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Efficient XML
Taking Net-Centric Operations to the Edge

Topics: Net Centric operations, disadvantaged users, XML, web-services, SOA, bandwidth, battery life, throughput, speed, compression

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Abstract

As the military shifts toward network-centric operations, the vision of sharing common information objects between command centers, aircraft, maritime vessels and mobile land forces over a single global network seems closer than ever. One of the fundamental challenges of achieving this vision is bridging the gaps between enterprise C2 systems that can use net-centric web technologies and tactical C2 systems that require more efficient data representations.

Efficient XML addresses this challenge by optimizing net-centric web technologies for environments with limited bandwidth, processing power and/or battery life. Efficient XML is the basis for the emerging World Wide Web Consortium (W3C) standard for Efficient XML Interchange (EXI) and independent measurements indicate it can make XML data small and fast enough for the most demanding tactical applications. The U.S. Navy's 2006 Joint Rapid Architecture Experiment (JRAE) and the U.S. Air Force's 2006 Joint Expeditionary Force Experiment (JEFX) independently assessed the utility of Efficient XML for military applications, measuring XML data transfer speeds over 100 times faster using less than 1% the bandwidth. This paper describes the challenges we face using XML on tactical networks, describes how Efficient XML addresses these challenges and provides real-world results achieved during JRAE '06 and JEFX '06.

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1 Introduction

As the DoD shifts toward network-centric operations, the vision of sharing common information objects between command centers, aircraft, ships and mobile land forces over a single global network seems closer than ever. One of the fundamental challenges of achieving this vision is bridging the gap between wired command centers that share information using XML and the "edge" users that require more efficient data representations.

XML and XML web-services are being widely deployed in the DoD to share information across a broad range of systems. The amount of information available in XML is rapidly increasing due largely to the low cost, high quality, rapidly evolving tools generated by the competitive XML marketplace. However, transmitting XML data over wireless data links and processing it on embedded and mobile platforms has proved challenging due to the size and complexity of XML data. It is often impractical or impossible to use XML in systems where efficiency is critical or bandwidth is limited.

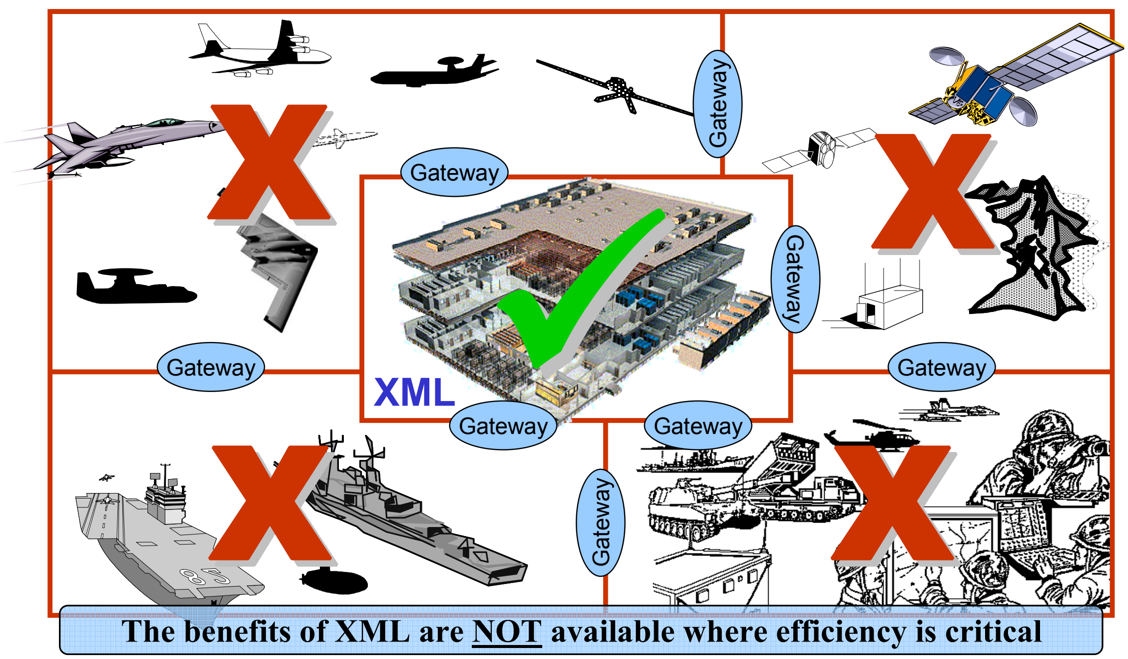

Figure 1. XML and XML web services do not work well in tactical environments

This situation creates a data representation rift between the systems that can effectively process XML and those that cannot. Consequently, moving information between fixed, mobile and embedded platforms often requires an expensive series of proprietary, special-purpose gateways and the associated risk that information fidelity and accuracy will be lost. In addition, it prohibits "edge" users from leveraging the economic and interoperability benefits of XML. Figure 1 above illustrates typical military environments where XML can and cannot be used.

Efficient XML addresses this challenge by optimizing net-centric web technologies for environments with limited bandwidth, processing power and/or battery life. It affords mobile users direct access to the wealth of enterprise information encoded in XML and gives decision makers direct access to information from the "edge" of the network. In addition, it increases the performance of existing XML solutions and introduces numerous new opportunities for exploiting COTS software on embedded and mobile platforms.

The U.S. Navy's 2006 Joint Rapid Architecture Experiment (JRAE) and the U.S. Air Force's 2006 Joint Expeditionary Force Experiment (JEFX) independently assessed the utility of Efficient XML for military applications, measuring XML data transfer speeds over 100 times faster using less than 1% the bandwidth. Both experiments recommended immediate fielding and broad adoption of Efficient XML. Industry's World Wide Web Consortium (W3C) also conducted a detailed, independent assessment of XML optimization technologies and adopted Efficient XML as the basis for the emerging web standard for Efficient XML Interchange (EXI).

This paper describes the challenges we face using XML on tactical networks, describes how Efficient XML addresses these challenges and provides real-world results achieved during JRAE '06 and JEFX '06.

2 Background

2.1 XML is Ubiquitous

It's no secret, XML and XML web services have become the standard mechanism for sharing data on and off the web. A highly competitive marketplace has emerged around developing the best XML solutions for the lowest price. Industry leaders, such as Microsoft, IBM, BEA, Sun and Oracle have cited XML as a central part of technical strategy and have re-architected their products around it. Company wide initiatives, such as Microsoft's .NET strategy are evidence of this movement. Consequently, the products most people use every day at work, at home and in the command center are XML enabled.

Not surprisingly, national and international defense organizations, including the U.S. DoD [9] and NATO [19], have taken a keen interest in XML. Major defense programs, such as the Global Command and Control System (GCCS) and Net-Enabled Command Capability (NECC) have adopted XML. In addition, major defense message standards, such as the United States Message Text Format (USMTF) program and NATO Allied Data Publication 3 (ADatP-3), have adopted XML. As such, it is now possible to obtain low-cost, excellent quality COTS software for sharing and manipulating defense data in a platform independent manner

2.2 Efficiency is a Challenge

Unfortunately, however, XML was not designed with efficiency in mind. Consequently, XML files and messages are typically very large relative to their content, requiring 10-100 times more storage, memory, bandwidth and processing time compared to previous text and binary formats used across the DoD (see Figure 2 below).

This lack of efficiency has been problematic for organizations shifting from more efficient, formats to XML and prohibitive for others. It is a frequently discussed problem in the XML community [10] and has been cited as a major issue by commercial XML users, such as UPS [31].

XML's lack of efficiency is particularly problematic for wireless users and mobile devices, where storage, memory, bandwidth and processor power are at a premium. In these environments, higher bandwidth, more powerful processors and more memory translate to larger, heavier devices with shorter battery life. Given the constraints of these devices, large files take too long to access, require too much memory and require lengthy processing times, draining the battery. In addition, on commercial mobile networks, where users are often billed by the kilobyte, larger files result in higher monthly operating expenses..

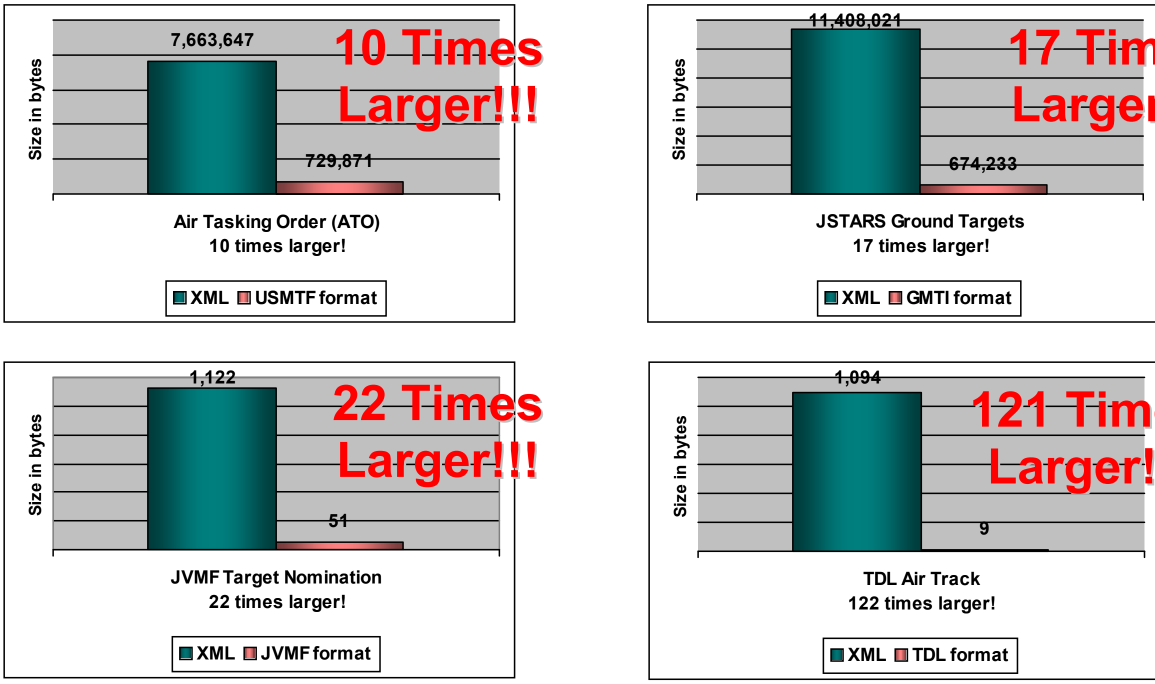

Figure 2. Traditional XML compared to existing tactical data formats

2.3 Efficient XML

Efficient XML dramatically reduces the size of XML data and simultaneously accelerates XML processing using fewer computational resources. In fact, it generally meets or exceeds the efficiency of the best tactical data formats and the requirements of demanding defense applications (see Figure 3 below).

Efficient XML maintains interoperability with existing XML technologies, tools, applications through popular and standard XML Application Interfaces, such as thee W3C Document Object Model (DOM), Simple API for XML (SAX), Streaming API for XML (StAX), etc. Applications using Efficient XML can continue to use traditional XML and maintain backward compatibility with systems not yet using Efficient XML. The XML APIs provide an abstraction layer that insulate applications from the data transport and provide a common, familiar data model for processing XML information.

The W3C has created an emerging global web standard for Efficient XML Interchange (EXI) based on Efficient XML. As part of this initiative, the W3C conducted a comprehensive, independent analysis of competing XML optimization technologies, benchmarking compactness, processing speed and a variety of other characteristics. They found Efficient XML consistently achieved the best compactness across every test group, use case and class of applications. They also found that Efficient XML was one of the fastest XML data formats, even compared to those focused primarily on speed at the expense of compactness.

As the developers of Efficient XML, we proposed the creation of the EXI standard in 2003 and have been working closely with our colleagues in the W3C to ensure it continues to meet the demanding requirements of defense applications.

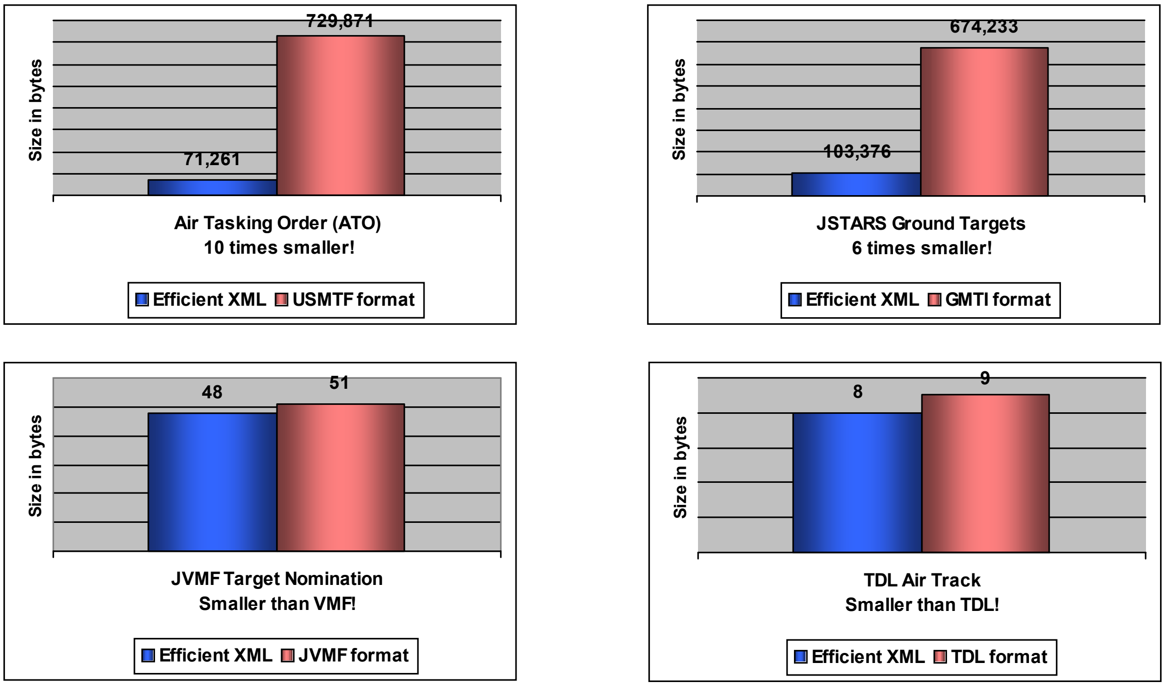

Figure 3. Efficient XML enables XML to be used for the most demanding applications

3 Independent Military Assessments

While Efficient XML is relatively new to the W3C, it was developed several years ago and there are already mature COTS products available that implement the emerging standard. The military utility of these products was independently assessed in the Navy sponsored JRAE '06 experiment and the Air Force sponsored JEFX '06 experiment. The following sections summarize the results of these assessments.

3.4 JRAE '06

JRAE is a Joint lab-based experimentation venue in which acquisition agencies collaborate on system engineering approaches to deliver near term interoperable solutions. The JRAE (formerly "Joint Raptor") series of experiments focus on Target Management in a Service Oriented Architecture (SOA) supporting the Joint along with other tactical missions Time-Sensitive Targeting (TST) Operations Thread Model. JRAE is a cross Service effort and one of the Navy's Sea Trial events, and as such emphasizes speed to capability, Joint interoperability, comprehensive Service focus, relevance to the warfighter, and economy of effort.

JRAE '06 assessed the ability of Efficient XML to extend the reach of Net-Centric web services to tactical users with limited bandwidth. The following sections provide details about specific scenarios and measurements from JRAE '06.

3.4.1 Scenarios and Systems

The JRAE '06 scenario centered around a NCES SOA pub-sub architecture for nominating, coordinating, prosecuting and assessing targets. The NCES Joint Target Management (JTM) service provided the core service functionality used by all clients during the experiment.

Like all NCES capability modules, the JTM service uses XML-based web-service as a core part of its architecture. The lab environment enabled JRAE assessors to independently control the bandwidth of various communications links to simulate realistic tactical environments. The assessors took a wide range of measurements comparing the overall performance, speed and bandwidth utilization of the JTM web services with and without Efficient XML over various speed links, including 100 Mega-bits-per-second (mbps), 128 Kilobits-per-second (kbps), 9600 bits-per-second (bps) and 2400 bps.

To support the experiment Efficient XML was integrated into several programs of record, including the JTM service, USAF TBMCS 1.1.3, USN GCCS-M, USA AFATDS, USMC C2PC, and the U.K. system JETTS. Figure 4 shows where Efficient XML was used in the JRAE '06 architecture.

JRAE 06 was divided into two spirals. Spiral 1 measured the performance of both standard XML and Efficient XML with high and low bandwidth connections. Spiral 2 examined the impact of applying Information Assurance protocols, specifically Public Key Information (PKI), Policy-Based Access Control, XML Digital Signatures and the Security Assertion Markup Language (SAML) with Efficient XML to control access to the JTM service.

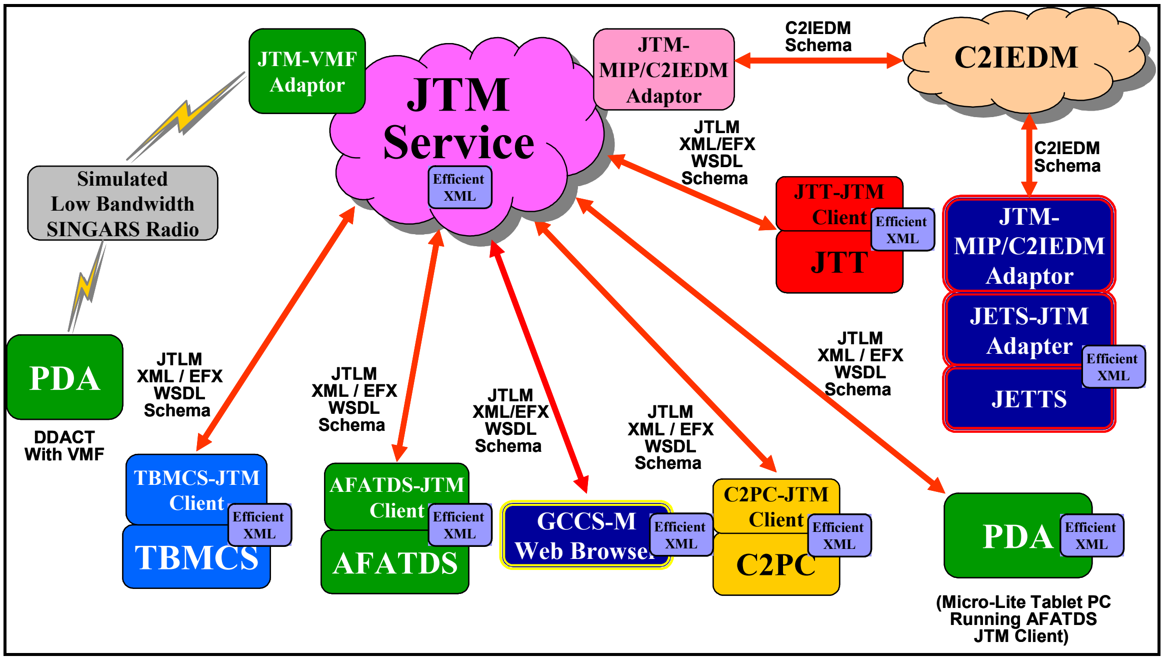

Figure 4. JRAE '06 systems and architecture overview

3.4.2 Summary of results

In aggregate, JRAE ’06 assessors measured a 100 fold improvement in JTM bandwidth utilization and overall performance using Efficient XML. Individual speed and bandwidth measurements ranged from 20 times better to over 480 times better. Figure 5 and Figure 6 show specific JTM message size measurements taken by assessors during JRAE ’06.

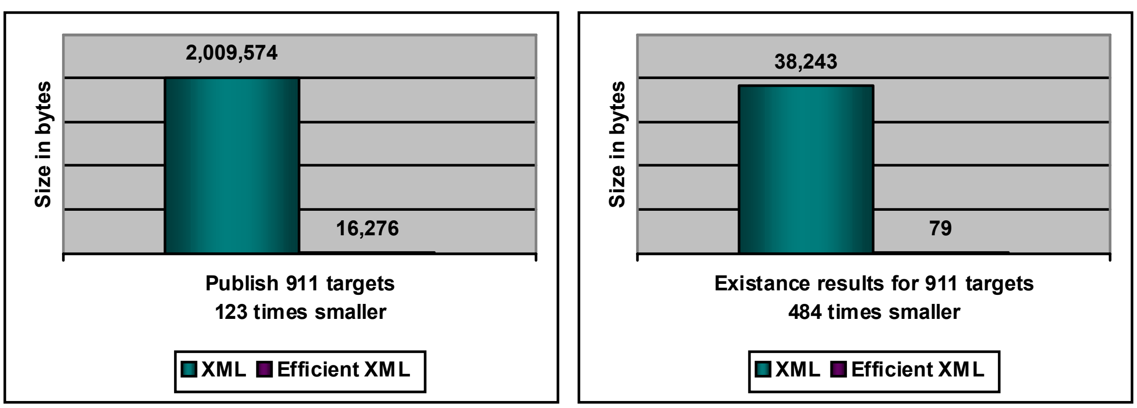

Figure 5. JRAE '06 JTM message sizes (Efficient XML vs. XML)

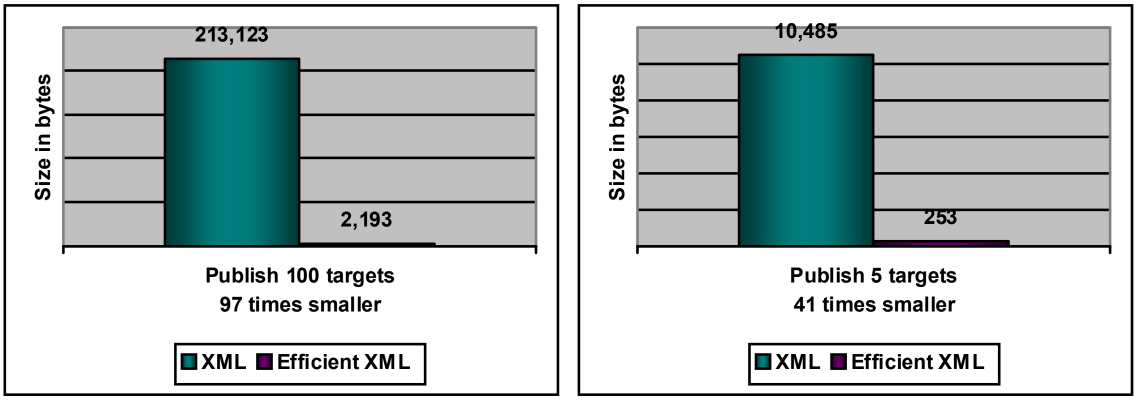

Figure 6. JRAE '06 JTM message sizes (Efficient XML vs. XML)

JRAE '06 also looked at XML and Efficient XML message sizes compared to several existing tactical data formats, including Joint Variable Message Format (JVMF), Link-16 Tactical Data Link Series J (TDL-J) and NATO STANAG 4607 Ground moving Target Indicator (GMTI).

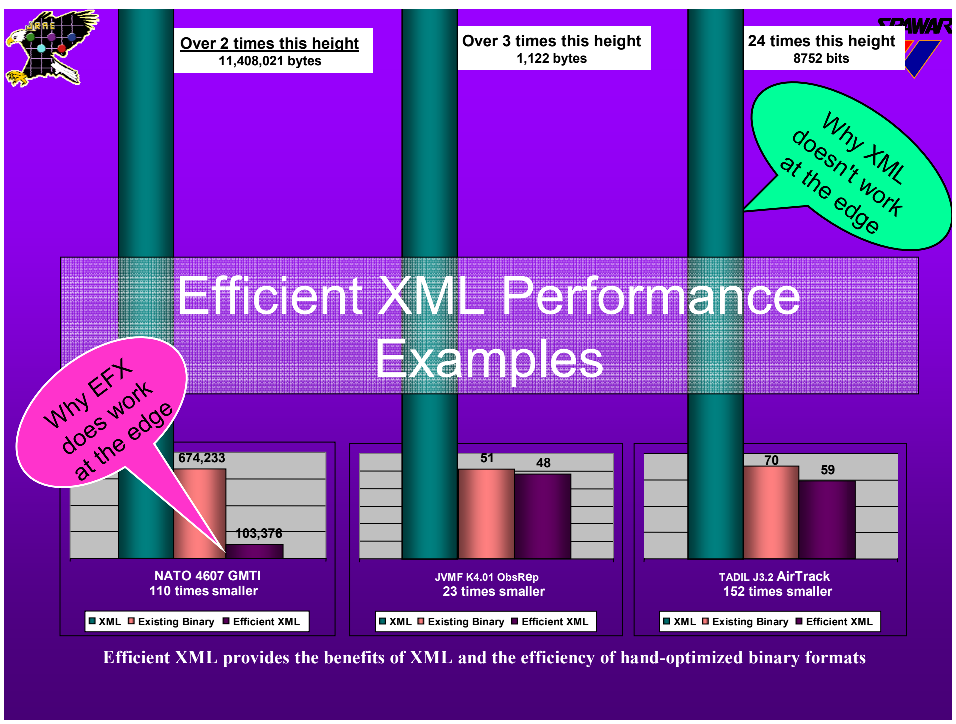

Figure 7. JRAE '06 comparison of XML and Efficient XML (EFX) to tactical data formats

Figure 7 is a JRAE '06 slide showing the results of these comparisons. In every case, XML proved to be prohibitively large for these messages, but Efficient XML was actually smaller than even the most efficient tactical data formats. As such, Efficient XML proved to be efficient enough for use in the most demanding tactical environments.

JRAE ’06 extended its review of Efficient XML to see how well it worked on a variety of other tactical data exchanges. Figure 8 is a JRAE ’06 slide summarizing these results.

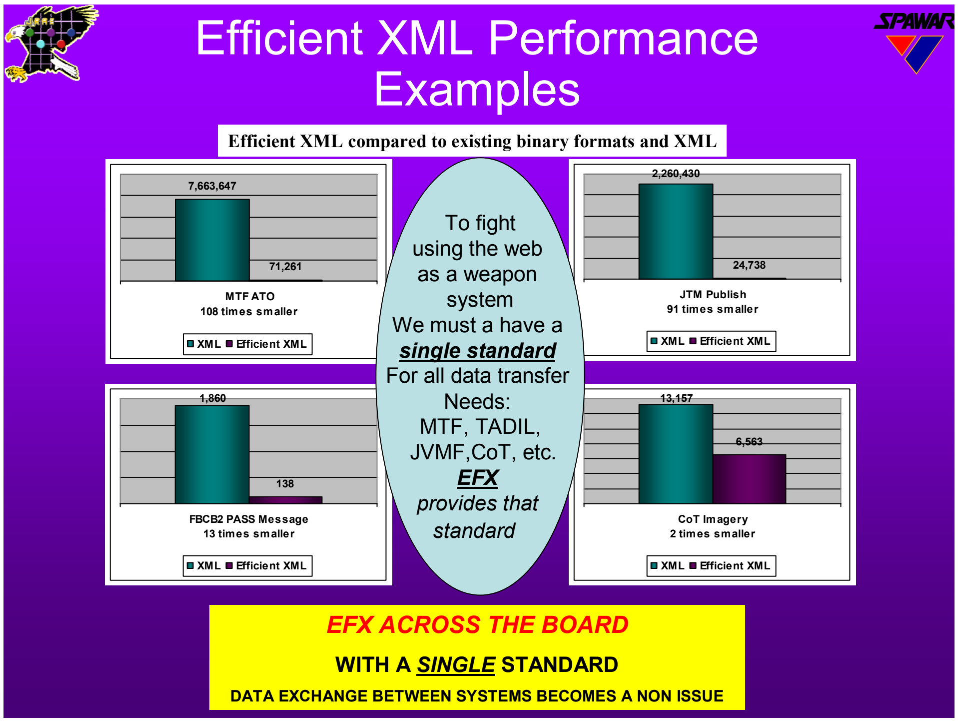

Figure 8. JRAE '06 review of Efficient XML (EFX) for other tactical applications

In every case, the JRAE ’06 staff found that Efficient XML was far more efficient than existing methods. As such, JRAE ’06 recommended the DoD look at migrating toward Efficient XML as a single, interoperable commercially-supported standard for all DoD data exchanges.

The JRAE ’06 final report called Efficient XML a *“transformational capability”* and recommended it be *“incorporated as a standard for all future data sharing systems and services, including JTM SOA development.”* Figure 9 below is the recommendations slide from SPAWAR’s JRAE ’06 executive out-brief. Efficient XML recommendations are highlighted.

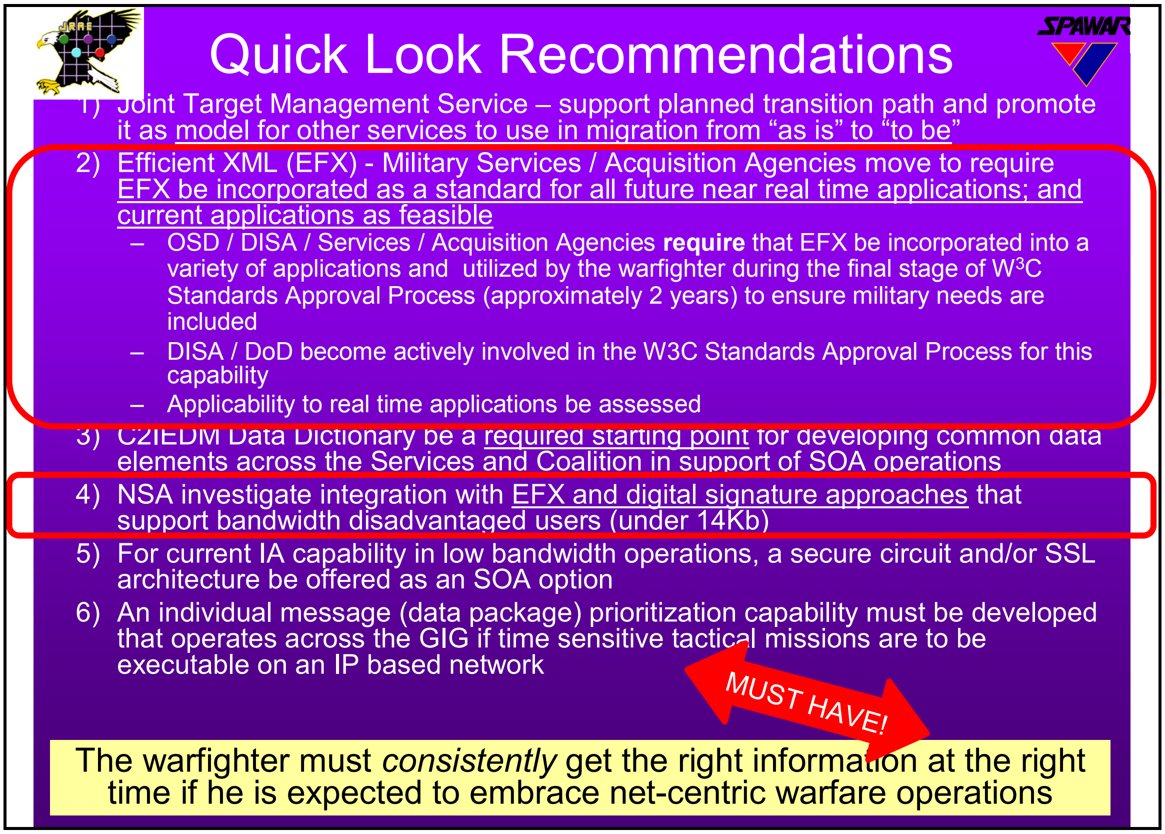

Figure 9. JRAE '06 Recommendations

3.5 JEFX '06

JEFX 06 was the sixth in a series of large-scale CSAF-directed experiments. It is designed to achieve the approved Capability Goals (CG) by integrating innovations in organizations, tools, and processes. The CGs help the experimentation enterprise fill gaps identified in the Integrated Capability Review and Risk Assessment (I-CRRA) process, the capability-based planning process and ongoing operations. JEFX 06 is highly focused on assessing and validating capabilities that produce desired effects in the battlespace and can rapidly transition (i.e. 6-24 months) to the warfighter upon completion of the experiment. To accomplish this, approximately nine initiatives were selected for assessment in JEFX 06. The Efficient XML initiative was called "Binary XML."

The following sections provide details about specific scenarios and measurements from JEFX '06.

3.5.1 Systems and Scenarios

Efficient XML was used in a wide variety of scenarios, networks and systems in JEFX '06, both planned and spontaneous. It was used on Navy E-2C aircraft, Army Future Combat Systems (FCS) vehicles, Air Force Special Forces (AFSOF) tactical computers, TBMCS, Cursor-on-Target and the Army Publish and Subscribe Service (PASS). Efficient XML was also used over a wide variety of communication links, including the CNET LAN, SIPRNET, TTNT wireless network, TACSAT satellite link, Combat SkySAT near-space relay and direct line-of-sight links between SOF PRC-117F radios. Note, that Efficient XML is transport independent so it works well with both future TCP/IP networks and with existing radios and communications links, such as the TACSAT satellite links and PRC-117F radios used in JEFX. Figure 10 provides an overview of the systems, communications links and architecture for the JEFX '06 Efficient XML initiative.

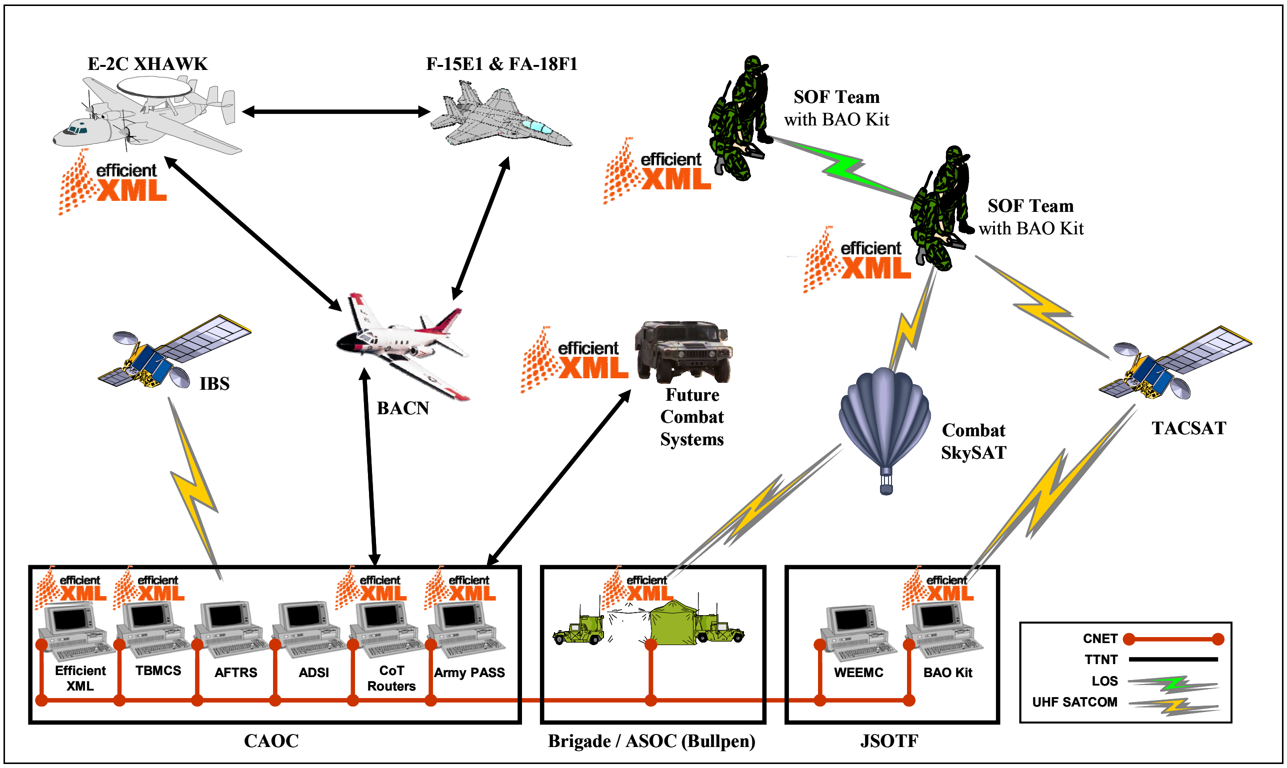

Figure 10. JEFX '06 Efficient XML architecture and systems overview

The experiment scenarios focused on efficiently moving two different kinds of data to and from various edge users (aircraft, vehicles and SOF units) over various communication links.

The first kind of data was very large data sets that have not been accessible over tactical communications links previously. In particular, Efficient XML was used to move large Air Tasking Orders (ATOs), Airspace Coordination Order (ACOs) and ATO sub-sets (e.g., CAS missions) from TBMCS and Army PASS in the CAOC to the E-2C aircraft, Army FCS vehicles and AFSOF units over the CNET LAN, TTNT wireless network, TACSAT satellite, Combat SkySAT link and line-of-site between SOF units using PRC-117F radios.

The second kind of data was high-frequency, high volume streams of small messages. In particular, Efficient XML was used to move real-time CoT tracks (aircraft, ground units, targets, etc.) and CoT imagery between the CAOC, JSOTF, E-2C aircraft, Army FCS vehicles and SOF Teams over the CNET LAN, TTNT wireless network, TACSAT satellite, Combat SkySAT near-space relay and line-of-site between AFSOF units using PRC-117F radios.

3.5.2 Summary of Results

3.5.2.1 High Volume Cursor-on-Target (CoT) Tracks

Efficient XML flawlessly processed over 100,000 CoT tracks a day during JEFX '06 and significantly improved the bandwidth utilization, speed and overall throughput of Cursor-on-Target applications. Because each individual CoT track is relatively small (300-900 bytes), conventional data compression techniques have very little impact on CoT messages. Efficient XML CoT messages, on the other hand, were about 5 times smaller than XML CoT messages and 4 times smaller than compressed XML CoT messages. Figure 11 compares the size of a typical stream of 1600 CoT messages using XML, compressed XML and Efficient XML.

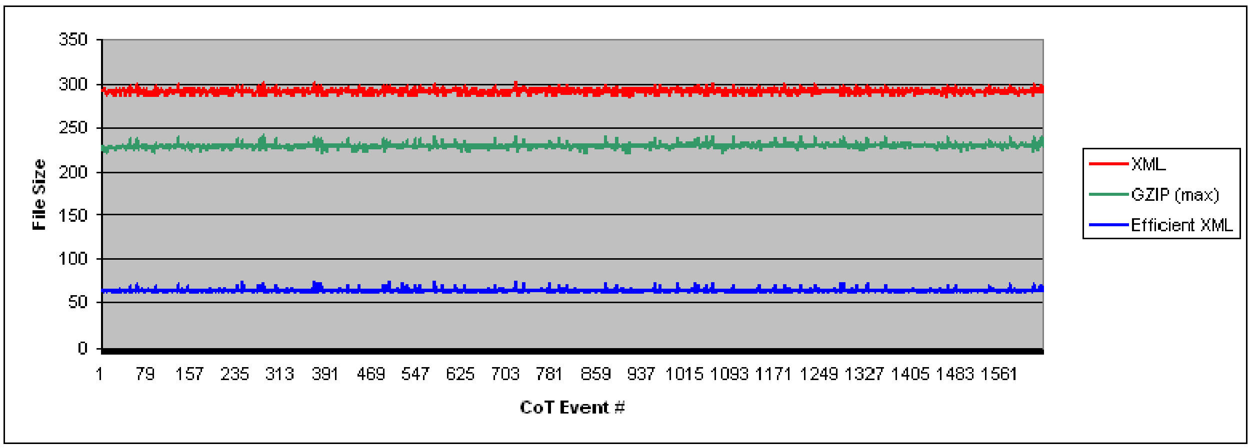

Figure 11. Data compression and Efficient XML on high volume streams of small messages

Efficient XML worked far better for CoT message than any other technology and can increase situation awareness, available bandwidth, available battery life and available radio time. AFSOF units using CoT generally have very limited, shared bandwidth resources. They also have a limited set of batteries available for their radios and tactical computers. And weight restrictions limit them to only one radio for receiving situation awareness, requesting air support, making calls for fire, etc. So, using this resource efficiency is critical.

JEFX also experimented with Efficient XML's burst mode, which sends larger groups of tracks in shorter bursts using less radio time. Burst mode further increased available bandwidth, throughput and performance from 500% to over 2000% in some cases. Figure 12 illustrates the effect of burst mode on Efficient XML compactness. Without burst mode, CoT messages were consistently about 5 times smaller using Efficient XML. However, with burst mode, CoT messages were 10 times smaller for a burst of 11 tracks, 15 times smaller for a burst of 101 tracks and over 20 times smaller for a burst of 1001 tracks.

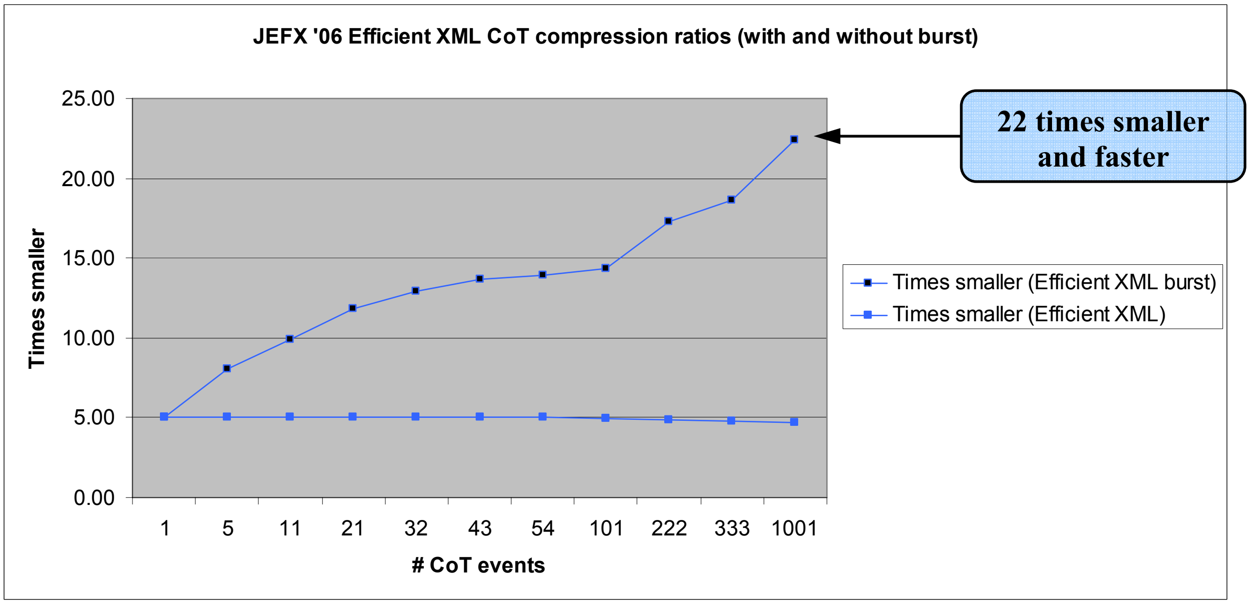

Figure 12. Efficient XML burst-mode further increased bandwidth and throughput

These compactness improvements translate directly to faster transmission times using less bandwidth, less radio time and less battery life. Figure 13 compares the 2400 bps UHF TACSAT transmission times for various sets of CoT tracks using XML, Efficient XML and Efficient XML Burst.

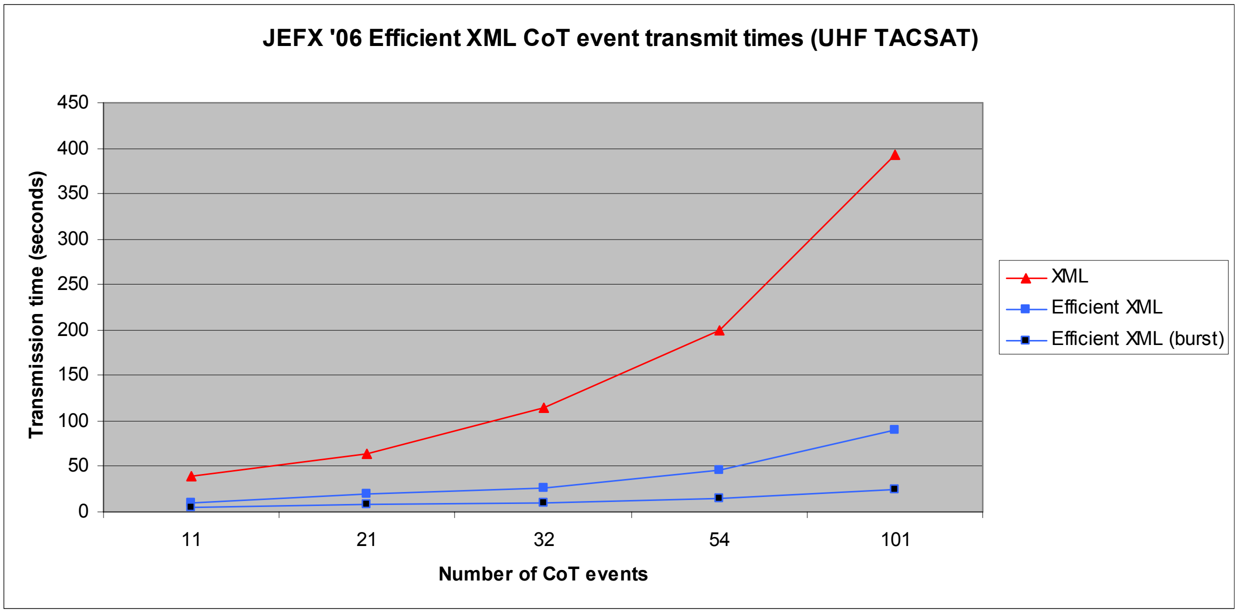

Figure 13. CoT transmit times over UHF TACSAT using XML, Efficient XML and Efficient XML Burst

The burst mode feature significantly increased available radio time and allowed SOF users to control the frequency of track updates. With Efficient XML and burst mode, they could now get up to 100 of the nearest tracks instead of the nearest 5 or they could get up to 300 tracks updates per minute instead of 15 tracks per minute. This increased throughput may enable new concepts, such as using existing satellite links and tactical computers for near real-time air-traffic-control. Previously, the track updates were not fast enough to support this.

3.5.2.2 Large Air Tasking (ATO) and Airspace Control Orders (ACO)

Efficient XML worked extremely well for large messages like the Air Tasking Order (ATO) and Airspace Coordinate Order (ATO). On average, Efficient XML ACOs were over 80 times smaller than XML ACOs and Efficient XML ATOs were over 100 times smaller than XML ATOs. Figure 14 shows the Efficient XML and XML sizes for all the ACOs transmitted during JEFX ’06 sorted by size. Figure 15 shows the Efficient XML and XML sizes for all the ATOs transmitted during JEFX ’06.

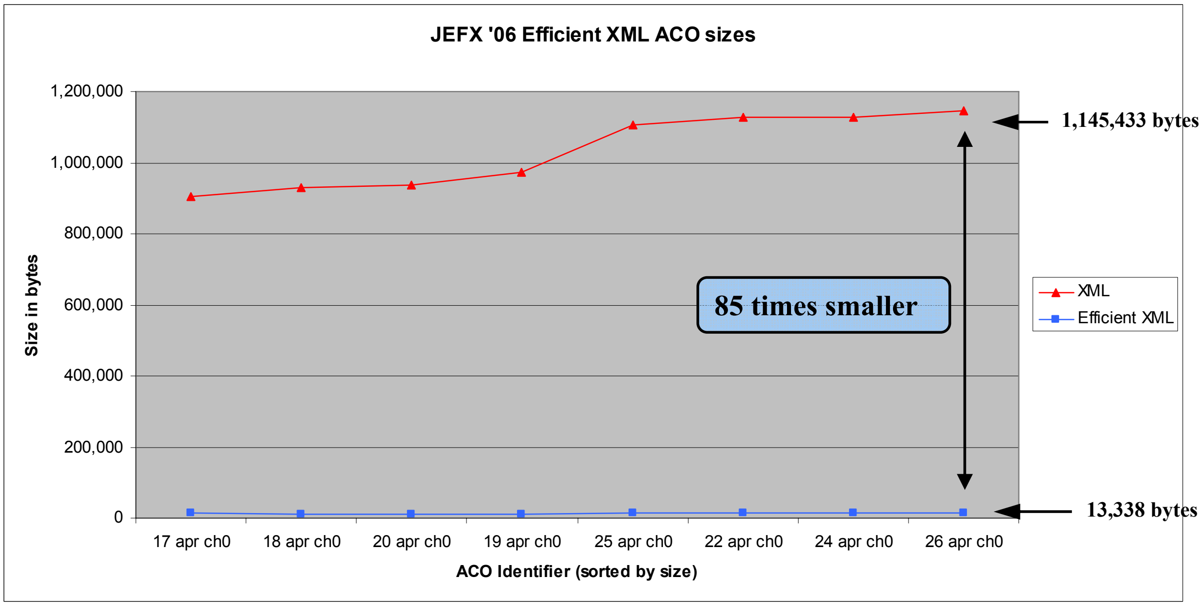

Figure 14. JEFX '06 Efficient XML ACO sizes

The enormous bandwidth savings achieved by Efficient XML on the ATO and ACO enabled them to be sent for the first time to the AFSOF units over their existing 2400 bps SATCOM connections as well as the 2400 bps Combat SkySAT relay. In addition, it enabled the rapid transmission of ATO and ACO data to airborne C2 aircraft and Army ground vehicles. Figure 16 compares the time required to transmit the ATO and ACO over the TTNT network to the airborne E-2C aircraft using XML and Efficient XML. The improvement was very dramatic. The Efficient XML ATO was 114 times faster than the XML ATO, taking less than 1 second to transmit compared to 1 minute, 53 seconds using traditional XML. The Efficient XML ACO was 133 times faster than the XML ACO, taking just 1 second to transfer compared to 2 minutes, 23 seconds required by the XML ATO.

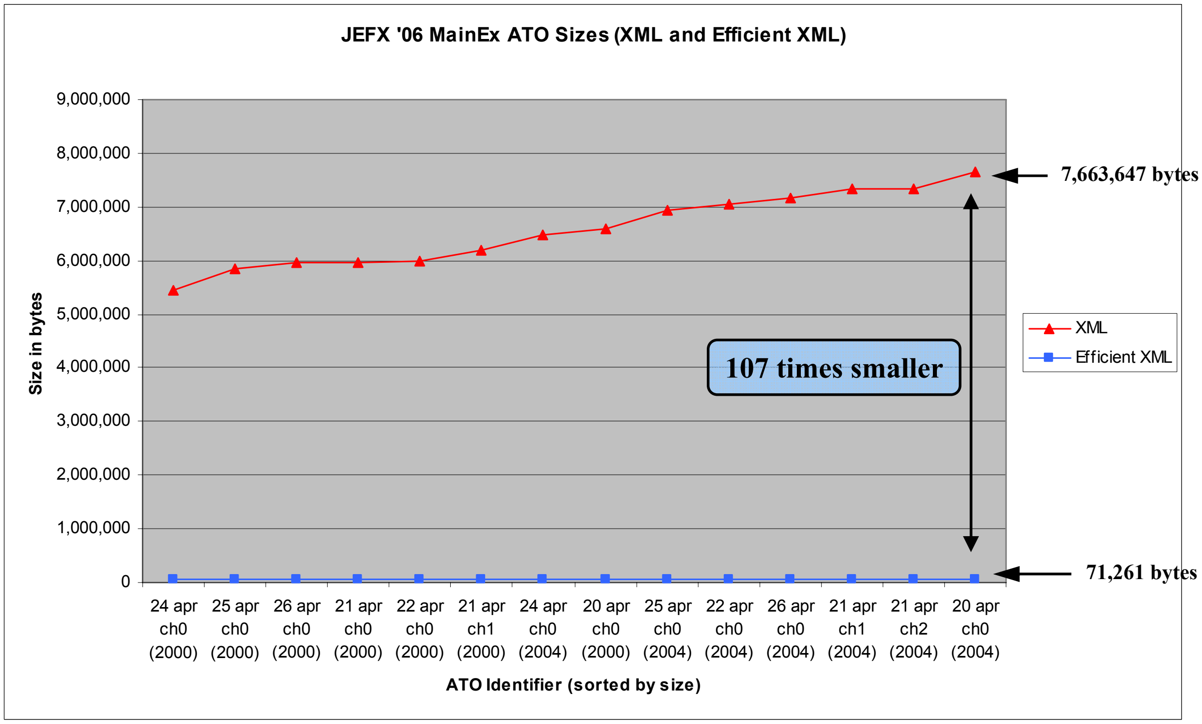

Figure 15. JEFX '06 Efficient XML ATO sizes

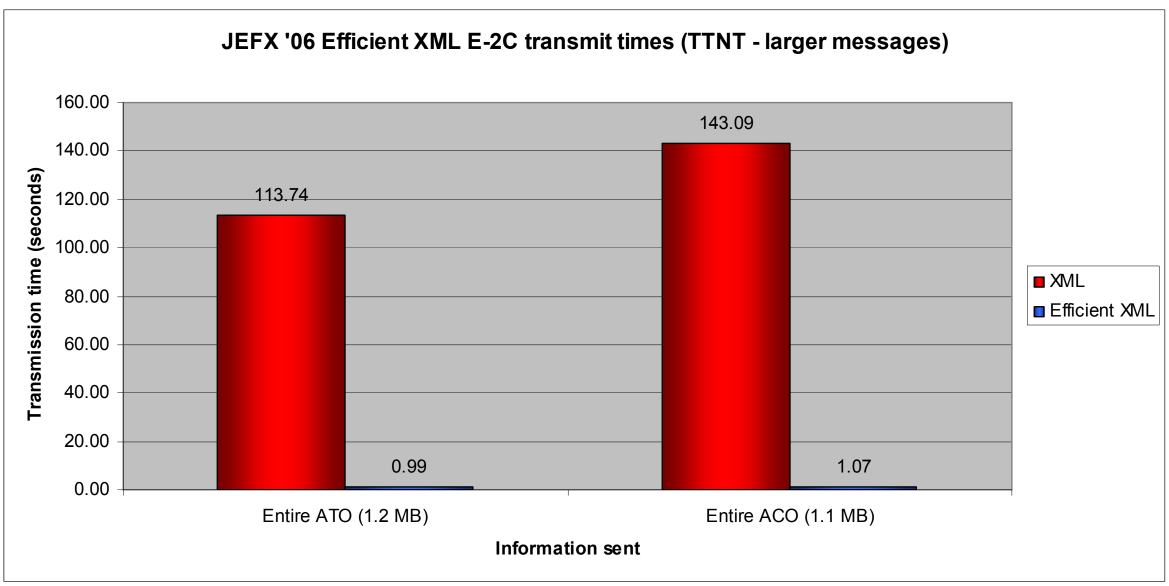

Figure 16. Efficient XML ATO and ACO transfer times to E-2C over TTNT network

In addition to transmitting the entire ATO to aircraft, vehicles and SOF units, JEFX ’06 also used Efficient XML’s ability to efficiently encode query results and document fragments for transmitting ATO sub-sets to those that needed them..

For example, the AFSOF units do not generally need or want the entire ATO. So, an XML query was used to extract and transmit the close air support (CAS) missions that mattered most to them using Efficient XML fragments.

The results were astonishing. The initial test used a 1.2 MB XML ATO containing 68 Kbytes of CAS missions. Efficient XML encoded the 68 Kbytes in only 697 bytes, allowing the SOF units to receiving everything they needed from the ATO over a 2400 bps SATCOM link in only 5 seconds. Figure 17 compares the size of the CAS missions extracted from each JEFX ’06 ATO with and without Efficient XML. On average, the CAS missions were over 180 times smaller with Efficient XML and in the best cases, they were over 200 times smaller!

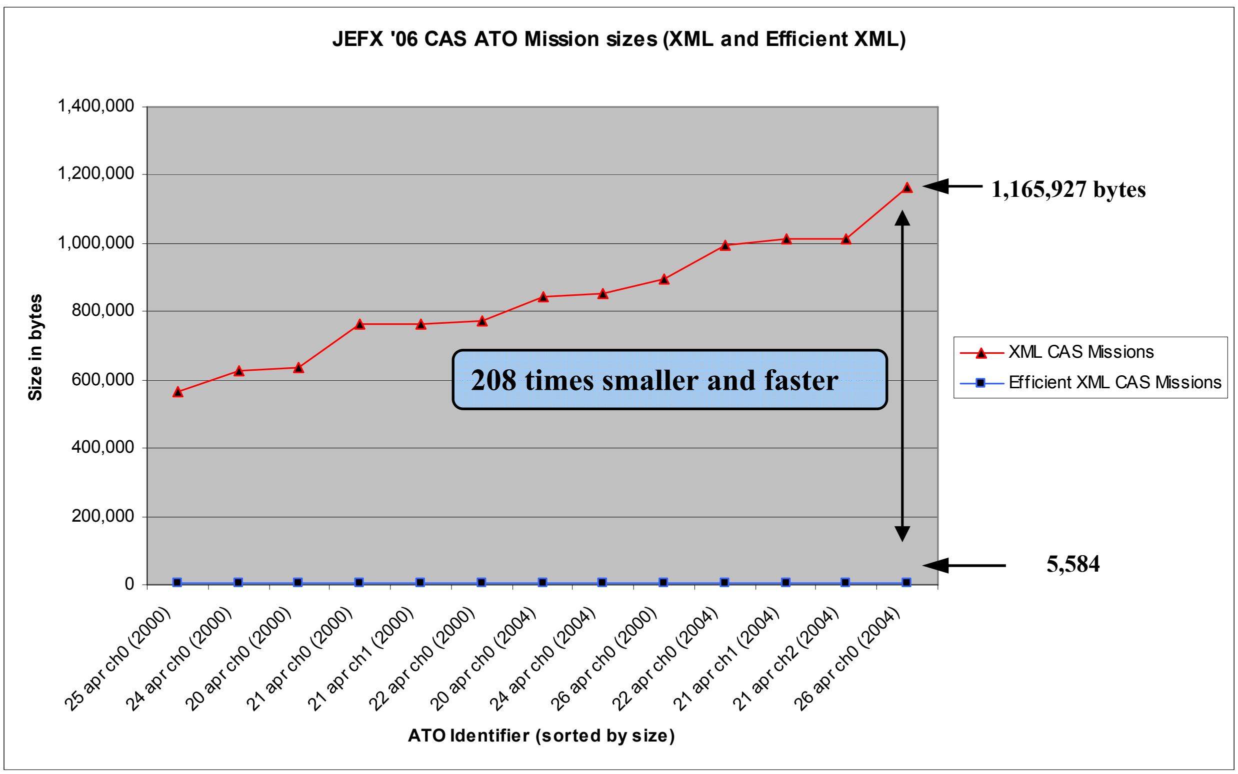

Figure 17. XML and Efficient XML sizes of CAS missions extracted from the ATO

Figure 18 shows the combined effect of Efficient XML and the CAS missions query on ATO sizes in JEFX ’06 using a logarithmic scale. In general, the XML CAS missions were about 7 times smaller than the entire ATO, while the Efficient XML CAS missions were over 1300 times smaller than the entire XML ATO.

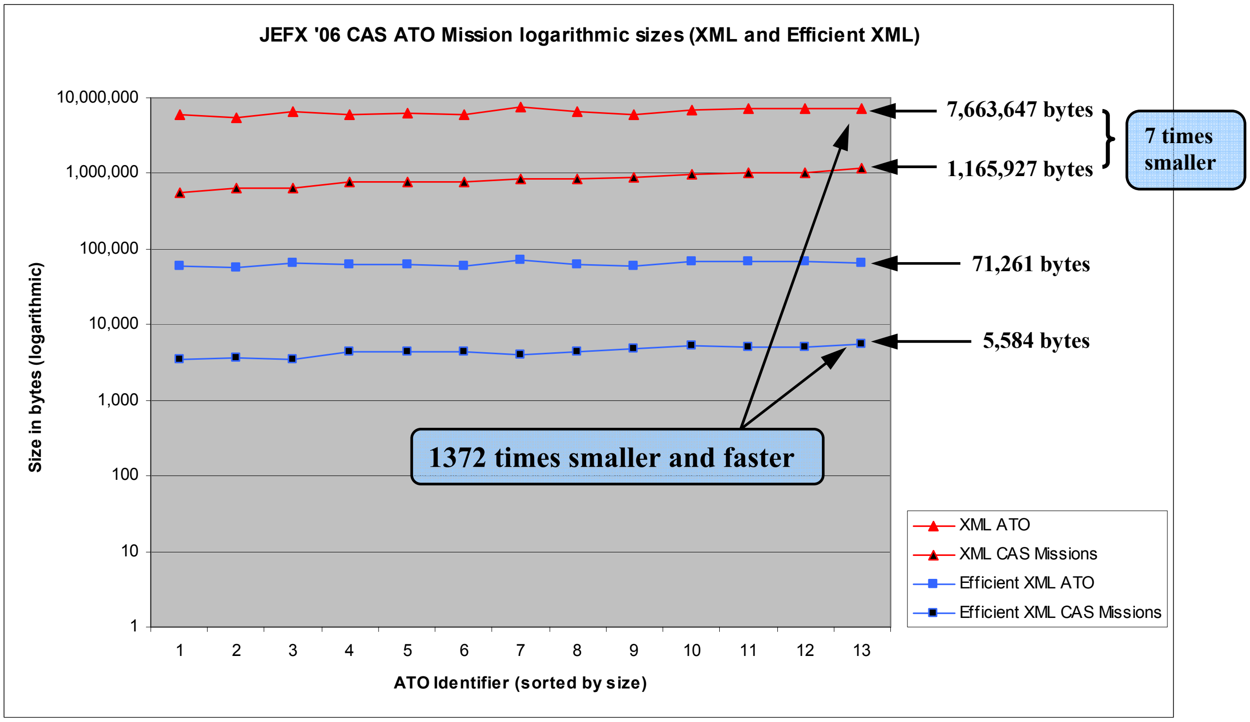

Figure 18. Combined effect of Efficient XML and queries on ATO CAS missions.

Based on their measurements and observations, the JEFX '06 assessors recommended immediate fielding of Efficient XML to TBMCS and recommended Army FCS and Navy E-2C contractors work with AgileDelta to investigate opportunities for optimizing their data exchanges.

The JEFX '06 final assessment said Efficient XML was operationally needed, technically mature and recommended immediate fielding. The JEFX '06 Constellation-Net Final Report called specific attention to the success of Efficient XML, saying *"The real winners in JEFX '06 that filled our capability goals were BACN and Binary XML."*

4 Conclusions

The number of systems connected to DoD and Allied networks that communicate using XML is very large and growing dramatically. Unfortunately, XML is anywhere from 10 to 100 times larger than previous tactical data formats, so it is not often possible or practical to transmit XML over low bandwidth data links or use XML in systems where efficiency is critical, such as aircraft, ships, satellites, surface vehicles and handheld devices. Consequently, there is a growing information rift between the systems that can process XML and those that cannot. And moving information between wired, wireless and mobile systems often requires a series of proprietary gateways that are expensive to build and maintain, limit information flow to a rigidly pre-defined set of data elements and introduce the risk that information fidelity and accuracy will be lost in translation.

Efficient XML eliminates this rift by dramatically optimizing XML and making it efficient enough for the most demanding tactical applications. Efficient XML has been the subject of several large scale, independent assessments including the Navy sponsored JRAE ’06 experiment, the Air Force sponsored JEFX ’06 experiment and the W3C’s assessment of XML optimization technologies. In all cases, Efficient XML was better than every other approach, including custom binary formats, and in several cases achieved over 100 fold (10,000%) improvements in throughput and bandwidth utilization. Both JEFX and JRAE identified Efficient XML as a game changing technology, recommending immediate fielding and widespread adoption across the DoD. The W3C identified Efficient XML as the best-of-breed and adopted it as the basis for an emerging, global web standard.

Efficient XML is expected to expand the use of the web and web technologies to a broad new set of use cases and dramatically increase the performance of existing XML use cases. It will extend the economic and interoperability benefits of XML to networks and systems where efficiency is critical. This will increase the ability of the DoD to get the right information to the right people at the right time. It will also yield rapid economic dividends by enabling the DoD to begin migrating toward a common set of inexpensive, interoperable, open web standards and COTS technologies across the full breadth of the GIG.

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