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A proposal of autonomous wireless mesh network with autonomous mobile robot for sustainable smart-rural*

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Abstract: This paper proposes a sustainable IP network using small-scale power generation facilities and renewable energy in off-grid areas with wireless LAN APs that consist of adaptive autonomous mobile robots. The wireless LAN access points are designed to use biodegradable materials as much as possible to minimize the impact on the natural environment, even if they break down during operation and are difficult to recover. We will also design and implement a new mesh network protocol among wireless LAN APs that is robust to changes in the natural environment.

1. Objectives and goals

Forested and mountain areas in Japan cover 70% of the country. Some research groups are trying smart forestry with IoT devices. Difficulties of these trials involve the lack of power supply and base stations of the mobile networks. The use of mobile networks and the number of base stations are like the relationship between a chicken and an egg. I can find some efforts to build IP networks with mesh networks by deploying wireless LAN access points (APs) using small, low-power-consumption with one-board microcomputers. Meanwhile, It is difficult to maintain them continuously especially in the forested and mountain area.

The term "smart city" is used to describe a sustainable city or district that utilizes new technologies such as ICT to address the challenges faced by cities and achieve total optimization. As a result of such efforts, urban areas will become more convenient, while underdeveloped (rural) areas will become relatively less convenient. This polarization increases the concentration of people in the cities and overpopulation makes it difficult to sustain economic activity against disasters.

Total costs to operate an IP network with multiple APs consist of the fees to install, operate, and withdraw respectively. However, in forested and mountainous areas, the installation, operation, and withdrawal of APs are all expensive due to the difficulties of transporting equipment and staff to these areas. When the communication quality deteriorates due to changes in weather conditions, it can improve the deterioration to shorten the distance between APs and increase their radio output. However, it is difficult to deal with this problem in conventional APs with fixed locations, especially in off-grid areas. In order to reduce the operation costs, it can become threats that security vulnerabilities of APs will be left unaddressed. In addition, there are concerns about the adverse effects on the environment due to the unattended installation of the APs.

Therefore, this study aims to construct a sustainable IP network using small-scale power generation facilities and renewable energy sources in off-grid areas by using wireless LAN APs with adaptive and autonomous mobility to cope with changing weather conditions (Fig. 1). The wireless LAN access points will be designed with biodegradable materials to the greatest extent possible to minimize the impact on the natural environment, even if they break down during operation and are difficult to recover. The mesh network protocol between the wireless LAN APs, which is robust to changes in the natural environment, is also newly designed and implemented.

The proposed method extends the IP network provided by existing mobile and wireline networks to off-grid areas. The purpose of this study is to reduce the hurdles for introducing services such as Mobility as a Service and the sharing economy in underpopulated areas, and to realize a sustainable underpopulated area "Smart Rural" by total optimization.

In the first year, we will conduct fieldwork to measure the signal strength of carrier networks in several depopulated and mountainous areas as a preliminary investigation for the second and subsequent years of the demonstration experiment. In the second year, we will design, implement, and evaluate a new wireless LAN protocol based on the results of these experiments. We will start demonstration exper-

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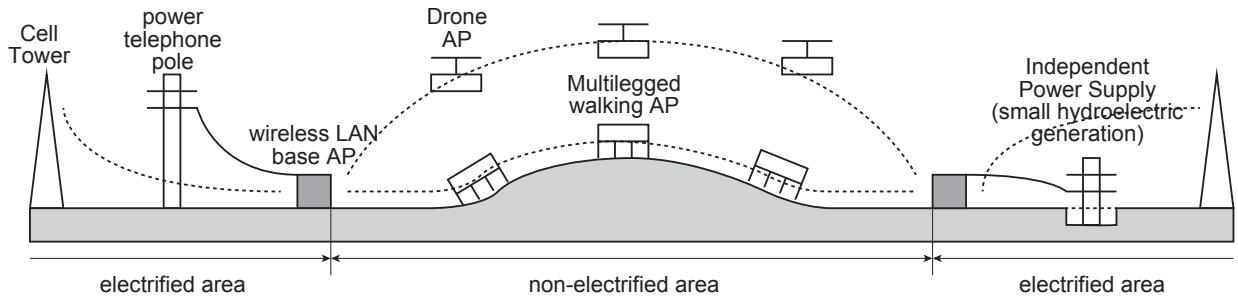

Fig. 1 A schematic diagram of mobile wireless LAN in forested and mountian areas

iments in conjunction with services that will realize smart rural areas and promote standardization of the wireless LAN protocol designed in this research proposal.

1.1 Significance of the project as an investment in the future

Smart agriculture and smart forestry initiatives have been on the rise in the last five years. Power-saving communication methods such as LPWA are mainly used, but they suffer from the high cost of installing and removing APs and the difficulty of adapting to changing weather conditions. In some cases, a number of organizations, including local governments, are bearing the brunt of the cost burden. However, this system is not able to keep up with the fast cycle of technological innovation, and there are concerns that the equipment will become obsolete in a few years.

This research proposal can construct an experimental IP network by distributing APs, which can be manufactured using inexpensive materials, in an adaptive arrangement through both autonomous decentralized and centralized approaches. This research proposal can be started small and can be scaled up and scaled out based on the findings from a small-scale deployment. The fact that the equipment can be relocated and reused at other locations is also beneficial in terms of return on investment.

The smartification of agriculture and forestry will involve a diverse range of disciplines. Aside from agronomy, APs with autonomous mobility capabilities can be equipped with sensors to measure steady physical conditions in areas that are difficult for humans to reach on a regular basis, which could contribute to meteorology and biology. This will contribute to the reduction of survey costs for mobile communication carriers to install base stations, which will also contribute to regional development and tourism.

1.2 Challenge, originality, usefulness, and feasibility of the research

Similar research has been conducted on wireless sensor networks for a long time. This research is mainly based on the premise that APs can be moved by a relatively simple drive system with a good view, such as in a desert area, so that there is little need to dynamically relocate the APs once they are placed. However, in Japan's forested and mountainous areas, the weather changes rapidly on a daily or monthly basis and the distance between APs must be shortened in case of rainfall, so that dynamic relocation is frequently required.

Efforts to build mesh networks by connecting wireless LAN APs to drones to provide IP connectivity in temporary events, assuming sufficient power supply, have been made at home and abroad. However, the security of the operating system of wireless LAN APs and environmental considerations have not been taken into account. In this study, we propose that the wireless LAN APs will be continuously updated between electrified and off-grid areas, and even if they become inoperable and difficult to collect, they will decompose naturally to reduce the environmental burden.

As society demands that the quality of Internet service be guaranteed, mobile carriers will only build base stations in areas where it is profitable to do so. As long as we depend on the IP connectivity provided by the mobile carriers, it is difficult to find value in mountain and forest areas. This study does not prioritize quality assurance, but realizes a patchwork of IP networks in unprofitable and off-grid areas. This will make it possible to conduct a comprehensive survey in mountain and forest areas, which will lead to new value discovery and value creation.

1.3 Possibilities for development towards joint use and research at university-based institutions

At present, SINET5[*1] is providing a Wide-Area Data Collection Infrastructure (WADCI)[*2] service demonstration experiment, but in this service demonstration experiment, its use is limited to the range where mobile communications carriers can reach. However, in this service demonstration experiment, the use of this service is limited to the range where mobile communication carriers can reach. If we can provide stable communication to the electrified areas using the WADCI communication network, and deploy the proposed autonomous wireless network with the nodes of the

[*1] Science Information NETwork 5 - Science Information NETwork 5
https://www.sinet.ad.jp/en/top-en
[*2] SINET Wide Area Data Collection Infrastructure Demonstration Experiment
https://www.sinet.ad.jp/wadci

network as gateways, we can expect to provide a wider range of SINET connectivity.

Since 2011, the proponents of this research have been building a globally distributed computer environment called Distcloud[*3], which connects the computer resources of national universities in Japan via SINET5 [1], [2]. This environment provides a globally distributed file system that allows data owned by each site to be transparently accessed by other sites. By combining this environment with WADCI and the proposed method, we plan to develop machine learning based on a large amount of data collected from a wide area and AP control based on the data.

1.4 Expected results (academic, social, and improvement effects)

The most significant impact of this research proposal is to reduce the cost of providing Internet connectivity to off-grid areas, which has been difficult to achieve in the past. This impact will not only contribute to smarter agriculture and forestry, but will also enable the tourism industry to make better use of diverse content by converting a wider range of mountainous areas to IP. This could also contribute to mitigating mountain accidents, a problem that has become apparent in mountain tourism.

In addition, the implementation of the autonomous mobile AP and network protocol designed in this proposal will be released under an open source license, so both hardware and software can be produced without the need for a large factory. This could be used to circumvent the restrictions in countries where Internet connectivity is severely restricted by the state, for example.

1.5 Trends in Academic Research in Related Fields at Home and Abroad

There has been a lot of research on wireless mesh and wireless sensor networks since the 1980s, and they have been standardized and sold as products. Efforts to make APs mobile rather than fixed have also been active, especially with the development of drone technology in the last five years. However, not much research has been done to solve the problems of "dynamic environmental change" and "off-grid" that characterize outdoor areas, especially in mountainous areas.

At the beginning of this year, NTT East began joint experiments with municipalities and unions in Yamanashi Prefecture and a number of companies to install LPWA base stations in mountainous areas. This demonstration experiment is short, lasting about six months, and is not designed to deal with environmental changes, especially during the snow season. In addition, the number of base stations is about four, and they are limited to a 1 km square area.

In this study, we propose a wireless mesh network simulation based on the information collected by an autonomous mobile AP that collects environmental information and network information with other APs in the vicinity to dynamically reconfigure the location of the AP. The uniqueness of this research lies in the fact that the reduction of the usable bandwidth due to broadcast traffic, which is characteristic of mesh networks, is suppressed by redesigning the protocol, and the investment effect of communication quality is measured and controlled from the viewpoint of total power consumption.

[*3] Distcloud project
https://ricc.itrc.net/distcloud

2. Project Plan

2.1 overall plan

In the first year, we will conduct demonstration experiments by combining existing technologies and quantitatively evaluate them. In the second and subsequent years, we will survey the areas where we will conduct the demonstration experiments and estimate the equipment needed for the experiments.

In the second year, we will conduct demonstration experiments in rural areas (satoyama), which are relatively easy to test in underpopulated areas, and we will design and implement a system that simulates the experiments conducted in the first year based on information obtained from sensors installed in the AP, and that feeds back the results to reconstruct the position of the AP. The project is designed and implemented. We will also design and implement a mesh network protocol based on the premise that the location of the APs can be dynamically reconfigured. Based on these results, we will also make proposals for other competitive research funds and for joint research.

In the third year, we will conduct demonstration experiments of the protocol implemented in the second year. We will evaluate the system implemented in the second year and deploy the results. Standardization activities for the protocols implemented in the second year will also be started. The continuation of the standardization activities and the expansion of the scale of the demonstration experiment will be dependent on the competitive research funds to be obtained in the third and subsequent years, and the activities of this research proposal will be dissolved.

2.2 Plans for each fiscal year

2.2.1 FY 2020

We design and implement an autonomous mobile AP by combining a drone or a multi-legged robot with a one-board microcontroller, which can be manufactured for several tens of thousands of yen. We will build at least five of these APs and place them at a distance of 100 m to 1 km from each other to measure the radio strength, transmission quality (loss ratio) and throughput of the wireless LAN. Each AP is equipped with a sensor and GPS. The system will be implemented to measure the position of 10 cm order using a quasi-zenith satellite system, and to send this information to the gateway computer (edge computing platform) periodically.

In order to find candidate sites for the second and subsequent years, fieldwork will be conducted at six sites in Japan. The one-board microcontroller, sensor/GPS unit, and bat-

teries of the aforementioned AP will be used to search on foot from electrified to off-grid areas to measure the signal strength of each mobile network carrier. The results of these measurements will be used to determine the target of the demonstration project. The results of these rudimentary designs and implementations, as well as the results of the fieldwork, will be developed in a domestic research group.

2.2.2 FY2021

We design and implement a system to dynamically reconfigure the location of APs by calculating the throughput improvement in power consumption investment based on various information collected from APs. Based on the measured meteorological conditions and network information between the APs, the throughput after the reconfiguration of the location is evaluated by a network simulator. The results of this evaluation are used to relocate the APs. The APs will not continue to move in the vicinity of a certain location, but the entire AP will be made to operate in a continuous cycle, so that all the APs will periodically arrive at the gateway computer, where they can be recharged and hardware refurbished. For this purpose, we will conduct demonstration tests in a satoyama area with well-developed mountain roads, where it is relatively easy for humans to collect APs.

We will design and implement an original mesh network protocol and implement it in the AP. Comparing existing and proposed protocols, we will build new APs in addition to those built in FY2020 to increase the total number of APs and evaluate their scale-out performance and coverage, as well as evaluate how quickly biodegradable materials can be decomposed in the real environment. We will make proposals for competitive research funding and joint research, and prepare for the continuation of our activities in 2023 and beyond.

2.2.3 FY2022

We will evaluate the system designed in FY2021 and develop the results through presentations and papers at international conferences. In addition, by collaborating with groups and companies that are researching sharing economy services, we will evaluate real applications in underpopulated areas and propose a mesh network protocol designed and implemented in FY2021 to the IEEE802.11WG[*4] for standardization. We will establish a consortium to continue the standardization activities and the development of the research results, which will bring this research proposal to a close.

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[*4] IEEE 802.11, The Working Group Setting the Standards for Wireless LANs
https://www.ieee802.org/11/

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