Digital Multi-Mode, Multi-Mission Satellite Communications Solutions

Combating emerging threats and increasing C4ISR system flexibility

Tony F. Sewell
DataPath, Inc
Atlanta, GA, USA
tony.sewell@datapath.com

Abstract—**The threat environment for military communications is evolving quickly, demanding greater resilience, adaptability and flexibility for communication planners. The variety of mobility platforms to communicate with is expanding, and so too the diversity of communications (particularly space-based) mediums. In parallel, government procurement agencies are seeking more 'bang for the buck', and standards-based approaches to ensure future-proofed investment. This paper analyzes this new strategic context based on public defense communications policy statements, and proposes technology and implementation solutions to address these challenges. As communications technologies converge, we find that a systems-based approach can potentially achieve significantly greater flexibility for mission planners, while maximizing economies over the life of the systems.**

Keywords- SATCOM, satellite, phased-array, virtualization, networks, waveforms, C4ISR

I. Introduction

The last 20-30 years has seen significant change in the way military and Command Control Communications and Computers Intelligence Surveillance and Reconnaissance (C4ISR) operations are conducted; driven by a fast-changing threat environment. Post 9/11, coalition military operations have been postured largely against non-state actors and counter-insurgency missions; however, the geopolitical environment is changing quickly, presenting a significant threat to the way C4ISR assets are employed in the battle field to 'win the fight'. With the rise of adversaries like Russia and China, mission planners are seeing the pendulum swing in the opposite direction, thus presenting a full-spectrum conflict risk from a 'near peer'. Within this context, conflict will be characterized by a much more complex electromagnetic environment, with the threat of effective and mature Electronic Warfare (EW) and Information Warfare (IW) capabilities that could have a significant impact on allied combat effectiveness. This new threat environment requires the implementation of new technologies and communication techniques to support the warfighter.

Additionally, while the threat environment is becoming more complex, defense procurement organizations are also faced with a wider range of C4ISR mediums, pressuring government budgets. Advances in antenna technologies, and the ability to transition many critical functions to a virtual environment present the opportunity to develop true multi-mode and multi-mission (M^4) solutions driving mission flexibility, and procurement budget savings.

SATCOM has proven fundamental to the effective conduct of expeditionary operations, and the evolving threat presents a significant challenge to this vital mission capability. This paper will explore the integration of several new technologies and communication techniques to address operations in the congested and contested environment. Acknowledging that defense missions also operate under benign conditions, leveraging both commercial and military communications capabilities, the paper will also address how these technologies can support life cycle cost minimization objectives and flexibility to operate across emerging communications platforms.

II. Strategic Context

The U.S. Army is actively addressing C4ISR capability gaps emerging as a result in a changing geopolitical environment. Training and Doctrine Command (Phillips, 2018) discuss an 'era of accelerated human progress through 2035' characterizing operational environments with highly effective offensive EW and Cyber capabilities, and ISR systems with the capability to locate and destroy friendly network nodes. These observations are also consistent in the Australian context. The Defence White Paper (Commonwealth of Australia, 2016) discusses the threats posed within the cyberspace and space environments, shaped by capability modernization regionally and globally. The Australian Defence Force acknowledges the reliance on space-based capabilities to execute military operations, and the vulnerabilities becoming apparent to commercial and military SATCOM.

To address these challenges military networks among other things will be highly mobile, able to be dynamically adapted to meet real time threat events, reliable and resilient, as well as providing the maneuver commander the flexibility to employ the network as a weapon system in 'the fight'.

Implementing network technologies to allow a transition to operating within this environment, however, requires the acknowledgement of deficiencies not only in current technology solutions, but also in the approach to procurement. The U.S. Department of Defense (2018) 'Analysis of Alternatives' describes a 'current state' of wideband communications capabilities characterized by individual, optimized space segments, highly customized terminals and ground infrastructure, and a collection of system-level monitor and control (M&C) capabilities. To meet the objective of operation within the new and dynamic threat and technology environment, the future will be characterized by federated enterprise level M&C, flexible and standards based terminal interfaces, and the ability chose space segment based on mission need, price point, technology insertion and resilience, with flexible communications devices and infrastructure.

The concept of the M4 solution draws on a range of existing and near-term technology concepts and application techniques to support these transition needs.

III. Solution Architecture

The M^4 terminal concept fundamentally involves the integration of five key technologies and techniques:

- Passive Electronically Steerable Array (PESA) flat panel antenna technology;
- Radio frequency (RF) or Intermediate Frequency (IF) digitization;
- Virtualized signal processing and baseband functions;
- Advanced Opportunistic Modem waveform technology; and
- Enterprise Network Management

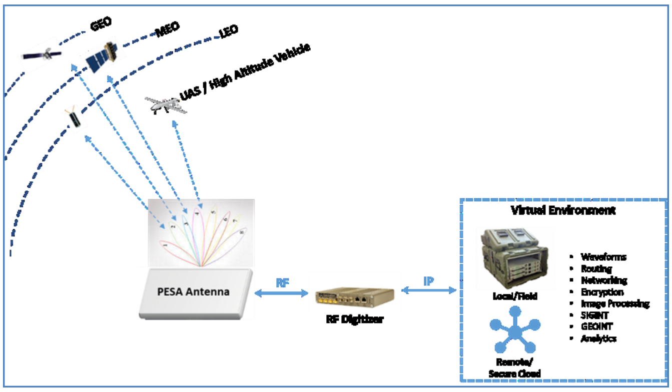

Figure 1 Example implementation of technologies for a mMmM system operating over GEO, MEO, LEO and high-altitude communication platforms

A. PESA

Most current approaches to flat panel technology involve active techniques to form and steer the antenna beam or beams. These Electronically Steerable Arrays (ESAs) typically have radiating elements with active transmit or receive amplifiers and phase-shift components so each element is essentially an active antenna. The full array is sized with tens or hundreds of these active elements to achieve the gain required to ensure proper end-to-end communication over the satellite. Because each element is active, the ESA approach is costly, has high-power consumption and often requires special techniques to manage the heat dissipation. As such, use of this approach, except in special applications, is not as practical and cost effective as traditional parabolic solutions. Some cost savings can be realized by using an ESA in one axis and mechanically rotating the ESA in the second axis to achieve the desired beam steering. However, this negates some of the reliability benefits of a full ESA approach. PESA offers significant cost advantages in terms of production as well as multi-application implementations.

PESA is a technique where a beam of radio waves can be formed electronically and steered to point in different directions using an RF lens. This lens and the antenna array are wideband passive devices that cover multiple SATCOM frequency bands and are fed by a single band specific transmit and single receive amplifier. Beam 'selectability' is accomplished by electronically selecting the appropriate RF lens input. The PESA antenna can produce a beam in various azimuth and elevation angles up to +/- 40 degrees from boresight without changing the physical antenna orientation. In the PESA design process, beams are formed by shifting the phase of the signal emitted from each radiating element to provide either constructive or destructive interference to steer the beams in the desired locations. Adoption of PESA technology will realize a step change in the flexible application of the SATCOM system, as well as significant cost and logistics benefits:

1) Multi SATCOM Constellation Capable: Legacy SATCOM antenna technology is currently limited to operation with one or two orbital types (e.g. Geostationary Earth Orbit (GEO), Medium Earth Orbit (MEO), and Low Earth Orbit (LEO)), but each relies on high cost and Size Weight and Power (SWaP) mechanical systems to track satellites. PESA technology not only supports communications across the full range of satellite constellations (both military and commercial), but also can support ultra-wideband operation from L to Ka band using two passive array case-mounted assemblies. Operational planners will have greater flexibility to determine how a system is used in the field, and the ability to quickly adapt to the operational environment.

2) Multi-Mode Operation: PESA antennas can simultaneously support communication with non-satellite systems, including high altitude aircraft (e.g. drones) and UAS. With this capability, the commander has a true multi-mode C4ISR solution that can support ISR collection as well as range extension of terrestrial communications. The ability to support multi-mode operation also future-proofs capability investment, as the system can evolve with user/mission requirements.

3) Multi-Mission Operation: PESA presents the ability to adapt the system for use in remote SIGINT missions; being able to track and capture RF transmission of multiple satellite types passively. Because a common flat panel array can be used, the PESA technology is highly suitable for remote deployment and easily supports multiple mission needs. When combined with RF digitization, the system can provide powerful recording and storage, and live or post processing of signals. PESA elements can also be conformally integrated to mobility platforms to minimize the tactical impact on vehicle operation.

B. RF Digitization

The process of digitizing RF transport directly at a SATCOM ground terminal has proven to be a highly effective technique to enhance the operation of diverse earth station architectures and loss-less transport over public and private networks. RF/IF over IP (also known as packetized IF) moves digitized spectrum deterministically anywhere over an IP network (e.g. the Internet), for reconstruction at the destination, processed by either digital or analog equipment. Continuously tunable over a range of 50-2500MHz, the devices capture a group of carriers within the defined spectrum of instantaneous bandwidth. Core applications of this technique are as follows:

- Eliminate distance constraint between antennas and hub systems allowing centralization of gateway equipment (for hubs, modems and encryption equipment);
- Reduce operational overhead such as personnel and power (thus lowering cost); and,
- Support effective antenna diversity applications

Digitization of the RF spectrum also offers new applications suited to military C4ISR operations:

1) Optimization of real time applications: With transport of high definition video streams prevalent in the modern battlefield, transport via TCP/IP isn't optimal. By digitizing IF, the impact of jitter is more effectively addressed through adjustment of deterministic delay as well as reducing packet loss with Forward Error Correction (FEC).

2) Improved security: Data security is inherently greater, as traffic remains in the 'transport' layer until it is processed at a centralized location. This provides the ability to move sensitive equipment to central locations, away from potentially compromised, or unpatrolled locations.

3) Flexible antenna deployment and hub centralization: By being able to extend the distance between the antenna and signal processing at the RF/IF level, planners have more flexibility about the location of hub systems, that are high value and require highly trained operators. Additionally, by removing the limitation of distance between a hub and an antenna, networks can be established through hubs that aren't even within the footprint of a satellite beam location.

4) Antenna combining: The digitization device can also be used to combine the receive signals from two separate antennas to increase gain. For example, the receive signal from two 1m antennas could be combined to provide an additional 3dB of receive gain at a site, creating a multi-beam antenna and replicating a larger one. For missions that require less visible deployment, or to reduce logistics cost, this application provides significant benefits.

5) Ground based beam-forming: As a SIGINT application, the system could capture RF signals from multiple antennas or a single steerable beam antenna (for instance PESA) for digitization and storage in a cloud or virtual environment to conduct immediate or post processing of signals from desired satellites.

C. Virtualization

While the previously discussed architecture can be implemented with current hardware-based modem and baseband solutions, the concept of digitizing the RF in a virtual compute and storage environment presents a significant opportunity to:

- Enhance and optimize the quality of the RF receive spectrum;
- Select or provision communication waveforms and modem codes to interoperate with existing networks;
- Establish virtual-secure and non-secure baseband network routing; and
- Implement value-added software applications such as SIGINT processing, data analytics, security solutions, situational awareness, change detection, artificial intelligence, and similar applications.

Instead of regenerating the RF/IF for injection into a modem, the opportunity exists to translate the RF/IF signal to I/Q data, for modulation or demodulation at a central location and processing in the virtual environment. Taking the concept of a software defined radio one step further, the system would implement virtual instances of a proprietary waveform (for example Datum, ViaSat, Hughes, L3, etc.) which could process the I/Q data in the virtual environment for subsequent baseband distribution. The advantages of this CONOPS include:

- Network agnostic terminal systems that provide greater flexibility for network and deployment planning. Additionally, as truly multi-modal terminal systems, the specific mission application becomes a function of software implementation, rather than hardware.
- Greater interoperability in the joint and coalition environment, with common equipment sets at the joint level, and interoperability enabled at the virtual level in the coalition context.
- Enhanced security as virtual solutions can be established as needed for the mission or connection and then taken down and re-established when required.
- Upgrades and system capability can be pushed out to remote terminals more efficiently and securely in a 'Dev/Ops' manner by the system administrators.

D. Flexible and Resilient Waveforms

Within the congested and contested environment, attention to the characteristics of a waveform is also critical to ensure reliable and resilient operation. Whether operating within a software defined radio architecture, or a virtualized environment, the flexibility of waveform application is important to support true multi-modal operation. Using spectrum aggregation and interference mitigation provides increased resilience, and reduces operational expenditure (OPEX) of satellite bandwidth.

Called an ‘Opportunistic Modem’ (OM), the technology allows for the creation of multiple carriers across a disjointed and fragmented spectrum that are digitally aggregated into a single channel. An example application is illustrated in Figure 2. As is often the case on satellite transponders, portions of bandwidth often remain unused due to infrequent grooming. The OM technology can utilize this ‘stranded’ spectrum to create new channels out of otherwise unused bandwidth. While this is not only cost advantageous (as satellite operators may charge a lower rate than for a contiguous bandwidth), the technique also creates interference resistance, by combining disjointed spectrum across a bandwidth of up to 72MHz with up to eight channels. To further increase the resilience of this method, bandwidth can be dynamically reallocated to address interference on one or more of the sub-carriers. This capability can be implemented with minimal overhead resources.

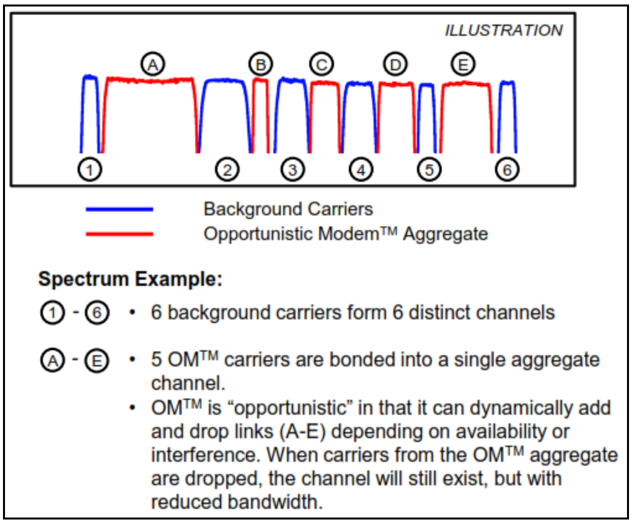

Figure 2 OM implementation example

The technology implemented for OM (with multiple mod/demod and carrier aggregation) also inherently supports a troposcatter application, adding additional multi-mode flexibility to the system.

E. Enterprise Network Management

As observed by the U.S. DoD in its ‘analysis of alternatives’ (2018) moving from a system of disparate and stove-piped monitor and control capabilities, to a truly federated enterprise-level capability. This has implications at the M^4 user level, through to operational and strategic communications management levels.

At the terminal level, a robust and standards-based M&C capability will play a critical role supporting operation, configuration and optimization at the local level. User views should be intuitive and flexible, supporting the range of software-defined functions and applications of the terminal system, while also providing scalability across a range of user display capabilities.

In an environment where networks must transition across different commercial and military space segments, and architectures and associated terminals are truly hybrid, an integrated enterprise management capability will be critical. It must ensure optimal use of bandwidth resources, efficient mobility across network topologies, and the ability to adapt to dynamic mission conditions while maintaining maximum network availability.

IV. Conclusions

While operational and procurement environments are fundamentally challenging the effectiveness of current C4ISR capabilities, new technologies integrated and applied in novel ways present significant opportunities for military communications planners. The increased reliance on spectrum across a range of devices and platforms in the operational environment creates complexity and new vulnerabilities, but also provides the context for a fundamental transition to true hybrid systems and architectures. Multi-role terminals capable of operation in line of site, beyond line of site, across LEO/MEO/GEO satellites, while simultaneously executing various mission effects are fast becoming a reality. Consideration of SATCOM capability in this paradigm will also herald an important transition in the way both industry and procurement organizations think about systems, from being hardware-centric, purpose built devices, to being capability-centric, hybrid solutions supporting the transition of entire networks across space-based platforms to support the threat situation.

Acknowledgment

The author acknowledges the input of DataPath technology partners from Antenna Research Associates, RT Logic, and Datum Systems for their support in developing the solution concepts.

References

[1] Commonwealth of Australia (2016), ‘Defence White Paper’, Department of Defence, Canberra

[2] Phillips, G. (2018), ‘Operational Environment and Threat’, Tactical Network Industry Forum, U.S. Army TRADOC, 6 Feb 2018

[3] Witsken, J.R. (2018), ‘Mission Command Network: Operaitonal Needs & Requirements’, Tactical Network Industry Forum, Mission Command Center for Excellence, 6 Feb 2018

[4] U.S. Department of Defense (2018), ‘Wideband Communications Services Analysis of Alternatives’, DoD/Industry COMSATCOM Industry Round Table, 13 Mar 2018