Proposal for WPT Drone Spectrum Allocation Policy

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***Abstract* - The global market for drones is growing fast thanks to their efficiency, flexibility, and new values embedded in various fields. They, however, have some limitations of operation due to battery issues. This article suggests how to resolve the battery issue, how to define the WPT drone, and how to find the most optical spectrum allocation for WPT drones through literature reviews and field specialist interviews. After considering 4 major constraints, this paper proposes that 2.45GHz or 5.8GHz allows more flexible and efficient use of spectrum in the future. These important changes are expected to create further opportunities for drones to support a variety of applications, ranging from real-time monitoring for disaster, public safety, dynamic outside broadcasting and networking.**

Keywords—component; Commercial Drone, WPT (Wireless Power Transmission), Spectrum Policy

I. INTRODUCTION

The drone market has recently been extended to converge with various industries including aerial imaging, agriculture, and transport logistics (Figure. 1) [1]. Even though the industry is to create new values of drones, it faces challenges in the weight of the drone with a battery. It makes difficult to keep the drone in the air longer than 20 minutes, which is one of the hurdles to the growth of the drone industry. To increase drone flight time, it is required to develop technology of the power supply. As to the solution, the wireless power transmission (WPT) technology as a method to supply power to a drone by using a spectrum has been attracting the world's attention. If the WPT system is commercially available, the limitation of the drone flight time due to the battery issues can be overcome. Few has, however, been discussed on policies for implementing the WPT technology to drones.

In cases of the existing drones, the spectrum band for control (5030~5091MHz) was allocated in December, 2015 and the spectrum band for visual transmission (5091~5150MHz) was also allocated in August, 2016. On the other hand, even though another spectrum band for the WPT has to be allocated for WPT drones, the third spectrum band for them has not been allocated yet. The spectrum band should not be interfered with the spectrum bands for control and visual transmission. Moreover, important is to prevent electromagnetic wave interference from other communications equipment in the areas where the WPT drones operate.

MSIP(Ministry of Science, ICT and Future Planning)
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This study is to propose policies to select an effective spectrum band and avoid wave interference in order to apply the WPT system to drones. For this purpose, expert interviews were carried out to find out some critical issues: 1) what are the spectrum bands appropriate for WPT drones? 2) Is it possible to share the same spectrum band with other wireless equipment? 3) Is there any way to use WPT drones without interfering with other wireless equipment? Issues emerging from the interview responses will be thoroughly investigated in order to promote drone technology system. The implications drawn from this study will work as guidelines to build public supports and set up regulations for drones both in Korea and worldwide.

The following chapter represents previous research as the theoretical background of this study and chapter 3 shows the methodology of this research. Chapter 4 describes the analysis of the issues emerging from the research methodology. Chapter 5 shows the analysis results and chapter 6 provides the conclusions, implications and suggestions for further research.

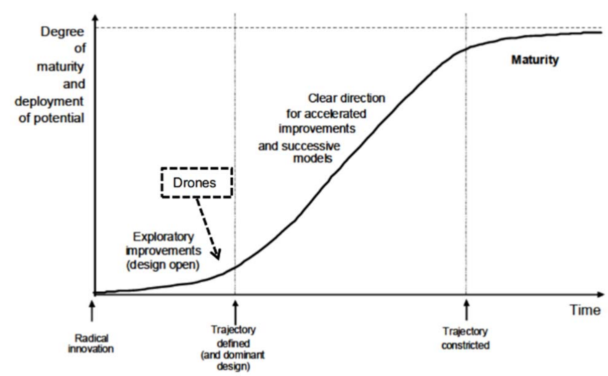

Figure 1. The Trajectory of an Individual Technology
(Source: Oppenheimer & Co. Inc, 2016, Reconstructed)

II. PREVIOUS RESEARCH

A. Drone Spectrum

Generally, the spectrum to control drones is essential to remote control (RC) drones from the ground. Some commercial drones use two spectrum bands in order to control the drone and to transmit information such as video-image data and locations of the drone.

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Table 1. Characteristics of drone spectrum bands

Spectrum band	Characteristics	Usage and characteristics
900MHz	Medium-size drones	Using for Downlink to transmit videos and Telemetry. Overlapping with spectrum band for mobile communications spectrum, IoT Wi-Fi and wireless Lan in Korea and some European countries
1.3GHz	Majority of drones	Using for Downlink to transmit videos and Telemetry. Interference effects on GPS receiver loaded in the drones due to spectrum adjacency to 1.2GHz L spectrum band of the GPS satellites
2.4GHz (2400~2483.5MHz)	Small-size drones	Using for Uplink for drone control. Spectrum band for ISM (Industry, Scientific and Medical), which is generally used for many devices.
5030~5091MHz	Drones for civil purposes	Serving as a spectrum exclusively used for the drone ground control Korea is the first country to allocate the exclusive spectrum (2015.12)
5091~5150MHz	Mid-large size drones	Using for Downlink to do tasks (visual transmission, crop-dusting) (additionally supplied in 2016)
5650~5725MHz	Small size drones	Using for Uplink to do tasks (hobbies, leisure) (additionally supplied in 2016)
5.8GHz (5725~5850MHz)	Drones for civil purposes	Using for Downlink to control videos and telemetry of drones

(Source: MISP(Ministry of Science, ICT and Future Planning) of Korea, 2016)

Although the spectrum bands vary depending on the policies that countries have, the range used as the communication link in general is 900MHz, 1.3GHz, 2.4/5.8GHz [2]. The types and characteristics of spectrum bands which are currently used for drones are depicted in Table 1.

So far, drones have mainly used Wi-Fi spectrum bands. As the use of spectrum bands for mobile data increases rapidly, there might have occurrences of propagation interference between bands. Even though WRC-12 set the standards for the ground control dedicated spectrum in 2012, there has been no country to adopt it. In December 2015 in Korea, a new band was allocated in the spectrum band of 5030~5091Mhz with 61MHz for drone control only. Since this band is not for other low-power radio equipment but only for drone use, accidents such as collisions and crashes which are caused with electromagnetic wave interference can decrease. In addition, since the output power can be up to the maximum of 10W, the operating range of the drones was widely expanded over the current distance limit [3].

B. WPT technology

The Wireless Power Transmission (WPT) technology is the technology to deliver power from the power source to the electrical load without man-made conductor. This wireless power delivery technology is also known as wireless power transfer or wireless energy transfer.

This technology needs the transmitter to send electromagnetic waves and the rectenna to convert the received waves into the power. The power-transmission efficiency varies in response to a variety of the distance and the spectrum bands.

The technology is generally linked to electromagnetic induction, low-power system using magnetic resonance, short-range power delivery system (short-range wireless charging system for mobile phones), high-power deliver system to deliver the power generated from the stratosphere to the ground by using electromagnetic waves, long-range power delivery system (SPS, Solar Power Satellite) and mid-range power delivery system (HAPS, High-Altitude Platform Stations). [4]

However, there are challenges to apply the WPT system to drones. The existing systems with short-/mid-/long-ranges have operational problems because drones work within the altitude permit of 150 meters above the ground. Depending on the altitudes, WTP systems can be classified as shown in Figure 2.

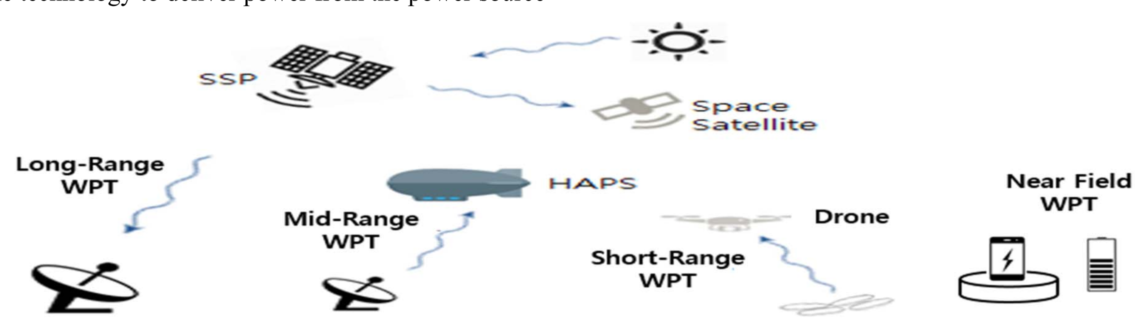

Figure 2. Cases to use the WPT technology

- Long-/mid-range WPT: SPS system, inter-satellite power supply system, HAPS system
- Near-field WPT: short-range IoT devices
- Short-range WPT: WPT drone system

Studies on the WPT system that have been done mainly focused on long-/mid-range or near-field systems. Few studies were carried out on the mid-power and short range power delivery technology.

Therefore, this study focuses on the short-range-only WPT located in between the Near-field and the mid-/long-range WPT.

C. WPT drones and their spectrum

Drones are Unmanned Aerial Vehicles(UAVs), that is, remote controlled aircrafts without a pilot on board. In this study Focuses on commercial drones which are used within the altitude of 150 meters for broadcasting, parcel delivery, agriculture, and Public services. It is as shown in Table 3. However, the battery limits prevent them from operating during some length of time. As an alternative, the drone supported with the WPT technology is defined as the WPT drone in this paper.

The WPT drone system needs WPT-only spectrum bands for wave-to-power transfer as well as control and image transmission, which are different from the general drones mentioned above. Therefore, the WPT drone system requires three spectrum bands for control, image transmission and power transmission.

III. METHODS

This research carried out written interviews with experts in order to find out efficient spectrum band allocation and interference avoidance policies to promote the WPT drone system that supplements weaknesses of existing drone systems. The interview questions were divided into two parts (WPT drones and drone spectrum). The interview question sheets were distributed to the experts from August 20 through September 10, 2016. The questions were about the spectrum policy for WPT drones and issues about existing drone spectrum. The participants in the written interviews were composed of eight experts: three professors at colleges, three researchers at research institutes, and two office workers in public and private sectors. Interview questions are as follows:

Table 2. Interview question examples

Topic	Content
WPT drones	• Services and promising areas which use WPT and can apply WPT technology • Issues and effects of WPT drones • Policy direction of WPT Spectrum band
Drone spectrum	• Main issues about current drone spectrum allocation • Policy direction of spectrum Interference • Characteristics of organizations working for the Korean drone industry and their current and future policies

Table 3. Commercial UAV Applications

Sector	Applications	Example
Agriculture	Crop monitoring	Drone can survey at a much higher Resolution than satellites and at a third of the cost. More accurate monitoring of crop growth is generating efficiencies, for example in the use of fertiliser, estimated to have increased revenue by ~EUR50.
	Precision Agriculture	In Japan, around 40% of the rice crop is sprayed using drones. Over 2,400 drones are now in service
Public Services	Border control	Predator drones patrol the US borders with Mexico and Canada. They have been credited as a major contribution to border security.
	Assisting emergency services	In the UK, the West Midlands Fire Service uses drones to collect information for use in firefighting, such as surveying the extent of the fire, identifying access points and locating casualties.
Logistics	Parcel deliveries	In Australia, drones have been used for over a hundred test deliveries of textbooks
	Delivery of medical supplies	In Germany, a drone has been used to deliver medicine to remote locations.
Wildlife Protection	Prevention of poaching/hunting	Kenya is due to deploy drones into all of its national parks following a successful pilot project where the use of drones reduced poaching by 96%
Media	News production	News media organisations are increasingly making use of drones to enhance their coverage
	Film and Entertainment	Drones have been uses for the production of several feature films including 'Wolf of Wall Street' and 'Skyfall'
Research	Data gathering	Researchers have used drones since 2010 to collect breath samples from sperm whales as part of the Cetacean Health and Life History Programme to assess their health
	Analysis	Archaeological mapping of a former Inca settlement in Peru has been achieved by a drone equipped with a high resolution camera

(Source: Oppenheimer & Co. Inc, 2016)

IV. DIRECTION OF WPT SPECTRUM ALLOCATION

Currently, technological research in the WPT drone system has not been done enough yet but there is a growing demand for research into it. The essential factor to be considered to develop the WPT drone system is to select a WPT spectrum band. It is because the spectrum is not resources only for one country but for others and thus the appropriate spectrum must be officially allocated. Besides, the allocated spectrum has critical effects on the wave environments and works as an essential factor to decide the antenna size, energy conversion efficiency from electric power to wave energy, and space loss. The existing spectrum users, in particular, should not be interfered.

In this chapter, based on the literature review and expert interviews on WPT drones and spectrum-related issues, some implications to the appropriate WPT spectrum band allocation are suggested.

A. Effects on wave environment

WPT drones operate about at the altitude of 150M above the sea level. The spectrum is therefore within the band range that affects least on the atmosphere environment. The rate of the attenuation of an electromagnetic wave on the atmosphere environment of the Earth is as shown in Figure 3 below. The figure shows that within the band above 5.8GHz electromagnetic waves are absorbed by molecules of oxygen and water vapour or affected by clouds. Therefore, the spectrum should not be allocated within the band range affected by these factors. Empirical investigations must be carried out in order to investigate effects of rain and snow. [5]

B. Sizes of antennas and the ease of use of technology

The sizes of the two antennas (one for transmitters on the ground and another for drone rectennas to transfer electromagnetic wave to power) are related to the wavelength of the allocated spectrums. The higher the spectrum is (i.e., the shorter the wavelength is), the smaller size of antenna a drone needs.

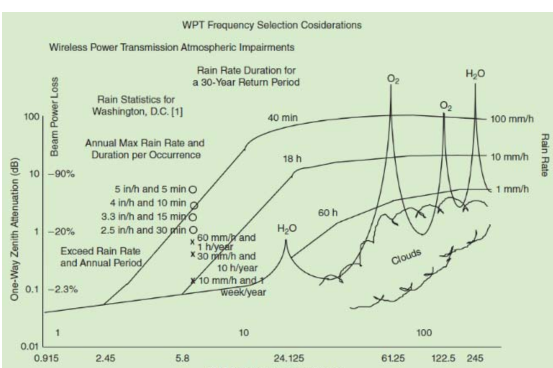

Figure 3. Atmosphere effects by ISM spectrum bands
(Source: L. J. Ippolito, 1989)

Depending on the transmitters and the rectenna size, higher spectrums can be considered as appropriate. However there might have some fundamental problems since it is affected by the atmosphere as the spectrum increases.

C. High spectrum band with high efficiency of power conversion

The power conversion efficiency is affected by the allocated spectrum, electric current elements, and types of antennas, among others. This study, however, narrows down the focus onto the matter of spectrum and considers the efficiency of the power conversion.

Brown, who has studies on WPT technology, showed that the efficiency comes up to 92% at 2.45GHz [6].

In 2000s, Donchev presented that C-band (≈5.8 GHz) had the efficiency of 60~85% theoretically and experimentally and all the other bands showed lower than 70% efficiency [7]. These results reveal that the spectrum band of 2.45GHz~5.8GHz must be efficient for operation of WPT drones. It is as shown in Figure 4 below.

D. Interference effects on the existing spectrum band users

Several spectrum bands including ISM (Industry, Scientific and Medical) can generally be used for Industry, Scientific and Medical purposes without permission by the government. Although ITU did not allocate any exclusive spectrum bands for WPT yet, historically, various developments and experiments have been performed within the spectrums of 2.45GHz, 5.8GHz, or above 8GHz, that is, within the ISM band [8]. Even though lots of devices use the ISM band, the WPT uses the radial type moving towards the narrow range of atmosphere different from other communications spectrums moving towards the wider range of atmosphere.

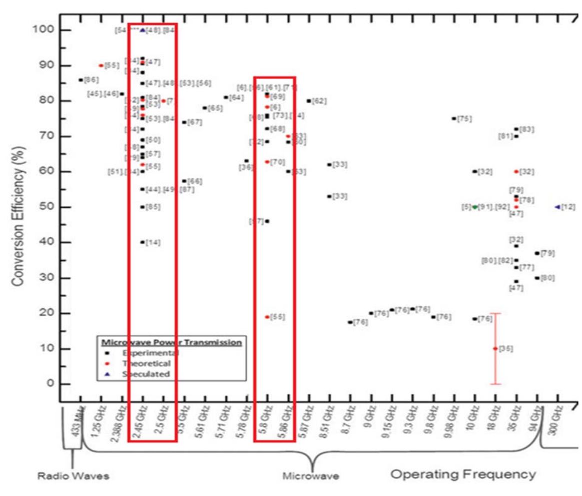

Figure 4. Reported conversion efficiencies at their maximum operating frequency of a rectenna device.
(Source: Donchev, 2014)

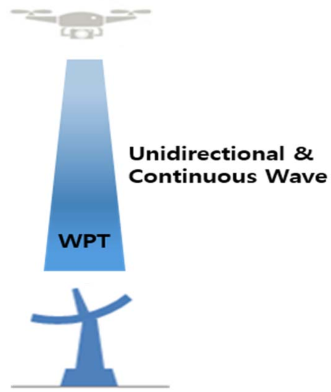

Figure 5. Non-interference Using by Continuous Wave

The WPT also uses the continuous wave (CW), which does not produce any extra waves(Figure. 5). Accordingly, since the ISM band is expected to give less effects on the surroundings, it seems to be worth considering.

V. RESULT

The review on the spectrum band allocation focused on electromagnetic wave environments as shown in Table 4. On the basis of the review of previous research, this study proposes appropriate spectrums of 2.45GHz or 5.8GHz as the primary application. Considering the fact that at the current level of the technological development, these spectrums can provide the highest efficiency rate of power and make it possible to prevent interference within and out of the bands.

Table 4. Direction of the WPT drone Spectrum Allocation

Direction of the Allocation	Summary of the content
Effects on the electromagnetic wave environment	Consider the spectrum band that affects least on the atmosphere environment
Size of the antenna and ease of use of technology	Since the transmitters and the rectenna size should be considered, as the spectrum is higher, the size of the rectenna is smaller and the efficiency is better.
Bands with high efficiency of power transmission	Consider bands with high efficiency of power transmission for efficient operation of WPT drones.
Consideration of the interference effects on the existing spectrum users	Need to allocate the exclusive WPT spectrum band for drones due to the possibilities of mutual interference among devices using electromagnetic waves in terms of the wave output and the band.

VI. IMPLIICATIONS & FURTHER RESEARCH

As mentioned in the above chapter, this research proposes the optimal spectrums of 2.45GHz or 5.8GHz as the primary application. This study aimed to review the rapidly developing drone market and its limitations and to propose policies for the WPT spectrum band allocation as a way to overcome the shortcomings. From the literature reviews and the expert interviews, the optimal spectrum band and ways to prevent interference were suggested. If the WPT drone system is available with the help of the results of this research, real-time long operation of drones can be possible, leading to develop new niche markets as follows.

First, the WPT drone system can be used to enhance the public services such as disaster control and rescue services. As depicted in Figure 6, by using the high-quality camera loaded on the drone, various public services such as real-time broadcasting at the disaster area, public safety control, and measurement of climate changes.

Second, in the ITC area, the existing network systems based on the cell towers will be changed into the network system using unmanned aerial vehicles that can be charged at the WPT areas, which makes it possible to provide better network services to areas that have difficulties to build cell towers.

Third, in the outside broadcast services, the WPT drone system, together with 5G wireless communication networks and high-quality UHD video technology, can be used at big events such as PyongChang 2018 Winter Olympics, for instance(Figure 7). This will make it possible to provide real-time three-dimensional video services from the air. In these contexts, future broadcast services can provide better quality contents.

Figure 6. Instance of the application of image control WPT drone system on the beach

Figure 7. Instance of the application of image control WPT drone system on the PyongChang 2018 Winter Olympics

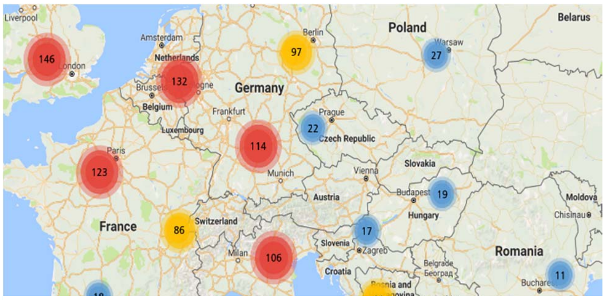

Figure 8. Cases of Charging Stations

Fourth, as depicted in Figure 8, if WPT zones are built at specific areas as charging stations, it will overcome the existing battery issues to operate longer period of flying time for near-/short-range services. It will also be possible to operate year-round. Through the applications to the traffic control system, WPT drones can be used for real-time video surveillance and field control.

Limitations of this research include lack of empirical studies. It is because this is about technology that is not commercially available yet. Further empirical research should be done to provide innovative business models which integrate the WPT drone system with ICT technology. The results of this research suggest that there needs to apply the WPT system, allocation of the optimal spectrum in advance, and creation of new demand in order to develop the commercial drone industry. In this vein, this research proposes that there needs to have a specialized organization to build up development strategies for long-term spectrum and drone services.

This research helps to provide valuable information as a guideline to offer policy supports and system setup strategies facilitate drone use in countries at the initial stage of commercial drone industry.

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