Efficiency of dynamic content adaptation based on semantic description of web service call context[1]

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***Abstract*—This article tackles the problem of supplying the low level commanders with information from information sources located on higher command levels, distributed using web services, the most commonly used technology in modern command and control systems. There has been proposed the Adaptation Framework For Web Services Provision (AFRO) that defines a mechanism for effective web services invocation in tactical networks, which are considered disadvantaged in terms of available throughput, delay and error rate. Its implementation, in the form of AFRO Proxy performs so called adaptation actions, which are modifications of the SOAP XML messages by changing their encoding to more efficient or dropping information that are accepted to be removed by the service requester. The proposed adaptation mechanism gives promising effects for low level commanders located at the battlefield. They can be supplied with information generally available on high command levels, which, up to now, were very rarely distributed to tactical networks.**

***Index Terms*—adaptation, edge proxy, context, ontology, reasoning, ubiquitous computing.**

I. INTRODUCTION

Modern coalition operations are conducted in a dynamic environment, usually with unanticipated partners and irregular adversaries. In order to act successfully they need technical support that gives modularity and flexibility in connecting heterogeneous systems of cooperating allies. To support such co-operation in the NATO community the Service Oriented Architectures (SOAs) [1] are recommended as the crucial Network Enabled Capability (NEC) enabler [2][3].

The most mature implementation of SOA, recommended by NATO and widely applied in the commercial sector, are Web Services (WS) [5]. WSs are described by a wide range of standards that deal with different aspects of their realization, namely: transport, orchestration, semantics, etc. They provide the means to build a very flexible environment that is able to dynamically link different system components to each other. These standards are based on the eXtensible Markup Language (XML) and have been designed to operate in high bandwidth links. XML gained wide acceptance and became very popular for the reason that it solves many interoperability problems, is human- and machine- readable and facilitates the development of frameworks for software integration, independent of the programming language. Nevertheless it undoubtedly adds significant overhead, both in terms of necessary computation power and consumption of network resources while being transported. The challenge is therefore to apply SOA in low bandwidth tactical communications systems, which usually cope with high error rates, frequent disruptions and intermittent connectivity.

The solution that this article focuses on is to enable the client to use the service in disadvantaged network in a limited way (with limited number of information provided or provided by a different mechanism) and adapt the service provision mechanism to the client's software and hardware possibilities.

II. CONTEXT-AWARE SERVICE PROVISION

Context – aware applications refer to a general class of mobile systems that can sense their physical environment, and adapt their behaviour accordingly. They derive from the ubiquitous (or pervasive) computing concept, presented in 1991 by Mark Weiser [3], who set its foundation. This concept developed for the commercial applications began the new field of interest of many researchers where the area of context-aware applications became an important part.

In context – aware service provision it is generally important where the client is, what are his actions/duties, what terminal is he using, what resources are nearby, etc. [8]. In many applications the most important aspect is location, but this can be extended to include different characteristics (user actions, device, surrounding environment, etc.). Context recognition allows users to take full advantage of the local capabilities within a given environment, and be able to seamlessly roam between several environments, choose different services, even as the defined context change.

The idea of context – aware service provision was used in the development of the Adaptation Framework For Web Service Provision in disadvantaged environment (AFRO). It is aimed at improving successability of SOAP web services' invocation in tactical environment, which is characterized by dynamic changes in throughput, error rate and delay. Successful service invocation in this case is understood as the

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possibility to deliver response message requested by the client from the target service.

The major assumption of AFRO is minimization of the amount of data transmitted to the user in order to allow efficient invocation of web services. The actual traffic flow related to web services' interactions is burdened with the XML overhead which greatly limits communication link throughput. It is highly recommended therefore to improve encoding efficiency, i.e. to enhance the ratio of the user data to the management data in the SOAP message, and to reduce the number of unnecessary data (or data that cannot be consumed) to the users of degraded networks.

Limiting the size of traffic flow to the users of wireless networks will improve the successability of web service calls and will support users with information crucial for their operation in the battlefield.

Message adaptation actions can be therefore twofold: lossless – e.g. actions that improve message encoding sustaining the possibility of the consumer's side to decode it without losing any of the data, and lossy – cutting out information that the user agrees to be filtered out.

Selection of appropriate adaptation action is not a trivial task and needs to be based on several types of information. First of all, adaptation does not have to be performed when the connections are stable, network has high bandwidth, acceptable delay, no losses, and therefore, does not provide limitations for web service provision. The information about the network state is important in order not to spoil time on unnecessary actions.

Additional problem is related to the intermittent connectivity, very common in tactical communications networks. Unless the TCP connection is closed (lost) information will be successively sent to the receiver, however the throughput will be reduced. Longer disconnection periods (about 2 minutes) cause TCP connection termination – and in case of SOAP message transmission – causes SOAP fault at the client side. In this case it could be helpful to use caching proxy on both sides of the connection that would divide the information into smaller parts and send them one-by-one when the connection is up.

The second important aspect is necessity to take into account users' preferences in terms of adaptation. They will be included in, so called, user profile, within which the user will state his adaptation preferences, and device profile, which defines his terminal's software and hardware possibilities. This set of information is necessary for selecting the actions that would meet the user intentions and, at the same time, would not make it impossible for the user terminal to receive and decode the message. This results from the fact that when the message is received at the user terminal it is firstly processed by the software libraries installed on it. Existence of particular software libraries implies therefore possibility of particular message encoding actions. Additionally, information about the terminal can help in parameterizing images and video streams that would be directed to the user device.

Such an approach makes it necessary to provide a mechanism for provisioning and then efficiently using information about the user, his terminal, the network and invoked services. This problem has been defined as the need to identify the context of the service call. It has been proposed in the form of ontology that allows to clearly define parameters of entities taking part in the information distribution process and then, on the basis of the set of rules and the rule engine, efficiently support the decision process enabling to take adaptation actions improving service successability.

On the basis of those considerations the architecture of the Adaptation Framework For Web Service Provision has been proposed (see Fig. 1). It bases on the Decision Support Engine that uses information about the context of the service call as the input data and, on the basis of ontology rules, defines the adaptation actions to be triggered on the SOAP body and SOAP attachments by the Adaptation engine. Such a modified SOAP message has smaller size than the original one. The modified one is sent to the requester.

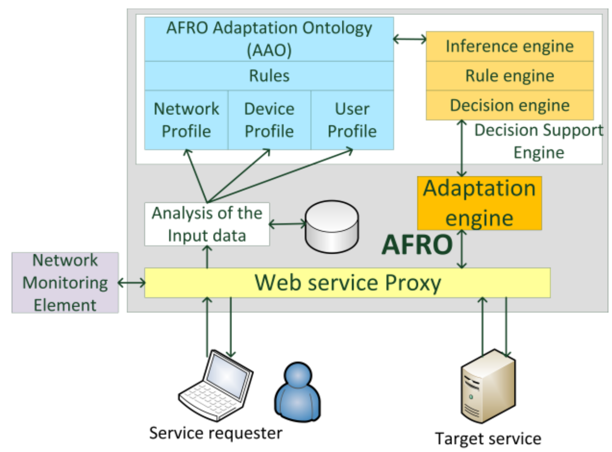

Fig. 1. : AFRO architecture framework.

The proposed ontology and the rule engine strongly support dynamic selection of adaptation actions appropriate for the user. They are used by the Decision Support Engine that returns in response a set of actions. These actions derive from the Proxy functionality. They can be embedded (e.g. take the form of the Adaptation engine, see Fig. 1) or, taking different approach, distributed. The latter one can be implemented using SOA services' orchestration. In this case after the Proxy selects appropriate actions for the user, it would search for the services that provide appropriate mediation (carry out the action).

Whatever approach to Proxy implementation one can take, the application of the Decision Support Algorithm and the proposed AFRO Adaptation Ontology (AAO) will supply him with the dynamic selection of actions to be taken.

It is also assumed that the Proxy will make use of information provided by external element – Network Monitoring Element that will support it with information about currently observed network performance on the link to the user. This performance information (in terms of throughput, delay and error rate) will be used by the decision support algorithm. In case the network is categorized as disadvantaged, the Proxy will make the modifications stronger, decreasing the amount of information that is sent to the user (in terms of image modifications), however making it more probable to be transferred to the consumer.

A. *Reflecting user requirements*

One of the elements of the proposed Method is context of the service call. In case of the AFRO proxy context consists of collection of information about the user: What modifications of the SOAP messages' content is the user willing to accept? What is the user end terminal? What access network is he using?; about the device: What are the characteristics of the device hardware (resolution of the screen, CPU frequency)? What are the characteristics of the device software (operating system, supported libraries)?; about the service: What is the service description?; and underlining network: What is the network type? What is the current link performance?

The reason for the dynamic adaptation to be based on the pre-distributed information is that the user – from the point of view of his activities – may not wish the mechanism to modify contents of the message and modify the attachment (resize, compress, decrease color depth) (see Fig.2). In order for the non-standard XML encoding to be used at the receiver, the device must be equipped with appropriate libraries. It is very often an issue in mobile devices that use limited operating systems and limited set of libraries and do not support software implementations regularly used in laptops or PCs. The environment the adaptation framework is to be used in assumes utilization of mobile hand-held devices, the configuration of which (software and hardware) is important in terms of successful web services adaptation.

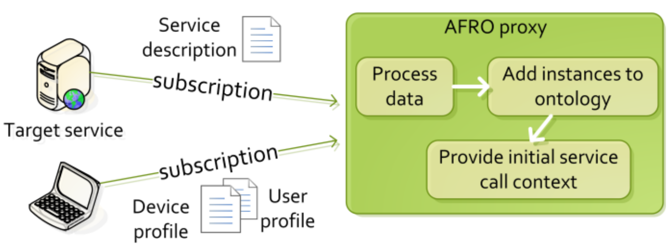

Fig. 2. : Pre-processing of the data gathered during the subscription process

The context of the service call has been modeled semantically with the Web Ontology Language Description Logic, (OWL DL [4]), which is the most powerful ontology description language and promising in terms of further processing, rule enforcement and inference.

For the purpose of selecting the adaptation actions the decision engine uses the AFRO Adaptation Ontology. The context information in AAO has static and dynamic elements. It generally consists of: user context (adaptation preferences – static), device profile (static), service context (QoS profile – static), network context (Link performance – dynamic). It also describes all the actions that can be taken by the proxy, reflecting the user preferences.

In order to make use of the adaptation ontology a set of rules has been defined. Rules are important in OWL to state facts about instances of classes. The rules in AFRO define requirements for particular actions based on information that are provided in the context of the service call. They have been defined using the Semantic Web Rule Language (SWRL) [5], combining sublanguages of the OWL DL and Lite with those of the Rule Markup Language.

Adaptation actions are modifications of the SOAP XML messages. In the proof of concept GZIP compression algorithm and Efficient XML were used for XML messages adaptation. Images attached to SOAP messages were modified by changing their resolution, color depth and limiting their quality. With these actions, the sizes of messages are significantly diminished making them better tailored to the tactical networks.

The dynamic elements of the context should be gathered at run time by agent entities and forwarded to the proxy. In this case they relate to the current link performance.

After the user logs in, his every request is perceived as a Service call. On the basis of rules defined in the Proxy, appropriate adaptation actions are selected. An exemplary rule defining the ChangeResolutionAction as preferred for the user when his device has low CPU is as follows:

uses(?x, ?y)^hasHWlimitations(?y, ?z)^LowCPU(?z)→ hasPreferredAction(?x, ChangeResolutionAction)[2]

In AAO the Action class is divided into two subclasses: SOAPAdaptationAction and AttachmentAdaptationAction. They allow for creating different actions that the Proxy can provide (or can invoke in an external entity).

The adaptation ontology can be further expanded as additional components reflecting actions available in the AFRO proxy will be introduced.

III. VERIFICATION

In order to verify correctness of the adaptation process functionality and compare with the regular web service invocation, the verification phase has been taken up. In general, it aims at proving that the proposed method improves successability and application response time parameters of web service realization in disadvantaged networks. However particular steps are devoted to check different elements of AFRO. The verification phase was to answer the following questions in 3 Experiments: Experiment 1: AAO ontology evaluation; Experiment 2: Verification of information originality after running attachment adaptation actions; Experiment 3: Verification of the Method in Disadvantaged Environment.

A. *Results of Experiment 1*

The scope of the AFRO adaptation ontology (AAO) has been set up by the problem it was designed to solve. It is aimed at supporting the dynamic selection of adaptation actions taken on the SOAP messages exchanged between the web service client and server. It defines:

• entities that take part in the service invocation as classes (User, Device, Network, Service, Action class),

• relationships among entities as object properties (connects ↔ isConnectedBy, hasAdaptationPreferences,

[2] ?x means variable representing OWL individual. According to [5] variables are indicated using the standard convention of prefixing them with a question mark (e.g., ?x).

hasDeviceProperties, hasPreferredAction, hasProhibitedAction, usedBy ↔ uses, hasNetworkType, isInvokedBy ↔ invokes),

• characteristics of entities as data type properties (userName, deviceName, qualityValue, resolutionValue, colorDepthValue).

The TBox ontology model describes relationships among defined entities. On its basis knowledge about the service call context (defined in ABox entries) is collected. After each user registers to the proxy, the knowledge about the user preferred, prohibited actions and his device properties are saved in ABox entries. This allows to set the Initial Service Call Context (ISCC). After the network state is checked, the final AFRO Defined Actions set (ADA) is defined.

The AAO is the basis for running the Decision Support Algorithm and setting the actions that should be performed by the AFRO Proxy.

Ontology rules defined for the purpose of selecting the actions take into account the following cases:

• the terminal does not support particular file format → the attachment is discarded (rule 1 – 5),

• the terminal supports particular encoding techniques → the encoding actions is added to the list of preferred (rule 11 – 13),

• the terminal has too low CPU frequency (processing power) → it will be difficult to process big images – e.g. change image resolution (rule 6),

• the terminal has limited color display – decrease color depth (rule 7 – 9),

• the terminal is connected by disadvantaged network link (general rule – true for all cases) – decrease image quality (rule 10).

Moreover, the preferred and prohibited actions that the user defined at the registration phase are also taken into account. They may derive from the role of the user and his duties at the battlefield.

The AAO defines all entities that are necessary to take appropriate adaptation decision and enables to automatically select appropriate adaptation actions. Its scope covers the required level of detail in describing the entities and relationships among them taken in the initial phase of ontology development. It covers so called competency questions [6] defined for the purpose of AAO. Additionally, the set of rules monitor all basic terminal characteristics that may influence usability of messages delivered to the user.

The second ontology evaluation step consists in checking the ontology consistency. According to [7] ontology is consistent (also called satisfiable) when it does not contain a contradiction. The lack of contradiction can be defined in either semantic or syntactic terms. The syntactic definition states that a theory is consistent if there is no formula *P* such that both *P* and its negation are provable from the axioms of the theory under its associated deductive system.

The ontology model that contains formal definitions of classes, properties and individuals allows inferring new knowledge from knowledge that is already present. The fact that it is based on formal description logic makes it prone to logical reasoning and enables to infer knowledge from existing facts[3] and axioms[4].

The aao.owl model has been verified in the Protegè 3.4.6 using the Pellet 1.5.2 reasoner for consistency on the machine with the following configuration: Processor: Intel Core i7 (2 cores 2,8 GHz each); RAM: 6 GB; Operating System: Windows 7 (64 bit). The consistency check on this machine was successful. AAO has been proven consistent.

B. Results of Experiment 2

Attachment adaptation actions are lossy. That is why Experiment 2 is aimed at verification of the information degradation factor when particular attachment adaptation actions are performed. For the purpose of Experiment 2 there has been defined the Information Originality Factor (IOF) that is aimed at measuring how big are changes that have been introduced in the original attachment.

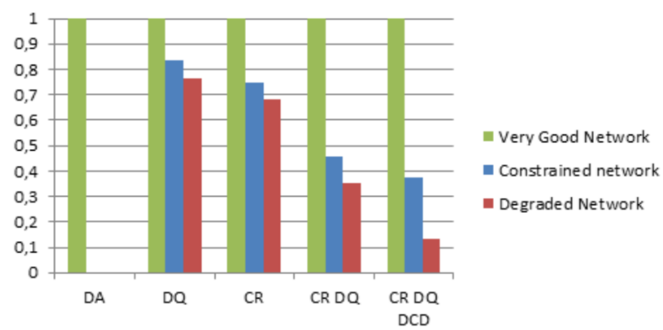

Fig. 3. : Results of IOF for images adaptation.

For original attachments the IOF = 1, which means that no changes have occurred. When the image is discarded, IOF = 0, which means that no original data will be transferred to the client. The adaptation actions defined for the AFRO Proxy are: Discard Attachment (DA), Decrease Quality (DQ), Change Resolution (CR), Decrease Color Depth (DCD). The IOF will therefore be dependent on these four actions in the following way:

$$IOF = \begin{cases} 0 \; if \; DiscardAttachment \in ADA \\ \frac{1}{3} * cr + \frac{1}{3} * dq * cr + \frac{1}{3} * dcd \end{cases} \quad (1)$$

Cr – change resolution factor, which measures the ratio of the area of adapted image to the area of the original image. It means how much the image's size (in pixels) was reduced.

$$cr = \frac{area\ of\ the\ adapted\ image}{area\ of\ the\ original\ image} \quad (2)$$

Dq – decrease quality factor, which measures the ratio of the quality of adapted and the original image. It means how much was the quality of the image reduces.

$$dq = \frac{quality\ of\ the\ adapted\ image}{quality\ of\ the\ original\ image} \quad (3)$$

Dcd - decrease color depth factor, which measures the ratio of the color depth in bits for the adapted and the original

[3] *"Fact states information about a particular individual, in the form of classes that the individual belongs to plus properties and values of that individual"* [4].

[4] *"Axioms are used to associate class and property identifiers with either partial or complete specifications of their characteristics, and to give other information about classes and properties. Axioms used to be called definitions, but they are not all definitions in the common sense of the term and thus a more neutral name has been chosen."*[4].

image. It means how much was the color depth reduced.

$$dcd = \frac{color\ depth\ in\ bits\ for\ the\ adapted\ image}{color\ depth\ in\ bits\ for\ the\ original\ image} \quad (4)$$

The values of IOF for adapted images are shown in Fig 3. The IOF for images prepared for degraded network is lower than for constrained network which means that this image has limited detail. However when the network resources are scarce, the message size has great influence on the successability of its delivery. Therefore it is strongly recommended to use the AFRO adaptation mechanism and deliver adapted images, even though Information Originality Factor is below 1.

C. *Results of Experiment 3*

The efficiency of assumed adaptation actions was verified in the Experiment 3 which measured two web services performance metrics - the response time and successability - for invocations of web services directly and through the AFRO Proxy. The Experiment 3 was divided into 10 scenarios, each devoted to check the AFRO adaptation mechanism efficiency for two exemplary target web services and five exemplary network performance conditions. The selected network types are the most often used in modern communications systems, prepared to be working in NEC military operations, delivering information to users on low levels of command [9]. These are the most representative examples from within the disadvantaged networks. They give the worst case in terms of delay – SATCOM, throughput – CNR and error rate – WIFI2. There is also an example of a very good performance network – LOS, with relatively high throughput, small delay and no errors, and constrained network – WIFI1 – with relatively high throughput, medium delay and small PER.

Since the adaptation actions consider modifications of SOAP messages and image attachments, there has been considered evaluation of two web service types: The NFFI service that returns tracks of objects as SOAP XML messages (5 messages of the size from 1 kB to 93 kB were sent), and the Image service that returns still image files in JPEG format (an image of 900 kB size was sent).

TABLE I.
SUMMARY OF RESULTS ACHIEVED FOR EXPERIMENT 3 IN CASE OF NFFI SERVICE INVOCATION

Network	AFRO			Original web service invocation	
	Response time	*Successability*	*Penalty*	*Successability*	*Penalty*
SATCOM	Improved (by 2 times for small msg By 10 times for large msg)	100% for all messages with GZIP and EXI	0 for all messages adapted with GZIP and EXI	100% for all messages	0 for all messages
LOS	The same – no adaptation	100% for all messages with GZIP and EXI	0 for all messages adapted with GZIP and EXI	100% for all messages	0 for all messages
WIFI1	Improved (20-40 ms for small mess 2 times for large msg)	100% for all messages with GZIP and EXI	0 for all messages adapted with GZIP and EXI	100% for all messages	0 for all messages
WIFI2	Improved (~2-3 times for small msg 31 times for GZIP and large msg)	100% for all messages with GZIP and EXI	7 for Message5 encoded with EXI; 0 for the rest of messages adapted with GZIP and EXI	100% for Message1 87,3% for Message2 90,4% for Message3 52,3% for Message4 44,4% for Message5	0 for Message1 5 for Message2 22 for Message3 76 for Message4 297 for Message5
CNR	Improved (about 30 times for GZIP and large msg)	100% for all messages with GZIP and EXI	0 for all messages adapted with GZIP and EXI	100% for all messages	0 for Message1 0 for Message2 0 for Message3 37 for Message4 81 for Message5

TABLE II.
SUMMARY OF RESULTS ACHIEVED FOR EXPERIMENT 3 IN CASE OF IMAGE SERVICE INVOCATION

Network	AFRO			Original web service invocation	
	Response time	*Successability*	*Penalty*	*Successability*	*Penalty*
SATCOM	Improved 3-12 times shorter	100% for all images	22 for D3; 0 for all other images	100% for image1	38 for image1
LOS	The same – no adaptation	100% for all images	0 for all images	100% for image1	0 for image1
WIFI1	Improved 2,5-6 times shorter	100% for all images	0 for all images	100% for image1	0 for image1
WIFI2	Improved	Av. 91,5%	Av.90,45	0% for image1	1000 for image1
CNR	Improved	0% for D3; Other images: 100%	44 for D2; 1000 for D3; 0 for D4; 0 for D5	0% for image1	1000 for image1

Additionally the test investigated the measured response times in terms of their adherence to the requirement set in the G.1010 [8] ITU-T recommendation. It states that in order for the user to be satisfied with the transfer of the bulk data, it should be delivered in time less than 15 seconds, without errors. It was the reference level for evaluating results. Any result above 15 s is given so called "penalty" equal one point for each second. If invocation is 100% unsuccessful, penalty of 1000 points is given.

Tables 2 and 3 show summary of results. The AFRO Proxy SOAP adaptation actions provide a very big advantage, especially in case of networks that are classified as degraded (SATCOM, WIFI2, CNR). In a very good network (LOS) there was almost no difference of response time for SOAP XML and encoding techniques. It results from the fact that message modifications are also time consuming, but when the transmission lasts a few seconds, they can be a significant coefficient of the total observed response time. In networks that the network state classification algorithm would classify as having enough performance (very good networks) no adaptation would occur. The results proved that in such a network all original messages would be sent in satisfactory time (less than 15 seconds) and with 100% successability. In constrained network it is visible that the SOAP adaptation gives additional benefit in case of big messages (msg 4 and 5).

In case of image service invocation the attachment adaptation actions give response time improvement and successability increase in all scenarios. However for degraded networks with high error rate (WIFI2) and low available throughput (CNR) the attachment adaptation action that only decreases image quality is not sufficient (this is the case of sending file D3). It is necessary to provide at least two adaptation actions, i.e. change resolution and decrease quality.

The results of using AFRO prove that this method improves web service application response time and successability of web services invocations in networks that suffer from low throughput, high delay, error rate and are classified as constrained or degraded. The efficiency of the Method is however also dependent on the accuracy of the network performance evaluation by the Network Monitoring Element. It is especially important in case of attachment adaptation actions that take different adaptation preferences in case of constrained and degraded networks. The Adaptation Decision Support Algorithm is composed in such a way to give the user information with the highest fidelity (highest IOF value) so that stronger actions are performed in case of degraded networks.

In general, the attachment adaptation actions triggered by the Proxy will be dependent on the user and device profile. Moreover, the resulting files will be also dependent on the original file sent in response. In the tests done in Experiment 4 the original file has high resolution and large size (904 kB). Therefore, the results collected give the overview of the AFRO functionality in the worst case scenario.

The results also show that the packet error rate has higher influence on response times and successability of web services invocations than delay and throughput. In conclusion it has been assumed that, given an erroneous channel with quite high throughput (like WIFI2), in order to get better response time and successability, it is better to employ some error correction techniques and decrease channel throughput. When the error rate is high, so many packets are lost that the communications parties interpret losses as disconnections. When the adaptation is introduced, messages are significantly smaller and the successability as well as application response time of web services invoked through the AFRO Proxy is increased.

High delay in channels (like SATCOM) is interpreted by the TCP as congestion, so the source is decreasing its speed of sending data. This results in higher transmission times, however does not influence successability. In case of low throughput the transmission times are longer, which is caused by the physical performance of the channel. However decreasing the amount of information sent results in improving the application response time in case of SOAP web service invocations and improving successability and response time in case of image web service.

IV. Summary

This article presents semantic description of the service call context defined for the purpose of the Adaptation Framework For Web Services Provision (AFRO).

There has been proven that the proposed AFRO Adaptation Ontology model is semantically and syntactically correct and consistent. Reasoning over it provides the possibility to support the adaptation actions decisions taking into account the user preferences deriving from his role and limitations of his terminal. The SWRL rules defined for AFRO strongly support the automatic process of defining the preferred actions.

The proposed adaptation mechanism gives promising effects for low level commanders located at the battlefield, which can be supplied with information generally available on high command levels which, up to now, were very rarely distributed to tactical networks.

Following the loosely – coupled architecture of the AFRO proxy the idea of dynamic web services adaptation can be extended with the orchestration engine that would search for services that would carry out the adaptation action defined by the decision algorithm. Additionally, it would be interesting to combine the results of work in terms of Delay Tolerant Networking with the idea of AFRO Proxy that works in the application layer to assess what is the benefit of applying such a combination in a disadvantaged environment.

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