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Research paper



Allocation of Control and User Data Channels for Private UAV Networks

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Abstract

Unmanned Aerial Vehicle (UAV) industry shows rapid growth in producing sophisticated UAVs for civilian use in recent years. With the invention of private UAV networks, these UAVs can now be used in a UAV network owned by a single organization or a person. For example, a private UAV network gives the ability for a farmer to monitor the farm from one location or to locate people in a natural disaster-stricken area. The wireless communication paths between UAVs and the ground station in a private UAV network play a vital role in transmitting video to the ground station. It is also necessary that the control signals are sent over the private UAV network to the UAVs to control their movements. Since the control signals cannot be delayed and videos received at the ground station should be of high quality, separate channels should be created for user data and control data traffic. In this paper, we present a channel allocation approach for private UAV networks to transfer control data as well as user data. For high quality video transmission, we recommend bonding of basic video channels. This new channelization also avoids congestion and packet drop issues of video and control data traffic in private UAV networks.

Keywords: *Channelization; Video and control traffic; Private UAV networks; UAV communication*

1. Introduction

Nowadays, commercial applications of UAVs are on the rise. We can estimate their demand as prominent firms such as Amazon [1], Google [2], and Facebook [3], invest their time and money in the research of applications of UAVs.

At present, DJI, AeroVironment, 3D robotics and Parrot SA are the most popular drone manufacturing companies in the world [4]. All of these commercial UAVs work on the standard UAV and remote controller (RC) communication principle to transfer the control information and user data to and from a ground station. In this standard UAV communication principle, a UAV is bound with its ground station controller, and the video and other data captured by the devices mounted on the UAV are directly sent to the ground control station.

Small commercial UAVs serve in various application domains such as agriculture, surveillance, delivery, rescue and many more. The role of each UAV in all of these applications is to capture the real-time videos and stream them live to the ground station, using a robust communication system between the UAV and the ground station. A UAV can serve better if it works together with other UAVs belonging to the same owner, forming a private network of UAVs. Such a private UAV network requires an Inter-UAV communication mechanism where the first UAV passes its data to the second UAV, and the second UAV passes its own data as well as the data that came from the first UAV to the third UAV and so on. There are many applications where a private UAV network could provide better service compared to a single UAV to ground station combination. For example, in the case of a natural disaster, with the help of a private UAV network, we can cover a wider area and pass the messages to the ground station quickly. Farmers can also monitor their farms of many hectares with the help of private UAV networks. In the existing UAV market, no UAV manufacturing company still produces UAVs that can communicate between them and there is not much research undertaken on Inter-UAV communication as well.

We studied the currently available commercial UAVs that have built-in cameras with them and found that most of them use two frequency bands in the spectrum to transfer their video data and control data to the ground station controller. They use 5 GHz band for their video transfer and 2.4 GHz band for the control signal. However, some UAV designs have these two frequency bands swapped. As the RC controllers produce analog signals, UAV manufacturers use these two different frequency bands in order to avoid interference. It would be inefficient and cumbersome to use two different frequency spectrums in a private UAV network where the communication takes place via digital WiFi signals.

In a Wireless Local Area Network (WLAN), neighbouring cells operate at different frequency channels of the same frequency spectrum to avoid the common channel interferences (CCI). Since the locations of UAVs can change at any time, it is difficult, if not impossible, to maintain different channels in neighbouring UAVs in other types of UAV networks. However, in private UAV networks, we can configure each alternative UAV to operate in the same frequency channel and let the control and user data share the available capacity of the links between UAV pairs. However, this requires the creation of different channels for data and control information. It should be emphasized that these are not frequency channels but data channels whose capacities are expressed in bps.

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As such, in this paper, we introduce the new channel allocation to transfer user data and control signals through UAV networks operating in 2.4 GHz as well as 5 GHz frequency bands. We created the channels considering the minimum bandwidth required for video data transmission by the cameras mounted on commercial UAVs and the bandwidth required for control data transmission.

The structure of the remainder of the paper is organized as follows. Section 2 deals with the IEEE 802.11 standards and their channel classifications. Data channels of UAV network is presented in Section 3. Section 4 discusses the approach that can be taken to increase the channel capacity for video if required. Finally, the paper is concluded in section 5.

2. IEEE 802.11 standards and channel classifications

IEEE 802.11 describes various standards for transmitting data from a source node to a destination node in a wireless network. Private UAV networks are also types of wireless networks and hence, can use these IEEE 802.11 standards to transmit the control and video data through the network. In this section, we investigate the existing IEEE 802.11 standards to find out their maximum data transmission rates, frequency bands and the bandwidth of communication channels.

2.1. Summary of the existing IEEE 802.11 standards

Legacy 802.11 is the first IEEE 802.11 family standard published in 1997. The data rate of this standard is 1 Mbps and 2 Mbps, and it uses 2.4 GHz spectrum for data transmission [5]. In 1999, IEEE 802.11a was published, increasing the data rate to 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. This increase in the data rates was due to the different modulation techniques used. IEEE 802.11a uses the 5 GHz frequency spectrum for data transmission, and it has 12 non-overlapping communication channels [6]. In the same year, IEEE published one more standard 802.11b that works over the 2.4 GHz frequency band. The maximum data transmission rate of this standard is 11 Mbps [7]. IEEE 802.11g was released in the year of 2003. This standard uses the 2.4GHz frequency spectrum with a maximum data rate of 54 Mbps. It has three non-overlapping channels for data transmission [8]. IEEE 802.11n was released in 2009. It works on both 2.4 and 5 GHz Frequency spectrums. The maximum data transmission rate of this standard is 54 Mbps, but in 40 MHz operation with three transmitters and receivers, the maximum data rate can reach 450 Mbps as shown in Table 1 below [9].

Table 1: Maximum data transmission rates of IEEE 802.11 n

Mode	20 MHz	40 MHz	20 MHz	40 MHz	20 MHz	40 MHz
Transmitter & Receiver	1TX, 1RX	1TX, 1RX	2TX, 2RX	2TX,2RX	3TX,3RX	3TX,3RX
Maximum rate	72.2 Mbps	150 Mbps	144.4 Mbps	300 Mbps	216.7 Mbps	450 Mbps

IEEE 802.11ac Wave 1 was released in 2014 with 866 Mbps maximum data rate. In 2016, the next version of IEEE 802.11 ac Wave 2 was published. It can support up to 1.73 Gbps maximum data rate as it can use 160 MHz width channel for communication [10]. Both these IEEE 802.11ac standards use 5 GHz frequency spectrum for communication. The different data rates for these standards are shown in Table 2 and 3 below.

Table 2: Maximum data transmission rates of IEEE 802.11 ac Wave 1

Mode	40 MHz	40 MHz	80 MHz	80 MHz
Transmitter & Receiver	1TX, 1RX	2TX, 2RX	1TX, 1RX	2TX,2RX
Maximum rate	200 Mbps	400 Mbps	433 Mbps	866 .7 Mbps

Table 3: Maximum data transmission rates of IEEE 802.11 ac Wave 2

Mode	40 MHz	40 MHz	80 MHz	80 MHz	160 MHz	160 MHz
Transmitter & Receiver	1TX, 1RX	2TX, 2RX	1TX, 1RX	2TX,2RX	1TX,1RX	2TX,2RX
Maximum rate	200 Mbps	400 Mbps	433 Mbps	866 Mbps	866 Mbps	1.73 Gbps

The following Table 4 shows the overall details of all IEEE 802.11 standards with their maximum theoretical data rates.

Table 4: Summary of IEEE 802.11 standards

Year	Standard	Frequency Bands	Channel width	Max theoretical transmission rate in a single stream
1997	IEEE 802.11	2.4 GHz	22 MHz	1, 2 Mbps
1999	IEEE 802.11 a	5 GHz	20 MHz	6,9,12,18,24,36,48,54 Mbps
1999	IEEE 802.11 b	2.4 GHz	22 MHz	1,2,5,5,11 Mbps
2003	IEEE 802.11 g	2.4 GHz	20 MHz	6,9,12,18,24,36,48,54 Mbps
2009	IEEE 802.11 n	2.4 or 5 GHz	20/40 MHz	Up to 450 Mbps
2013	IEEE 802.11 ac wave 1	5 GHz	20/40/80/160 MHz	Up to 866.7 Mbps
2016	IEEE 802.11 ac wave 2	5 GHz	20/40/80/160 MHz	Up to 1.73 Gbps

2.2. Channel allocation in 2.4 & 5 GHz frequency spectrum

We can see from IEEE 802.11 standards discussed in Section 2.1 that all of them use either 2.4 GHz or 5 GHz frequency spectrum to transmit data.

Table 5: 2.4 GHz spectrum channels and their frequencies

Channel No.	Center Frequency(MHz)	North America (FCC)	Japan	Europe(ETSI)
1-11	2412-2462	Y	Y	Y
12	2467	N	Y	Y
13	2472	N	Y	Y
14	2484	N	802.11 b only	N

Each of them has predefined frequency channels. The total number of frequency channels in the 2.4 GHz frequency spectrum is 14, and out of these, some are reserved and not available for users. Similarly, the 5 GHz frequency spectrum also has predefined frequency channels. The summaries of these channel allocations in both spectrums are given in Table 5 and 6. Therein, the following acronyms have been used. DFS, TPC, and SRD are used for Dynamic Frequency Selection, Transmit Power Control, and Short Range Devices respectively. The term ETSI stands for the European Telecommunication Standard Institute.

Table 6: 5 GHz spectrum channels and their frequencies

Channel Number	Center Frequency (MHz)	North America (FCC)	Japan	Europe (ETSI)
36-48	5180-5240	Y	Y	Indoors
52-116	5260-5580	DFS	DFS / TPC	Indoors / DFS / TPC
120-128	5600-5640	N	DFS /	DFS / TPC

			TPC	
132-140	5660-5700	DFS	DFS / TPC	DFS / TPC
149-165	5745-5825	Y	N	SRD

3. Data Channels for private UAV networks

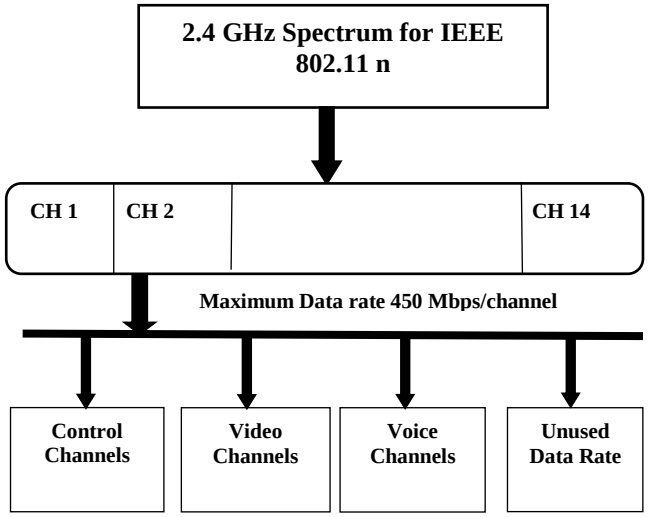

Fig. 1: Channel Allocation in 2.4 GHz for IEEE 802.11 n

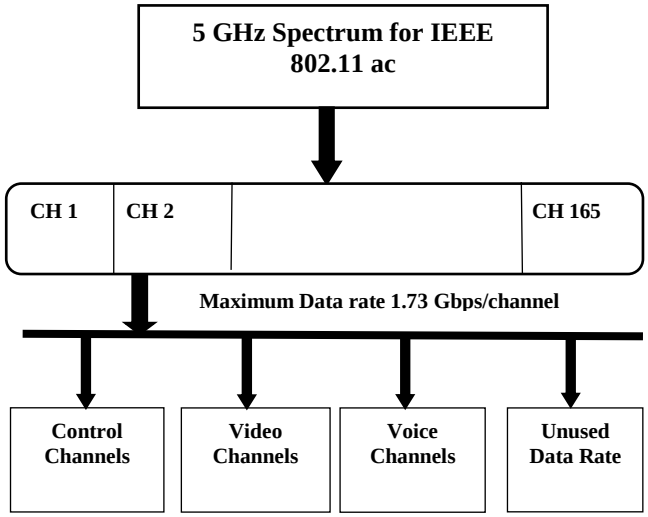

Fig. 2: Channel Allocation in 5 GHz for IEEE 802.11 ac

Private UAV networks will use a single frequency channel from the 2.4 GHz or 5 GHz frequency spectrum. In future, UAVs can be designed with a configuration to select a particular channel in its spectrum of operation.

We can create new video and control data channels within the selected frequency channel of 2.4 or 5 GHz spectrums. For this purpose, we use 2.4 GHz spectrum with IEEE 802.11 n standard and 5 GHz with IEEE 802.11 ac standard as shown in Fig. 1 and Fig. 2 respectively. Note the frequency channels have channel bandwidths measured in MHz, but the data channels have bandwidths or data rates measured in Mbps or Gbps.

3.1. Bandwidth requirements for transferring videos

As mentioned before, the user data as well as control data have to be transmitted through a UAV network. Considering the applications of commercial UAVs, private UAV networks would carry many live video streams simultaneously. For any wireless application scenario involving IEEE 802.11 standards, the designer has to select one allowed channel from the channels provided in Table 5 or Table 6, depending on the frequency spectrum used. If the entire channel is used for the UAV network without separate data channels, the control traffic may be delayed when the user data traffic load is high such as in the case of video transmission through a private UAV network. Therefore, after selecting a frequency channel, the designer of the private UAV network has to allocate data channels for various user and control traffic.

In order to perform the data channelization, we need to understand the minimum data rate required to transmit videos of different quality and control signals. The standard bandwidth requirement for transmitting high definition (HD) video is 15 Mbps, but the actual bandwidth requirement depends on the camera's video quality and other parameters. For commercial UAVs that are currently available in the market, the minimum bandwidth requirement for video transmission varies to some extent. In DJI Phantom 4 UAV [11], the live video can be watched with 720p at 30 frames per second on the DJI app. Most small commercial UAVs, such as DJI photo 4, DJI inspire 2, DJI Mavic pro, DJI Phantom, DJI Spark, Parrot Bebop 2, Yuneec Typhoon, can send their live video feeds at 720p with their inbuilt camera [12]. Furthermore, most of the UAV cameras use H.264 video encoding format, and the required data rate for this video transmission is 1.5 Mbps with 720p at 25 Fps [13]. The data rate requirement calculation for 720p at 30 frame video transmission shows that 1920 kbps data rate is enough for this purpose [14]. As such, we can conclude that with the currently available UAV with built-in cameras or the cameras recommended by the UAV manufacturers, videos can be transmitted over 2 Mbps data channels. This bandwidth is sufficient for most applications of private UAV networks. Therefore, our channelization scheme will use 2 Mbps data rate for video channel creation.

3.2. The bandwidth requirement for control channels

A commercial UAV is maneuvered by a controller residing in the ground station. The ground station controller sends and receives radio control signals to and from the UAV. In a private UAV network, control signals have to travel through several UAV nodes before arriving at the destination. Therefore, to allocate channels for the control signal transmission, it is important to know about the minimum bandwidth required. For this purpose, we need to investigate the bandwidth allocations used for control channels in other types of known networks.

In Integrated Service Digital Network (ISDN), they use 64 kbps for the control signalling [15]. The common channel signalling protocol SS7 also use 64 kbps for control signalling [16]. As such, this data rate should be sufficient to send controls signals in UAV networks.

3.3. Channel creation for private UAV network

As mentioned in section 2, IEEE 802.11 n and IEEE802.11 ac standards provide the highest data rates for communication, and they are operating on 2.4/5 GHz and 5 GHz spectrums respectively. Besides, all commercial UAVs available today use these two frequency spectrums for their communication. Therefore, we create video and control channels to be used with UAV networks for both these standards.

3.4.1. Data and control channels with IEEE 802.11n

As shown in Table 1, IEEE 802.11n standard can support up to 450 Mbps data rate. It is the maximum theoretical data rate supported by this standard. Since the minimum data rate required for transmitting video traffic is 2 Mbps as estimated earlier in Section 3.1, we can create 218 new video channels in the available data rate of 450 Mbps. These 218 video channels will consume a total of 436 Mbps, and the remaining 14 Mbps will be used to create control channels. Since we allocate 64 kbps for each control channel, 218 control channels can be created. The video and control channel allocation for private UAV networks which follows the IEEE 802.11n standard is shown in Table 7.

Table 7: Channels for IEEE 802.11n standard

Max Data rate	Data rate requirement for video transmission	Total no of video channels	Data rate requirement for control signal transmission	Total no of control channels
450 Mbps	2 Mbps	218	64 kbps	218

The IEEE 802.11n standard can operate in 2.4 or 5 GHz spectrums. Fig. 3 shows the channel allocation of IEEE 802.11 n in 2.4 GHz spectrum.

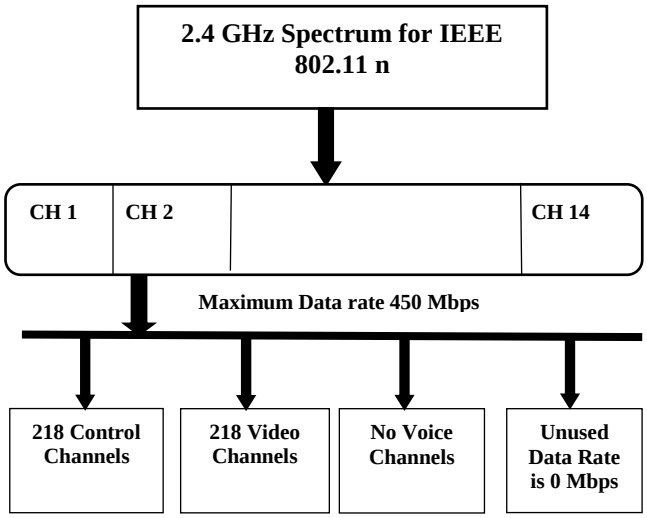

Fig. 3: Video and control Channels in 2.4 GHz for IEEE 802.11n

3.4.2. Data and control channels with IEEE 802.11 ac

IEEE 802.11ac is a powerful wireless communication standard which works on the 5 GHz frequency spectrum. According to Table 3 and 4, this standard can support up to 1.73 Gbps data rate when it works at 160 MHz bandwidth. Since the required data rate for a video and a control channel is 2 Mbps and 64 kbps respectively, we can create 838 video channels and 838 control channels out of the total available data rate. After creating these channels, we still have an unused data rate of 370 kbps. This unused capacity can be used for other types of data such as voice. According to the ITU recommendation G.726 [17], 48 kbps data rate is enough for voice over IP transmission. We use this data rate and create the voice channels from the unused capacity of 370 kbps.

Table 8: Channels for IEEE 802.11 ac standard

Data rate requirement for video transmission	Total no of video channels	Data rate requirement for control signal transmission	Total no of control channels	Number of voice channels	Unused
2 Mbps	838	64 kbps	838	7	34 kbps

The summary of this channelization is shown in Table 8. Fig. 4 shows the video and control channel allocations for IEEE 802.11 ac in 5 GHz spectrum.

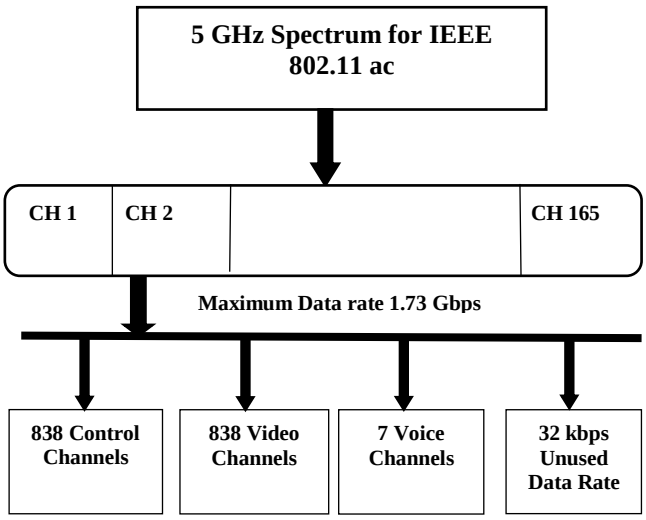

Fig. 4: Video and Control Channels in 5 GHz for IEEE 802.11n

4. Increasing channel capacity for video

The new channelization for private UAV network allows us to send multiple videos and control signals simultaneously through a UAV network without any interference. As mentioned in section 3, 218 and 834 video and control connections can coexist in a communication link of a UAV network using IEEE 802.11n standard and IEEE 802.11ac standard, respectively.

In some situations, and in particular, when the quality of UAV cameras improves in the future, a 2 Mbps channel will not be sufficient to transmit videos of better quality. For example, to transmit HD quality video, we need 15 Mbps. For this purpose, 8 channels can be bonded together to support HD quality video transmission. Furthermore, the bonding of 8 channels acts as a single channel, and we need only one control channel for all these 8 channels. In this situation, with IEEE 802.11n, the number of video channels will be 28 (each video channel is a combination of eighth channels of 2 Mbps data rate), and the number of control channels will be 28 (see Table 9). The unused capacity of 208 kbps can be assigned to 4 voice channels.

Table 9: Channel bonding with IEEE 802.11 n

Number of video channels bonded together	The data rate of one channel	Number of video channels	Number of control channels	Number of voice channels	Unused capacity
2	4 Mbps	110	110	61	32 kbps
3	6 Mbps	74	74	26	16 kbps
4	8 Mbps	55	55	135	0
5	10 Mbps	44	44	149	32 kbps
6	12 Mbps	37	37	75	32 kbps
7	14 Mbps	31	31	292	0
8	16 Mbps	28	28	4	16 kbps

Similarly, with IEEE 802.11ac standard, to transmit 15 Mbps HD video, the number of video and control channels will be 107 with 232 voice channels (see Table 10). Table 9 and Table 10 show the number of video and control channels possible with channel bonding to obtain different capacity video channels.

Table 10: Channel bonding with IEEE 802.11 ac

Number of video channel bonded together	The data rate of one bonded channel	Number of bonded video channels	Number of control channels	Number of voice channels	Unused capacity
2	4 Mbps	425	425	58	16 kbps
3	6 Mbps	285	285	36	32 kbps
4	8 Mbps	214	214	89	32 kbps
5	10 Mbps	171	171	188	32 kbps

6	12 Mbps	143	143	48	0
7	14 Mbps	123	123	2	32 kbps
8	16 Mbps	107	107	232	16 kbps

5. Conclusion

In this paper, we presented a new channel allocation structure to transfer control and user data in private UAV networks. We studied the existing commercial small size UAVs and found the minimum bandwidth requirement for video and control data transmission. After studying the frequency channel allocations in 2.4 GHz and 5 GHz spectrums, we created new video and control data channels for IEEE 802.11n and IEEE 802.11 ac standards that can be used in private UAV networks. Using bonding of user data channels, high-quality video can also be transmitted through a private UAV network using our data channel allocation scheme. We believe that such user and control data channel creation is required to avoid packet drop and better control of UAV movements and for the smooth operation of private UAV networks.

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