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UAS in the NAS Project

Communications Modeling and Simulation

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UAS in the NAS – Analysis Results and Recommendations for
Integration of CNPC and ATC Communications

Simulation Report

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BACKGROUND

Since 2011 the NASA, UAS in the NAS project group at NASA GRC has been involved with research work to develop prototypes, flight test, and provide standards performance information for control and non-payload communications (CNPC) data link radios for unmanned aircraft (UA). This work has been accomplished using a CNPC prototype radio design developed in a joint venture between NASA and Rockwell Collins that has produced several versions of a radio leading to a fifth and final generation radio. In a parallel effort, GRC has also developed models of the prototype radios for performance assessments in regional air-traffic simulations, and concept large-scale, Relay and Non-relay communication architecture models. The large-scale simulations place the radio models onboard UA for NAS communications system performance testing with ATC operations, in traffic scenarios that introduce UA into the NAS. For both the radio and NAS communications architecture models, the development process involved iterations on each model and system in a progressive approach that added complexity and capabilities to enhance the models as new specifications or new versions of models were available. Testing and verification of the simulations capabilities have been reported on in several verification and model characterization reports through the lifespan of the project.

INTRODUCTION

This report addresses a deliverable to the UAS-in-the-NAS project for recommendations for integration of CNPC and ATC communications based on analysis results from modeled radio system and NAS-wide UA communication architecture simulations. The report focuses on recommendations at a high level since the results of our simulations and the performance implied by our results are based on prototype hardware components and concept architectures. However, from the testing and characterization of the modeled systems that occurred throughout the development and verification process, several predominant issues related to performance of the simulated systems have raised questions and exposed areas for further study and development, which are reflected in these recommendations. For each recommendation, a brief explanation of the rationale for its consideration is provided with any supporting results obtained or observed in our simulation activity. Due to time constraints, no additional simulations were run for this evaluation.

APPROACH

The process to identify these recommendations involved polling the team of engineers and software developers who developed, tested and provided performance assessments of the radio models and NAS-wide simulation capabilities for individual recommendations. The responses were primarily observations from experience with the models, which were summarized into common categories. Each team member also provided input to the assumptions that they based their recommendations on, which are also summarized below. These assumptions also served as the guidelines for our simulation requirements over the duration of the modeling and simulation development effort.

Assumptions

- UA used for varying applications with appropriate equipage for required communications services will be operational in the NAS in the future.
- UA of all classifications will be integrated into the NAS and managed in common airspace with current air traffic.
- UA will be managed by ATC in the NAS using current operating procedures as are used for piloted aircraft.
- For any UA planned to fly in managed airspace, ATC expects to use current communication systems to guide those aircraft through all phases of flight. (i.e. VHF Radio and/or digital messaging systems)
- UA will be equipped with a terrestrial, data link radio system for control and non-payload communications (CNPC).
- The CNPC radio used onboard a UA will provide the capability to carry voice data and digital messaging data for bidirectional ATC-UA Controller communications.
- The CNPC data link radio will provide command and control instructions to the UA, and downlink surveillance, telemetry, weather system and other critical system data from the UA to the UA Controller.
- For UA classes where ATC dialog with the UA controller is required (i.e. UA larger than small UAS) the communications system is required to provide continuous contact with each UA controller throughout the duration of the UA flight.
- A Relay communication architecture option is under consideration as a primary communications architecture for UAS in the NAS. A Relay architecture provides voice-VHF and CPDLC messaging for ATC communications conveyed between ATC and UA Controllers routed through the UA, data commanding and telemetry/services data downlink capabilities for all communications service Class of UA, and voice and messaging to Piloted aircraft.
- A Non-relay communications architecture option is under consideration as a primary communications architecture for UAS in the NAS. A Non-relay architecture provides voice-VHF/digital-CPDLC ATC communications conveyed between ATC and UA Controllers and Piloted aircraft via a ground network infrastructure and the data commanding and telemetry/services data downlink capabilities for all communications service class of UA.

RECOMMENDATIONS

- 1) For a Relay architecture system, use ATS digital messaging for routine ATC UA dialog to help minimize the use of voice communications for UA ATC. Provide voice relay capability, but use voice as needed for ATC to UA controller special instructions and emergency information.

Rationale

Based on earlier assessments of the impact UA would have on NAS capacity (identified in ATC/CNPC Communications Performance Impact on NAS Delay and Capacity report) and the relationship between NAS capacity and ATC workload, UA traffic added to simulations for communication system characterization identified increasing trends in VHF channel utilization for voice messaging. This would translate to added time in human factors for servicing aircraft in airspace where only piloted aircraft existed before. In addition to this, all aircraft being handled by a particular controller are using the same frequency. As the number of flights air traffic controllers must handle steadily increases (as UA are introduced), the number of aircraft using each channel also increases, increasing the opportunity that dialog will incur step-on situations and require retransmission, adding additional time to ATC workload to manage aircraft.

In the system architecture models that were developed in the NAS-wide simulation capability, CPDLC over VDL2 as ATS data is included and tested as an optional messaging capability, with ATS messaging included in the radio design as part of data streams carried over the C2 uplink and telemetry downlink. Since the CPDLC messaging application includes message elements corresponding to voice messaging employed by air traffic

control procedures, with limited human factors overhead and the ability to convey multiple messages within a single transmission, use of CPDLC could greatly reduce ATC overhead in the NAS systems for UA applicability. In addition, digital messaging would also serve to help overcome or minimize issues with use of voice messaging over the CNPC radios by reducing bandwidth requirements and improving bandwidth utilization, while helping to ensure message reception, since digital messaging would be less affected by air traffic load variations.

- 2) For a Relay architecture implementation, continue research and technology development of system components to reduce latency associated with voice messaging. Identify accurate specifications for acceptable latency and target those specifications for improvements to the system.

Rationale

From simulations run with both the Relay and Non-relay NAS-wide communication architectures, the Relay architecture results were found to produce the longest latency for communicating ATC voice messaging to the UA Controllers. Typical delay numbers seen in our simulations for the relay architecture were found to averaging 380-390 ms. in both the forward and return direction for UA, and messages sent to, or received from, piloted aircraft averaging 60 ms. Since it was assumed that operationally ATC would not have to differentiate between manned and unmanned aircraft, having a subset of pilots that takes a longer time to receive and respond to messages could impact overall ATC performance due to the complexity of handling varied delay time in a system where wait time for some responses is increased, questions arise as to whether a message actually was delivered, and the need to move on to address other aircraft needing servicing is compromised.

In addition to problems that arise from the inconsistent voice latency for UA vs piloted aircraft, our simulations also identified that delay times in moving messages through a Relay architecture could result in situations where either ATC or the UA controller could be unaware of messages being conveyed to them, with messages delayed in subsystems of the architecture along their route. In these situations, messages would occupy the VHF channel for a time before they are actually being heard by the target recipient who might initiate a new message that reaches the VHF channel, causing an unexpected step-on situation to occur. In testing, this situation was found to cause a higher than desired number of step-on's in Relay architecture simulations, which was remedied by implementing a process as a human factors compensation that detected when a message was already being heard by the recipient and allowed a complete message sequence to continue before any other could be initiated. If the detection scheme was unable to determine this and a message was sent, a step-on occurred. In implementing this process step-ons in our simulations were greatly reduced, but at the expense of implementing a strategy that would need to be employed by ATC which would contradict the plan to manage UA using current operating procedures employed for piloted flight.

- 3) For relay architectures, refine the CNPC radio voice traffic implementation for optimal radio performance

Rationale

To reduce data traffic and reduce delays of lower priority traffic (ATS relay, surveillance, and weather traffic) a 'squellch' of the voice system generating data packets that carry silence over the link could be implemented such that data is only generated and transmitted through the CNPC link when the voice radio is being utilized. (Reference Gen2 regional sim report results section 4.3, comparing 100% utilization values (no squellch) to indicate COCR loads). With this capability, squellch would also allow the playback buffer on the receive side to be depleted after each transmission, allowing recovery from any large delays should they occur (high delays common on startup as header compression is established – packets with full size headers take longer to get through)

Even with a squelch implementation, CNPC links should be sized assuming 100% voice utilization to handle traffic peaks. The voids in voice communications allow room for the bursty ATS data relay messages (as proven by Gen2, Gen5 regional simulations and large-scale sims). If alternate provisioning methods are used to reduce the size the link assuming squelch, proper care must be taken to ensure that the voice, surveillance, and ATS data relay messages maintain appropriate delays during high link usage.

The reference voice relay codec implemented in the simulations is non-optimized and exhibited delays near or, in a few rare cases, above the assumed limit of 400ms. System designers should consider additional measures to ensure that delays can be controlled to meet the requirements:

- On the UA and in ground configurations where the CNPC radio is co-located with the voice codec equipment, some synchronization between the generation of codec frame bundles and the CNPC frame structure may be obtainable to reduce queuing delays at the CNPC radio (just-in-time delivery of codec frame bundles to radio for transmission in the next frame, supported by Gen5 regional report section 3.1 and 3.4). Non-optimal synchronization can add up to 50ms of delay.
 - In ground configurations where the CNPC radio is separated from the voice codec equipment (as would be expected using a network of ground CNPC radios), synchronization between the codec and CNPC is likely not feasible as network delays can greatly affect the arrival time of the codec frame bundles at the radio.
 - The reference codec implementation assumes a codec with 20ms samples and 5 samples per bundle (the minimum required to form a multiple of the CNPC frame size – 5 codec samples = 2 CNPC frames). This requires a full sampling of 100ms of audio before generation of a bundle. Reducing the bundle size would allow bundles to be generated sooner reducing delay. [Bundle generation needs to be matched with CNPC frames to allow synchronization above]. Decreasing the bundle size to fit into a single CNPC frame will increase overhead (more network layer packets = more network layer overhead) but could reduce delays by up to 50ms (not documented in any reports but easily shown in simple simulations—already verified)
 - Voice delays have been noted to be increased around handoff events (supported by 700+ms delays in LS sim report, verified to occur very close to handoff events). Increased delays and loss near handoffs are to be expected. If possible CNPC handoffs should not be performed during ATC communication exchanges or in critical phases of flight.
- 4) Develop reliable, effective systems that use ground networks for ATC communication for UA in a Non-relay communication architecture implementation. Make this a priority architecture approach over an architecture that relays ATC communications through the UA in a Relay architecture.

Rationale

The near-term introduction of unmanned aircraft into the NAS will most likely adopt the use of a relay architecture with ATC managing UA using existing VHF and ATS/CPDLC communications resources, with messages passed through the UA and over the CNPC link to/from the UA controllers. To help enable this introduction, NASA GRC has developed prototype, terrestrial, datalink CNPC radios that provide this capability, and through this effort has been instrumental in assisting RTCA SC228 in the completion of a Command and Control Data Link MOPS for terrestrial based CNPC radios that incorporate the message relay approach. With the lack of an alternative system, and in keeping with the original objectives of the project that targeted operating UA the same as other aircraft, the use of the current VHF and CPDLC infrastructure for UA integration would provide an ATC-familiar, baseline platform as the concept for operation for integrating UAS in the NAS continued. However, since current ATC systems were not designed with relay architectures (and their inherent delays) in mind, and may be limited in their ability to support growth due to UA and the added workload imposed on ATCo's, non-relay architectures using ground networks should be considered a priority in planning as a long term solution.

As a possible response to this long term approach, two programs that are being undertaken as part of NextGen upgrades that promise to provide networked ATC service to the FAA are the NAS Voice System (NVS) and the ongoing development of the Federal Telecommunication Infrastructure, which together could enable these services for UA. With these systems eventually in place, the resources to communicate with UA could transition to a non-relay approach using the same radios without relaying voice and ATS data service. This would provide greater consistency for ATC service between piloted and UA flights, greater safety that would enable continuous contact with UA controllers, higher reliability and lower message latency. This transition would also make the radios more efficient by reducing the amount of data transferred over the CNPC link (still used for C2 and downlinked UA data) to maintain spectrum and reduce delays for these services.

To support the potential delay implications in recommending a non-relay architecture over a relay approach, our simulations included running a same-traffic scenario simulation that flew 49 unmanned aircraft along with 40 piloted aircraft in ZAU Center using ATC voice messaging in both architectures, in both architecture models to provide a rough comparison of latency performance. For the non-relay architecture, the simulation was run with default settings and with worst case settings for piloted air traffic baseload (i.e. day in the NAS loading) and the network delay model, link-capacity settings. Comparing the results from the simulations, the relay architecture message latency was found to average 387ms for the combined 2965 UA messages sent in the forward and return directions, and from the non-relay simulation for the same messages with the worst case baseload and link capacity the average latency numbers were 43ms and 68ms respectively, which support the rationale that non-relay architectures will provide improved delay performance over relay architectures.

CONCLUSION

The recommendations provided in this report are derived from input provided by the members of our team, and are believed to capture some of the dominant technical performance issues that have been observed in assessing our models/simulations performance. Although every effort has been made to accurately define our models, some system components (especially in the large-scale models) could only go so far in creating accurate representations due to the limited amount of information available. Results, data and reporting from this modeling effort has attempted to capture characteristics of the systems and provide best representation of technical performance and trends from models that our recommendations are based on. These recommendations are presented for future planning of the communications components and architectures for UAS in the NAS integration as their development continue.