Impact to NextGen of the Telecommunications Industry Evolution from Time Division Multiplexing (TDM) Technology to Internet Protocol (IP) Technology

Mark Graham
mgraham@harris.com
Harris Corporation

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ABSTRACT:

The telecommunications industry is evolving from the use of traditional Time Division Multiplexing (TDM) as a fundamental transport technology to newer technology better suited for Internet Protocol (IP) transport. Some of the major telecommunication carriers have announced their intention to discontinue their offering of TDM-based services by the end of calendar year 2020. The National Airspace System (NAS) relies heavily on the use of TDM technology and will be impacted by this technology transition. This paper describes the purpose of the TDM-to-IP-based transport technology evolution, the expected benefits, and the effect of this technology conversion on NextGen. Technology alternatives are identified and discussed in terms of "pros and cons" to NextGen, and high-level plans are emphasized as they will serve necessary in preparation for this change.

Key Words:

- Automatic Dependence Surveillance–Broadcast (ADS-B)
- Data Communications (Data Comm)
- Enroute Automation Modernization (ERAM)
- Terminal Automation Modernization and Replacement (TAMR)
- Terminal Flight Data Manager (TFDM)
- NAS Voice System (NVS)
- System Wide Information Management (SWIM)
- NAS Enterprise Messaging System (NEMS)
- FAA Telecommunications Infrastructure (FTI)

WHAT IS HAPPENING IN THE TELECOMMUNICATIONS INDUSTRY

Growth of the Internet and widespread adoption of packet-switched data established around IP technology has evolved and is becoming the dominant, worldwide telecommunications transport technology. Additionally, the advancements in optical networking with Dense Wavelength Division Multiplexing (DWDM) have increased the bandwidth capacity of the existing fiber infrastructure and new fiber builds. Broadband communication has caught up to the world of wireless communication, with new 4G Long Term Evolution (LTE) wireless networks, supporting broadband, mobility, and the widespread deployment of millions of handheld and tablet devices. These revolutionary and rapid changes in telecommunications within the last two decades have necessitated the move away from legacy TDM transport to more efficient and flexible IP transport. This transition from one transport technology to another is inevitable and it is imperative that the NAS and NextGen are ready for this change.

CHALLENGES REMAIN

Constant evolution in technology is a continuous reality and an improvement that provides conveniences and benefits, once accepted. For example, imagine going to work, traveling on business, or simply going out to dinner without your smart phone. Since a majority of the population has become dependent on these devices, the thought would not be considered in today's environment. However, one could argue that cell phones come with drawbacks such as the distractions they create for drivers or the environmental impact from the thousands of towers required to provide service coverage. But most people would agree that the benefits of cellular telephony outweigh the drawbacks.

The point of this analogy is that new technology often comes with drawbacks, and the same is true for the "TDM-to-IP" conversion. TDM technology inherently provides deterministic performance, which is critical in the Air Traffic environment where safety is of paramount concern. In mathematics and physics, a deterministic system is defined as a system where there is no randomness when further developing future states of the system. For a communications system, this means that the performance of the TDM circuitry can be consistently and accurately predicted due to the use of technology that separates network traffic in timeslots that cannot be shared by more than a single user at each end of the circuit (sender and receiver). Said more simply, when a user's data is transmitted over a TDM circuit, the user is not concerned about another user interfering and/or causing congestion on the user's designated timeslot resource. Many of today's air traffic control (ATC) applications and systems depend on determinism and will most likely have to be redesigned.

Conversely, packet-switched technology is inherently stochastic, introducing an element of randomness that must be considered. In mathematics and physics, a stochastic system is defined as "non-deterministic." In a communications system, the randomness is caused by the sharing of the transmission medium between multiple users and the dependency on time and volume, increasing the possibility of congestion. When congestion occurs it becomes more difficult to accurately predict the performance, causing increased latency and/or lost data in the form of dropped or discarded packets.

For the NAS and NextGen, the deterministic performance that has endured over the last few decades through use of point-to-point TDM circuits will no longer be supported by the new IP packet-switched technology. To provide deterministic performance, TDM technology requires a precise frequency-based timing and synchronization system that is not typically needed by an IP-based system. Hence, this is one of the most significant technical challenges that must be overcome in the technology evolution, as many of the legacy NAS systems rely on precise timing. Other areas of concern that must be solved are the inherent security benefits of TDM circuits and the more accurate and predictable latency performance of the network.

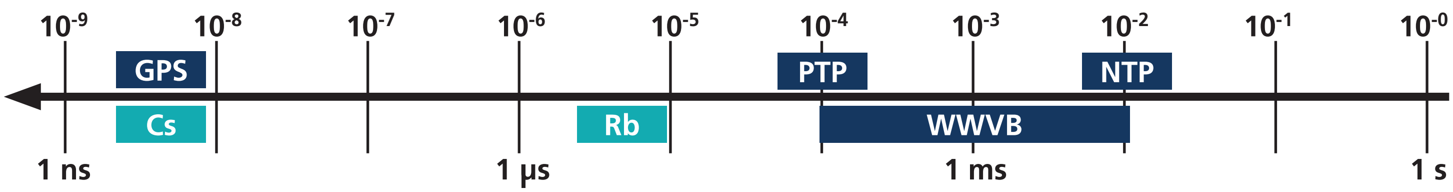
Currently the Federal Aviation Administration (FAA) is focused on seven NextGen programs that will be deployed using IP transport technology supporting the technical challenges of the "TDM-to-IP" evolution. The scheduling of these program(s) deployment schedules are "out-of-sync" and the "sun-setting" of the TDM telecommunications technology timeframe need to be addressed. Another detail to be considered is the absence of some of the existing NAS systems that use TDM transport technology in the modernization of the NAS through NextGen programs. In spite of these challenges and considerations, the transport technology change is unavoidable due to the benefits that IP transport will bring to the telecommunication industry.

THE BENEFITS OF IP OUTWEIGH THE DRAWBACKS

System engineers know there is never a perfect solution—all solutions are a tradeoff between the benefits and the drawbacks. IP packet-switched technology offers many benefits that will be leveraged by the NextGen focus programs. The most significant benefit provided by IP transport is the cost savings associated with the use of a shared infrastructure, taking advantage of the communications infrastructure through economies of scale. IP transport also provides high availability service through dynamic routing, which maximizes the use of multiple communication paths. Dynamic routing is ideal for supporting NextGen objectives such as facility consolidation and dynamic re-sectorization.The flexibility of IP to provide "any-to-any" connectivity supports many NextGen requirements and another reason all NextGen programs use it.

OVERCOMING THE CHALLENGES

Network timing and synchronization is the most significant challenge to overcome. With TDM-based technology, precise timing that is traceable to a Stratum-1 source is required to keep senders and receivers synchronized with one another. Providing precise timing can be expensive, as Stratum-1 sources are derived from Global Positioning System (GPS) satellite or Cesium clock sources. It is common to distribute traceable Stratum-1 timing through the use of T1 telecommunication circuits operating at 1.544 Mbps. Frequency-based timing provides a more accurate timing and synchronization service when compared to message-based time protocols used by IP technology such as Network Time Protocol (NTP) and Precision Time Protocol (PTP). However, NTP and PTP alone are not used for timing synchronization. This is because they are designed to communicate Time of Day (ToD), which is not interchangeable with network time synchronization. Methods for timing synchronization combining ToD and Adaptive Clock Recovery (ACR) have been developed using NTP and PTP, but do not deliver the same accuracy as frequency-based synchronization. The figure below depicts the relative accuracy of commonly used message-based and frequency-based time services.



The relative accuracy of commonly used message-based and frequency-based time services

A point that needs to be clarified is that the title "TDM-to-IP" is a misnomer for many reasons. First, the impact of the evolution is more apparent in what is described as access in the telecommunications industry. "Access" is the connectivity from a customer site (e.g., an Air Route Traffic Control Center [ARTCC] in the NAS) to a core network. Core networks have been operating IP backbones for many years and most are implemented as Multi-Protocol Label Switched (MPLS) networks today. The evolution is occurring in these core networks as well, but it is more in the underlying medium used for transport and is transparent to users. From a user perspective, the infrastructure will still appear and behave as an IP network. It is in the access from the customer site to the core backbone where the evolution is more noticeable to users because the primary change is moving from TDM access circuits to Ethernet access services. Ethernet service is a Layer 2 service in the Open Systems Interconnection (OSI) reference model, which is a switched service and different from a Layer 3 IP routed service.

Although Ethernet is not the same as IP, it is well-suited for transporting IP packet data and it is the preferred technology for both access and the core backbone. Today Ethernet standards are still being developed and there are differences in the way it is implemented, but what is most important is whether the Ethernet service is private or shared. Ethernet Private Line (EPL) is best for mission-critical services because it possesses a more deterministic performance characteristic, similar to TDM. In contrast, shared Ethernet services such as Ethernet Virtual Private Line (EVPL) or Virtual Private LAN Service (VPLS) will display more stochastic behavior, similar to packet-switched technology. The word "virtual" means that it is not really private because some resources are shared.

Other variations in Ethernet implementation include:

- Ethernet over the Plesiochronous Digital Hierarchy (PDH), e.g., T1s or T3s
- Ethernet over the Synchronous Digital Hierarchy (SDH),e.g., SONET
- Ethernet over DWDM
- Ethernet over pseudo-wire

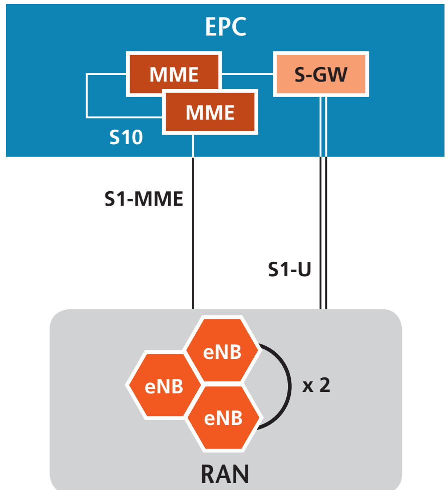
The FTI program implements EPL service using three of the four implementations (all but pseudo-wire) for IP traffic today. TDM services requiring precise timing are not implemented over Ethernet. Regardless of the implementation used, Ethernet is an asynchronous service and not well-suited for precise network timing and synchronization. An evolving exception is Synchronous Ethernet (SyncE), which provides accurate timing that can be traced to a reliable source. However, the cost and complexity of the reliable source is part of what the telecommunications industry is trying to avoid. Because of this trend, widespread deployment of SyncE is not anticipated.

Asynchronous Ethernet (and IP) do not require costly timing sources or a means to distribute timing, but many NAS systems still need and rely on accurate timing and synchronization. NextGen focus programs should overcome this reliance to a great extent, but some of the NAS legacy systems are not included in NextGen programs. The current seven NextGen focus programs that use or will use IP transport are:

- ADS-B
- Data Comm
- ERAM
- TAMR
- TFDM
- NVS
- SWIM

A concern with these programs is the timing of their respective deployment schedules and their alignment with the telecommunications industry timeframe for discontinuing TDM-based service.

There are other legacy systems and services that are not modernized by these seven programs, such as Flight Handoffs (IDAT), Beacon Data (BDAT), and Radar Data (RDAT). All of these services are important from either a safety or efficiency perspective and must be upgraded in order to be supported by IP-based technology. The FAA is starting to look at alternatives such as Service Oriented Architecture (SOA) upgrades using NEMS. SOA technology uses software to simplify the task of implementing and using applications over a network and is well-suited for using IP transport. Part of the challenge will be the determination of when and where funding for these SOA upgrades will be obtained.



Control Interfaces	Legend
S1-MME = MME to RAN	eNB = eNodeB
S10 = MME to MME	RAN = Radio Access Node
	EPC = Evolved Packet Core
User Data Interfaces	MME = Mobility Management Entity
S1-U + S-GW to RAN	
X2 = eNB to eNB	S=GW = Serving Gateway

S1-MME interface in the generic standards-based 4G LTE architecture

Another evolution in telecommunications, which is expected to become more pervasive, is 4G LTE wireless communications. 4G LTE is still maturing and most service providers do not offer Service Level Agreements (SLAs) at this time. These services may be suitable for some NAS applications, but they are not specifically designed and well-suited for fixed point-to-point access communications needed in the NAS. LTE systems are designed for broadband mobile communications and are usually priced on a usage basis. Their focus on mobility also requires a control channel to the Mobility Management Entity (MME), as shown and represented by the S1-MME interface in the generic standards-based 4G LTE architecture. The handshaking control protocol between the MME and the Radio Access Node (RAN), combined with the user data communications path identified as the S1-U interface, cause stochastic behavior. This makes latency performance difficult to predict and even more so when the network is congested. Techniques for "always on" communications are also required and can be costly in a usage-based billing scenario. Still, 4G LTE communications may be useful as a backup service and even as a primary service for less critical services such as Automated Surface Observation System (ASOS) weather observations, which only need periodic updates.

NEXTGEN PRIORITIES

As stated earlier, the "TDM-to-IP" characterization is somewhat of a misnomer. Nowhere is this more evident than when it comes to thousands of analog tail circuits still operating in the NAS. Many ATC facilities, such as Remote Communication Air-to-Ground (RCAG), VHF Omni-Directional Radio (VOR), and other unmanned remote sites, are served by analog tail circuits in the last mile that pre-date TDM technology. These circuits are difficult to maintain, as spare parts have become increasingly obsolete and qualified trained personnel have diminished over time. These circuits represent risk to the NAS because they generally provide a lower quality of service and cause frequent service outages. There are no silver bullets for addressing this problem, and it will require funding to upgrade the analog technology to digital technologies such as Ethernet and 4G LTE, as described previously. NextGen programs such as NAS NVS and ADS-B support the IP transport technology and interfaces to deal with the new telecommunications technologies, but upgrades to the commercial telecommunications infrastructure are still required. Since commercial telecommunications infrastructure upgrades are driven by market demand, rural areas will be especially challenged. Another cost factor is that because newer services provide much more capability and bandwidth than the analog services they replace, the associated recurring costs will increase.

Because of the risk analog circuit technology presents to both current operations and NextGen, it needs priority attention. Funding and technical solutions also need to be identified for services that are not modernized by NextGen programs. Finally, all of the NextGen focus programs need to continue to stay on schedule and be implemented before TDM services are discontinued.

SUMMARY

The TDM-to-IP evolution in telecommunications will have an impact on NAS operations and NextGen. The FAA has mitigated the impact to some extent by being proactive and adopting IP-based interfaces for the NextGen focus programs. However, there are other NAS legacy systems that rely upon analog tail circuits and TDM-based services. They represent a risk to NAS operations if they are not addressed. Implementation plans for addressing these gaps need to be developed and funded. Analog tail circuit upgrades coupled with the deployment of NextGen focus programs are the priority. The change is inevitable and the FAA and NextGen must be ready for it. While there will be some added costs, there are significant operational benefits that the FAA can realize by modernizing from TDM to IP.

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Government Communications Systems
P.O. Box 37
Melbourne, FL USA 32902-0037

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