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# Using Web Services to Realize Service Oriented Architecture in Military Communication Networks, published in IEEE Communications Magazine

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## Sammendrag

En tjenesteorientert arkitektur kan muliggjøre sømløs informasjonsutveksling, og er således viktig for å oppnå selve grunnprinsippet bak Nettverksbasert Forsvar. Web services er i skrivende stund den mest vanlige måten å implementere en tjenesteorientert arkitektur på. Problemet er at Web services er utviklet for bruk på Internett, og dermed er optimalisert for en helt annen nettverkstype enn den man finner i militære taktiske nettverk.

Denne rapporten inneholder en artikkel vi har publisert i oktoberutgaven til IEEE Communications Magazine i 2007, en spesialutgave med fokus på militær kommunikasjon. I artikkelen presenterer vi mulige løsninger (og gjenværende utfordringer) på veien mot å ta i bruk en tjenesteorientert arkitektur også på det taktiske nivået. Målet er å kunne utnytte fordelene ved en tjenesteorientert arkitektur på alle nivåer i Forsvaret, fra strategisk til taktisk nivå.

## English summary

The principles of network enabled capability highlight the need for seamless information exchange. The service oriented architectural paradigm has been recognized as one of the key enablers to achieve this. At the same time, Web services have become the de facto standard for implementing service oriented architecture. However, these technologies have been developed for environments with abundant data rates, environments which are very different from military tactical networks.

This report contains our article in the October issue of IEEE Communications Magazine in 2007, a special issue on Network-Centric Military Communications.  In this article, we present possible solutions and remaining challenges on the way toward also realizing service oriented architecture on the tactical level. Our goal is to make it possible to take advantage of the benefits promised by this architectural paradigm at all military levels, ranging from strategic to tactical networks.

# Contents

# 1 Introduction

In this report, we present our paper titled ”Using Web Services to Realize Service Oriented Architecture in Military Communication Networks”, which was published in IEEE Communications Magazine in October 2007.

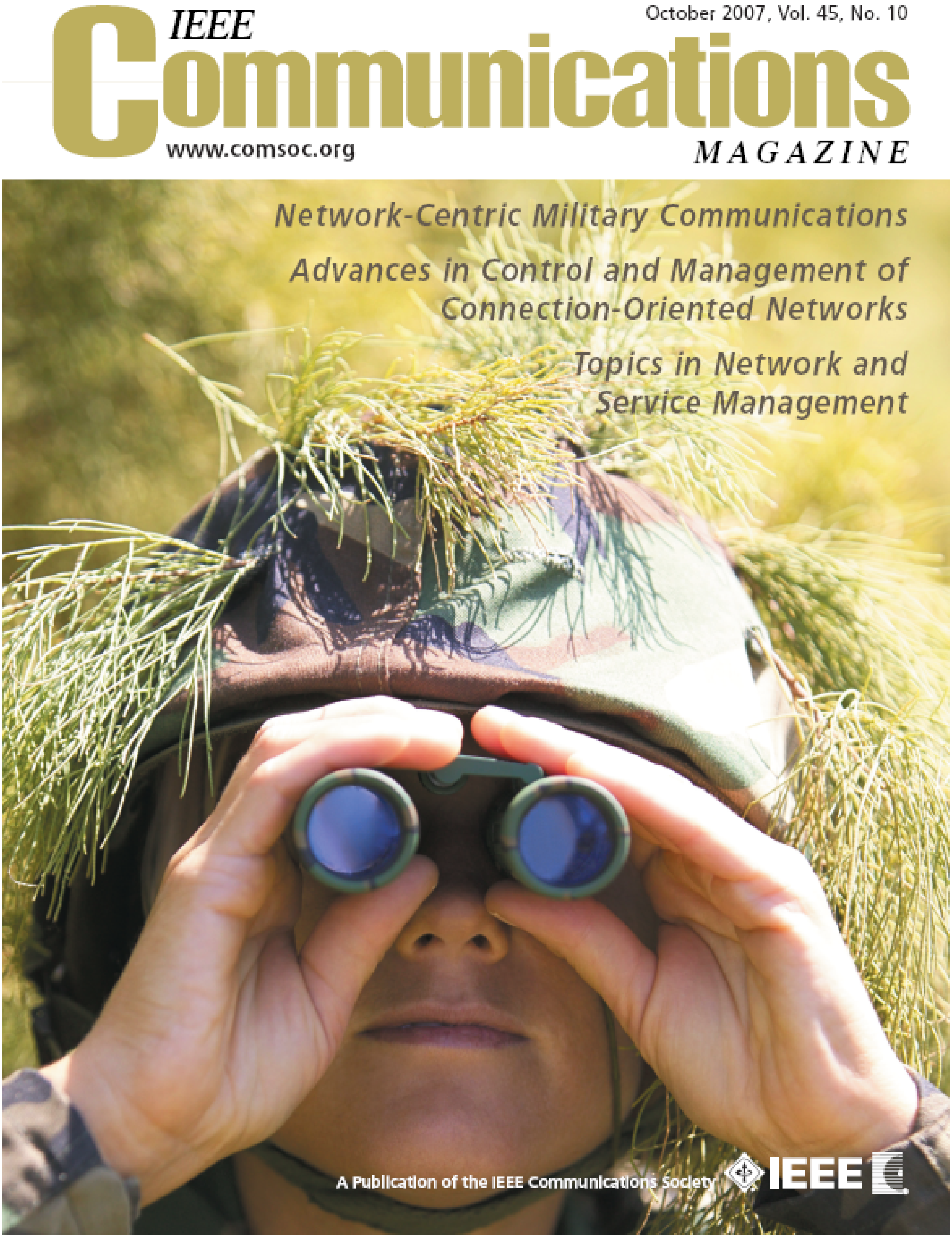
The paper addresses some of the challenges we have foreseen in adapting Web Services for use in tactical networks. Topics include:

- Asynchronous communication: publish / subscribe
- Compression
- Optimized data representations
- Using MMHS as a transport layer for Web Services
- Proxy servers
- Service registry
- Quality of Service issues and adaptation

The paper mainly presents research ideas and challenges, and we are currently pursuing many of the open issues we pointed out there in our current efforts in project 1086 “Secure pervasive SOA”. See Appendix A for our contribution to IEEE Communications Magazine.

# Appendix A The publication

The following pages present our publication as it appeared in IEEE Communications Magazine.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# Using Web Services to Realize Service Oriented Architecture in Military Communication Networks

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## ABSTRACT

The principles of network enabled capability highlight the need for seamless information exchange. The service oriented architectural paradigm has been recognized as one of the key enablers to achieve this. At the same time, Web services have become the de facto standard for implementing service oriented architecture. However, these technologies have been developed for environments with abundant data rates, environments which are very different from military tactical networks.

In this article, we present possible solutions and remaining challenges on the way toward also realizing service oriented architecture on the tactical level. Our goal is to make it possible to take advantage of the benefits promised by this architectural paradigm at all military levels, ranging from strategic to tactical networks.

## INTRODUCTION

Shared situation awareness among military units is essential for network-enabled capabilities (NEC) operations. This requires increased access to information to ensure that the units that best can utilize the information have access to it. In addition, NATO's new operational environment and focus on rapid reaction, demands more adaptive and efficient solutions for information exchange, to quickly create and dynamically update a relevant operational picture. In NATO, there is a focus on the establishment of a service oriented architecture (SOA) to enhance interaction within the allied forces. SOA is a way of making military resources available as services so they can be discovered and used by other entities that need not be aware of these services in advance.

The NATO NEC feasibility study (NNEC FS) [1] was created to help develop a NATO concept to adapt national concepts such as the U.K. NEC and U.S. network-centric warfare to the NATO context. One of the main goals of this study is to establish a strategy and a roadmap for developing the communication and information systems aspects of NNEC. The NNEC FS states that an information infrastructure for NNEC must support all the communication requirements of the member nations' forces, and it specifically mentions communication among people, such as the capability to support shared situation awareness and end-to-end quality of service (QoS).

The study also recommends the architectural principles and the technologies that are most suited to implement such an information infrastructure. One of the most important recommendations made is that this infrastructure should be implemented as a SOA. It also recommends the use of IP as a common protocol to be used in all network types. The chosen technologies facilitate easier interoperability both across network types and across national systems.

SOA is most commonly realized through Web services, using XML formatted documents. This technology is defined in a number of standards and although this standardization work is ongoing, Web services remain the most mature SOA implementation technology. However, Web services are designed to be used over high bandwidth networks, rather than in limited-capacity military networks. In addition, the XML documents tend to be large, containing significant overhead.

In NEC, the challenge is to enable users to exchange information with each other at all operational levels. This includes users in the field who only communicate with others over disadvantaged grids (tactical communication systems with low data rate, high delay, and frequent disconnections). Radio systems such as HF or VHF may have a data transfer rate lower than 1 Kb/s in practice, due to the need for long range signals and jamming resistance. In addition, some radio systems suffer from long turn times for directional changes, plus long set-up times for connections. However, we think that there are measures that can be taken to use SOA technologies over disadvantaged grids. Some of these measures are described in this article, which focuses on the use of Web services in tactical networks.

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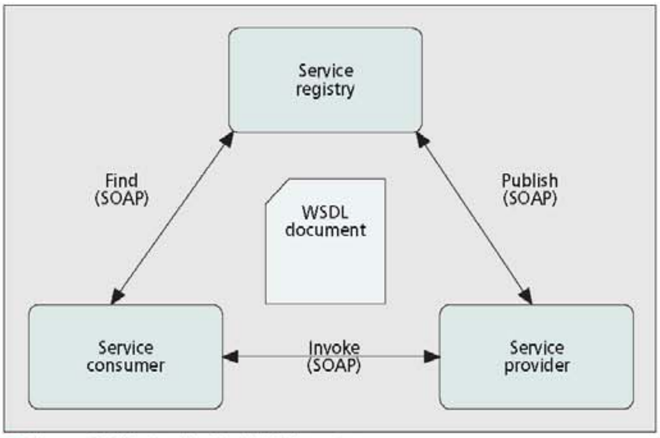


■ **Figure 1.** *SOA realized with Web services.*

## SOA AND WEB SERVICES

SOA is a concept that enables resources to be provided and consumed as services, allowing for dynamic information sharing between military units. Web services are currently the preferred technology for implementing a SOA. The main functional components of Web services are the service provider, service consumer, and service registry, as illustrated in Fig. 1. A service provider can publish the services it is willing to share with others in a service registry that announces their availability. A service consumer may browse the service registry to retrieve the relevant announcements that describe where and how the services may be invoked.

Web services are based on a set of XML-based standards. Three of the basic specifications are Simple Object Access Protocol (SOAP), Web services description language (WSDL), and universal description discovery and integration (UDDI).

SOAP is the XML messaging protocol used for transport of information between the Web services components. An important property of SOAP messages is that they can be delivered over a number of application, transport, and network protocols. Today, HTTP is normally used for transporting the SOAP messages between hosts. Other possible protocols are Simple Mail Transfer Protocol (SMTP), military message handling systems (MMHS), File Transfer Protocol (FTP), Java messaging service (JMS), and so on.

The service registry is often realized using UDDI, which provides mechanisms for publishing and discovery of services. More specifically, UDDI provides access to the WSDL documents describing the protocol bindings and message formats required to interact with the Web services listed in its directory. UDDI can be used for both design-time and run-time discovery of services.

One of the main aspects of Web services is the loose coupling of entities that allows for the adaptivity required in NEC. In a SOA, consumers and providers need not know each others' locations; they need only know where the service registry is. Likewise, the service registry need not know in advance where the consumers and providers are located. Because minimal preplanning is required, the following is possible:
- Easier sharing of information
- Faster fielding of new technologies
- Dynamic reconfiguration of functionality
- Ad hoc organization of entities

### PUBLISH/SUBSCRIBE

The publish/subscribe principle makes it possible to link together data producers and data consumers into loosely coupled, scalable, and dynamic networks. One of the advantages of publish/subscribe is asynchronous communication; after creating a subscription on a specified topic, data automatically is delivered to subscribers when it is produced. There is no requirement to poll the producer to check if any new data is available, which would be required if using the classic request-response interaction pattern.

Currently, there are two publish/subscribe standards for Web services: WS-notification from the Organization for the Advancement of Structured Information Standards (OASIS) and WS-eventing from the World Wide Web Consortium (W3C). The two standards offer similar functionality to realize the publish/subscribe pattern using Web services. It is important to note that both WS-notification and WS-eventing in a normal configuration apply a point-to-point message distribution; for each notification to be transferred, a separate transport level connection is set up. In larger scenarios with many subscribers, this could prove to be a bottleneck in the system. Therefore, multicast distribution mechanisms and more efficient transport level communication must be considered in such cases.

Another important aspect of publish/subscribe is QoS. In a military context, coalition members must rely on each other's systems to receive meaningful and correct data at the right time. However, current publish/subscribe standards for Web services do not specify any QoS and flow control parameters for the publish/subscribe communication mechanism.

## RELATED WORK

The idea that Web services also are suitable for military applications is supported both by NNEC FS, and the Network Centric Operations Industry Consortium (NCOIC). Standardization efforts are being undertaken by two organizations, OASIS and W3C. As current research shows, NEC enabled by Web services can be a great benefit to the war fighter [2], but there are also a number of new challenges that arise, as we show in this article. Other research groups have pointed out several inherent problems that can arise when indiscriminately adopting Web services [3].

Although Web services are suitable at the strategic level, it also is desirable to push them all the way out to the tactical level. This is also stressed by [2] that states, "As network capacity will often be a limiting factor, the networking systems must be dynamically managed, through both information management and adaptive network management to ensure maintenance of force responsiveness under high network loads." However, technical aspects are not discussed in this work.

Within NATO, a research task group (RTG-012/IST-030) has performed a four-year study of information management over disadvantaged grids [4]. The group has limited its scope to a national context, that is, interoperability is not an issue. Using SOA in a military context, which is the main focus of our work, is not addressed. However, the group has identified important requirements for enabling information exchange in disadvantaged grids, and this also is an input to our work.

## Enabling Web Services in Disadvantaged Grids

XML and Web services have a considerable amount of information overhead and therefore are not a very efficient means of communication in disadvantaged grids, if used as is. The resulting communication delay would be unacceptable both for end users and also for lower-level delay-intolerant communication protocols. In addition, both HTTP and UDDI have properties that are incompatible with the characteristics of tactical networks. We investigated techniques and mechanisms that can contribute to making the use of Web services feasible in disadvantaged grids and identified where further research is required.

### Compression

The main challenge of XML in the context of disadvantaged grids is the large overhead [5]. We have considered two types of techniques for reducing the size of XML documents: general compression and binary XML. General compression techniques, such as GZIP, can compress any kind of data, both XML and non-XML; binary XML operates only on XML data. The main advantage of binary XML is that the documents remain structured, although represented in a compact binary format. This means that software applications can parse and modify the binary XML documents directly, without converting back to text-based XML. Because of this, binary XML also may lead to faster document processing and fewer memory and CPU requirements, which is especially advantageous on mobile devices.

Today, there are several binary XML initiatives, including Fast Infoset from Sun Microsystems and Efficient XML from AgileDelta. The W3C working group, Efficient XML Interchange, currently is working on standardization for a binary XML format.

We performed measurements of compression rate for several techniques, by compressing XML-encoded command and control information exchange data model (C2IEDM) [6] tracks ranging in size from 5 KB to 539 KB. The results are summarized in Fig. 2. Schema-based Efficient XML yields the best compression on messages smaller than approximately 50 KB, while GZIP performs best on larger files.

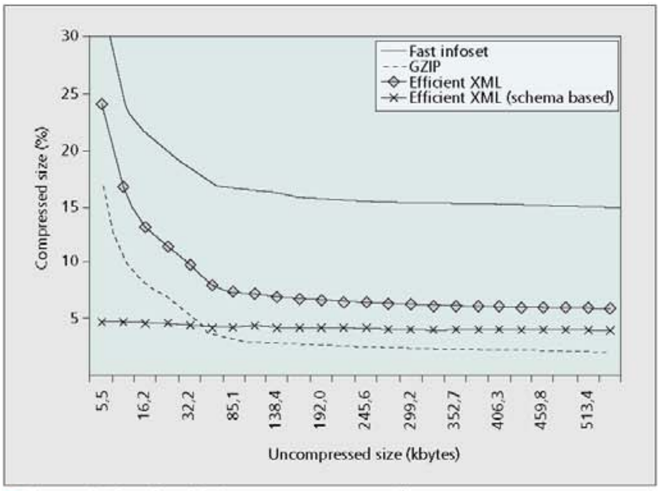


**Figure 2.** *Results of different compression techniques.*

Our experiments show that XML is very compression-friendly and in many cases, more than 95 percent compression can be achieved. Therefore, we consider the use of compression a requirement when using Web services in disadvantaged grids. As part of our NATO Coalition Warrior Interoperability Demonstration (CWID[1] 2007) experiments, we have evaluated the effectiveness of various compression algorithms in the context of the NATO friendly-force information system (NFFI) [7]. The NFFI XML documents also are compression friendly but because of the more efficient data representation, the compression ratio was lower than for C2IEDM. Still, the more tracks contained in an NFFI message, the better the compression ratio.

### Optimized Data Representation

For example, when using Web services for building a common operational picture, large amounts of information must be transferred over the available communication infrastructure. We already have shown how compression can be used to significantly reduce this amount; however, given the resource situation on the tactical level, we still must use all possibilities for reducing data traffic.

One such measure is to optimize the information model. In other words, we must ensure that the data representation of the information to be transferred is as efficient as possible. In earlier experiments [8], we used a subset of the object-oriented XML version of the C2IEDM. This is a data model that was machine-generated from a relational schema and not optimized with respect to efficiency in information representation. Our experiments with this model showed that the model imposes a considerable overhead when used for sending messages. As an illustration, we optimized the model and achieved a reduction in size of more than 60 percent without losing information.

On the other hand, an important aspect of SOA is interoperability and especially for operations involving multiple nations, it is important to use a standardized data model for informa-

*[1] NATO Coalition Warrior Interoperability Demonstration (CWID) is an annual event designed to improve interoperability within the alliance.*

After an efficient data representation is established, the next step is to ensure efficient data exchange. The main point here is to take advantage of the properties of the underlying network to achieve a more efficient data transfer.

tion exchange. This means that information representation currently is a tradeoff between representation efficiency and standardization. Thus, in a military context, there is clearly a need to establish an efficient and standardized data model, and one possible starting point could be NFFI.

## DATA EXCHANGE

After an efficient data representation is established, the next step is to ensure efficient data exchange. The main point here is to take advantage of the properties of the underlying network to achieve a more efficient data transfer.

Our focus is on disadvantaged grids. Measurements have shown that for such networks, there is a connection between packet size and achievable data rate. In [9], performance testing of military HF systems showed that with a packet size of 2–5 kB, only 50 percent of the maximum throughput was achieved. This means that we want to send as small amount of data as possible, but at the same time, we do not want to send packets that are too small. This picture is further complicated by the fact that tactical networks can have a relatively high error rate. In such cases, increased packet size increases the negative effect of packet loss, since more data must be retransmitted. Admittedly, this can be alleviated using forward error correction (include redundant information to enable reconstruction of damaged packets), but this also will increase the amount of data to be transferred. Finally, we want to keep the number of changes in transmission direction at a minimum, because the turnaround time often can be quite high.

In [6], three different mechanisms for information exchange are described.

- *Referentially complete message information exchange* means exchange of self-contained XML documents. Using Web services, this mechanism can be realized using either a traditional request-response mechanism or a publish/subscribe mechanism.
- *Replication-based information exchange* implies that the participants first perform an initial exchange of data in order to start off with identical data sets. Subsequently, only updates are exchanged between the parties using push technology, that is, publish/subscribe when using Web services.
- *Query based information exchange* can be compared to traditional request-response information exchange and is also realized this way in Web services. One party requests information from another by submitting a query, which in turn returns the result of this query.

Intuitively, replication-based information exchange seems most suited, because both the amount of information sent and the number of direction changes are kept at a minimum. However, the fact that the internal structure of the database is exposed when using this mechanism means that interoperability could become an issue, for example, when dealing with coalition operations. In addition, the replication concept is not ideal, seen from a SOA point of view, where everything should be context-independent services. Therefore, we used a hybrid solution, where we used push-based exchange of NFFI-messages to keep our databases synchronized. As described earlier, we can reduce the message size considerably by using compression, making it feasible to also use this solution in disadvantaged grids.

### COMMUNICATION SOLUTIONS

To fully support the NEC vision, the SOA services must be made available to users at all operational levels. One of the challenges in this context is to use Web services over the heterogeneity of communication systems used in the different operational levels in a military network.

HTTP is the binding protocol normally used for transport of SOAP messages. It is synchronous, which means that when a SOAP request is sent, the HTTP connection is kept open until the SOAP response is returned in the HTTP acknowledgement. If the connection times out because of delays or for any other reason, there will be a problem routing the SOAP response back to the service consumer. Therefore, using HTTP over disadvantaged grids or a combination of heterogeneous networks does not work well.

A better solution is a store-and-forward overlay network that can cope with the differences (e.g., data rates, delays, and frequency of disconnections) of military communication networks. Such an overlay network must be asynchronous and message-based, because it will be necessary to store and forward the information in transit between the networks.

Standardization Agreement (STANAG) 4406 ed. 2 (S4406) is a NATO standard for MMHS and defines three protocol profiles adapted to different communication networks. Systems compatible with the S4406 standard have been and are being implemented widely by NATO nations and by the NATO organization.

The original connection-oriented protocol stack defined in S4406 Annex C was developed for strategic high data rate networks and is not suitable for channels with low data rate and high delays. Therefore, the protocol profiles TMI-1 and TMI-4 were developed for use over disadvantaged grids. With the inclusion of these protocol profiles in Annex E of S4406, a common baseline protocol solution exists that provides for the use of MMHS in both the strategic and tactical environments.

For each of the three protocol profiles, Table 1 shows the approximate overhead in bytes per message, together with the number of changes in transmission directions, during one message transmission.

In addition to military messaging, MMHS also can be used as an infrastructure for interconnection of other applications (e.g., Web services). In this perspective, the MMHS can be viewed as an overlay network that can tie the Web services applications together and be used over communication systems with different quality and data rate. The benefits of using MMHS in this way can be summarized as follows. It provides:

- Reuse of an already established messaging infrastructure in NATO and the NATO nations.

- Three protocol profiles that can be used to tailor the messaging system to the communication networks (simplex, half duplex, or duplex). All protocol profiles are compatible at the message level. Two of the protocol profiles are very bandwidth-efficient.
- Support for both reliable and unreliable transmission.
- An asynchronous store-and-forward system, able to traverse different communication networks.
- Support for priority and pre-emption mechanisms for handling time-critical information.
- Support for both multicast and unicast of messages.

An MMHS message transfer agent (MTA) is a switch in the message transfer system. It is a store-and-forward application and can be used as a gateway between the strategic and a tactical messaging system. The MTA can have a triple protocol stack, implementing both the strategic connection-oriented protocol profile and the two tactical protocol profiles. Therefore, this MTA can route messages between infrastructure wide area networks (WANs) and low data rate tactical links (Fig. 3). When using the MMHS for transfer of SOAP messages, the MTAs and the Web services functionality are integrated, and therefore, there is no additional delay for checking or connecting to a message store.

### PROXY SERVERS

A proxy is a unit that functions as an intermediary between two communicating parties. A proxy operates on the application layer (layer 7 in the open systems interconnection (OSI) model), which means that a proxy has access to more information than a router or a firewall that operates on lower layers of the OSI model, enabling it to employ more advanced (content-based) techniques, for example, when filtering. At present, we are unaware of any proxy solutions that support Web services. We are currently researching how proxy techniques employed for Web pages on the Internet can be adapted for use with Web services in disadvantaged grids.

Disadvantaged grids are characterized by low bandwidth and frequent disconnections, making the use of proxies worthwhile. We are considering content adaptation and filtering and also are looking into caching techniques that can further improve system response times and reduce bandwidth requirements. An important advantage is that bandwidth is saved between server and proxy, giving the system greater scalability. Caching also increases availability, because a copy is accessible in the proxy even if the origin server is unavailable. Furthermore, the proxy can adapt the mode of transmission to better utilize the transmission medium between itself and the clients, which can lead to a substantial reduction in bandwidth requirements; for example, by utilizing multicast when relaying notifications as an intermediary in a publish/subscribe service. A disadvantage is that the proxy becomes a possible single point of failure in the network, and it may become a bottleneck in the system if the processing it performs is computationally expensive. This last point is less of a problem in disadvantaged grids, because processing power is abundant compared to the very limited network resources that are available.

| Protocol profiles | Domain | Message overhead (bytes) | Change in transmission directions per message transmission |
|---|---|---|---|
| STANAG 4406 Annex C | Strategic | 2700 | 8 |
| STANAG 4406 Annex E TMI-1 | Tactical | 700 | 2 |
| STANAG 4406 Annex E TMI-4 | Tactical | 20 | 0 (1 using the retransmission option) |

**Table 1.** *Overhead and change in transmission directions for the different S4406 protocol profiles.*

### SERVICE REGISTRY

UDDI does not seem to be the ideal solution in a tactical environment (note that here we focus on run-time discovery, not design-time discovery). A UDDI registry is a centralized solution, while a tactical network represents a distributed and very dynamic environment. It is likely that a centralized registry will be unavailable at times, if there is no network path between the client and the registry. Having multiple synchronized registries probably is not a good solution, because the synchronization process itself would create too much traffic for a tactical network.

In addition, services come and go all the time, and therefore it will be difficult to keep the registry updated at all times. Thus, there is a real risk that a client will be directed to a service that is no longer available. Also, if the service providers are to keep the registry updated at all times, this can create considerable network traffic.

Consequently, more research is required to provide suitable solutions for service discovery in tactical environments. In particular, we believe a decentralized, low-overhead solution is required, and one possible approach could be the multicast-based WS-discovery specification.

## QOS AND ADAPTATION

In disadvantaged grids, it is important to utilize the scarce resources as efficiently as possible. Therefore, often it will be advantageous to adapt or even reconfigure the application and system according to the prevailing conditions to maintain an acceptable QoS. Different types of data will traverse the same network and compete for the same resources. Not all data is equally important and as it may not be possible to satisfy the needs of all users simultaneously, one should categorize the information according to priority. For example, important orders should be relayed quickly through the system, whereas routine information can be delayed or in some cases even discarded.

As part of our NATO CWID 2007 experiments, we looked at filtering of NFFI messages.

it is important to keep in mind that Web services will never be the most efficient information exchange technology. Thus, the interoperability and flexibility gained through the use of Web services must be traded against the reduced communication efficiency.

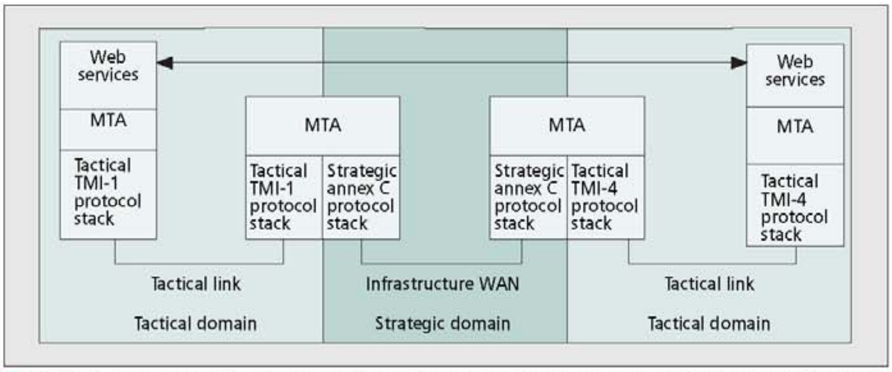


**Figure 3.** *Seamless interconnection of Web services over heterogeneous communication networks by using MMHS as an overlay network.*

The simplest form of filtering was to discard all track information that was outside a squad's area of operation. Only information that was valid and relevant was transmitted to the squad, thus saving resources on the tactical network. In addition, we further reduced network traffic by filtering messages at varying intervals. Tracks close to the squad's position were sent most often, with decreasing frequency as one moved further away from the squad. This ensured that information about units close to the squad was always up to date, while still being aware of what was going on a bit further away although with coarser time resolution. All messages that were outside the map view were discarded, thus avoiding the wasting of bandwidth.

This experiment is an example of adaptation of the application to provide best possible QoS in an environment with scarce resources. In this case, the adaptation was static, but it can be extended in a relatively easy way to dynamically adjust the update rates according to the available network bandwidth.

In a Web services context, an application to a large extent is a collection of individual services, and therefore, the task of configuring an application consists of selecting the best implementations of the different service types. At design time, it is difficult to predict the correct configuration of an application; information about the resources that are available and in what quantity is only available at run time. Therefore, we need functionality for automatically configuring applications based on resource availability and user requirements. These issues are subject to further research.

## Conclusion

In this article we discussed different aspects of using Web services to realize SOA in NEC. Today, the most common implementation of SOA is Web services based on XML and SOAP, but it is primarily designed for use on the Internet, that is, in networks with high data rates. Our focus is how to apply this technology in disadvantaged grids. We have investigated different ways of reducing XML overhead and suggest using S4406 instead of HTTP as the transport for SOAP messages on the tactical level.

We also suggested additional ways to improve the system performance, such as using compression, optimizing the message representation and content, and also by introducing proxies. However, as we have shown in this article, adapting Web services for use in disadvantaged grids is a challenging task, and much work remains before we can take full advantage of the benefits promised by SOA on the tactical level.

Finally, it is important to keep in mind that Web services will never be the most efficient information exchange technology. Thus, the interoperability and flexibility gained through the use of Web services must be traded against the reduced communication efficiency. It may be that there is a lower bandwidth limit, below which Web services are no longer feasible, and where other mechanisms must be employed to realize SOA.

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