



Discussion on the Application of 5G Technologies in Data Link Network of UAV Formation

Yu Zhang^(✉), Kai Zhou, and Dongwu Mu

Aviation University of Air Force, Changchun 130022, Jilin, China
Zhangyu1a9z@163.com

Abstract. UAV formation is a research focus currently. Data link network plays a key role in the information exchange in UAV formation, but there are many technical problems to be solved. With the advantages of high speed, low latency and large capacity, 5G communication has been commercialized, and some key technologies of 5G have provided idea inspirations and application feasibilities for data link network of UAV formation. This paper analyzes the characteristics and advantages of key technologies of 5G, such as new network architecture, D2D communication, millimeter wave communication and Massive MIMO, discusses their application methods in data link network of UAV formation, and gives a suggestion on the development of data link network of UAV formation.

Keywords: UAV formation · Data link network · New network architecture · D2D communication · Millimeter wave communication · Massive MIMO

1 Introduction

In recent years, unmanned aerial vehicles (UAVs) have developed rapidly, and UAV formation has become a research focus because of its advantages over a single UAV. UAV data link implements the communication in UAV system. The current UAV system generally takes the mode that one station controls one UAV or that one station controls multiple UAVs, in which the telecontrol data, telemetry data and sensor data are transmitted between the UAV and the ground control station (GCS) through the data link [1]. In the case above, the data link only needs communication between one GCS and one UAV instead of the network communication between UAVs. As UAV formation becomes a developing trend, the traditional data link needs to be extended to data link network to meet the data exchange requirements in a UAV formation. In addition, compared with other wireless networks, data link network of UAV formation is very special, because nodes in this kind of network have strong autonomy, strong mobility, high collaboration requirements, high security requirements and limited energy.

5G technologies are the fifth generation of mobile communication technology [2]. Compared with 4G communication, 5G communication has the advantages of high speed, low latency, low cost, large capacity and energy saving. 5G technologies are

applicable to three application scenarios: enhanced Mobile BroadBand (eMBB), ultra-Reliable Low-Latency Communication (uRLLC) and massive Machine-Type Communication (mMTC) [3]. 5G communication involves some key technologies, such as new network architecture, D2D communication [4], millimeter wave communication [5], massive MIMO [6] and so on. The *White Paper on 5G UAV Application* released by IMT-2020 (5G) Promotion Group gives the application case of 5G cellular network (on the ground) for industrial and low-altitude UAV formation [7]. However, the given case only considers the industrial UAV formation which has low performance, carries the same payloads and flies below 200 m, while the data link network of military UAV formation is not considered. At present, the data link network of military UAV formation is not supported by the 5G cellular network on the ground. Even so, some key technologies of 5G provide idea inspirations and application feasibilities for data link network of military UAV formation.

In this paper, the technical requirements in data link network of UAV formation and the technical principles of advanced communication technologies are analyzed, the application feasibility of key technologies of 5G is discussed, and the suggest on the develop of the data link network of UAV formation is given. It should be noted that the data link networks discussed below are all aimed at military UAV formation.

2 Enlightenment from New Network Architecture of 5G

2.1 New Network Architecture of 5G

A base station generally consists of three parts: BaseBand processing Unit (BBU), Remote Radio Unit (RRU) and antenna. In 1G and 2G communication, a BBU and corresponding RRU are placed in a same cabinet. In 3G and 4G communication, a BBU and corresponding RRU are separated, and the RRU is placed close to the antenna. In 5G communication, RRUs are closer to the antennas than before, and multiple BBUs are concentrated in the central machine room [8]. In addition, 5G network architecture adopts Network Function Virtualization (NFV) and Software Defined Network (SDN) technology to get more flexibility and better performance. NFV decouples software and hardware. SDN separates the control function and the forwarding function [9]. The new network architecture in 5G communication can not be applied directly to data link network of UAV formation, but the idea of fine function-division is enlightening for data link network of UAV formation.

2.2 A Network Architecture Based on Air Base Station for UAV Formation

Currently, a military UAV often undertakes multiple tasks such as reconnaissance, attacking and communication. As a result, a UAV needs to carry multiple payloads and communication equipments, resulting in a large size of a UAV. This leads to lots of negative impacts on the maneuverability, stealth and endurance of a UAV. In data link network of UAV formation, each UAV is a node. We may assign as few tasks as possible for each node, such as having each node carry a single payload and using team's power to complete all tasks. Figure 1 shows an architecture based on air base station for data

link network of UAV formation. In Fig. 1, all nodes are divided into three categories according to their task-division: a reconnaissance cluster (cluster A), an attacking cluster (cluster B) and air base stations (① and ②).

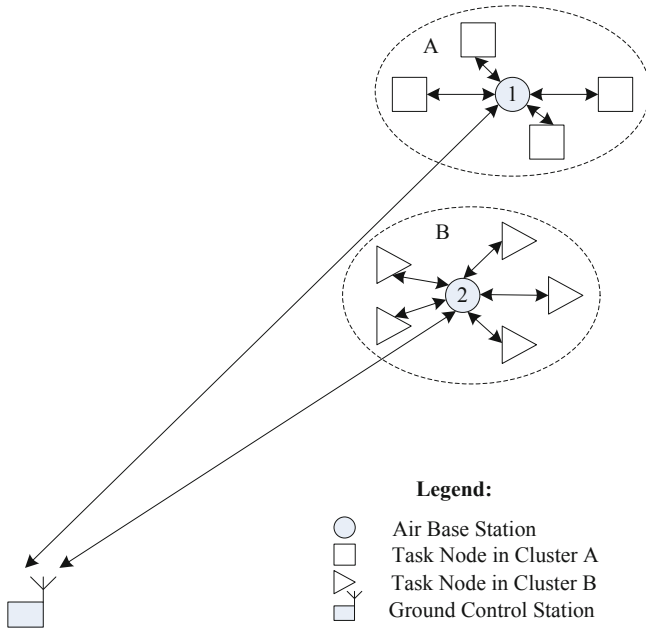


Fig. 1. An architecture based on air base station for data link network of UAV formation

The communication backbone nodes act as air base stations, and they are only responsible for the communication. Air base stations carry equipments for communication, positioning and navigation rather than for reconnaissance or attacking. For an air base station, there are three types of communication objects: a task node (refers to a reconnaissance node or an attacking node), the GCS and another air base station. In addition, air base stations also act as the cluster heads of the reconnaissance cluster and the attacking cluster. That is, the task nodes move following their cluster head to keep the formation. In Fig. 1, the air base station ① is responsible the following tasks: transmitting the telecontrol data from the GCS to task nodes in cluster A; transmitting the telemetry data and sensor data from task nodes in cluster A to the GCS; transmitting formation collaboration data between task nodes in cluster A; transmitting cross-cluster collaboration data between self and air base station ②. The air base station ② is responsible the following tasks: transmitting the telecontrol data from the GCS to task nodes in cluster B; transmitting the telemetry data from task nodes in cluster B to the GCS; transmitting formation collaboration data between task nodes in cluster B; transmitting cross-cluster collaboration data between self and air base station ①.

The network architecture above has the advantages of simplicity and practicality. Because a task node is close to others in a cluster, and only just the collaboration data is required to be exchanged between task nodes in a cluster, that the collaboration data

between nodes in a cluster are transmitted through the cluster head is feasible. So there is no direct communication between task nodes. This architecture reduces the computing load and traffic load of task nodes, simplifies formation collaboration process, and the task nodes do not even need satellite positioning and navigation equipment. However, this architecture also has disadvantages, that is, because of the star topology of each cluster, the air base stations are easy to become the key targets and traffic bottlenecks. Once an air base station collapses, the whole cluster collapses. Therefore, it needs to consider backup and redundancy for air base stations.

In some earlier studies, cluster heads in UAV formation have been mentioned, such as in paper [1]. But those cluster heads are essentially powerful UAV leaders, which are tasked with reconnaissance and attacking. The cluster heads in this paper are 5G air base stations, which are communication infrastructures built on UAV platforms. In the future, 5G air base stations will evolve into the air counterpart of the ground mobile cellular network and provide third-party communication service for air customers.

3 Application of D2D Communication

3.1 D2D Communication

D2D communication has attracted lots of attention since the age of 4G communication, and has become one of the key technologies of 5G communication. In its early application, D2D communication is mainly used to solve the problem of overload of base stations in the cellular network. D2D communication refers to direct communication between devices without any base station [10]. D2D communication uses the frequency range of the cellular network, and its communication distance is farther than WIFI and Bluetooth. D2D communication has the characteristics of high spectrum utilization, high speed, low latency and low power consumption [11]. D2D communication not only reduces the load of base station, but also improves the robustness of communication network, which is important for data link network of UAV formation. At present, there is no D2D communication protocol for UAV formation, but there are D2D communication protocols for cars and other ground users. These protocols can be modified for UAV formation.

3.2 Application of D2D Communication in Data Link Network of UAV Formation

Task nodes in a cluster can directly exchange formation collaboration data by D2D communication, and then adjust respective parameters such as the current speed, height, route and so on. Furthermore, with the development of UAV autonomy, task nodes can also exchange more data which can help other task nodes to finish a task. Figure 2 shows an architecture for data link network of UAV formation using D2D communication. In Fig. 2, all nodes are divided into three categories according to their task-division: a reconnaissance cluster (cluster A), an attacking cluster (cluster B) and air base stations (①–⑩).

There are two differences between Fig. 2 and Fig. 1. In Fig. 2, either a single air base station or a group of several air base stations can act as a cluster head. When a group of

several air base stations acts as a cluster head, the fine task-division can be determined either in advanced or on the spot according respective traffic load. Air base stations are not only responsible for cross-cluster communication and cluster-GCS communication, but also for relay communication under special circumstances. This can provide routing redundancy for data link network. D2D communication can be used to communicate directly between task nodes in a cluster.

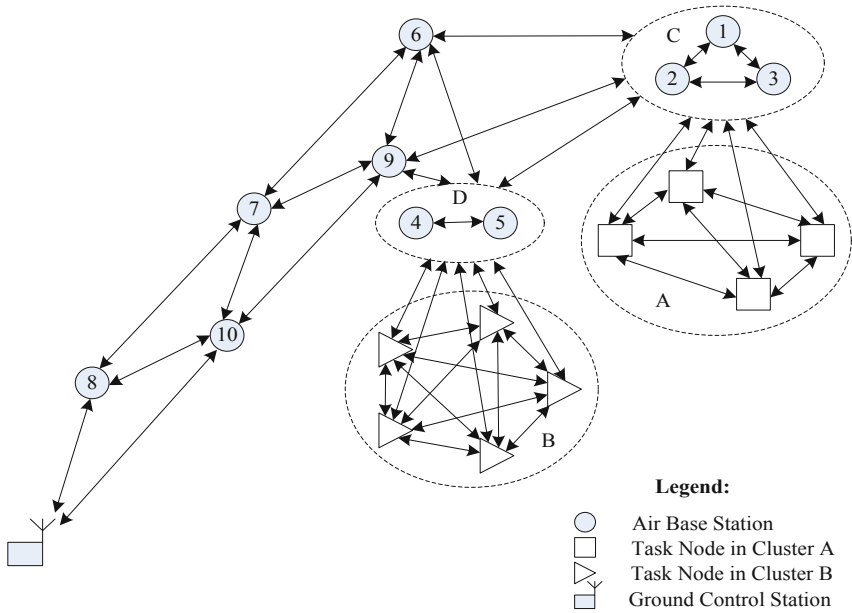


Fig. 2. An architecture for data link network of UAV formation using D2D communication

The network architecture above has the advantages of flexibility and reliability. Since backup and redundancy have been considered for air base stations, the collapse of one air base station will not cause the collapse of the whole cluster. When an air base station collapses, other backup air base stations can continue to complete the communication task, which increases the robustness of the network under bad environment. However, the direct communication between task nodes in a cluster also increases the computation load and traffic load, which makes the formation collaboration process more complex. In addition, each task node needs to carry satellite positioning and navigation equipment for keeping the formation.

4 Application of Millimeter Wave Communication and Massive MIMO

4.1 Millimeter Wave Communication

In 5G communication, due to the requirement of broadband, large-capacity transmission and anti-jamming communication, millimeter wave communication has become a very

important technology. However, millimeter wave communication is not a unique technology of 5G. Millimeter wave communication is widely used in radar, guidance, tactical and strategic communication, electronic countermeasure and so on. Millimeter wave is a kind of electromagnetic wave whose frequency is between 30 GHz–300 GHz and whose wavelength is between 1 mm–10 mm. Millimeter wave communication refers to the communication that takes millimeter wave as the medium. Millimeter wave communication has rich spectrum resources, narrow beam and good directivity. In addition, the antennas for millimeter wave communication have smaller volume, lighter weight and lower power consumption than usual antennas [12]. However, millimeter wave communication also has disadvantages. Millimeter wave transmitting in the atmosphere undergoes frequency-selective attenuation, and the rainfall has great influence on the quality of millimeter wave communication. Therefore, most of the application researches on millimeter wave communication focus on several atmosphere window frequencies and several attenuation peak frequencies [13].

4.2 Massive MIMO

Traditional Multiple Input Multiple Output (MIMO) technology generally include two categories: one is spatial multiplexing technology for increasing the channel capacity and spectrum efficiency, by which data for different users are transmitted on respective channels; another is space diversity technology for improving the communication quality in multipath attenuation [14], by which multiple antennas transmit multiple copies of a same data flow. Massive MIMO wireless communication was proposed by Marzetta from Bell Laboratory [15]. The foundation of massive MIMO communication is that, on the multi-user channels, additive white Gaussian noise and small-scale attenuation disappear gradually with the increase of the number of base station antennas. Massive MIMO communication needs to configure an antenna array which consists of dozens or even hundreds of individually controlled antenna elements in base station. 3D beam forming technology can be used to increase the gain of the antenna array. Massive MIMO technology is one of the key technologies of 5G, B5G and 6G communications.

4.3 Application of Millimeter Wave Communication and Massive MIMO in Data Link Network of UAV Formation

Figure 3 shows a data link network of UAV formation using millimeter wave communication and massive MIMO. In Fig. 3, all nodes are divided into two groups: one group consists of the reconnaissance cluster A and the air-base-station cluster C, and the other group consists of the attacking cluster B and the air-base-station cluster D. Communications inside each group (in the ellipses with shadow in Fig. 3) use millimeter wave and massive MIMO antennas, while cross-group communications and group-GCS communications use traditional radio wave and traditional antennas. Because in each group of data link network of UAV formation, the nodes are close to each other and the data traffic is large, such application method in Fig. 3 can make full use of the advantages of millimeter wave communication and massive MIMO.

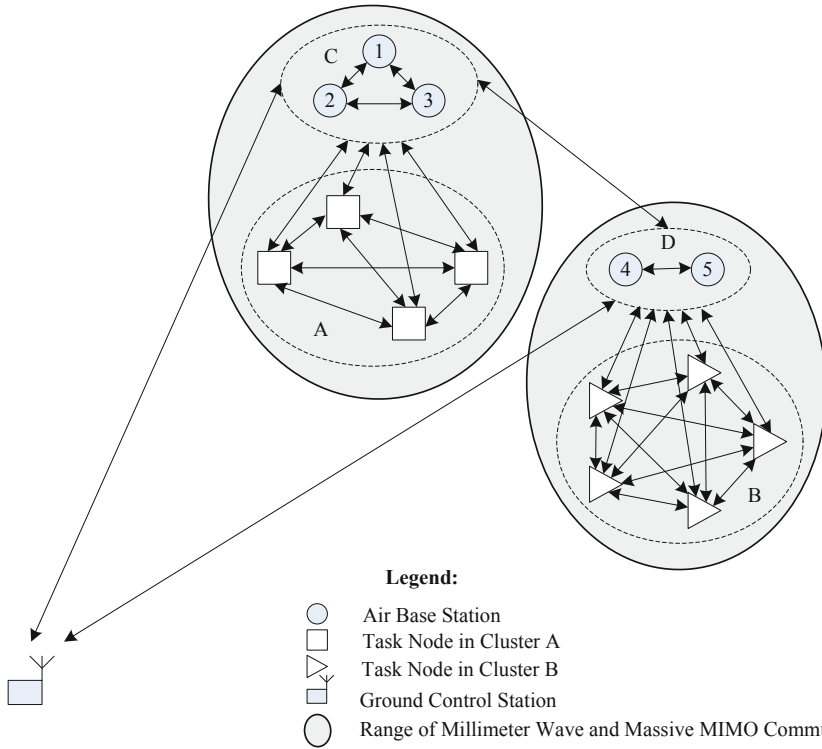


Fig. 3. Data link network of UAV formation using millimeter wave communication and massive MIMO

Millimeter wave communication is a promising technology for data link network of UAV formation. It has the characteristics of large communication capacity, good anti-intercept and anti-jamming performance, and its small antennas are easy to integrate. First of all, the available bandwidth of millimeter wave communication is much wider than the available bandwidth of microwave. The effective bandwidth of millimeter wave communication near several atmosphere windows adds up to more than 100G. Considering the use of channel multiplexing technologies such as SDMA and orthogonal polarization, the channel capacity is even larger. So millimeter wave communication is suitable for transmitting broadband images and videos in data link network of UAV formation. In Fig. 3, each reconnaissance node in cluster A can transmit broadband data to an air base station in cluster C through millimeter wave communication. Secondly, the data link network of UAV formation requires the abilities of anti-intercept and anti-jamming, which the millimeter wave communication is good at. Because the millimeter wave has a short propagation distance in the atmosphere, the millimeter wave signal will become very weak beyond this distance, which increases the difficulty for opponents to intercept or jam. Moreover, the beam is very narrow and the sidelobe is very low in millimeter wave communication, which further reduces the probability of being intercepted and jammed. Thirdly, millimeter wave has strong penetration ability in dust

and smoke, and can pass through dust and smoke almost without attenuation. Under the environment of strong scatter caused by explosion and metal chaff, millimeter wave communication will only attenuate in the short term, and will restore communication soon with the diffusion and fall of scattering source. This characteristic is beneficial for UAV formation under highly confrontational environment. Finally, in order to solve the problem of rainfall attenuation of millimeter wave communication, sufficient power attenuation margin should be reserved when designing the network of millimeter wave communication.

Massive MIMO communication is cut out for data link network of UAV formation. There are several flexible ways to applied massive MIMO communication here. Firstly, when there are a mass of task nodes in a cluster of data link network of UAV formation, the air base station can use massive MIMO system to communicate simultaneously with all task nodes in a same frequency, which increases the channel capacity and spectrum efficiency. Secondly, when there are a few of task nodes in a cluster of data link network of UAV formation, the antenna array of massive MIMO system can be divided into several small arrays, each of which can communicate with a task node and use 3D beam forming technology. Finally, massive MIMO communication and millimeter wave communication can be applied in combination. There is a strong requirement of antenna miniaturization for UAV, so it needs to be avoided that the size of antenna array is too big. The size of an antenna element depends on the wavelength of the transmitted electromagnetic wave. The interval between two adjacent antenna elements is usually designed to be half of the wavelength of transmitted electromagnetic wave to avoid interference. It follows that the millimeter wave is cut out for massive MIMO system. Because the wavelength of millimeter wave is very short, the corresponding antenna array can be designed to be a small one. Furthermore, the beam forming gain of antenna array can compensate the atmosphere attenuation of millimeter wave.

5 Conclusions

Many contents of this paper need to be discussed further. The design of data link network with good performance and great practicability is very difficult. Both direct use and indirect reference of all advanced technologies are relatively convenient routes in the design of data link network of UAV formation. It is greatly worthy of our research to apply 5G technologies in UAV formation.

References

1. Cao, K.: Research on Networking Technology of UAV Data Link Network. Xidian University, Xi'an, China (2014)
2. Shafi, M., et al.: 5G: a tutorial overview of standards, trials, challenges, deployment and practice. *IEEE J. Sel. Areas Commun.* **35**(6), 1201–1221 (2017)
3. ITU-R: IMT vision-framework and overall objectives of the future development of IMT for 2020 and beyond (2015). <http://www.itu.int/rec/R-REC-M.2083-0-201509-I/en>
4. Fodor, G., et al.: Design aspects of network assisted device-to-device communications. *IEEE Commun. Mag.* **50**(3), 170–177 (2012)

5. Rappaport, T.S., et al.: Millimeter wave mobile communications for 5G cellular: it will work! *IEEE Access* **1**, 335–349 (2013)
6. Rusek, F., Persson, D., Lau, B.K., Larsson, E.G., Marzetta, T.L., Tufvesson, F.: Scaling up MIMO: opportunities and challenges with very large arrays. *IEEE Signal Process. Mag.* **30**(1), 40–60 (2013)
7. IMT-2020: (5G) Promotion Group: White Paper on 5G UAV Application (2018). <http://www.imt2020.org.cn/zh/documents/download/102>
8. CSDN Blog: 5G Network Architecture (2021). <https://blog.csdn.net/k916631305/article/details/107523269>. Accessed 22 July 2021
9. IMT-2020: (5G) Promotion Group: White Paper on 5G Network Technology Architecture (2018). <http://www.imt2020.org.cn/zh/documents/download/18>
10. Zhihong, Q., Xue, W.: Reviews of D2D technology for 5G communication networks. *J. Commun.* **37**(7), 1–14 (2016)
11. Zhang, Z.: Research on Establishment Mechanism and Resource Reuse for Device-to-Device Communication in 5G Cellular Networks. Southwest Jiaotong University, Chengdu, China (2017)
12. Wu, B.: Research on Key Technologies of Hybrid Precoding for of Millimeter Wave MIMO System. Southeast University, Nanjing, China (2015)
13. Xiaohai, W.: Development and application of millimeter-wave communication. *Telecommunications Inform.* **10**, 19–21 (2007)
14. Weng, J.: Research on Wideband Millimeter-wave MIMO Antennas. South China University of Technology, Guangzhou, China (2018)
15. Marzetta, T.L.: Non-cooperative cellular wireless with unlimited numbers of base station antennas. *IEEE Trans. Wireless Commun.* **9**(11), 3590–3600 (2010)