held by people in distress. We will realize and validate the effectiveness of locally produced and locally consumed services of data, where edge processing is realized in a distributed manner at appropriate portable nodes close to the data generation and utilization locations.

The ultimate goal is to build a sustainable IP network in non-electrified areas using small-scale power generation facilities and renewable energy (see Figure 2 below). The portable nodes will be designed using biodegradable materials as much as possible to minimize the impact on the natural environment in the event that they break down during operation and cannot be recovered.

3. Social Needs

According to the "Leisure White Paper: Current Leisure Situation and Industry/Market Trends" by the Japan Productivity Center, a mountain climbing boom emerged in 2009. This boom was driven not only by so-called "peak hunts," in which climbers aim for the summit, but also by picnics, hikes, and outdoor walks in mountainous and forested areas. The total number of people enjoying these leisure activities is estimated to be over 30 million in

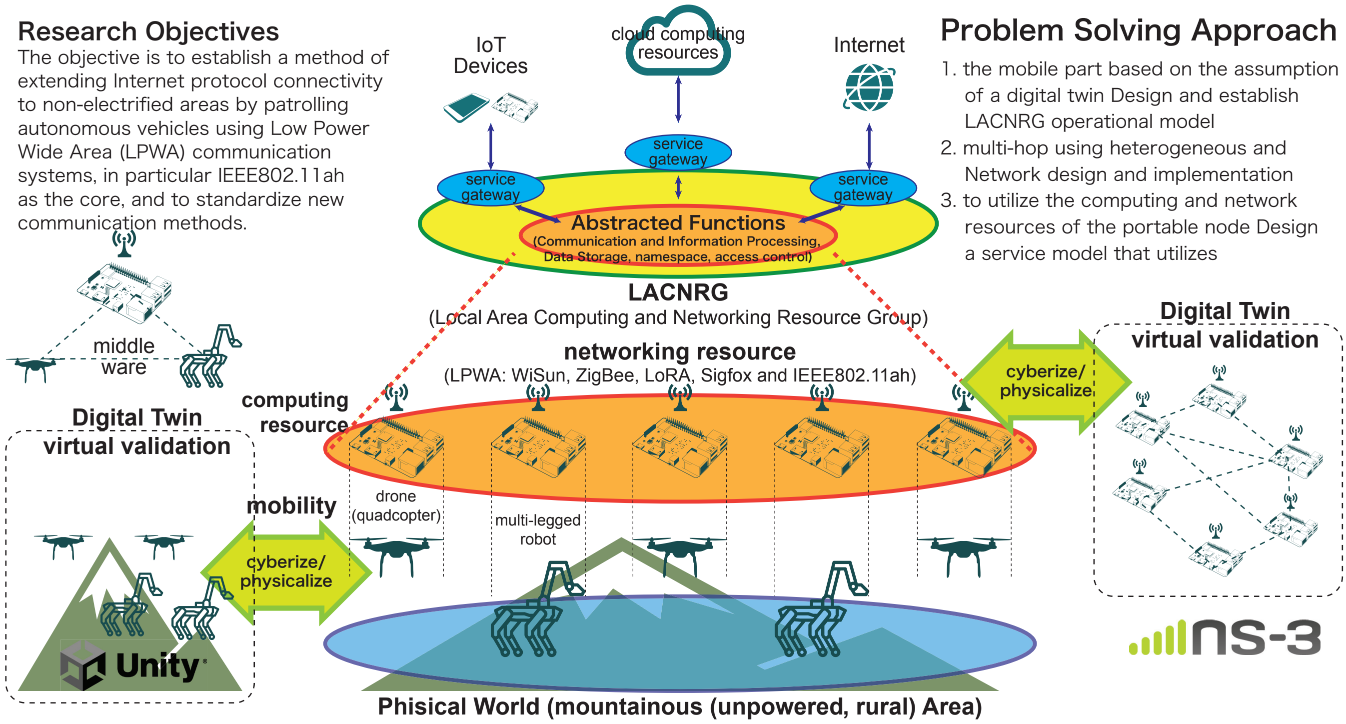

Fig. 2 Schematic diagram of the proposed method.

FY2016. According to a survey conducted by NHK (Japan Broadcasting Corporation), the majority of the people who have experienced "getting lost" have been in mountains less than 1,000 m (1,000 ft.) in height. Since these mountains are not as famous as those listed in Hisaya Fukada's "One Hundred Famous Mountains of Japan," mobile carriers are not actively developing their communication environment. In order to make effective use of tourism resources in rural mountainous areas, it is extremely important to improve the communication environment so that people do not get lost, or can find their way even if they do get lost.

According to the results of the census, the number of people working in the forestry industry, the primary industry, has been monotonically declining since 1980, and by 2015, the number of people working in the industry had decreased to 45,000, less than 1/3 of the number in 1980. The aging rate is also higher than in other industries, while at the same time the percentage of young people is on the rise, and this is also the reason for the active forestry IT efforts. However, the majority of cases of collaboration between the agriculture, forestry, and fisheries industries and IT are limited to short-term research and development, and the reasons for the lack of continuous operation are that most of the initial investment is spent on equipment and the scale of research and development is limited to small- to medium-scale projects. A communication system that can provide wide coverage at a relatively low cost, as proposed in this paper, has the potential to reduce the cost of initial capital investment, which has been a barrier to collaboration between the agriculture, forestry, and fisheries industries and IT, and to generate initiatives that contribute to continuous operation by enabling verification on a larger scale. The system has the potential to reduce initial capital investment costs, which have been a barrier to collaboration between the agriculture, forestry, and fisheries industries and IT.

In addition, this research proposal is also useful in terms of providing network connectivity to isolated areas in the event of a disaster. The car-mobile base stations are large vehicles and can be used for a wide range of applications. On the other hand, since vehicle-mounted base stations are large vehicles, they require well-developed roads, and it has already been pointed out that when roads are damaged due to earthquakes or landslides, the communication range provided by vehicle-mounted base stations is limited. In particular, there is a restriction known as the "72-hour barrier" in times of disaster, where the survival rate drops significantly after 72 hours from the onset of the disaster. Therefore, it is essential to know as many rescue targets as possible during the 72-hour period. Since this research proposal expands coverage by using unmanned mobile vehicles, we believe we can claim superiority in terms of disaster resilience.

Disasters caused by typhoons, earthquakes, and volcanic activity occur frequently not only in Japan but also in other countries, especially in island countries similar to Japan, especially in Southeast Asian countries. The Asia Pacific Advanced Network (APAN), an Internet research conference in the Asia-Pacific region, has established a working group on disaster mitigation. In addition to natural disasters such as these, there have been cases of Internet connectivity being lost and state censorship being introduced due to sudden political instability, such as in Afghanistan, just in the last five years. This research proposal will also contribute to the construction of citizen-controlled Internet bypasses in such regions.

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