WHITEPAPER

A Standards-Based Integration Platform for Reconfigurable Unmanned Aircraft Systems

Executive Summary

This paper addresses the system design and integration challenges involved in meeting the requirements for coordinated deployment of multiple re-configurable Unmanned Aircraft Systems (UAS). It will present and discuss an open standards based software architectural approach that demonstrably addresses – and simplifies - these new and evolving issues. UAS developers are continuously challenged to adapt their UAS designs beyond originally conceived mission capabilities. Re-configurable payloads may provide some flexibility for deployment of UAS but do not fundamentally extend the UAS for comprehensive and dynamic multi-mission support. When we consider emerging requirements to support multi- UAS operational coordination and to control swarms of unmanned aircraft, an intricate combination of system integration and dynamic re-configuration challenges emerges for next generation UAS developers. Addressing these issues requires a system-of-systems approach to UAS development and an open development platform for system-to-system communication, particularly as multi-UAS integration becomes a common mission requirement. This paper discusses a UAS systems architecture and platform that addresses these requirements using open standards and COTS technology. The approach demonstrably addresses and simplifies the evolving issues that re-configurability, multi-UAS coordination, safety and security requirements pose for next generation system designs. Meeting the new challenges and simultaneously maintaining system wide integrity for real-time capabilities, high availability, security and safety is an evolving process. Some UAS developers have already adopted open standards based technology and are well positioned to respond to these next generation system requirements. We will include several examples of UAS successfully deploying this architectural approach to illustrate its advantages in actual applications.

Introduction

Next generation UAS are not going to be a simple combination of one Ground Control Station (GCS) and one UAV fulfilling one mission requirement. There will be a many to many relationship between GCS's and UAVs capable of supporting multiple mission objectives.

The system of systems needed to deliver this multi-mission capability will include self-coordinating UAVs controlled by multiple GCS's, with UAVs and manned aircraft as well as space systems, all co-operating to meet a continuously changing set of mission criteria. This is the vision at the heart of the net-centric environment.

Visionary research papers from the US DoD[i] and requirements statements from the U.S. Air Force[ii] have defined these requirements for UAS developers. Designers of UAVs and GCS's that participate in this net-centric

[1] These operations typically follow a pattern called "CRUD"—Create, Read, Update, and Delete—because most supporting technologies have parallels to these operations. In SQL [4], the operations are INSERT, SELECT, UPDATE, and DELETE. In HTTP, they are POST, GET, PUT, and DELETE. In DDS, they are WRITE, READ, DISPOSE, and UNREGISTER.

environment have to ensure that every element of their capability (as implemented in a sub-system) is accessible to every other relevant participant to the net-centric environment, not just to their current controlling GCS. For example target data obtained by a UAV extrapolated from a video stream may need to be shared with any number of combat systems, over any one of a number of different communication links, in real-time.

The further dimension to architect into next generation net-centric enabled UAS's is adaptability; whether that is a re-configurable capability in the UAV design or a multi-mission capability for the whole UAS. Central to the success of this emerging environment will be the efficient use of the communication infrastructure. Bandwidth, latency and real-time response and throughput requirements placed upon the communication links will vary exponentially with the number of participating GCS's and UAVs, multiplied by the number of reconfigurable elements within those systems, further multiplied by the number of mission configurations the system of systems will have to respond to.

Recognizing this new reality, the US DoD has laid out a plan for the evolution of the underlying technology that will be needed to deliver this enhanced capability in their 'Unmanned Systems Roadmap 2007-2032' the thrust of which has been echoed in many international forums such as NATO and country specific UAS initiatives. This paper will focus on the challenges associated with developing a software communication platform that supports two of the six goals laid out in this Unmanned Systems Roadmap:

- Goal 2: Emphasize commonality to achieve greater interoperability among system controls, communications, data products, and data links on unmanned systems.
- Goal 3: Foster the development of policies, standards, and procedures that enable safe and timely operations and the effective integration of manned and unmanned vehicles.

These goals set a technology framework objective, but they need to be articulated into specific requirements for UAS capabilities in next generation systems. The U.S. Air Force has done this in their Advance Notice to Industry of Next Generation UAS Inputs to UAS Concepts, Systems, Missions. This paper will discuss the architectural and technology solutions required to meet the specific capabilities of interest to a multi-mission reconfigurable UAS design as set out in the US Air Force document, which include:

- Modular, adaptable, and upgradeable vehicle architecture integrated with modular, adaptable, and upgradeable mission control station architecture for multi-mission capability either in single or multiple ship formation
- Mission Specific Tailoring - Adaptable system (sensors, payload, C2)
- Weapons payload of mixed/modular weapons capable of precise and scalable weapon effects
- Modular sensor suite
- Fleet Compatible - Sense & Avoid, Terminal Area Operations, Airspace Management, Net Centricity and Interoperability (i.e. TCDL or equiv.)
- Adaptable for long term component development (upgradeable, spirals)

Core UAS Processing and Communication Technologies

Past research and investigations[iii] have shown that processing technology is advancing far faster (more processing for less cost, power and weight) than the communications infrastructure (throughput) in UAS's. This means UAVs will become smarter and more autonomous, parsing data obtained more extensively before passing it into the net-centric environment. While this may serve to decrease the bandwidth and communication requirements of existing systems with a fixed mission requirement, the multi-mission requirements for UAS's will demand far more bandwidth than will be saved from smarter on-UAV data processing. A reconfigurable multi-mission UAV will create even more data tomorrow than it is capable of obtaining and processing at the moment as ever more capable data acquisition and processing modules are integrated into it. A multi-mission UAS will need to co-ordinate with an even greater number of UAS's and manned systems than is the case today.

More Efficient Communication Infrastructure Utilization

The necessary conclusion therefore is that to deliver against the net-centric vision for UAS deployment the efficiency of utilization of the communication infrastructure, not just between UAVs and GCS's, but also within the UAV across their internal busses and networks, has to be a primary architectural design focus. The historic idea that communication issues can be narrowed down to a series of well-defined point-to-point channels, whether between a GCS and UAV, two UAVs or even between two modules on board a UAV is already obsolete. What is needed is a distributed system of systems development framework that meets the real-time needs of next generation net-centric capable UAS's.

Any end-point must be able to communicate to any end-point and meet the real-time needs of that specific communication channel. The greater issue is that in a net-centric environment the definition of the communication end point may not exist until after the system has deployed, indeed the capability of that end-point may not even have been defined at the time a particular UAS was deployed! This information may very well not even be known at design time of the next UAS's, so what can be done?

What we can know, as evidenced by the vision and requirements examples we have laid out earlier, is that there will always be a strategic framework and plan for how the net-centric vision will impact the UAS design requirements. The challenge will be how to design a UAS around a communications platform that can be easily adapted to the continuously evolving net-centric system environment.

Baseline Capabilities for a UAS Integration Platform

Before we can define the efficient communication and integration framework for next generation multi-mission reconfigurable UAS we must define the basic capabilities such a development platform must provide. Focusing on the communication infrastructure we can make the following specific requirement statements regarding the basic principles that should apply to a viable integration platform:

1. It must be based on Open Standards for both the application API and the on-the-wire communication.
   a. So that there are multiple competitive vendor solutions
   b. So that any UAS can be guaranteed (by an independent 3rd party) to interoperate with other UAS supplier systems
2. It must be architected as a true peer-to-peer framework a. In the battlefield environment, there should be no single point of failure such as a server based technology would require
3. It must be portable to any physical set of communication media
   a. While RF is the communication medium of today, research has started to show the viability of optical links as a potential for the future
   b. Even within the RF spectrum there are multiple RF implementation standards, such as TCDL, Link11 and Link16, etc
   c. It must execute over high speed (potentially proprietary) internal (to a UAV or GCS) networks so that every system module is an addressable part of the net-centric environment
   d. It must integrate seamlessly with a net-centric backbone based upon SOA, Web Services, and other enterprise communications infrastructure
4. It must be available for heterogeneous system environments
   a. GCS's are predominantly built upon mainstream OS's such as Linux and Windows on mainstream CPUs such as Intel x86
   b. UAVs tend to be built on embedded processors such as ARM and PowerPC, in memory constrained environments, running specialist OS environments such as MILS or ARINC653 based systems, or RTOS's such as VxWorks
   c. It must be adaptable for certification requirements such as DO-178B
5. It must seamlessly integrate differing communication payload definitions a. For example it should be able to integrate a STANAG 4586 messaging structure

These basic requirements can be considered 'gating conditions'. In other words the communication and integration platform has to meet these basic criteria in order to be implementable in a UAS environment. However none of these actually address the development requirements of an efficient real-time communication platform, capable of sustaining a multi-mission reconfigurable remit.

The Communication Requirements "Matrix of Pain"

In a net-centric environment the data that needs to be communicated falls into one of three distinctly different traffic types:

1. Command and control data, generally requiring high availability and integrity in its communication
2. Sensor data streams, generally requiring high throughput capabilities
3. Status, intelligence, mission and supervisory data with varying degrees of availability and integrity requirements

But there are different communication and interoperability requirements for each data type, including response time, priority, reliability, volume of data, and stealth mode (one way communication).

Add in that each physical communication channel has differing characteristics in terms of: latency, bandwidth, lossy nature of the communication, availability (may suffer regular planned and unplanned disconnected periods), and asymmetric bandwidth (e.g. downlink vs. uplink). It quickly becomes clear that even with this simple breakdown of the communication and interoperability requirements the matrix of pain for system-to-system integration rapidly becomes unmanageable for a multi-mission reconfigurable net-centric capable UAS, unless modular and adaptable systems architecture is applied.

Building Down from the Data, Not Up from the Hardware

Building such a net-centric capable UAS for next generation system of systems integration clearly requires a new architectural approach for the software communications infrastructure based around the following key issues.

Solution Requirement 1: Data has to be first class citizen of a reconfigurable UAV

Sub-systems within a reconfigurable UAV may change, but each sub-system always knows what data it is capable of providing and under what terms. It will also know what data it needs and how it needs that data to be received. Hence every sub-system of a reconfigurable UAV can add to a pervasive data model of the mission by signaling its inclusion to the net-centric environment. It also follows that every UAV and GCS is a combination of data providers (publishers) and data consumers (subscribers). In this concept commands are considered a form of data.

This approach directly supports Goal 2 in the Unmanned Systems Roadmap referenced earlier by focusing on commonality between sub-systems to achieve greater interoperability. Rather than creating a proprietary UAS where the integration problem of inserting that UAS into the multi-mission environment is forced upon the recipient of the UAS, the approach allows for a UAS to be defined in terms of its data and thus its contribution to the shared operational picture. In effect the data definition becomes the integration language by which UAS developer and multi-mission force integrator can communicate. As illustrated in Figure 1, the approach results in a high level of decoupling between the subsystems in a UAS, allowing reconfiguration, upgrades and replacement of system components, including payloads and mission-specific application software.

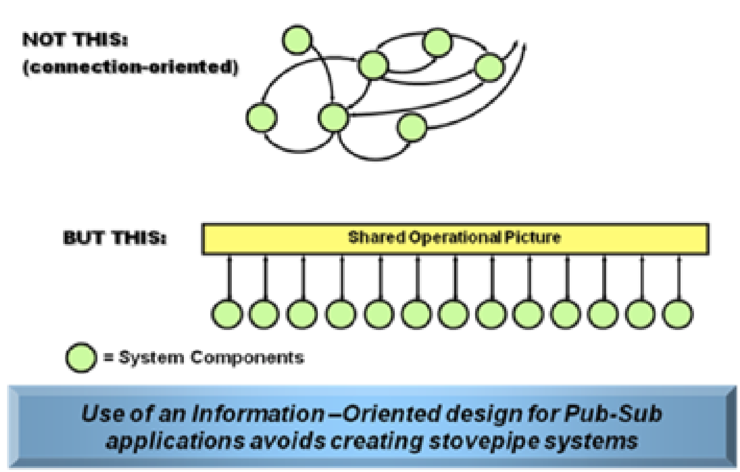

Figure 1. Raytheon Keynote Presentation Sept. 2006 at DDS Information Day, Anaheim, CA.

Solution Requirement 2: Data has to be coupled with its send & receive requirements

In order to support the dynamic establishment of communication channels across any part of the system of systems that is necessary to the development of a configurable multi-mission UAS, each publisher and subscriber must be able to define exactly how they can deliver or how they need to receive data. This means, as illustrated in Figure 2, that a Quality of Service (QoS) capability or requirement must be associated with each publisher or subscriber and each data set to address all the use cases and communication challenges that were laid out in the 'matrix of pain' earlier. By making these service associations with every publisher and subscriber we facilitate a dynamic binding of service between any two sub-systems at any time (or indeed one-to-many, many-to-many or many-to-one), that is completely independent of the topology of the internal UAV bus system, the data link RF capabilities, or the GCS connection to the wider net-centric system in which the mission requirement exists. It means that as a new module is plugged into a reconfigurable UAV it can define the data it is capable of providing to the mission environment and under what terms. Any module or sub-system that can make use of that data can subscribe to this new information and use it to enhance its operational effectiveness or to help meet its mission objectives, assuming a service level agreement can successfully be agreed between the two entities.

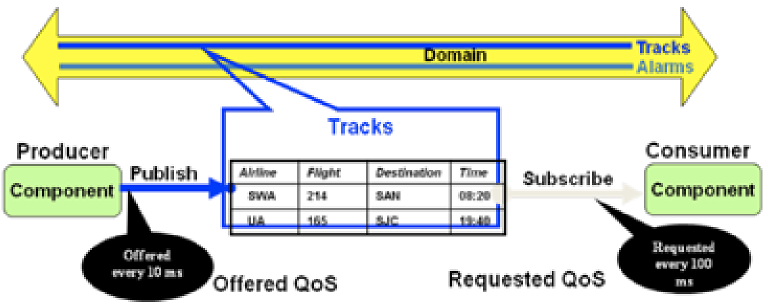

Figure 2. Example QoS capabilities and requirements for publishers and subscribers.

So as a UAS joins a mission situation, it can provide its capabilities to the net-centric environment. It can request the information it needs to operate, and add its data to the information picture of the battlefield, all dynamically, and independently of the topology of the network implementation.

Solution Requirement 3: Adaptability of the Data Model to future requirements

The term adaptability is used many times in the DoD and US Air force vision and requirements. While the model we have defined is adaptable to known data sets that can be added to a multi-mission context, an evolving net-centric multi-mission system will continuously be adding new sensors into the mission environment, creating new data to be shared. If we take the simple example of a system update of a 2D radar creating positional information to now add 3D positional information, how is the 3rd dimension data added to the data model without breaking the legacy systems using that data? The integration framework must support runtime data type evolution. An efficient implementation of an integration framework leveraging this data model would even go as far as to recognize that a subscriber that cannot use the 3rd dimensional information should not even be sent it.

An Open Integration Platform

An integration platform that provides the baseline system capabilities we have defined, addresses the communication matrix of pain we outlined, and uses an architectural model that matches the 3 top level solution requirements mandated above already exists as an open standard integration platform. It is the Data Distribution Service for Real-Time Systems (DDS) standard[1] defined by the Object Management Group[2]. More importantly it has been successfully deployed, and indeed mandated in several programs, in order to ensure compliance with several highly strategic defense requirements such as the DoD Net-Centric Checklist[iv], the SPAWAR FORCEnet

[1] http://portals.omg.org/dds

[2] http://www.omg.org

Technical Reference Guide[v] and NESI[3], and the US Navy Open Architecture. There are many successful net-centric compliant system deployments such as the Aegis Weapon System from Lockheed Martin, the DDG 1000 Zumwalt Class Destroyer, as well as deployments in the Ground Station of the Predator and several UGV deployments using DDS, like the German Armed Forces RoboScout. In addition integrating DDS into a MILS platform has enabled Boeing to develop the concept of net-centric security policy management into their embedded platform environment[vi].

Interoperability between multi-vendor developed UAS's will depend on proven standards. While these successful system deployments show that large scale systems of systems can be integrated using DDS, it may not provide the confidence that multiple vendor implementations, whether your own DDS implementation or a 3rd parties will truly interoperate. This is the function of the independent standards body of the OMG who recently proved that the three leading vendors' DDS implementations interoperate at the application API level and 'on the wire'[4].

Conclusion

An open standards based, data oriented architectural approach is the key to building a true reconfigurable multi-mission UAS interoperable platform that is adaptable, flexible and scalable.

About Real-Time Innovations

RTI is the world leader in fast, scalable communications software that addresses the challenges of building and integrating real-time operational systems. RTI Connext solutions meet the needs of enterprise-wide integration—from the operational edge to the enterprise data center. The RTI standards-based software infrastructure improves the efficiency of operational systems while facilitating better decisions, actions and outcomes for the business enterprise.

For over ten years, RTI has delivered industry-leading products and solutions for customers in markets ranging from Aerospace & Defense, Process Automation, Financial Services, Energy, Automotive, Health Sciences and Transportation Management.

Founded in 1991, RTI is privately held and headquartered in Sunnyvale, California.

[i] Unmanned Systems Roadmap 2007-2032, U.S. Department of Defense, 2007.

[ii] Advance Notice to Industry of Next Generation Unmanned Aerial System (NG UAS) Inputs to UAS Concepts, System, Missions, Concepts in Jul 08, Department of the Air Force, 2008.

[iii] Unmanned Aircraft Systems Roadmap 2005-2030, U.S. Department of Defense, 2005.

[iv] Net-Centric Checklist, Version 2.1.4, Office of the Assistant Secretary of Defense for Networks and Information Integration/ Department of Defense Chief Information Officer, July 30, 2004.

[v] FORCEnet Technical reference Guide For Program Managers, Office of the FORCEnet Chief Engineer SPAWAR 05, 2005.

[vi] J. M. Schlesselman, "Data Distribution Service and MILS: A Powerful Combination." COTS Journal, November 2009.

[1] http://nesipublic.spawar.navy.mil

[2] http://www.omg.org/news/releases/pr2009/03-25-09.htm

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