

Cyber-Physical Systems Challenges in Next Generation Aviation Systems

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1 Introduction

The air transportation system, already capacity-limited, is facing increased pressure due to the expected increase in demand over the next few decades. The need to meet the increased demand has motivated efforts to transform the air transportation system, through the use of new technologies and operating concepts. In the United States, this effort is known as the Next Generation Air Transportation System (NextGen).

2 Role of CPS in NextGen

A key NextGen technologies (and probably the most well-known) is the Automatic Dependent Surveillance – Broadcast (ADS-B) system, which uses satellite-based navigation and aircraft broadcasts of position, velocity and intent, in contrast to today’s radar-based surveillance systems. ADS-B, due to its greater accuracy and the possibility of both aircraft-ground and aircraft-aircraft communications, is expected to enable more efficient routes, and to potentially increase system capacity.

The increased information-sharing and expected increase in demand motivate the development of algorithms for coordination and planning in NextGen. The combination of the physical elements (aircraft, aviation infrastructure, air traffic controllers, etc.) and the automation (decision support tools, onboard computers, etc.) present a wide range of opportunities and challenges in the realm of cyber-physical systems.

3 CPS Challenges

The design of algorithms for NextGen that leverage the increased information sharing between aircraft present unique CPS challenges.

3.1 Risk assessment and mitigation

The first such challenge is the assessment and mitigation of the risks associated with sharing one’s information, as well as with using information broadcast by other aircraft. Along with the increase in efficiency, there is the concern of making malicious behavior easier [5, 6]. The high degree of decentralization offers a rich set of tools to pilots and air traffic controllers, but also present new vulnerabilities. For instance, adversaries may induce loss of separation between aircraft by injecting incorrect data in the satellite-based navigation system. The erroneous information may be retransmitted by other aircraft, and spread to the rest of the network. As programmable sensors and actuators become more pervasive in NextGen, cybersecurity becomes critical to the overall safety of the system. These challenges also present the opportunity to use innovative data fusion techniques to detect errors in broadcast data, build redundancy into the system, and improve overall performance [4].

NextGen technologies also suffer from what is known as the “equipment paradox”: Equipment such as ADS-B require considerable initial investment on the part of the airlines, but also need significant adoption within the fleet before any benefits are seen. As a result, airlines must be willing to risk the possibilities of programmatic delays while making investment decisions [2, 3].

Another source of risk in information sharing deals with its impact on airline operations. The Collaborative Decision Making framework considers ways in which to incentivize airlines to report information on flight delays and cancellations. In particular, when designing mechanisms for allocating scarce resources in NextGen, incentives to participate in data sharing, and to truthfully report preferences, become important considerations [1].

3.2 Handling uncertainty

Even though trajectory uncertainty is expected to decrease in NextGen, it will not be entirely eradicated, especially in the near-term. Algorithms proposed for conflict detection, resolution, scheduling and routing must therefore consider the uncertainties present in the system. While trajectory uncertainty impacts conflict detection and resolution, weather and congestion impact system capacity, and need to be accounted for in the resource allocation process.

3.3 Human-automation integration

NextGen will experience a considerable time of transition, while aircraft technologies transition from today's systems. Even in the long-term, the system will include human air traffic controllers with a greater level of decision-support. It is therefore important to understand air traffic controllers' decision-making processes. Considering communication, navigation and surveillance systems and airspace management, a particular challenge arises from hardware breakdowns, whose ability to gracefully degrade may be through a combination of hardware and operations reconfiguration (for example, existing procedures to handle sudden losses of radar coverage). Fundamental research topics associated with such graceful degradation include fault detection and isolation, as well as adaptive control.

In human-automation systems, failures can occur in human or automation performance, or in their interfaces, and also in work constructs that are too complex to be efficient and robust. They also present system verification and validation challenges relating to both the humans and the environment they interact with.

4 Conclusions

The NextGen air transportation system is a quintessential example of a large-scale cyber-physical system. As it undergoes a transformation in order to meet increased demand, it also presents unique challenges with regard to developing CPS methodologies for a system that also involves considerable human-automation interaction. The successful deployment of the future system will require the evaluation and mitigation of various sources of risk, the quantification and management of various sources of uncertainty, and better techniques for the design and operation of human-automation systems. In fact, in the absence of these solutions, the benefits of NextGen may be limited.

References

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