Opportunities and Challenges of Unmanned Aircraft Vehicles Networking in Confrontation Environment: Collaborative and Reliable Communication with Intelligence

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Abstract. With a wide range of applications of artificial intelligence (AI) technology in communication networks, collaborative and reliable communication with intelligence has enormous potential to improve the performance of unmanned aerial vehicles (UAVs) in complex confrontation environment. Two typical application scenarios of UAVs, assisted communication and swarm communication, are introduced after discussions of characteristics. In details, the preliminary network architecture is given to improve the adaptability in different scenarios. Then, combined with the characteristics of the UAVs and the anti-UAV countermeasures, the opportunities and challenges in UAVs cooperative communication are analyzed. Finally, highlighting the key design considerations of the AI technology gives possible solutions correspondingly, which deserves to be exploited for the cooperative and reliable UAVs’ communication.

1. Introduction
With their low cost, high mobility and reduced flight casualties, unmanned aerial vehicles (UAVs) have broadened application prospects [1]. The types of UAVs platforms are mainly divided into fixed-wing and rotary-wing ones [2], and their combat functions are also getting developed and supplemented continuously. Multi-functional UAVs such as target attacks and electronic countermeasures as well as small or micro UAVs have emerged, which play an increasingly important role in military applications such as information support and confrontation, fire strikes [3-4]. In order to break through the limitations of functions and scope during individual operations, it is necessary to strengthen the coordination between UAVs for sharing information and flexible assignment of tasks, which will improve the overall operational effectiveness greatly.

Artificial intelligence (AI) technologies such as machine learning, bio-heuristic algorithms, and fuzzy neural networks [5] have been extensively studied and applied in a variety of scenarios and complex environment, which use recursive feedback learning and local interaction for the performance optimization of computer systems and communication networks. Therefore, it has a low complexity relatively and can find local optimal solutions faster [6]. Therefore, the integration of AI technology on the UAV collaborative infrastructure has become a very promising trend to effectively solve the problem of cooperative and reliable communication of UAVs.
2. Typical architecture
At present, in the numerous applications enabled by UAVs collaboration, the assisted communication and swarms confrontation are expected to play an important role in future. In particular, UAV-assisted communication provides economically line-of-sight (LoS) wireless connectivity for some areas without infrastructure coverage or direct communication links, with the advantages of rapid deployment, flexible reconfiguration, and improved communication [7]. The UAVs swarms confrontation integrates some autonomous clusters for ensuring seamless linking, real-time control and coordination between the members and the cluster-to-ground or air control centers through the manned/unmanned control system. This organization can fully exploit the advantages of the group and centralize saturating specific targets attack [8].

2.1. UAV-assisted communication
At present, the typical application scenarios of UAV-assisted wireless communication include seamless coverage of the network and communication relay [9]. One is to deploy UAVs for assisting the existing communication infrastructure (when damaged or overloaded) to achieve seamless wireless coverage within its serving and supporting area, and the goal is to ensure the required communication services can be quickly recovery. The other scenario provides long-distance indirect relay communication in the case where there is no direct communication link or the communication is not reliable, to provide guaranteed communication with delay tolerant and security requirements. Figure 1 shows the application scenarios of the above two types for UAV-assisted communication.

![Wireless coverage.](image1.png)  
(a) Wireless coverage.  

![Relay communication.](image2.png)  
(b) Relay communication.

Figure 1. Two typical application cases of UAV-assisted wireless communication.

Correspondingly, according to the two basic communication links of the control link and the data link common in UAVs [10], figure 2 shows the basic networking structure of the UAV-assisted communications. Among them, the control and non-payload communication link (CNPC) requires high reliability, low latency and secure bidirectional communication capability, which generally operating in protected frequency bands such as the L-band (960-977MHz) and the C-band (5030-5091MHz), and with low rate for transmitting command and control information. In specific application, the CNPC usually exchanges the flight status and avoidance awareness among UAVs, and between swarms-to-control stations. Compared to CNPC links, the data links are intended to provide situation information and coordination information for the control stations, the relay nodes, gateway nodes, and etc., which satisfies the wireless data transmission requirements between the UAVs-control station, UAVs-Gateway node, UAVs-UAVs. Considering the data transmission delay and security, there is a certain degree of tolerance for the particular applications. The currently available data link technologies are (Tactical) Common Data Links TCDL/CDL, Link-11/14/16/22 [11], and usually used in X-band and Ku for satellite as well as HF and UHF bands for LOS communication.
2.2. UAV swarms communication

In the future, due to the adaptability, usage, and target design of different types of UAV platforms, there are large differences in communication modes, waveforms, and network operations, especially for numerous small/medium/micro sized and UAVs, swarms will become an important form of UAVs cooperative combat [12]. Moreover, the rapid information transit between platforms in battlefield is conducive to timely decision-making and distribution, and swarms communication will become "propellent" to fully utilize the performance of the UAVs. The communication support relationship is shown in figure 3 between UAV swarms confrontation.

At this stage, due to limitation factors such as the mobility, intelligence, and lack of fixed backhaul links, it is necessary to achieve partly centralized control in the loop, and the ground control station or the aerial control center is responsible for providing wireless communication service for UAVs swarms. Due to the swarms are limited by the individual size and power, the communication between multiple types of UAVs integrated in groups can facilitate the sharing of awareness, situation and other information, and get controlled or direct intervention by the control station according to the characteristics of the mission. Considering the development of UAV communication technology in the future, the faster, more flexible and reconfigurable next-generation Joint Tactical Radio System (JTRS) [13] will become an important means of tactical communication applications for UAV swarms. Among them, Tactical Targeting Network Technology (TTNT) can support more than 200 nodes for LOS IP network communication with low latency, high throughput, and mobile ad-hoc capability. In addition, Broadband Network Waveform (WNW) uses adaptive TDMA mechanism, parameter adjustment and neighbor discovery technology to achieve efficient channel access, reliable data transmission and timely topology management for the performance optimization in UAVs swarms communication network [14].

According to the swarm confrontation scenarios and communication support relationships, the following three decentralized communication structure of UAVs swarms are introduced, as shown in figure 4.
Figure 4. Basic communication architectures of UAV swarms.

(a) ad hoc networking. (b) Multi-group ad hoc. (c) Hierarchical multi-group.

The Ad hoc networking architecture doesn’t depend on the existing communication infrastructure, and each member UAV has the opportunity to participate in the data forwarding in the network. At the same time, in order to break through the limitations of the geographical environment, the aerial backbone node can be served as a border gateway for providing. Relay communication service, which greatly expands the coverage of the communication network shown in figure 4(a). In other ways shown in figure 4(b), the multi-group ad hoc architecture adapts to the communication connection of different heterogeneous networks, and divides the entire swarms into several groups according to task setting or networking characteristics. The ad hoc networking architecture is still suitable for each group, and different groups need to obey the corresponding air backbone network nodes and ground control stations to improve network management efficiency. The another communication architecture for networking multiple groups of heterogeneous UAVs is the hierarchical multi-group ad hoc architecture, and there are an example of multi-layer UAV ad hoc networks shown in figure 4(c). On the above basis, the group head nodes and the air gateway nodes that are elected or assigned by the underlying groups are interconnected to form a higher-level self-organizing mapping group to directly connect with the ground control station or the aerial control center, which is more scalable and robust.

It can be seen that the main capabilities and features of the UAVs cooperative communication network [15] are listed as follow: (1) self-configuration, where redeploy and update UAVs for automatic configuration before entering the running tasks. (2) self-recovery, where the platform and network can automatically sense the interference and adjust the waveform parameters from evading, and even perform the compensation mechanism whenever the damage occurs. (3) self-optimization, where the UAVs communication network can measure the status and optimize the settings to improve the performance taking into account system measurability and power conservation in terms of range, bandwidth, interference avoidance, and quality of service (QoS).

3. Challenges

With the development of UAVs technology, UAVs combat will become an important part of modern warfare. On the one hand, the technical difficulties of UAVs swarms operations and man-unmanned cooperative operations continue to break through, and the OFFSET and CODE programs continue to make new progress [16]. On the other hand, the threat of massive deployment of UAVs has driven the rapid development of anti-UAV technology and equipment, such as high-power microwave weapons, directional high-power radio frequency interference and other means continue to focus on actual combat. In general, the current anti-UAV methods can be divided into two types: electromagnetic interference and physical destruction. Among them, electromagnetic interference blocks the wireless communication chain between the UAVs and the control center by transmitting directional high-power radio frequency interference to the receiver, or through deceptive interference based on intercepted waveform parameters to tamper its position navigation information, thereby forcing the drone to land or crash. The physical destruction is to shoot down the target UAVs by artillery, laser and other anti-UAV weapon systems, or form the "fire bullet" in certain airspace to "hard kill" the UAVs coping with the saturation attack.

Therefore, combined with the characteristics of the platform and missions, the intelligent and reliable communication of the UAV in the complex confrontation environment will face severe security challenges, which seriously restrict the reliability with possible problems as follows.
3.1. Limited performance
Due to the constraints of size, weight and power consumption in UAV platforms, it may limit individual communication, computing and endurance capabilities. At the same time, with the augment requirements of internal communication in swarms, it is required to cooperate with the communication capabilities of each platform intelligently to maximize network throughput on the basis of energy conservation and improve the self-configuration abilities.

3.2. Communication interference
In view of the anti-UAV electromagnetic interference, the swarms can improve the overall capability of interference resistance by properly configuring different types of electronic countermeasures equipment, but at the same time, the various types and patterns of interference received by the swarms are also significantly increased, which require intelligent interference recognition processing to improve self-recovery ability.

3.3. Topology change
Taking into account the rapid mobility of the swarms, the platform will switch to different groups at any time according to the task needs, and will access and leave on demand, which require network routing to adaptively learn intelligently according to topology changes and quickly converge in order to improve self-optimization ability.

3.4. Node failure
In the face of the "hard destruction" of anti-UAV countermeasures, the UAV platform is vulnerable to crash failure, which will result in communication link interruption, and needs to further enhance the flexibility and robustness of network routing with certain anti-destructive capacity to improve the self-recovery ability.

4. Solutions
With the rapid development of technologies such as 5G and AI, some solutions deserved consideration are obtained for the intelligent cooperative and reliable communication of UAVs swarms, which can reduce the operating cost and intervention of the cooperative communication in optimizing network performance, coverage, quality of service and etc.

4.1. Performance and efficiency improvement
In order to improve the throughput of the UAVs cooperative communication, the channel intelligent coordination technology can be used to improve the network throughput and spectrum efficiency (SE) by overcoming the scatter and energy consumption constraints of MIMO and Full Duplex technologies in the specific application of the UAV. It is considerable that through reasonable power control with group intelligence technology such as particle swarm optimization (PSO) to optimize network performance and energy efficiency (EE).

4.2. Interference recognition and processing
In order to improve the anti-interference ability of UAVs cooperative communication, the heuristic learning method such as artificial neural network (ANN) can be used to improve the recognition ability of different types of interference, and on this basis, the cognitive radio communication ideas of the transforming domain are used to process different interference, which ensure low interception probability (LPI) and convert ability of communication.

4.3. Network routing reconfiguration
In order to improve the reliability of the route transmission of UAVs cooperative communication, the self-aware decision mode such as reinforcement learning (RL) can be adopted to adapt to the rapid
change of the network topology, and the re-routing mechanism is used for route optimization to improve the overall performance of the network.

4.4. Network resistant to damage
In order to improve the network connectivity of UAVs cooperative communication, the multipath routing method can increase the redundancy of the transmission path and improve the invulnerability of the network. At the same time, considering the intermittent connection of the communication, to ensure reliable transmission of data, the store-and-forward mechanism in the delay-tolerant network (DTN) and the opportunistic routing suitable for UAV cooperative communication are designed to improve the reliability of network communication in further.

5. Conclusions
With the continuous development of technology and capabilities for UAVs, the cooperation architecture will become an important way to function such as relay assisted and swarms confrontation. This paper is aimed at UAV assisted communication and swarms communication, and the preliminary network architectures are designed in typical application scenarios. Combined with the development of the UAV’s own characteristics and anti-UAV countermeasures, the problems and challenges that UAV cooperative communication may face are analyzed. Finally, the application of AI technology in the UAV communication network correspondingly gives possible solutions, which provides a new idea for the research of cooperative and reliable communication with intelligence of UAV in complex confrontation environment.

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