Comparison of Communication Protocols for UAVs and VANETs

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Abstract—**This decade sees a growing number of applications of Unmanned Aerial Vehicles (UAVs) or drones. UAVs are now being experimented for commercial applications in public areas as well as used in private environments such as in farming. As such, the development of efficient communication protocols for UAVs is of much interest. This paper compares and contrasts recent communication protocols of UAVs with that of Vehicular Ad Hoc Networks (VANETs) using Wireless Access in Vehicular Environments (WAVE) protocol stack as the reference model. The paper also identifies the importance of developing light-weight communication protocols for certain applications of UAVs as they can be both of low processing power and limited battery energy.**

Keywords— UAV; VANET; WAVE; communication protocol

I. INTRODUCTION

UAVs, commonly known as drones can fly autonomously to a specified location along a specified path and can also be remotely controlled by a human operator. In the beginning, UAVs were used for military purposes but nowadays UAVs operate in commercial environments as well [1]. In recent years, UAV technology has attracted many researchers due to its numerous application possibilities. Consumer Electronics Association (CEA) research predicted that UAV sales will touch $130 million this year (2015) which is more than 50 percent as compared to last year [2]. UAVs are classified according to their functions. These are target and decoy (used for target enemy aircrafts), reconnaissance (used for battlefield intelligence), combat (used for high risk missions), logistics (used for cargo operations), research and development (used for further research in UAVs), and civil and commercial UAVs (used for commercial applications) [3]. In the future, UAVs will be providing more services in various domains such as farming, disaster management, construction, surveillance, transportation, to name a few. Commercial UAVs are also available in various types depending on their payload, flying capacity and altitude. These are micro UAVs, generic UAVs, tactical UAVs, unmanned combat aerial vehicles, and civil UAVs [4]. UAVs are also classified by their flight altitude and flight distance. The smallest UAVs are hand-held which can fly up to 600 m of altitude and cover 2 km radius area. Larger UAVs can fly about 1500 m high and travel a distance up to 10 km. NATO type UAVs can fly up to 3000 m altitude and can cover an area of 50 km in radius. Tactical UAVs can fly at 5500 m altitude and cover 160 km distance whereas a MALE (medium altitude, long endurance) has the capability to fly 9000 m high and cover a range of over 200 km in radius. A HALE (high altitude, long endurance) UAV can fly over 9100 m altitude and cover an indefinite range [4].

As discussed in Section III of this paper, several wireless communication protocols have been already developed for UAVs. They have been designed for specific uses of UAVs. The wireless communication protocols developed for VANETs, on the other hand, have been standardized and are more mature. It would be interesting to investigate and understand whether the protocols developed for VANETs can be reused for communication in UAVs. As such, our motivation in this paper is to compare and contrast the existing protocols of UAVs and VANETs and identify any future directions of UAV communication protocol development.

The structure of the remainder of the paper is organized as follows. Section II discusses the existing communication protocol for VANETs and Section III investigates the communication protocols developed for various applications of UAVs. The comparison of communication protocols for UAVs and VANETs is undertaken in Section IV. Finally, the paper is concluded in Section V.

II. COMMUNICATION PROTOCOLS FOR VANETS

A VANET is a type of Mobile Ad Hoc Network (MANET). It is a wireless network that is used for communication between road vehicles. Vehicular communications are classified into three categories; in-vehicle domain where communication inside the vehicle using an application unit takes place, ad hoc domain where Vehicle to Vehicle (V2V) and Vehicle to Infrastructure (V2I) communications take place and infrastructural domain where the communication is between the vehicle and the Internet. The two types of communications in VANETs are V2V and V2I [5]. The Wireless technologies that are used by VANETs are cellular system, Wireless LAN (WLAN) and Wireless Fidelity (Wi-Fi), Worldwide Interoperability for Microwave Access (WiMAX), Dedicated Short Range Communications (DSRC)/Wireless Access in Vehicular Environments (WAVE) and combined wireless access technologies. A VANET is different from a MANET and its main characteristics are predictable mobility, providing safe driving, improving

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passenger comfort, enhancing traffic efficiency, no power constrains, variable network density, rapid change in network topology, a large scale network and high computational ability [5].

Previous research in VANET communication has proposed several communication protocols for V2V and V2I communcation. These communication protocols are based on the layers of WAVE protocol stack [6] shown in Fig. 1 that comprises of IEEE 1609 standard, IEEE802.11p standard and Society of Automotive Engineers (SAE) J2735 standard.

<table>
<tr><td>Non-safety Applications
VITP [8]</td><td>Safety Applications
SAE J2735</td></tr>
<tr><td>Transport Layer
TCP/UDP</td><td rowspan="2">WSMP
IEEE 1609.2 (Security)
IEEE 1609.3
Diffie-Hellman Protocol [9]</td></tr>
<tr><td>Network Layer
IPv6
V2I Protocol [11]</td></tr>
<tr><td colspan="2">LLC
IEEE 802.2</td></tr>
<tr><td colspan="2">MAC Layer
IEEE 802.11 P
IEEE 1609.4
V2V Protocol [11]
VCWC [10]</td></tr>
<tr><td colspan="2">Physical Layer
IEEE 802.11 P
V2V Protocol [11]
VCWC [10]</td></tr>
</table>

Fig. 1. VANET communication protocols shown in WAVE Protocol Stack

The most often used technologies for V2V communication are IEEE 802.11, dedicated short range communication and General Packet Radio Service (GPRS). The main challenges in VANET communication are scalability of protocol, security and high speed real-time communication [7]. Dikalakos et al. [8] proposed location aware services that can help inform the car driver about traffic condition and road side facilities. Vehicular Information Transfer Protocol (VITP) [8] is a location aware application layer stateless communication protocol which is based on the client server model. VITP defines the format for query and reply messages that exchange between vehicular clients and servers [8]. It is used to define syntax and semantics of messages which handle the queries and replies between nodes in VANETs. It works independently from VANET protocols that are used for transmission and routing purposes.

Diffie-Hellman protocol [9] is a secure communication protocol and a novel approach for car to X communication. It is considered as a secure protocol assuming that the discrete logarithm problem is intractable. In the implementation of this protocol, a group of vehicles is defined first by polling the neighborhood table. Thereafter, key fragmentation is defined for each vehicle by selecting the secret number. A group key is then calculated and shared between the communicating vehicles. Every group member uses this group key to sign the messages. This protocl operates in the transport and network layers of the secure WAVE protocol stack. Yang proposes a Vehicle Collison Warning Communication (VCWC) protocol that addresses the problem of achieving a low latency in delivering the Emergency Warning Messages (EWMs) in various road situations. VCWC is implemented over the physical and MAC Layer. The physical characteristic of the channel follows the 802.11b standard with a channel bit rate of 11Mbps. Whenever an abnormal vehicle supplies an EWM, the out of band busy signal is raised that is sensed by the vehicles within a distance of two hops. A rate decreasing algorithm for EWMs proposed by Yang helps achieve the real time transmission of EWMs [10].

A communication system is described in [11] which integrates the two systems, V2V and V2I. In this system, V2I is concerned about IPv6 network mobility and V2V uses the hybrid solution that is based on intelligent delivery and delay tolerant network. IPv6 has the large address space required by VANET for supporting the millions of entities which can easily exchange information during the communication. The V2V communication protocol uses the 802.11p interface to transmit packets between nodes.

III. COMMUNICATION PROTOCOLS FOR UAVS

There are several communication protocols for UAVs proposed by different authors. A UAV Search Mission Protocol (USMP) is proposed in [12] which is a combination of inter-UAV communication and geographic routing. Location update and way point conflict resolution are key areas in this research. Location update feature of USMP works with two design methodologies. In the first design, the message is passed explicitly to neighbor UAVs, and in the second design, Greedy Perimeter Stateless Routing (GPSR) location information is reused. The waypoint selection is performed with the reservation message. USMP implementation is based on key parameters such as transmission power, swarm size, sensor type and initial location. The result of this research was examined using analysis of variance (ANOVA). The outcome of this research changed the hypothesis that search performance of UAV improves by every geographic routing for waypoint conflict resolution. The experimental result also showed that the GPSR harvesting is not a replacement of explicit location update. As shown in Fig. 2, USMP protocol belongs to physical and MAC layers of the WAVE protocol stack.

Tuna et al. proposed a communication system in [13] for post disaster management. In this system, the UAV contains an on-board computer that has three subsystems for end to end communication, formation control and autonomous navigation. They describe a routing protocol that operates in the nertwork layer. Via simulation and experiments they prove that this communication system is a feasible solution for disaster recovery and is helpful in disaster management. Alshbatat and Liang [14] provided an idea of Adaptive Medium Access Control protocol for UAV communication (AMUAV). In this approach, each UAV has a primary directional antenna mounted on top of it and a secondary directional antenna fixed under it. There are also omni-directional antennas as in other UAVs. Both omni-directional and directional antennas partcipate in the communication between two UAVs. The switching of transmission from omni-directional to directional antennas was undertaken with the help of an information table. This protocol solved the problem of communication of UAVs among themselves without the need of a ground station. A Global positioning system (GPS) and Inertial Measurement Unit (IMU) are used in this protocol to update the location of UAVs. AMUAV packet transmission is achieved with IEEE 802.11 standard, and information table for message passing is updated with Direct Network Allocation Vector (DNAV). In this scheme, AMUAV protocol initiates the data packet transfer and it checks the distance between two UAVs. If this distance is less than the range of omni-directional antenna, then the data packet is sent by this antenna. Otherwise, MAC Layer checks the altitude of the first UAV and compares it with that of the second UAV. If it is less than or equal to the altitude of the second UAV, then the data packet will be sent by primary directional antenna and direction will be towards the second UAV. On the other hand, if the altitude of the first UAV is greater than the altitude of the second UAV, then the data packet will be sent by secondary directional antenna and direction will be towards the second UAV.

Non-safety Applications IMC Protocol [15]	**Safety Applications** **SAE J2735**
Transport Layer **TCP/UDP**	**WSMP** **IEEE 1609.2 (Security)** **IEEE 1609.3**
Network Layer **IPv6** Routing Protocol of [13]	
LLC **IEEE 802.2**	
MAC Layer **IEEE 802.11p** **IEEE 1609.4** USMP [12] AMUAV [14]	
Physical Layer **IEEE 802.11p** USMP [12]	

Fig. 2. UAV communication protocols shown in WAVE Protocol Stack

After successfully receiving the data, the second UAV sends the ACK to first UAV using omni-directional antenna. The outcome of this research shows a performance improvement by switching between the two antennas compared with the use of only omni-directional antennas [14]. This protocol operates in the MAC layer of WAVE protocol stack. Martins et al. proposed a communication protocol to communicate between the UAV and the ground station [15]. An Inter module communication (IMC) protocol was designed for exchange of real-time information between vehicle and the human operator. The communication between vehicles was performed by sending the IMC packet [15]. IMC protocol operates in the safety application layer of WAVE protocol stack. These protocols operate at the different layers in WAVE protocol stack as shown in Fig. 2.

IV. Comparison of UAV and VANET Protocols

The main purpose of this paper is to compare the UAV communication protocols with the VANET communication protocols. Comparison of Fig. 1 and Fig. 2 shows that the VANET protocols, VITP and V2I that have been discussed in the literature belong to the non-safety application layer and network layer of the WAVE protocol stack respectively. The Diffie-Hellman protocol discussed in [9] belongs to the secure transport and network layers of the WAVE protocol stack.

Similar to VANET protocols, UAV communication protocols can also be placed in the WAVE protocol stack. The USMP protocol is implemented over the physical and MAC layers of WAVE protocol stack whereas AMUAV operates in the MAC layer. The IMC protocol for UAV communication operates in the non-safety application layer. However, it seems that no further protocols have been developed at the application, transport and network layers for safety applications. WSMP, IEEE 1609.2 (Security) and IEEE 1609.3 protocols of WAVE protocol stack currently handle the transport and network layer functions of VANETs for safety applications.

A large difference exists between the requirements for designing VANETs and UAV networks. Unlike in VANETS, where the vehicles and roadside units can carry high processing power processors of considerable weight that are powered by mains or the engines of the vehicles, UAVs have a limited payload as well as limited battery power and therefore, low processing capabilities. Any protocol design for UAV communication should take these challenges into account. Given the large range of applications of UAVs, it may be necessary that tailor-made protocols are required for them. For example, for commercial and agricultural applications, though safety is required in the application layer, a light-weight protocol such as IPv6 with authentication or encrypted security payload extension header in the network layer may be sufficient, whereas for military applications, the existing protocols of WAVE protocol stack may provide the required security.

V. Conclusion

The rapid growth of application of UAVs in numerous areas has created a strong interest in UAV communication research and a considerable amount of work is being undertaken in this field. This paper studies the communication protocols for VANETs and UAVs found in the literature and the recent developments of communication protocols for VANETs and UAVs are compared with reference to the layers in WAVE protocol stack. The paper points out that purpose-driven new protocol development may be required in the network and transport layers for safety applications in the case of UAVs as they are used for variety of different purposes. For cases such as commercial and agricultural applications, a light-weight protocol may be needed in the network layer for UAVs, considering that they do not have high processing power processors and their battery time is limited.

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