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AeroMTP: A fountain code-based multipath transport protocol for airborne networks

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Abstract Airborne networks (ANs) are special types of ad hoc networks that can be used to enhance situational awareness, flight coordination and flight efficiency in civil and military aviation. Compared to ground networks, ANs have some unique attributes including high node mobility, frequent topology changes, mechanical and aerodynamic constrains, strict safety requirements and harsh communication environment. Thus, the performance of conventional transmission control protocol (TCP) will be dramatically degraded in ANs. Aircraft commonly have two or more heterogeneous network interfaces which offer an opportunity to form multiple communication paths between any two nodes in ANs. To satisfy the communication requirements in ANs, we propose aeronautical multipath transport protocol (AeroMTP) for ANs, which effectively utilizes the available bandwidth and diversity provided by heterogeneous wireless paths. AeroMTP uses fountain codes as forward error correction (FEC) codes to recover from data loss and deploys a TCP-friendly rate-based congestion control mechanism for each path. Moreover, we design a packet allocation algorithm based on optimization to minimize the delivery time of blocks. The performance of AeroMTP is evaluated through OMNeT++ simulations under a variety of test scenarios. Simulations demonstrate that AeroMTP is of great potential to be applied to ANs.

1. Introduction

Airborne networks (ANs), also called aeronautical ad hoc networks (AANETs), are special types of mobile ad hoc networks (MANET) that can be used on air vehicles, moving platforms, and ground stations to enhance situational awareness, flight coordination, and flight efficiency.[1] Due to the self-organizing multi-hop feature, ANs can greatly expand the connectivity over the line-of-sight limitation of radio wave and the limitation of transmission range. This benefit has attracted the attention of researchers in civil aviation to apply them for aeronautical communication in remote area such as ocean, deserts, etc. Data communications through ANs can provide the internet connection and periodic downloads of "black box" data in real time,[2,3] which can avoid spending too much time and effort on the search for black boxes after air crash, such as the search for the black boxes of Air France

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Flight 447 and Indonesia AirAsia Flight 8501. In military fields, current military airborne communication systems provide only their own mission specific implementations, and provide limited interoperability and autonomous routing capability. ANs are envisioned as hierarchical networks with the capacity of supporting diverse heterogeneous networks operating with various protocols and communication links. Moreover, ANs can satisfy the stringent requirements of military networks and reduce sensor-to-shorter timeline by combining data from disparate sensors, air platforms, and ground stations.[4,5]

ANs are formed rapidly in the airspace and have some attributes including high node mobility, frequent topology changes, mechanical and aerodynamic constrains, strict safety requirements, and harsh communication environment. Compared with general wireless networks, the most important characteristics and challenges posed by ANs are list as follows:

(1) Long and volatile delays: aircraft in ANs connect to each other mainly through the MANET formed by airborne platforms via Radio Frequency (RF) or Optical links. Due to the highly dynamic topology of the MANET, the total hops between any two aircraft may change frequently, which results in a volatile end-to-end delay. In addition, the long communication distance between two aircrafts brings about a long propagation delay, especially when Satellite Communication (SATCOM) links are used.
(2) High link error rates: in ANs, the wireless channels are subject to harsh communication environment such as interference, jamming, and channel impairments, which results in a high link error rate.
(3) Frequent blackouts: due to the harsh communication environment and high mobility, airborne links are likely to experience intermittent link blockages and signal losses. Consequently, the end-to-end connectivity between any two nodes may be broken frequently.
(4) Bandwidth asymmetry: in ANs, ground-based transceivers commonly have large steerable dish antennas, but aircraft are usually equipped with small omnidirectional antennas, which brings asymmetric links into ANs.

In order to provide interconnectivity with space and terrestrial networks, the future ANs will be based on the Internet protocol (IP).[2,5] An efficient and fair transport protocol should be designed for ANs to support Internet and data services. However, conventional transmission control protocol (TCP) would see variable capacity, unpredictable packet erasures and volatile delays from such communication paths in ANs. Frequent blackouts of the communication paths make TCP go to slow start phase frequently, leading to a severe reduction of the throughput. For an asymmetric link, TCP may cause reverse channel to be congested, resulting in packet losses in the reverse channel. Hence, ANs need a transport protocol that can tolerate volatile channel conditions and address the bandwidth asymmetry problem while maintaining stable goodput and latency for the networks. Airborne platforms commonly have two or more heterogeneous network interfaces (e.g., RF, Optical and SATCOM) which offer an opportunity to form multiple independent communication paths for any two nodes in ANs.[6] Each of those paths experiences blackouts, losses, delay and capacity variations independent of other paths. This type of network that can simultaneously establish multiple independent paths between any two hosts is called multihoming network. Studies have shown that transmissions over multiple paths can significantly improve the transmission capacity and quality.[7] Therefore, ANs can operate as multihoming networks to improve the performance, and then transport protocols for ANs should counter the volatility of a single path by transmitting data across different paths intelligently and leverage diversity among paths to yield stable and high goodput.

In this paper, a fountain code-based multipath transport protocol is proposed for ANs, called aeronautical multipath transport protocol (AeroMTP). AeroMTP uses fountain code as the packet-level forward error correction (FEC) code and deploys a TCP-friendly rate-based congestion control mechanism for each path. The congestion control mechanism has the ability to control the amount of traffic on the reverse channel of a path, which well solves the bandwidth asymmetry problem in ANs. A novel packet allocation algorithm is designed for AeroMTP based on optimization to minimize the delivery time of blocks. The rest of the paper is organized as follows. We discuss the related work in Section 2 and present the architecture of AeroMTP in Section 3. The overall design of AeroMTP is addressed in Section 4. We present and discuss our simulation study in Section 5 and conclude the work in Section 6.

2. Related work

Recently, some domain-specific protocols are proposed for ANs.[8,9] Rohrer et al. presented a transport protocol, AeroTP, for the aeronautical telemetry network.[9] AeroTP is designed to meet the needs of the highly-dynamic network environment while being TCP-friendly to allow seamless splicing with conventional TCP at the network edge. AeroTP uses a strong cyclic redundancy check (CRC) to detect bit errors in the wireless channel, which allows a corrupted payload to be corrected on an end-to-end basis using FEC. However, the payload CRC can only protect the integrity of the data, but cannot guard against packet losses. Consequently, the performance of AeroTP degrades significantly due to frequent retransmissions of lost packets in the network with high loss rate. Furthermore, since AeroTP transmits data via a single path, the performance is also seriously affected by the volatile path conditions in the harsh aeronautical environment. Many efforts have been made to explore the use of multiple paths simultaneously to improve the performance of networks. An existing multipath transport protocol that supports multistreaming and multihoming is stream control transmission protocol (SCTP).[10] However, in the basic SCTP design, other paths are only considered as the backups of a primary path, and concurrent multipath transfer (CMT) is not supported. CMT-SCTP[11] extends SCTP by adding CMT support, which is in the process of IETF standardization. Ford et al. attempted to design and implement a deployable multipath TCP that is backward-compatible with TCP which has been standardized in Ref.[12]. However, the above-mentioned protocols suffer from performance degradation due to frequent retransmissions and reordering in the network with high loss and delay. In order to improve the performance over lossy networks, packet-level FEC code is introduced into multipath protocols.[13–15] In these protocols, application layer data is divided into blocks which are then converted to a series of encoded packets. As long as the receiver