On the Efficacy of Pub-Sub in the Emerging Internet of Battle Things

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Introduction

The Internet is going through radical changes. Examples of change that are relevant to the research presented in this paper include low latency networking, the integration of advanced wireless technology, and the continued integration of the Internet of Things. The latter includes the ability to support constrained devices, gateways that bridge machine specific protocols and data to those used by the Internet, and the integration of data centric networking with current Internet protocols.

The motivations for these changes are due in part to the emergence of a new breed of Internet application which we refer to as ‘Application Systems’ (APPSYS). Current examples, such as drone swarms or cooperative autonomous vehicles, involve groups of mobile machines that work in a distributed manner to solve a problem. The participating nodes need to dynamically form a communications and computation environment that can support the requirements imposed by the underlying tasks performed by the machines. An APPSYS might involve a single wireless network or it might require the additional performance and reliability provided by a heterogeneous wireless network (HetNet). The underlying wireless network would be adhoc or a hybrid-adhoc system where certain nodes of the APPSYS temporarily serve the role of traditional infrastructure-based AP or BSs. The nodes in a specific APPSYS are likely to be heterogeneous where different nodes offer different computation and networking resources. We have developed a general framework, referred to as the Application Systems Framework (AFS), that supports the needs of one or more APPSYS’s co-located in the same geographic area. As computation as well as connectivity is required, an AFS includes components that manage one or more ad-hoc wireless network as well as provides distributed services to assist applications solve problems in a distributed manner.

The majority of relevant research in the literature has focused on message dissemination involving ad-hoc wireless networks utilizing forms of pro-active or reactive routing, and group communications through either wireless broadcast dissemination or multicast. While connectivity still remains the most significant challenge especially for highly mobile systems, cloud computing concepts such as Vehicular Cloud Computing provide distributed computation environments appropriate for vehicles in a Vehicular Ad-hoc Network (VANET). Recent developments related to unmanned aerial vehicles have led to the development of Flying ad-hoc networks (FANET). Forms of these systems, typically ‘hybrid’ variants, might have a subset of UAVs capable of serving as mesh nodes, with either WiFi or LTE, some of which might have backhaul through satellite communications.

A complementary set of developments have focused on systems or frameworks that provide computation resources to groups of devices or machines connected by wireless networks. Edge and Fog computing are concepts motivated by the ever-evolving Internet of Things (IoT) []. Many of the IoT frameworks that have been explored in the literature are 'vertically oriented' by supporting the requirements of a specific application domain, such as vehicular systems or smart grid systems. Economic and security issues have prevented wide deployments of general purpose IoT infrastructure that can support any number of domains and stake holders. In these situations, different types of applications must be isolated (such as with containers) with an overall system operator that manages shared access to slices of the compute and network resources.

The rapid evolution of Autonomous Vehicles is likely to represent the first APPSYS that is widely adopted by society. The original architectural and protocol solution for a vehicular distributed system involved a variant of 802.11a referred to as 802.11p or more generally as DSRC. The networking stack and application environment was defined by a number of standards collectively referred to as WAVE. DSRC addresses the difficult task of supporting a set of highly mobile vehicles by providing a broadcast wireless network that did not require an AP or that did not involve messaging that is required in other infrastructure-less operating modes of WiFi. A significantly improved version of DSRC is going through the IEEE standards process. IEEE 802.11bd increases the range, throughput, and reliability by incorporating portions of the IEEE 802.11ax MAC layer into DSRC [ ]. The IETF has standards that allow IPV6 to support WAVE applications [ ]. Recent WiFi chipsets natively support the OCB broadcast mode that has been tied to exclusively to WAVE.

The 3GPP community's equivalent to an APPSYS are use cases that require "ultra-reliable low latency communications" (URLLC) [ ]. Future 3GPP systems will allow an operator to provide slices of compute and network resources. Emerging 5G protocols support low-latency wireless networking by reducing UE association and with new peer-to-peer modes that allow UE devices to communicate directly with each other.

While it's unclear exactly how the 3GPP direction will unfold, the general direction is similar to our ideas with one significant difference: there will be APPSYS's that require degrees of freedom to build network and compute infrastructure on-demand with requirements that exceed those provided by a particular operator or by the current uncontrolled nature of systems that depend on unlicensed spectrum. APPSYS need to be able to select from a set of wireless spectrum and access method options, some of which needing robust and fair co-existence policies.

The AFS system we describe in this paper differs from this prior work for at least two reasons:

the autonomy and ad-hoc infrastructure freedom provided to APPSYS. An APPSYS inherently needs to allow nodes to join, form a group that organizes and creates a functional distributed computation platform that interconnects nodes through one or more ad-hoc wireless systems. By autonomy, we draw the analogy between a specific APPSYS and the Internet's notion of an autonomous system. We define the term Autonomous Wireless System (AWS) to reflect a single administrative entity that is responsible and liable for the nodes operating in the APPSYS. This frees the APPSYS from limitations imposed by a cellular operator. Collectively we believe the development of an open source ASF will stimulate innovation across many sectors. We leave for future study the other critical dimensions to the APPSYS design space such as dynamic spectrum management and potential co-existence or potential resource sharing with infrastructure-based wireless systems that are in the same geographical area as the APPSYS. Finally, we leave for future study and AFS that is able to support multiple APPSYS concurrently, with each under the administrative authority of different AWS[1].

We assume IP is the point of convergence. We identify three critical design requirements:

- APPSYS nodes need a standard command and control protocol and command set.
- The architecture must isolate the data and control planes (either virtually or physical).
- The system is architecture and design should be data-centric in nature
- Finally, an APPSYS inherently needs a programmable infrastructure. The AFS control plane allows this level of interaction with an APPSYS. requirements.

We focus on a small subset of this very large problem. Our collaborators at MIT Lincoln Lab's provides a unique perspective that has given us the opportunity to re-think our ongoing work in this direction. The military community is currently going through a significant design phase for systems that will be used in future battlefields. Their key requirements for systems that are inherently autonomous and operate in an ad-hoc manner collectively provides the most appropriate set of design patterns. In particular, we focus on emerging military systems and scenarios such as autonomous UAVs, autonomous land vehicles, drone swarms, cooperative autonomous machines, along with command and control of operations on the battlefield or of a remote operation involving machines. With recent Department of Defense mandates to modernize future tactical military systems, the DOD has an opportunity to put into practice advanced technology that could help evolve the Internet, and perhaps most importantly move today's boundary of the Internet from the wireless network out to user devices operating emerging application systems.

In this paper, we illustrate the AFS using a rather simple APPSYS: a group of UAVs or drones tasked to search, detect, classify, and track moving ground objects that traverse the UAV group's flight plan. The research question of interest is to evaluate the efficacy of a data centric system design model for future military wireless networks and systems. We conjecture that an AFS that blends application level information dissemination with the control of underlying network support of group communications will lead to an environment that presents the most degrees of freedom allowing the APPSYS and underlying infrastructure to adapt and mitigate challenging RF and wireless connectivity scenarios.

An APPSYS will be data-centric, utilizing a novel blending of application level dissemination using publish-subscribe with underlying system support including a hierarchy of nodes with certain nodes tasked to manage connectivity or multicast groups and to provide message caching so that applications won't fail when outages occur. The use of data centric design patterns along with a managed HetNet provides many degrees of freedom for adapting the infrastructure to meet application requirements subject to changing RF conditions.

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[1] We believe an ASF can support multiple APPSYS with multiple AWS's but only if an organization such as the FCC provides the necessary top level authority, management, and policy enforcement. We anticipate this will occur over the next decade as the Nation's Critical Infrastructure continues to become further dependent on wireless technology. Protecting the National Critical Infrastructure falls to the Department of Homeland Security, https://www.cisa.gov/critical-infrastructure-sectors

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The research presented in this paper is motivated by our observation that emerging application systems, whether they be for military, social, or industrial use, will require wireless networks that incorporate data-centric network design principles. Inherent in these systems is the need for efficient and customizable group communications. To date, IP multicast over the Internet has seen limited deployment. Multicast in specific application scenarios, such as military or public safety, is quite common. However, it has been shown that multicast in ad-hoc wireless scenarios can be challenging when mobility or scale is a factor [ ].

The Internet has been struggling with two critical aspects of data-centric networks: From the Internet perspective, named data networking has been proposed to address the gap between the core Internet services and data-centric capabilities.

In this paper we focus on the potential benefits of incorporating a publish-subscribe design pattern to future military systems. The study assumes emerging applications will require extremely adaptive infrastructure that can form a robust distributed computing environment using whatever wireless systems or spectrum that might be available. As applications will be distributed, group communication across peer stations as well as to potentially a hierarchy of compute nodes is crucial. Our research introduces a novel system that supports various forms of dissemination and communications services to meet these requirements. Our work offers two contributions:

- An approach for data dissemination to a group through an integrated of network multicast routing with application level publish-subscribe data dissemination
- An ontology that can provide a common vocabulary for describing data through meta-date and topic names

System Model

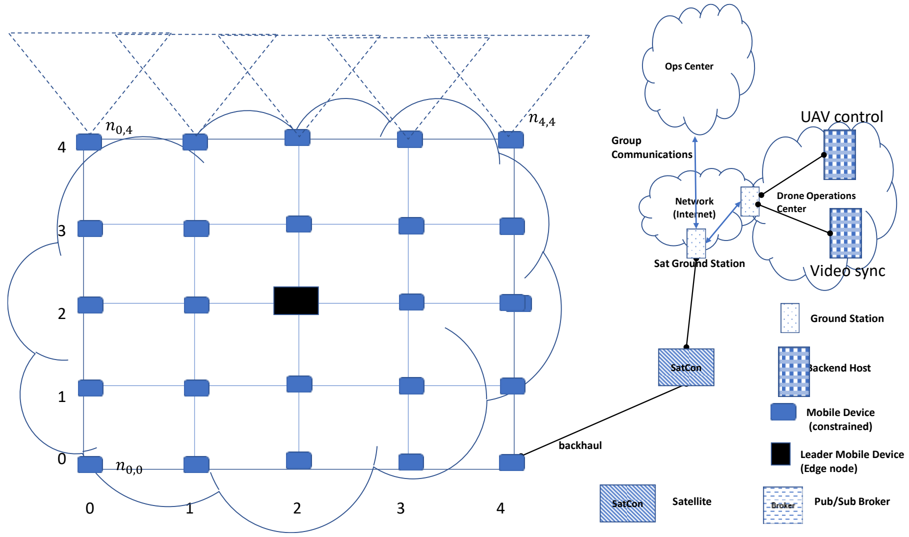

Figure 1. Drone Scenario

To focus our work, we assume an application system consisting of a set of UAVs that have a variable range of sensing, processing, and network capabilities. The results are likely applicable to vehicular systems but unlikely to generally apply to complex military battlefield scenarios. Figures 1 illustrates the basic system model used in the study. A number of nodes form a group and are able to move in a desired mobility pattern. We assume the nodes are UAVs and each is either given a flight plan or one or more leader nodes is given the flight plan and other nodes follow a designated leader based on a desired controller strategy. We do not model physics-based motion of the nodes. Instead, to assess the impacts of mobility, we apply periodic instantaneous jumps of the group to a new location with controlled levels of internode distances such that route updates are likely but at least for the research reported in this paper, the group stays connected.

Stations potentially consist of multiple radios, however in this paper we assume one radio per station. An illustrative specific example is that the radios are 802.11n and can operate over one or more channels at the 2.4 GHz or 5.0 GHz unlicensed spectrum bands. Our baseline system will utilize proactive routing approaches based on well understood algorithms such as OSPF-MDR or OLSR.

The choice of work loads along with the mobility assumptions are critical to any wireless systems study. We will use a combination of standard application work loads (voice, video, large data transfer, on/off periodic messaging) along with emerging applications that leverage advanced capabilities that are becoming available in end devices. The figure shows a set of drones that might be tasked to search for specific activities or objects. The current generation of military drone systems are purposely simple but reliable. Drones might be given a detailed flight plan prior to departure. The drones send back to the command center sensing, telemetry, video data over a network path that is likely to include satellite hops before reaching the command center. An operator can override the drone's flight plan in various ways, one of which is to actually control the drone with a steering/joystick device. One limitation is the centralized nature command and control. Drone technology is rapidly developing. Future drone systems will leverage group decision-making by drones to respond to unplanned events or to be able to perform more sophisticated missions. A problem that is common across all complex DoD systems is the lack of interoperability with other systems due to the use of vendor proprietary protocols and data formats. Future drone systems should produce sensing data in common formats based on metadata derived from common ontologies that might include military specific dialects but that include emerging standard Internet ontologies.

Methodology

Identify and describe in detail the system model.

Identify the 1 or 2 APPSYS of interest and how we will model or employ them in the study.

Identify the conjectures and analysis parameters

Results

Document and explain the findings

Literature review

A brief review of the most relevant literature. Compare any of our work to similar efforts….. identify those results and how our results either confirm or extend the body of knowledge.

Conclusions

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