

Communication Architectures and Protocols for Networking Unmanned Aerial Vehicles

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Abstract—A fundamental but challenging problem in cooperation and control of multiple unmanned aerial vehicles (UAV's) is efficient networking of the UAV's over the wireless medium in rapidly changing environments. In this paper, we introduce four communication architectures for networking UAV's and review some military communication standards applicable to UAV communications. After discussions of pros and cons of each communication architecture, we conclude that a UAV ad hoc network is the most appropriate architecture to network a team of UAV's, while a multi-layer UAV ad hoc network is more suitable for multiple groups of heterogeneous UAV's. By comparing various legacy and next-generation military data link systems, we highlight that one important feature of the next-generation waveforms is their capability of Internet protocol (IP) based ad hoc networking, which allows UAV's to communicate with each other in a single- or multi-layer UAV ad hoc networks.

I. INTRODUCTION

Unmanned aerial vehicles (UAV's) can fly autonomously or be remotely piloted by ground crews, and they can save lives when replacing humans in harmful environments. Typical applications of UAV's in such contexts include surveillance and reconnaissance [11], cooperative search and acquisition and tracking [10], persistent surveillance for homeland security [6], radio source localization [7], and forest fire monitoring [3]. Due to their enormous application potentials, research and development in UAV technologies have been expanding at an unprecedented rate over the past decade. Among the current research focuses is UAV autonomy [12]. Currently a UAV in operation requires one or more operators for control. In the future multiple UAV's with a higher degree of autonomy will be integrated into a team autonomously cooperating with each other through more advanced network protocols to achieve a common task [9], [14], [18]. The UAV team requires only one operator for control. In addition, the more autonomous the teams of UAV's, the less involvement of the human operator, the larger the size of the UAV team.

One of the main hypotheses supporting the development of cooperative multi-UAV systems is that the deployment of mobile assets in groups is expected to result in a more effective mission than if conducted with a single asset. This is the force multiplication effect expected from teams of UAV's. A great number of researchers worldwide are currently investigating the design of systems that use multiple autonomous vehicles to cooperatively conduct civil or military missions, with minimal human intervention. One of the obvious roles anticipated for the UAV's is the intelligence, surveillance and reconnaissance

(ISR) role. ISR includes, as one of its components, monitoring. Monitoring implies the use of one or more sensors to provide feedback to the commander [13], [17]. If each UAV contains a sensor, a system must be devised to assign the vehicles/sensors to positions in space and in time, and to move efficiently within a predetermined environment to ensure monitoring. Monitoring is related to various problems that have been studied in the past. A particular case takes place when a group of mobile sensors can be used to cover an area. This is the so-called coverage problem [5].

In summary, the benefit of multi-UAV cooperation and control is twofold. First, multi-UAV cooperation significantly reduces the operating cost by transferring the operation mode from many-to-one (*i.e.*, many operators control one UAV) to one-to-many (*i.e.*, one operator controls many UAV's). Second, multi-UAV cooperation and control can minimize the possibility of mission losses caused by human errors, and thus enhance the reliability of missions. Multi-UAV cooperation and control, however, critically depends on real-time or near real-time air-air and air-ground exchanges of information [1]. Moreover, the radio frequency spectrum is currently the only available transmission medium for these information exchanges because laser communications are not practical due to some technical challenges of airborne optical devices using lasercom links [12]. Consequently, a fundamental but challenging problem to be addressed in multi-UAV cooperation and control is efficient networking of UAV's over the wireless medium this is able to provide timely and reliable information flowing among the UAV's. In this paper, we refer to this problem as the UAV networking problem and focus on the networking issues with specific applications to UAV operation scenarios.

In particular, we focus on communication architectures and protocols that are applicable to addressing the UAV networking problem. We compare the features of various communication architectures for networking UAV's and discuss their pros and cons. Following the discussions we conclude that a flat UAV ad hoc network is more appropriate for a homogeneous group of UAV's, while a multi-layer ad hoc network is more suitable for connecting multiple groups of heterogeneous UAV's. In addition, we review communication protocols, or data links in the area of military communications, for UAV networks. Compared with the data links currently being used, one important feature provided in the next-generation data link systems is the capability of Internet Protocol (IP) based ad hoc networking, which allows for UAV's to communicate

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The proceedings of HPDC 3 comprise three invited papers and 34 contributed papers in technical sessions devoted to software tools and environments high speed networks and applications HPDC applications mapping and scheduling distributed shared memory systems partitioning and load balancing fau IEEE Open Architectures and Network Programming ,1998 **Proceedings of the International Conference on Multimedia Computing and Systems, May 14-19, 1994, Boston, Massachusetts** IEEE Computer Society. Task Force on Multimedia Computing,1994 The proceedings of the first IEEE International Conference on Multimedia Computing and Systems comprise technical sessions on scheduling and synchronization synthetic information and video generation networking operating systems content based retrieval distributed systems capture and creation *Proceedings of the IEEE First International Workshop on Systems Management* ,1994 **Upper Layer Protocols, Architectures, and Applications** Gerald Neufeld,1992 The primary objective of this volume is the exploration of important topics in the area of the upper layers that is networking functions beyond information control Contributions made by leading experts from around the world discuss aspects ranging from application layer development environments and presentation layer issues through services including electronic mail and directories to group communication protocols and architectural considerations In identifying new research directions it is hoped the book will stimulate scientists engineers and students in the future development of this area of computer and communications technology **Systems Management** ,1998 **Information Processing** ,1992

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