Communications and Networking Technologies: Guest Editors' Introduction

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This issue of the Johns Hopkins APL Technical Digest *highlights some of the recent work by researchers at APL in the areas of communications and networking. Included in the issue are eight articles on diverse topics such as satellite communication, networking and communication in deep space, and improving communication efficiency and robustness in the challenging RF environment. These articles represent work supported by both APL's external sponsors and internal research and development funding. Other work being done at APL covers a spectrum of communications and networking research beyond the scope of the articles in this issue of the* Digest*; however, the articles in this issue provide an impressive sample of the Laboratory's expertise and work in these areas.*

For several decades, researchers at APL have developed and applied expertise in communications technologies for the benefit of their government sponsors. Early focus was on satellite communication (SATCOM) and end-to-end network solutions for specialized combat systems. However, as wireless and optical communication and Internet Protocol (IP)-based networking stormed the commercial world during the last two decades, APL's sponsors began exploring ways to exploit advances in commercial communication and networking technologies to multiply force effectiveness. The concepts of network-centric warfare and the Global Information Grid were born. APL initiated a broad-based effort to help its sponsors address critical challenges in realizing the vision created by these concepts. Special focus has been on sponsors' needs that were not addressed adequately by the commercial technologies and on situations in which APL's sponsors must lead the commercial world in technology development. From the perspective of communications and networking technologies, as well as associated algorithms, protocols, and controls, APL's efforts include providing the following:

- Maximum wireless communication capability out of limited spectrum, especially in challenging communication environments, including intermittent and unpredictable link availability because of terrain, obstacles, weather, jamming, etc.; large delays in satellite-based communication and very large delays in interplanetary communication; and underwater acoustic communication
- Reliable communication among highly mobile users with minimal infrastructure support
- Very high data rates without the benefit of fixed optical infrastructure (e.g., between airborne platforms and between an airborne platform and a ground station)

- Communication among nodes in distributed sensor networks and between a sensor network and its "collectors"
- Communication over a highly heterogeneous set of networks spanning underwater, ground, sea surface, air, space, and deep space with varying degrees of link bandwidth, delay, mobility, and obstacles
- Secure communication and ability to trade off connectivity and security

This issue provides a sample of recent work by researchers at APL in the areas of communication and networking: Eight articles on diverse topics are included. These articles represent work supported by both APL's external sponsors and internal research and development funding. Other representative work has been presented in earlier issues of the *Johns Hopkins APL Technical Digest* (e.g., volume 25, issue 4, 2004; volume 26, issue 4, pp. 383–393, 2005; and volume 27, issue 1, pp. 32–40, 2006), at a variety of conferences [e.g., IEEE Military Communications Conference (MILCOM), IEEE Global Communications Conference (GLOBECOM), various SPIE conferences, etc.], and in journals (e.g., *IEEE Transactions on Wireless Communications*, *IEEE Communications Magazine*, *IEEE Transactions on Mobile Computing*, etc.).

SATCOM has been critical to military users. The first three articles in this issue discuss APL's recent contributions to three key SATCOM programs: Internet Routing in Space (IRIS), Mobile User Objective System (MUOS), and SATCOM on the Move for Warfighter Information Network-Tactical (WIN-T).

The first article, by Cuevas et al., describes IRIS, which was developed by an industry group as a Joint Capability Technology Demonstration sponsored by the DoD. The primary goal of IRIS was to assess the network capability and operational utility of an IP router in space, a paradigm shift from the traditional transponded ("bent-pipe") SATCOM. After a series of technical and operational demonstrations using simulated and prototype surrogates, the capstone demonstrations using on-orbit IRIS capability onboard a commercial satellite (Intelsat 14) were completed in March/April 2010. This article describes the IRIS network capabilities and presents the highlights of the on-orbit demonstrations along with key results and findings, focusing on technology maturity in key aspects and also the challenges to be addressed.

The second article, by Oetting and Jen, describes MUOS, the DoD's next-generation UHF SATCOM system. MUOS's design is groundbreaking because it uses the radio access network architecture and technology derived from the commercial cellular Third Generation Partnership Project (3GPP) standards systems. Spectrally Adaptive Wideband Code Division Multiple Access (SA-WCDMA), along with Rake receivers, advanced turbo coding, and state-of-the-art interference mitigation techniques, provide high spectral efficiency for both uplink and downlink. The heart of the MUOS system consists of the four active satellites in geosynchronous orbit and the four radio access facilities on the ground. In terms of the more familiar terrestrial cellular networks, each MUOS satellite corresponds to a cell tower, and each radio access facility corresponds to a base station. However, the "cell towers" are 23,000 miles high and the "cells" are more than 600 miles in diameter. This article describes the MUOS architecture as well as APL's contributions to system performance analysis, testing and evaluation of the ground hardware and software, network management, information assurance, and key management.

The article by Weerackody and Cuevas describes APL's contribution to the SATCOM on-the-move terminals as an essential component in the WIN-T program. WIN-T is the Army's on-the-move, high-speed, high-capacity backbone communications network, linking warfighters in tactical ground units with commanders and the backbone of the Global Information Grid, the DoD's worldwide network-centric information system. WIN-T uses true satellite on-the-move capabilities, network management, and advanced radio communication systems to keep the tactical forces in communication and connected with high-data-rate services. SATCOM on-the-move terminals often use very small antennas and thus exhibit large beam width, which affects the effective transmission power from the terminal. Furthermore, terminals in motion introduce potential antenna-pointing errors that may cause interference to adjacent satellites. The authors describe the technical and operational challenges of meeting the conflicting demands of maintaining sufficient transmission power to provide high-data-rate communication while limiting interference caused to adjacent SATCOM links. This article discusses the orbit and spectrum considerations and presents performance analysis of the SATCOM on-the-move terminal design, considering antenna-pointing errors, rain fading, and interference impacts.

Communication and networking in deep space—among nodes across long distances and with large delays and intermittent links—is a challenging problem. The fourth article, by Krupiarz et al., addresses this challenge. As the number of simultaneously active space exploration missions in the solar system increases, it is becoming increasingly important to move from point-to-point links between each spacecraft and Earth station (also, between orbiting spacecraft and landers) to an Internet-type network of nodes on planets, in orbits, and on Earth. This network introduces many new challenges caused by very long propagation delays, predictable and unpredictable link disruptions, and the lack of an end-to-end route at any given time instance. APL researchers have been working with many NASA centers to develop the delay/disruption-tolerant networking technologies in the areas of network management, onboard storage, and robotic telepresence. This article discusses the networking challenges and solutions and APL's contributions in designing and verifying these solutions.

The next two articles are aimed at techniques for improving communication efficiency and robustness in the challenging RF environment.

Hampton et al. describe multiple-input multiple-output (MIMO) channel measurements for use in urban military applications. Many years of research have shown that the MIMO communication techniques can enhance quality and efficiency of wireless communication in environments with heavy scattering. The magnitude of the efficiency enhancement depends on the specific channel propagation environment. Communication in urban environments has become very important to the DoD and Department of Homeland Security. The measurements in such environments are thus of critical importance. This article presents results from a measurement campaign to characterize the propagation features of a low-rise urban MIMO channel in the military UHF band. The results show that the MIMO techniques are very promising in this setting. The results also indicate best spacing and suggest a channel model suitable for system design.

The sixth article, on cooperative communication and networking, is by Zhang, Liu, and Leung. Cooperative communication promises significantly higher spectral efficiency and reliability in multihop wireless communication (as required in mobile ad hoc networks) by using cooperative diversity, a MIMO-like technique applied in a network setting. To achieve the full potential of this network MIMO, several important objectives need to be balanced: spectral efficiency and reuse, reliability, and fairness. The authors discuss the design and evaluation of a clique-based utility maximization algorithm that also incorporates the fairness requirements. They use mathematical analysis to evaluate the overall throughput and fairness. They also analyze and discuss the impact of noncooperative (selfish) nodes mixed with cooperative nodes and identify nodal density required for full connectivity.

The seventh article, by Dwivedi et al., also deals with enhancing physical layer capacity effectiveness. However, the focus in this article is on optimizing the physical and link layer topologies dynamically and then using effective routing over optimized topology. Although the underlying techniques can be applied more broadly, they are especially suited for mobile ad hoc networks using free-space optics or directed RF links. These networks are characterized by high data rates but unpredictable and intermittent connectivity and partial control of physical topology to create new and better links dynamically. The authors describe a novel topology optimization algorithm and schemes for topology transition. They also evaluate realistic theater data and show that the link dynamics are significantly slower than the time for topology optimization and transition, thus making dynamic topology optimization effective.

The last article, by Benmohamed, Cole, and Doshi, discusses a crisis in the scalability of routing in the Internet and in large intranets such as the Global Information Grid and proposes a novel architectural solution to eliminate this crisis. The scalability crisis arises because of the fact that the current protocol uses the IP address to denote identifier, address, and forwarding hierarchy. Mobility, desire to multihome for diversity, and desire to use multiple paths for routing destroy the hierarchical advertising and routing, resulting in an unacceptable growth in the number of entries in routing tables and the rate at which changes need to be communicated. The solution proposed by the authors separates the identifier and the address into two distinct entities, thus maintaining the hierarchy in addresses and allowing scalability even in the presence of mobility, multihoming, and multipath routing. The authors also define a hierarchical set of databases to allow scalable mapping from the identifier to the address of an entity.

This is a small sample of recent research at APL in the areas of communication and networking. Other work at APL covers a spectrum of research beyond the scope of the articles in this issue of the *Digest*—for instance, sensor networking, photonic communication, free-space-optics-based communication, and network security. However, the range and depth of APL coverage should be evident from the articles in this issue. Finally, we thank all authors who submitted their recent work to this issue and the reviewers who provided timely, valuable reviews.

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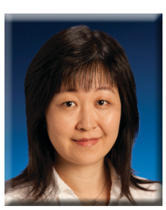

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