Protocols for Highly-Dynamic Airborne Networks

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ABSTRACT

End-to-end communication in highly-dynamic airborne networks is challenging due to the presence of highly mobile nodes and the inherent nature of wireless communication channels. Domain-specific protocols are required that can address these challenges and enable reliable transmission of data in this environment. We develop the ANTP (airborne network and transport protocols) suite that operates in this highly-dynamic environment while utilising cross-layer optimisations between the physical, MAC, network, and transport layers. We show how each component in the ANTP suite outperforms the traditional TCP/IP and MANET protocols through simulation using ns-3. Having verified these protocols through simulation and analysis, the next step towards deployment of the ANTP suite is developing a cross-platform implementation of the protocols. Towards this end we present an architecture for the protocol stack to be implemented in the Python programming language.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design—*Network topology, Wireless communication*; C.2.2 [**Computer-Communication Networks**]: Network Protocols—*Routing protocols*

General Terms

Algorithms, Design, Experimentation, Performance

Keywords

Airborne mobile wireless network, DTN (disruption-tolerant network), MANET, ns-3 simulation, Python implementation

1. INTRODUCTION

Highly-dynamic airborne networks pose unique challenges to end-to-end data transmission. Mobility poses a great challenge since the airborne nodes can travel at speeds as high as Mach 3.5. In addition, the network is bandwidth-constrained due to limited spectrum. Intermittent connectivity is also a challenge, which is caused by the extremely short contact duration between any two nodes [11, 10, 9].

A typical airborne tactical network as depicted in Figure 1 consists of three types of nodes: airborne nodes (AN), ground stations (GS), and relay nodes (RN). The airborne nodes contain a variety of data collection devices. The GSs are located on the ground (stationary or portable) and typically have a much higher transmission range than that of an AN. The GS also houses a gateway (GW) that connects the airborne network to several terminals that may run control applications for various devices on the AN. Furthermore, the GSs can be interconnected to do soft-handoffs from one to another while tracking an AN. The RNs are dedicated airborne nodes to improve the connectivity of the network [10].

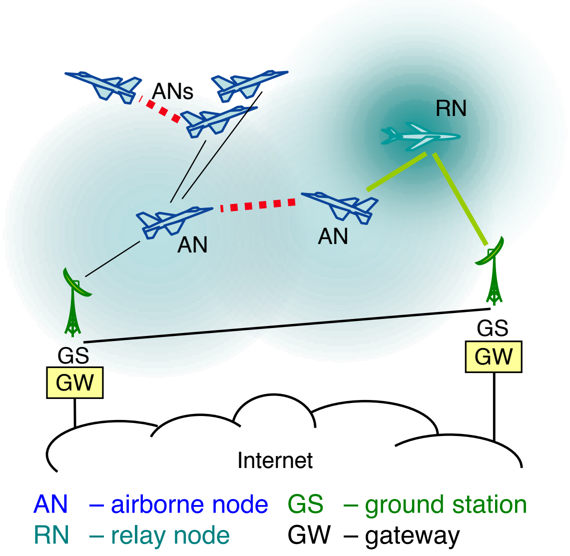

Figure 1: Dynamic airborne environment

The current TCP/IP-based Internet architecture is not designed to function in this environment. We have developed the ANTP suite (shown in Figure 2) that is optimised for the highly-dynamic airborne environment, while maintaining edge-to-edge compatibility with the legacy Internet architecture. These protocols include: *AeroTP* – a TCP-friendly transport protocol introduced in [12] with multiple reliability and QoS modes, *AeroNP* – an IP-compatible network protocol (addressing and forwarding) introduced in [4], and *AeroRP* – a routing protocol introduced in [4] and further evaluated in [7, 8, 5], which exploits location

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information to mitigate the short contact times of high-velocity airborne nodes. Both the source and destination for data transmitted may be native Aero-protocol devices or TCP/IP-based systems, however the IP protocol stack is not suitable for use within the airborne network itself. To overcome this challenge without requiring a total redesign of all sensors, peripherals, applications, and workstations, we introduce the Aero Gateway (AeroGW) [3]. This protocol suite is designed to perform well in an environment in which rapidly-changing topology prevents global routing convergence, as well as those in which long-lasting stable end-to-end paths do not exist.

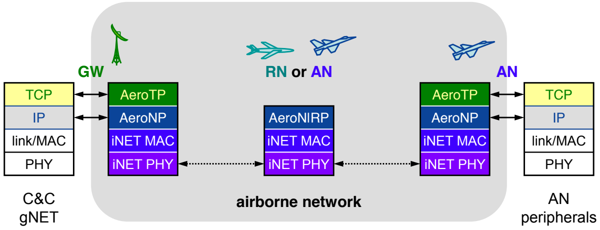

Figure 2: Airborne network protocols

2. SIMULATION MODELLING

In this section, we present the results of simulations conducted with the ns-3 simulator [1] to compare the performance of AeroTP with other transport protocols. We also compare the performance of AeroRP with the traditional MANET routing protocols.

2.1 AeroTP Simulation

AeroTP is designed to be TCP-friendly to allow seamless splicing with conventional TCP at the network edge in the GS and on the AN. AeroTP has several operational modes that support different service classes: reliable, nearly-reliable, quasi-reliable, best-effort connection, and best-effort datagram. The first of these is fully TCP compatible, the last fully UDP compatible, and the others TCP friendly with reliability semantics matching the needs of the mission. We compare AeroTP modes with TCP and UDP protocols. The selective-repeat ARQ algorithm is used to provide reliable edge-to-edge connection between nodes for the reliable mode, and FEC is used for the quasi-reliable mode of the AeroTP protocol [6].

Over the course of the simulation, both TCP and AeroTP are able to deliver the full 1 MB of data transmitted for low error rates (3.5×10^{-5}), but above that TCP performance drops rapidly while AeroTP is still able to deliver nearly all the data at the highest error rates as shown in Figure 3. In the same plot we see that UDP looses a percentage of the data due to corruption as the BER increases, and that the AeroTP quasi-reliable mode losses a much smaller percentage.

2.2 AeroRP Simulation

Both reactive and proactive routing protocols fail to operate in partially connected networks since a complete path may not exist at all time. Determining the next-hop is based on a metric called time to intercept (TTI) that is calculated based on inter-node distance, transmission range, and speed component [7]. AeroRP is tested in the ferrying, buffer, and drop modes as well as in both beacon and beaconless promiscuous mode that were discussed [8, 7, 5].

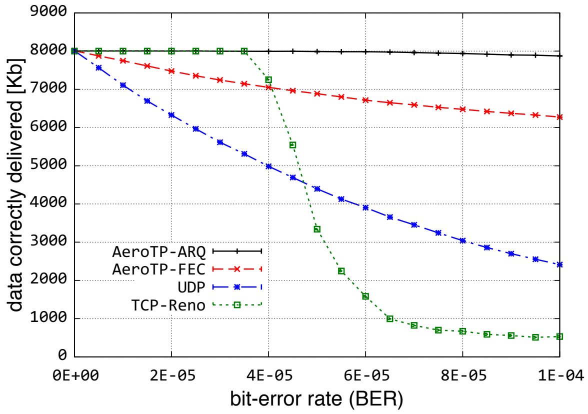

Figure 3: Cumulative goodput

Figure 4 shows the average PDR (packet delivery ratio) as the number of nodes are increased. The node density of the network affects all of the routing protocols with AeroRP ferrying packets in beaconless promiscuous mode performing the best. The PDR for all AeroRP modes increases as the number of nodes increase with the exception of a slight performance degradation as the number of nodes approaches 90% and higher. This suggests that as the number of nodes increase, AeroRP is able to make more intelligent decisions on how to move the data packets towards the destination whereas the MANET routing protocols are relying on non-geographic based links to move the packet to the destination.

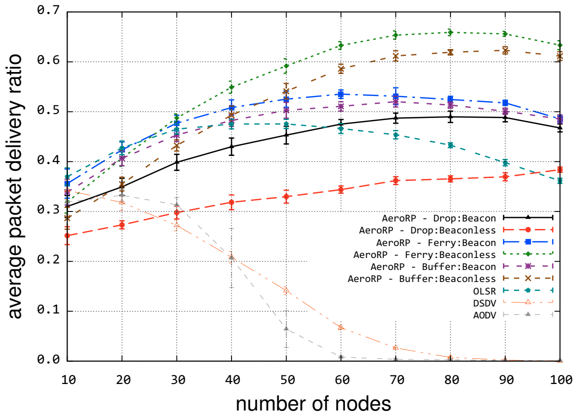

Figure 4: Effect of node density on PDR

3. IMPLEMENTATION ARCHITECTURE

The implementation architecture is designed to provide several features: maintainability, reliability, and data analysis accessibility. To achieve maintainability, the system is fully designed based on the object oriented programming (OOP) approach. This approach tries to eliminate the dependency between data structures, which gives us the option to upgrade the components with fewer errors. For reliability, the system employs try-catch error handling to avoid any I/O errors during runtime. For performance analysis, the system provides a shared logging system that can aggregate the logs in a single web server. Based on these considerations, the system is divided into several components as shown in Figure 5. AeroNP provides the interface between the higher layers of the ANTP protocol suite and airborne network [2]. The system architecture is implemented in Python in two phases. First, we implement each protocol separately and test their functionality on PlanetLab testbed. Finally, the implementation is deployed to embedded processors on radio-controlled aircraft and ground vehicles.

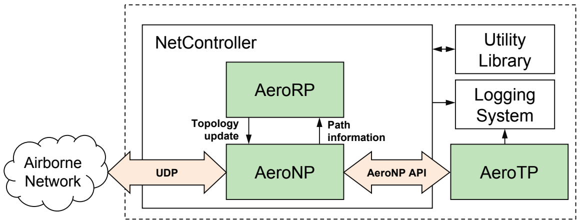

Figure 5: System architecture

4. CONCLUSIONS AND FUTURE WORK

The existing TCP/IP protocols are not well suited for applications in highly-dynamic airborne networks. We have developed domain-specific ANTP suite to leverage cross-layer information in optimising end-to-end performance in this challenging environment. We performed simulations showing significant improvements in end-to-end data delivery when using AeroTP instead of TCP. By predicting when links will be available based on trajectory information, as well as actively listening for nearby nodes, AeroRP can send data opportunistically towards its destination. We showed the prototype implementation design and architecture. For future work, we will deploy our Python implementation on embedded devices on radio-controlled aircraft and ground vehicles.

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5. REFERENCES

[1] The ns-3 network simulator. `http://www.nsnam.org`, July 2009.

[2] M. Alenazi, S. A. Gogi, D. Zhang, E. K. Çetinkaya, J. P. Rohrer, and J. P. G. Sterbenz. ANTP Protocol Suite Software Implementation Architecture in Python. In *Proceedings of the International Telemetering Conference (ITC)*, Las Vegas, NV, October 2011.

[3] E. K. Çetinkaya and J. P. G. Sterbenz. Aeronautical Gateways: Supporting TCP/IP-based Devices and Applications over Modern Telemetry Networks. In *Proceedings of the International Telemetering Conference (ITC)*, Las Vegas, NV, October 2009.

[4] A. Jabbar, E. Perrins, and J. P. G. Sterbenz. A cross-layered protocol architecture for highly-dynamic multihop airborne telemetry networks. In *Proceedings of the International Telemetering Conference (ITC)*, San Diego, CA, October 2008.

[5] H. Narra, E. K. Çetinkaya, and J. P. Sterbenz. Performance Analysis of AeroRP with Ground Station Advertisements. In *Proceedings of the ACM MobiHoc Workshop on Airborne Networks and Communications*, pages 43–47, Hilton Head Island, SC, June 2012.

[6] K. S. Pathapati, T. A. N. Nguyen, J. P. Rohrer, and J. P. Sterbenz. Performance Analysis of the AeroTP Transport Protocol for Highly-Dynamic Airborne Telemetry Networks. In *Proceedings of the International Telemetering Conference (ITC)*, Las Vegas, NV, October 2011.

[7] K. Peters, A. Jabbar, E. K. Çetinkaya, and J. P. Sterbenz. A geographical routing protocol for highly-dynamic aeronautical networks. In *Proceedings of the IEEE Wireless Communications and Networking Conference (WCNC)*, pages 492–497, Cancun, Mexico, March 2011.

[8] J. P. Rohrer, E. K. Çetinkaya, H. Narra, D. Broyles, K. Peters, and J. P. G. Sterbenz. AeroRP Performance in Highly-Dynamic Airborne Networks using 3D Gauss-Markov Mobility Model. In *Proceedings of the IEEE Military Communications Conference (MILCOM)*, pages 834–841, Baltimore, MD, November 2011.

[9] J. P. Rohrer, A. Jabbar, E. K. Çetinkaya, E. Perrins, and J. P. Sterbenz. Highly-dynamic cross-layered aeronautical network architecture. *IEEE Transactions on Aerospace and Electronic Systems*, 47(4):2742–2765, October 2011.

[10] J. P. Rohrer, A. Jabbar, E. K. Çetinkaya, and J. P. Sterbenz. Airborne telemetry networks: Challenges and solutions in the ANTP suite. In *Proceedings of the IEEE Military Communications Conference (MILCOM)*, pages 74–79, San Jose, CA, November 2010.

[11] J. P. Rohrer, A. Jabbar, E. Perrins, and J. P. G. Sterbenz. Cross-layer architectural framework for highly-mobile multihop airborne telemetry networks. In *Proceedings of the IEEE Military Communications Conference (MILCOM)*, pages 1–9, San Diego, CA, November 2008.

[12] J. P. Rohrer, E. Perrins, and J. P. G. Sterbenz. End-to-end disruption-tolerant transport protocol issues and design for airborne telemetry networks. In *Proceedings of the International Telemetering Conference (ITC)*, San Diego, CA, October 2008.