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The Case for an Agile SOA

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***Abstract*—Service Oriented Architectures (SOA) are increasingly being used by architects of business IT systems to encapsulate key business components and make them available for efficient reuse across multiple business functions. An SOA within a business is typically a managed environment relying on good IT management practice within a reliable networked infrastructure. In a military environment, reliable IT infrastructures are not guaranteed; particularly where ad-hoc wireless networks are used. When sensors are represented as services, additional metadata is required to describe, for example, their current energy status. This places further requirements on an SOA which are identified later. The need for an agile SOA which is more dynamic and flexible than existing business implementations is discussed and postulates for the additional features of SOA for wireless sensor network environment are proposed.**

***Index Terms*—Sensor Network, Service Oriented Architecture, Wireless Networks**

I. INTRODUCTION

In *Power to the Edge, Command and Control in the Information Age* by Alberts and Hayes [1] the authors develop a conceptual system architecture for Command and Control (C2) systems suitable for the Information Age. They develop their requirements by analysing current (referred to as Industrial Age) C2 structures and concepts and highlight how these are unable to deal with the flexibility and adaptability required for C2 systems to be successful in responding to the new threats and environments encountered by the military in the 21st century.

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In the Information Age, they argue that the way we think about information and the relationships between its sources and consumers have to change. Currently, C2 systems regard information as being provided by a set of monopoly suppliers and this has changed to an information exchange whereby users will have access to the variety of sources, views and perspectives necessary to make sense of the complex situations they will face. In this environment, information collection and analysis capabilities will dynamically evolve as circumstances change. The authors also argue that the dissemination of information has to move rapidly from a push-oriented mechanism to a pull-oriented one; this being the only way to satisfy the needs of a heterogeneous population of information users.

The approach to interoperability has to change as well. Given the rate of change of new technology, an approach based on application standards is no longer supportable. An approach based on data standards will give a community of users the opportunity to use applications that make sense to them whilst still providing the opportunity to exchange information; this also highlights the need to support peer-to-peer relationships and information exchanges that transcend individual systems and organisations.

The title, *Power to the Edge*, is given to their system design philosophy that meets the requirements of the Information Age. In the Information Age, the decision making process is moved from a central, monolithic C2 structure to one where all members of an organisation, particularly those at the edge, can contribute to the decision making process and its subsequent implementation by sharing information.

The book is the source of a set of high level requirements for a network-centric framework which can provide the starting point for a discussion and evaluation of how a Network Centric Warfare Framework (NCWF) may be implemented using a Service Oriented Architecture (SOA). Note that in the UK Ministry of Defence context, the term Network Enabled Capability (NEC) is used instead of NCWF.

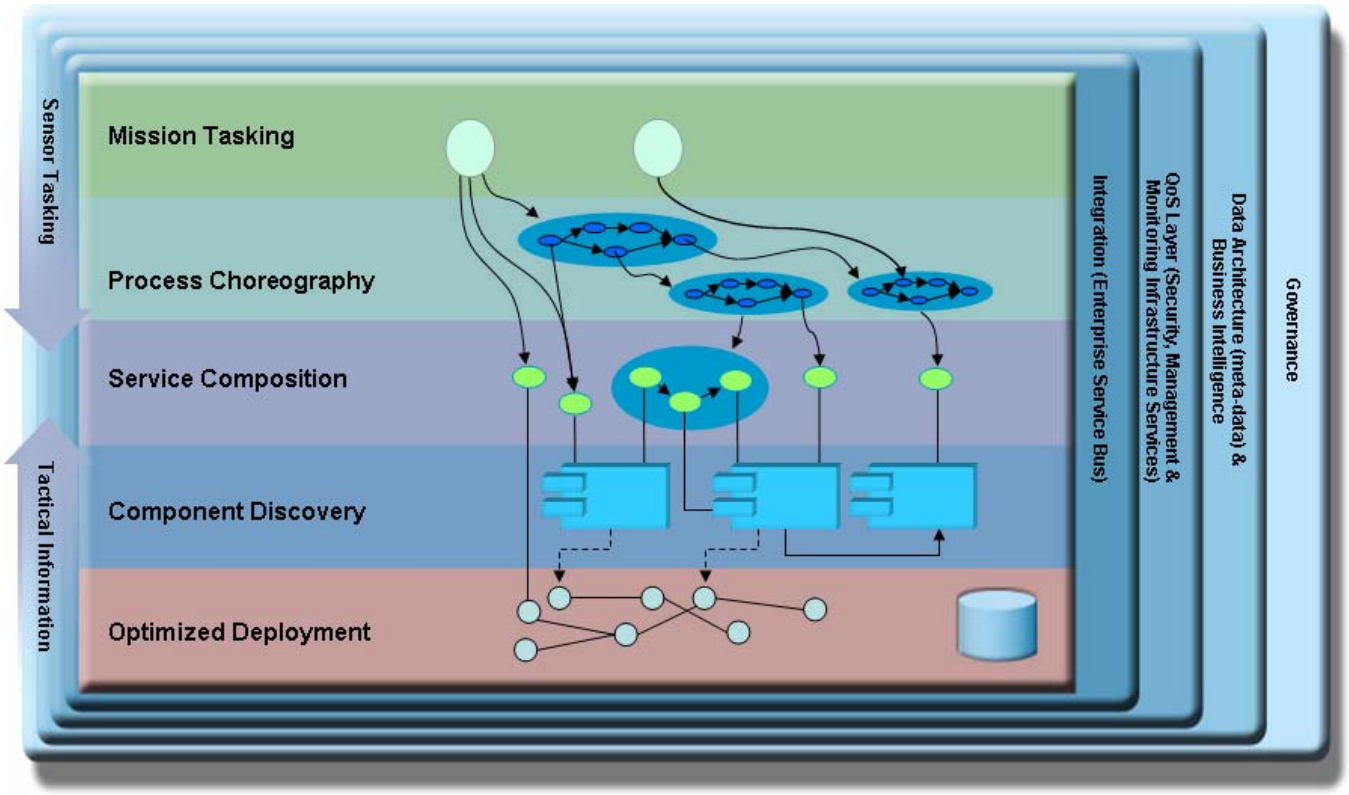

Figure 1. SOA Architecture

I. SERVICES AND THE SOA

In this section, we define the terms *Service and Service Oriented Architecture* (SOA). These definitions will be used to discuss the requirements listed in the following section in the context of an SOA.

A *Service* is a discoverable software resource which has an advertised service description. The service description is available in a repository, called a registry that can be searched by a potential consumer of the service. Given the service description, a service consumer can bind to and use the service.

The promise of web services was that the service discovery and binding process would be truly dynamic in that a service consumer would discover an available service on the web, bind to it and access the service. Once complete, it would then disconnect. In reality, this operating model has not yet been achieved. In part, this is because:

1. The richness of a service description has not yet reached a level where a service consumer can confidently identify a service to connect to.
2. Security specifications have not as yet reached a level of sophistication where a service consumer can truly trust an advertised service.

Services tend to be used in a more static way wherein a palette of available services is made available in a design tool and a developer selects the services that they require to implement a business process. The services are then combined into an application.

Services are composable. This means that a service can be assembled by combining a number of existing services. This can be thought of as a fractal structure in the way that services can themselves consist of services. Services are the primitive building blocks of a *Services Oriented Architecture* (SOA) illustrated in Figure 1.

An SOA is a business IT architecture for linking and choreographing services which are aligned to business functions. The primary element for an SOA is a service rather than a subsystem, system, or component [3] as in other architectural styles.

An SOA separates out the concerns of service consumers and service providers and their needs to achieve the following characteristics:

1. A strong alignment between business functions and the underlying IT infrastructure
2. Support for rapid changes of business requirements

3. Leverage of existing investments by allowing existing applications to be encapsulated as services and reused
4. A business level focus resulting from avoidance of function duplication, achieving consistency and joining up business processes

Given these definitions, we can now identify and discuss a set of requirements generated from the *Power to the Edge* book.

II. Requirements for Network centric warfare

The following paragraphs provide an informal set of requirements.

1) Information is provided as a marketplace whereby participants have access to the sources, views and perspectives necessary to make sense of complex situations.

A marketplace operates through the cost and value of the commodities traded. Information in the NCWF context is used to inform a C2 structure by providing situational information about the battlespace. Therefore, the cost of obtaining the information and the value (in the context) of the current information are important factors in determining the marketplace currency. To make sense of complex situations, the sources (or services) that provide the information must be described in a way that allows a higher level information retrieval strategy to assess the worth of a set of sources and from them construct a fused view of the current situation.

Currently, the mechanisms for describing and retrieving services from a registry are limited to little more than keyword based queries. Developments in the semantic web [2], [4] have led to their use as rich semantic service descriptions within a Web Services context; in particular the adoption of the Web Services Modeling Ontology [5] and the W3C Working Group on SAWSDL [6]. Note that in this context, the set of Web Service specifications are a particular implementation of an SOA; an SOA may be implemented using other technologies.

This requirement emphasizes the need for a rich description language which allows a higher level service or application to select, reason, and compose advertised services in order to support the implementation of a complex situational view from a set of available information sources represented as services within an SOA.

2) Information collection and analysis capabilities will dynamically evolve as circumstances change.

Consider the following use case. Through his planning processes a mission commander requires a target with a particular set of characteristics to be tracked within a certain geographical area. Given this objective, if a set of sensors are described as services within an SOA, how should the available sensor services be composed to meet the objective, and how should the composed service behave over its lifecycle?

A composed service in a business environment is subject to rigorous lifecycle management with the composed service or workflow only being modified and re-deployed under change management control. In the example use case, the services that make up the composed tracking service may change during the tracking service lifecycle. If the target is moving, then sensors that were within range of the target may later become redundant as the target moves outside their range. Similarly, the target may move into range of sensors that were not part of the composed tracking service. The addition and removal of services to and from a composed service must therefore be achieved automatically without the manual processes and overhead of business lifecycle management.

The set of deployed sensor services will also be subject to the characteristics of the network that interconnects them. Unlike a business IT environment, this will be inherently unreliable with available services appearing and disappearing due to temporary and permanent network effects such as wireless communication obstacles or sensor lifetime. This requirement imposes a more dynamic protocol between the service registry and the services that it is advertising to ensure that the registry entries accurately reflect which services are currently available to meet a particular task.

3) Information dissemination will be based on a pull model to satisfy the needs of a heterogeneous user population

A centralized C2 structure tends to push information to the services responsible for implementing the orders and to impose their execution regardless of the current needs of the users. With network enablement, the sources of information are accessible to all services connected to the network. This allows a pull information delivery model to be implemented where services pull only that information required to meet their objectives. This reduces the potential for information overload by a service because it can be selective in the information it pulls. Information overload occurs when a service receives more information than it can process resulting in potential confusion and error.

Within an SOA, this requirement means that all information sources must be describable and accessible to

allow services created in response to the users' requests to easily identify which sources are relevant to their current tasks and objectives. Semantic mediation of the information delivery as described by the WSMO framework [7] may be required in some circumstances, once again reinforcing the need for semantic descriptions of services and their support within a registry.

4) Interoperability will be based on data standards

The move to an SOA has shifted the interoperability model from one based on application standards to one based on data and interface descriptions which are expressed (in the case of Web Services) using open standards. Traditionally, the setting of data standards is a frustrating activity with a user community failing to agree to common interchange formats. Technologies underpinning the SOA concept permit information transformation to be achieved by the addition of metadata. This metadata allows users of the information to understand how it is represented and to perform appropriate semantic and syntactic mapping into their own data formats. Interoperability can therefore be achieved if the user of the information is aware of the different representations and their mapping to each other. The burden for this is shared between the source and users of the information.

5) There must be support for peer-to-peer relationships and information exchanges that transcend individual systems and organisations.

Whilst supporting traditional hierarchic organizational structures, an NCWF provides the opportunity for relationships to be created between resources based on other social and coalition-based criteria. These relationships are sometimes beneficial, especially in a military coalition setting, and can augment more rigid structures by forming dynamic communities with common interests and objectives. Representing resources as services allows them to be easily identified and included as such cross coalition communities are formed. Security considerations dictate that common policies should be applied to the community ensuring that the members and the resources as well as information that they share are not compromised.

6) An NCWF must allow members of an organisation to make sense of the current and arising situations. This must be achieved iteratively with the means to respond to changes in the situation and/or command intent being adjusted dynamically.

The messaging models that interconnect services within an SOA should provide different mechanisms for situational information dissemination. This can be achieved through selective push, pull and notification messaging frameworks as appropriate. Metadata and policies attached to services and data within the SOA can establish the nature of situational information which is to be disseminated within a coalition.

7) An NCWF must allow members of an organisation to orchestrate the response to a situation in a timely manner. This must be achieved iteratively with the means to respond to changes in the situation and/or command intent being adjusted dynamically.

Orchestration within a conventional SOA is a managed activity which is governed by lifecycle management tools and processes. For processes within the NCWF that are similar to business processes such as high level command patterns, this approach is still appropriate.

However, in a dynamic NCWF, there is a requirement for services to be algorithmically composed from available resources to meet situational objectives as discussed in requirement 2. This reinforces the need for a rich semantic description of services which can be used to dynamically compose and orchestrate services in response to rapidly changing situational circumstances.

The algorithmic composition of services based on rich semantic descriptions is an ongoing research topic.

8) An NCWF must distribute and match responsibility with authority as well as monitor the accountability of members in the organisation.

The distribution of responsibility and matching with authority is another facet of the service discovery, use and composition issues. The requirement to monitor accountability can be supported by making an NCWF "provenance-aware" so that the processes, acting as agents for members of an organisation and contributing to mission objectives, document their execution for later accountability. The provenance documentation can also be used during execution to guard against processes that break certain rules or introduce unacceptable risks. This kind of accountability is particularly important for missions executed by coalition forces.

Provenance technology is also part of the current SOA research agenda [7].

9) An NCWF must provide self-synchronization between all participants in the organisation

Self-synchronization or self-coordination is defined by the DoD Transformational Planning Guidance issued in April 2003 as an effort to "increase freedom of low level forces to operate near-autonomously and re-task

themselves through exploitation of shared awareness and commander's intent." The formation of dynamic communities to meet particular objectives fulfils this requirement.

To support this need, an SOA must facilitate the dynamic assembly of resources together with the deployment of a secure infrastructure that controls access to the necessary information sources. Identification of the resources and their composition to meet the dynamic high level mission objectives must be supported.

10) An NCWF will not constrain how command and control is accomplished

In an SOA, resources exist as individual services within the network with their interfaces advertised via a registry. These services can then be composed and choreographed in order to perform some task or mission. The mechanisms of choreography and composition are not fixed; therefore the inherent flexibility of an SOA will not constrain how C2 is accomplished.

11) An NCWF should provide a post-before-processing policy.

NCWF enforces a shift from a point-to-many to a many-to-many exchange of data. This will allow users and applications to leverage the same data and information sources. This extends the previous focus which was on standardized, predefined, preprocessed point-to-many interfaces. Therefore within an NCWF, the objectives of information delivery are to ensure that the information is available, visible and usable by a wide user community. It has to be available wherever and whenever it is needed.

To accelerate decision cycles, in an NCWF, unanticipated but authorised users or applications must be able to find and use information rapidly. The goal must be to populate the network with all data, both raw and processed, and to change the information paradigm from *processing-before-post* to *post-before-processing*. This change allows authorised users and applications access to data without delays for processing, exploitation, and dissemination.

Users and applications will post information to accessible spaces, increasing the amount of shared information while minimising private user or application specific data. All posted information will have metadata associated with it. This association will allow users and applications to discover the shared information and evaluate its utility. An NCWF that empowers users through rapid access to information may then be implemented using an SOA.

12) An NCWF should provide an infrastructure that promotes agility by allowing local optimizations to be exploited rather than relying on complex global optimizations

Systems that exhibit tight coupling between services cannot be subjected to local optimisation strategies. A key property of an SOA is that all services appear stateless and are loosely coupled to each other. Within such a framework, local optimisations may be exploited but at the potential expense of globally optimal performance which may be degraded.

13) An NCWF should support interactions between participants that are organised around communities of common interest and driven by situational circumstances

The formation of dynamic communities requires bringing together resources necessary to support the community participants in achieving their objectives. Driven by a statement of the community objectives, an SOA must be agile and responsive in providing the appropriate information sources, a resilient security framework, dynamic service composition and flexible network topologies to meet this requirement. The International Technical Alliance (ITA) research task in Project 9 is to identify where current SOAs fail to meet this requirement and how to correct this deficiency.

III. SENSORS AS SERVICES

Within the International Technical Alliance (ITA), managing large numbers of sensors as services within an SOA offers an opportunity to reuse the technologies deployed within enterprise IT systems whilst addressing the requirements for agility discussed in this paper. We now compare two uses of a service within an SOA; in the enterprise and in a future managed sensor infrastructure.

In an enterprise, for example a transaction ledger service for a back office application, the advertised service obligates the service provider to persistently store all transaction data, such as time, amount and account information in a database. The users of the service can query the transactions. The ability to query past transactions is a property of the service that is supported by the underlying IT infrastructure and advertised through its external service description. The lifetime and availability of the transaction data is declared through service level agreements (SLAs) between the service provider and its community of users. Note that the SLA may form part of the advertised service description.

Compare this scenario with a set of sensor services that are composed into a single "ledger" service that measures the temperature in a specific geographical area. To manage the set of composed sensor services, the ledger service must

be able to control:

1. How often sensors need to collect and store the temperature data?
2. At which locations?
3. Is estimation allowed for temperature and spatial positioning?
4. What are the permitted error ranges?

Hence, the ledger service that manages the recording of temperature in a region is ambiguous unless it can specify how frequently the temperature is to be measured and how dense the measured points should be. These parameters impact the energy budget of the sensors performing the measurements and the data storage strategy implemented by the composed sensor service.

In both cases, services can be represented by the same general SOA model. Sensor properties, including battery charge levels and transducer characteristics are included in a rich description that is contained within the service registry and is periodically updated. The registry may be centrally located or, more likely, distributed throughout the network. As long as the sensor can update its descriptive metadata within the registry, and can respond to messages from the composite service to change its characteristics, then it can form a first class service within an SOA. All of the decisions about where and when and how often data is collected are taken by the composite ledger service, not by the sensor. If the composite service requests a change in sensor deployment, it of course must take into account the "cost" of this redeployment. This constitutes a part of the "re-deployment" or "re-configuration" cost associated with changes to the composed service which must be managed by the composing ledger service.

IV. Conclusion

This paper has identified a set of key requirements for an NCWF and discussed how an SOA may (or may not) support them. A number of common issues for an SOA can be extracted from the discussion:

1. Services must be described in a way that allows algorithmic composition through semantic inferencing about the composed service properties. Current research in the semantic web services community provides a starting point but it is not yet sufficiently advanced to implement the kind of systems envisaged for Information Technology Alliance.
2. Services will exist in unreliable, low resilience network infrastructures such as MANETs and may have limited lifetime, e.g. sensor networks. Current SOA implementations are in the business domain where such network characteristics do not exist. Protocols that support unreliable and/or temporal service infrastructures, particularly distributed registry support, must be developed.
3. A security infrastructure that allows controlled access to services which exhibit the properties described in this paper must be developed. Services must provide information on a post-before-processing basis to all accredited users and resources based on data rather than application standards. Information must be available to whoever requires it whenever it is required.
4. The SOA must not constrain how C2 is implemented. It must also support the creation and management of ad-hoc relationships formed by members of a coalition in order to support their mission and task objectives. At a tactical level, an SOA must support the creation of dynamic communities of interest formed to perform a particular mission or task.

The authors contend that an agile SOA is one that meets the requirements identified and discussed in this paper and is an extension of the current architecture, which is based on requirements intended to support its deployment in the business domain.

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