Unmanned Aerial System Traffic Management with WAVE Protocol for Collision Avoidance

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Abstract**—**Recently, the number of drones for personal leisure as well as Unmanned Aerial Vehicles (UAVs) for such as military, commercial, agricultural, disaster response is increasing rapidly. When a large number of UAVs fly simultaneously in airspace, collision problems between UAVs can occur, which is likely to lead directly to human accidents or economic loss. Accordingly, there are growing needs for UAS Traffic Management (UTM) systems. In this phenomenon, various communication protocols for UTM are emerging. In this paper, especially, the application of UTM system based on Wireless Access in Vehicular Environment (WAVE) protocol is introduced as one of most efficient and stable protocols in environments with high-speed mobility and dynamic changing topology. Furthermore, we design a network architecture that supports direct communication among UAVs as well as UAV and ground station within the UTM framework. By applying WAVE protocol in the UTM system, it is possible to transmit messages promptly and accurately to prevent collision in the event of an emergency, and to configure the UTM system to manage all UAVs by applying a WAVE-based ad-hoc network.

Keywords—UAS; UTM; WAVE; IEEE 802.11p; IEEE 1609; FANET

I. Introduction

With the popularization of Unmanned Aerial System (UAS) in various fields, the idea of communicating between UAVs gives rise to Flying Ad-hoc Networks (FANETs) [1], which considers safety as the top priority when numerous UAVs fly simultaneously in the same airspace. In general, a FANET is formed by base stations or access points on the ground, UAVs equipped with wireless communication devices, and a central server that monitors the overall network configuration and flight status of UAVs [2]. With the increase in the number of low-altitude UAVs and the increase in the scale of FANETs, the role of management system for safety of UAVs in the airspace is becoming more important. The National Aeronautics and Space Administration (NASA) UTM project [3] is an effort on enabling low-altitude UAS flights. The goal of UTM project is to enable safe and efficient low-altitude airspace operations by providing services such as airspace design and dynamic configuration, congestion avoidance, and route planning. In order to safely provide such services, the network must be configured based on a communication protocol suitable for the UTM system.

A number of communication protocols have been used for traffic management and some protocols are still included in the candidate group for UTM system in the future. The following protocols exist in the candidate group: Automatic Dependent Surveillance-Broadcast (ADS-B) [4], Low Power Wide Area (LPWA) [5], cellular network [6], and Wireless Local Area Network (WLAN) [7]. The ADS-B has the advantage of having a wide communication range, but has a disadvantage that the delay is large and the transmission rate is relatively low. In the case of LPWA including Long Range (LoRa) and Sigfox, it also has a large transmission range, but has disadvantage in terms of data rate and latency. Because communication delay and transmission rate are critical factors in UAV network environments to send and receive safety related messages, these protocols are not suitable for the UTM system. In the case of cellular networks including 3G, 4G, and LTE-A, it has wide coverage and high data rate, which makes it suitable for UTM system than any other communication system. However, there are policy issues such as authentication of the module itself for using licensed bands and interoperability between different mobile service providers, or mobile carriers. On the other hand, most commercial UAVs are equipped with IEEE 802.11b/g/n-based Wi-Fi modules. Wi-Fi has a high data rate, but has a small communication radius and has a disadvantage that connection stability is degraded in a high-mobility environment.

The WAVE protocol is emerging to address connectivity and coverage issues of Wi-Fi in such high-speed mobility for Vehicular Ad-hoc Networks (VANETs) [8]. WAVE protocol consists of IEEE 802.11p [9] and IEEE 1609 standards [9-11]. Since WAVE is originally designed for vehicular communication, it has characteristics such as wide coverage, fast transmission speed and excellent communication performance in high-speed mobility environment. These characteristics are expected to show superior performance not only in vehicles on the ground but also in UAVs in the air. In addition, it is possible to utilize UAV-to-UAV direct communication through ad-hoc network configuration as well as communication between UAVs and base station within the UTM system.

In this paper, we briefly review the specification of WAVE based on standards, and analyze how its characteristics are applicable to the FANET-based UTM system. Based on the characteristics of WAVE, we design a novel UTM system that supports direct communication between UAVs as well as UAV and ground station for safety-related message exchange.

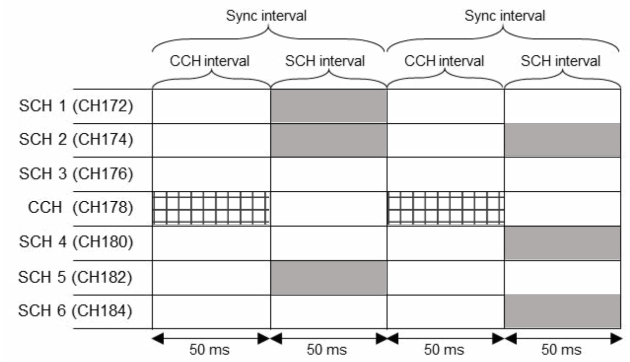

Fig. 1. Multi-channel operations in IEEE 1609.4 standard.

Version	PSID	Extension field	WAVE Element ID	Length	WSM Data

Fig. 2. The format of WSMP in IEEE 1609.3 standard.

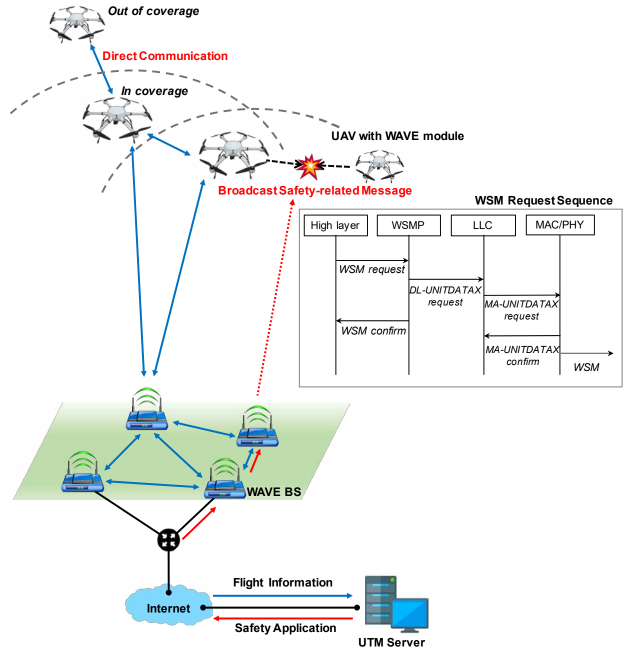

Fig. 3. UTM system with WAVE protocol.

II. WAVE Protocol for UTM

Among the various standards related to the stack that make up WAVE, we mention only a few standards which are directly related to the UTM system that we are designing. Basically, the PHY and MAC layer of WAVE operates based on IEEE 802.11p standard which is modified to improve performance in high-speed mobile environments. Compared to IEEE 802.11a, IEEE 802.11p uses 10MHz, which is half the bandwidth. In addition, WAVE uses a dedicated band of 5.85-5.925 GHz, whereas Wi-Fi uses unlicensed Industrial, Scientific, and Medical (ISM) radio bands. The most noticeable difference in the PHY layer of WAVE is that it uses 1.6μs as a guard period, which is twice that of Wi-Fi. In the MAC layer of WAVE, Enhanced Distributed Channel Access (EDCA) is user for Quality of Service (QoS). The application messages are categorized into different access classes. These characteristics enable the advantages in high-speed mobility environments such as UTM system: i) less inter-symbol interference, ii) better resistance against multipath error in an environment where the terrain is complex or building are densely populated.

On the other hand, MAC layer of WAVE also supports multi-channel operation based on IEEE 1609.4 standard as shown in Fig. 1. In IEEE 1609.4 standard, the spectrum is divided into 7 sub-channels, one control channels (CCH) and six service channels (SCHs). CCH is for transmitting control and safety packet. The safety-related messages can be broadcast in CCH interval. SCHs are for transmitting data packets, providing non-security service [12]. IEEE 1609.3 describes WAVE Short Message Protocol (WSMP) related to networking services. It defines transport and networking protocols in the data plane, and enables the exchange of messages in a rapidly varying radio frequency environment. WSMP is a simple message transport protocol which is used to communicate in case of safety-related applications [13]. The message format of WSMP is presented in Fig. 2. Version filed describes the version information of WAVE protocol, and PSID represents the Provider Service Identification. Extension field includes the information of used channel number, data rate, transmission power. WAVE Element ID represents the identification of WAVE elements which are used in WSMP, and Length means the length of WAVE Short Messages (WSMs) data. In WSMP, WSMs are possible to be transmitted and received between UAVs, or UAV and ground station up to 512 bytes of data. Thanks to standards that have safeguards such as securing channel for safety messages and short message format transmission, safe flight is possible by preventing collisions between UAVs moving at high speed in the air.

III. UTM System Design with WAVE

In this section, based on the safety related standards defined in the WAVE protocol mentioned in the previous section, we design a secure UTM system for collision avoidance. Fig. 3 illustrates the WAVE based UTM system. The central server is a UTM server that collects flight information of all UAVs flying on the airspace and monitors the status of the UAVs continuously. WAVE base stations (WAVE BSs) on the ground and UAVs with WAVE modules form a WAVE-based ad-hoc network, or WAVE FANET. One or more WAVE BSs have a plurality of network interfaces and are connected to an external Internet network, and serve as gateways to the UTM server. In this paper, a UAV with WAVE module play the same role as a general on-board equipment (OBE) in VANET, and a WAVE BS as a gateway serves as road-side unit (RSU) in VANET.

Prior to commencing flight, an UAV must obtain permission for the flight from the UTM server. Therefore, the UAV equipped with a WAVE module sends its ID, origin point and destination information to the ground WAVE base station (BS) nearest to its location. The WAVE base station on the ground transmits this information to the UTM server. The UTM server checks the ID of the UAV, determines the availability of the flight in the airspace, and then, grants permission for the flight. An authorized UAV initiates a flight and periodically sends its flight information data to its nearest ground BS from its current position during flight. In this way, the UTM server can monitor location information, flight information and flight path of all UAVs flying in the airspace. Based on the collected information, the UTM server can not only monitor the UAVs but also warn of dangerous situation such as path collision between UAVs. Because the UTM server has flight information of all UAVs flying through the airspace that includes the flight path, speed, and direction, it can predict that different UAVs will pass the same route at the same altitude and at the same time. The collision avoidance alarm message is transmitted to the WAVE BSs including the current position of the corresponding UAVs, and the BS broadcasts the safety related message to the UAVs in the CCH interval.

If a UAV in the airspace fails to belong to a transmission range of any WAVE BS, the communication link is disconnected so that the UAV's periodic information will not sent to the UTM server and safety-related messages from the UTM server will not be received. If the UTM server loses the location information of the flying UAV, the secure traffic management of the entire airspace becomes impossible. Therefore, even if the UAV exceeds the communication range of the WAVE BS, the location information of the UAV need to be continuously sent to the UTM server. Direct communication between UAVs is useful in this situation. Direct communication is possible by configuring ad-hoc networks with UAVs equipped with WAVE modules.

IV. Conclusion & Future Works

In this paper, we describe the use of WAVE protocol for UAV management for collision avoidance and stable connection in UTM system. By mounting WAVE module on UAV and installing WAVE base station on the ground, it is possible to quickly transmit messages related to safety in case of an emergency through WSMP. In addition, by using the channel assigned to the safety-related message, the successful transmission of the message can be guaranteed. Also by configuring the FANET among UAVs through the WAVE protocol, it is possible to manage the location and status information of all UAVs in the UTM system by ensuring availability through expansion of cell coverage.

Future research will ultimately aim to design a UTM system that can be used together with a cellular network in order to secure wide coverage and enhance link stability. LTE is attractive for UTM applications because it can exchange data information with high throughput with dedicated bandwidth and can use already established nationwide networks. However, since the commercial LTE network does not support direct communication, there is a problem that it cannot be utilized in a situation where direct information exchange between UAVs is required. Therefore, it is possible to construct more stable and secure UTM system by constructing the UTM system combining cellular networks and WAVE-based direct communication.

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