

Managing Systems of Systems Interoperability – Federated SOA and Reference Architectures

Chai Fung, Chang
Defence Science & Technology Agency
1 Depot Road #22-01
Defence Technology Tower A
Singapore 109679
cchaifun@dsta.gov.sg

Pong Heng, Tan
Defence Science & Technology Agency
1 Depot Road #22-01
Defence Technology Tower A
Singapore 109679
tponghen@dsta.gov.sg

Soh Khum, Tam
Defence Science & Technology Agency
1 Depot Road #22-01
Defence Technology Tower A
Singapore 109679
tsohkhum@dsta.gov.sg

Copyright © 2009 by Chang Chai Fung, Tan Pong Heng and Tam Soh Khum. Published and used by INCOSE with permission.

Abstract. New and emerging threats, technology advancements and the advent of the Knowledge Age are driving change in Armed Forces around the world. The Singapore Armed Forces is in the midst of transformation into the 3rd Generation SAF to meet these challenges. As military systems morph into increasing networked and interdependent system of systems, the Defence Science and Technology Agency (DSTA) has also adopted strategies and put in systems engineering efforts to manage the interoperability requirements and complexities of this system of systems. In 2006 DSTA adopted Enterprise Architecture (EA) to facilitate business-Information Technology (IT) alignment and subsequently established a Reference Architecture Framework to ensure interoperability across systems. In this article, we describe the Reference Architecture Framework, the linkage between EA and the Framework, and how the framework will guide the development of the solution blueprint to enable 3rd Generation SAF transformations.

Introduction – Imperative for change

The Singapore Armed Forces is on a journey of force transformation into the 3rd Generation SAF, a joint military that synergises the various capabilities in the air, sea and land dimensions to achieve optimum effects. To achieve this, fighting forces and supporting systems capability need to be organised and reorganised rapidly to meet evolving operational needs and operate in a highly networked manner to maintain an information edge over the adversary. A key part of this transformation is the Integrated Knowledge-based Command and Control (IKC2) paradigm that will enable a more integrated and networked SAF.

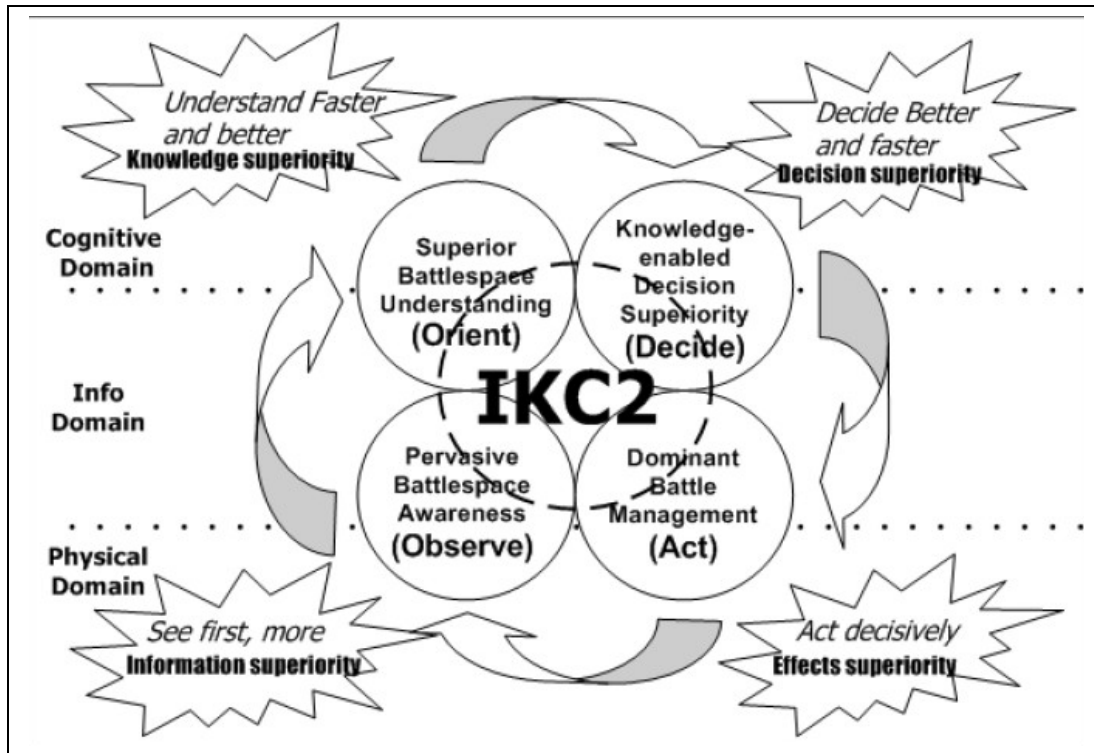


Figure 1. IKC2 Operational Formulation [1]

As military systems become increasingly interconnected under the IKC2 paradigm, a coherent and holistic strategy is needed to manage interoperability within complex software intensive system of systems. At the same time, systems need to be sufficiently agile to respond to changes in requirements and support a full spectrum of operations ranging from peace-time to war-time operations.

In this article, we will present our Reference Architecture Framework based on the Service Oriented Architecture (SOA) approach to help us in the development of the solution blueprint to meet IKC2 challenges.

EA Framework – Enterprise compass for alignment & agility

As the SAF transforms to become more flexible and capable of meeting new and emerging threats, in 2006 the Singapore Ministry of Defence (MINDEF) and the SAF adopted Enterprise Architecture (EA) as the Enterprise Compass [2] to facilitate self alignment within MINDEF and the SAF. The EA framework achieves this by providing a structure, processes and guidelines to integrate developments from multiple agencies within MINDEF and the SAF and bring them towards top-driven enterprise vision and objectives. Figure 2 shows the EA framework adopted from Meta Group. The framework comprises four main components representing logical separation of concerns and developments:

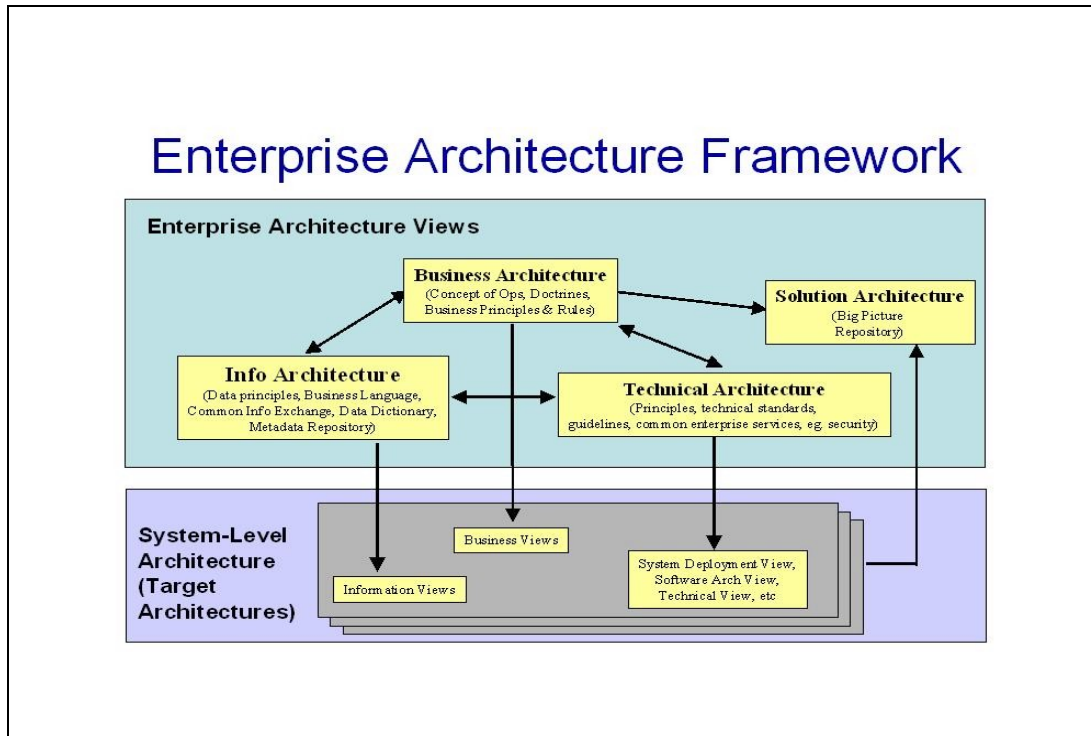


Figure 2. Enterprise Architecture Framework. [3]

- **Enterprise Business Architecture (EBA).** EBA is the expression of the enterprise's key operational strategies and their impact on operational functions and processes. The primary intent of EBA is to provide a common language for articulating operational requirements, policies, business processes and supporting technologies needed to achieve a high level of information and system operability. It also enhances visibility of the operations to facilitate quick response to change.
- **Enterprise Information Architecture (EIA).** An organisation's information is analogous to blood in the human body – precious and life sustaining. Its flows across the organisation to support military operations and facilitates decision-making. EIA includes data models, information exchange matrix, and knowledge management plans. It documents who is responsible for the data, where and how it is created, read, updated or deleted. EIA examines the information flows across business processes, and reveals the architecture requirements for information exchanges within the enterprise.
- **Enterprise Solutions Architecture (ESA).** An ESA is a model of the applications and infrastructure components that satisfy a set of operational requirements. It serves as input for operational users and developers in their planning and creation of the project portfolio, such that they can satisfy enterprise business and information architecture requirements. The ESA includes information on current inventory of applications and components and existing reference architectures, complete with relationships to supported operational processes, list of required functionality to fulfil unsatisfied EBA and EIA requirements and migration plans.
- **Enterprise Technical Architecture (ETA).** ETA is a logically consistent set of principles, standards and guidelines that serve as a guide in the design, acquisition, implementation and management of C2 systems. Using ETA to govern technology choices helps maintain

coherence to facilitate interoperability across systems, integration with legacy systems and technology obsolescence management.

SOA – Foundations for operational agility

MINDEF and the SAF adopted Service Oriented Architecture/Approach (SOA) as part of its Enterprise Architecture in 2006. SOA was adopted as a strategy to achieving enterprise agility, and it works hand in hand with EBA and EIA components. There are many myths and misconceptions surrounding SOA, the most common being equating SOA to enabling Web services interface to any system function. Looking beyond the myriad of definitions propagated by SOA technology and product vendors, SOA is really an outcome-driven way of thinking about architecture or a particular style of enterprise architecture.

The SOA concept says that operational processes and functionality of an enterprise (EBA) can be decomposed into self-contained reusable services that can be hosted and distributed on an infrastructure spanning the entire enterprise network. Services are discovered through service descriptions and they interact through messages, governed by service contracts (EIA). To implement the SOA concept and reap all its touted benefits of agility and interoperability, common standards and best practices are needed. More importantly, enterprise-wide standards for service descriptions, messaging and service contract need to be defined.

SOA has been the in the limelight of the Information Technology (IT) industry and on lips of most software to hardware vendors for the past few years. This is understandably so since the potential benefits to be reaped from SOA are of great value to both the operations and C2 systems. These include:

- **Operational Agility.** The 3rd Generation SAF, joint military that synergises the various capabilities in the air, sea and land dimensions to achieve optimum effects. To achieve this, fighting forces and supporting systems capability need to be organised and reorganised rapidly to meet evolving operational needs and operate in a highly networked manner to maintain an information edge. SAF must constantly change their strategies and business processes to stay ahead. Thus, it has become a requirement for modern C2 systems to be able to adapt quickly and efficiently to reflect those changes. SOA is a concept that advocates such adaptive C2 systems (Service oriented rather than technology oriented). In the traditional approach, changes to the C2 systems are often difficult and costly, and SOA is positioned to change that.
- **Seamless Integration.** Optimizing collaboration between various operational departments or divisions would be an advantage. In particular, if systems have to be integrated due to business process optimisation, the SOA concept can be used to enable collaboration across clearly defined interfaces. In this way, the strengths of the individual areas can be maintained, while simultaneously leveraging the potential synergies.
- **Cross-agencies Collaboration.** Moving ahead, military operations cannot work in isolation, it is essential for the SAF to collaborate with other agencies. This collaboration means more than simply buying and selling products. Products may be jointly developed, , and strategies jointly formulated. With enterprise SOA, it is wholly irrelevant whether a service is provided within the company or whether communication with another continent takes place.
- **Support for outsourcing and out-tasking.** The trend of outsourcing process steps to an

external provider that treats these process steps as a core competency is growing all the time. Using de-coupled services to map processes makes these distributed scenarios easier and faster to implement.

- **Reuse.** In the traditional approach, the only reuse achieved was that of the codes and algorithms. With SOA, the reuse of actual applications is now possible. Composite applications are made up of reusable components that can be used to form other composite applications. This allows new applications to be built with less time and resources. With regards to legacy systems, SOA allows them to be modified for reuse rather than rebuilding everything from scratch to replace them.

From the enterprise point of view, SOA would enable IKC2 systems to better react to SAF's evolving needs. The cross-departmental nature of services allows more efficient communication and collaboration among different units. Its centralised repository ensures information is accurate and up-to-date, something vital to SAF's operations. The reuse of components means faster development with reduced risk, thus the new and reliable IKC2 applications can be developed in much shorter time.

Reference Architecture Framework – Divide and Conquer

Military forces typically need to operate in diverse environment contexts – mobile devices with limited connectivity for individual soldiers, platform mounted systems, or full-scale back-office systems. The SAF's IKC2 paradigm pushes the envelope of Command and Control (C2) systems supporting military operations to even greater extents. Complex functionality of systems, diverse computing environments and fast pace of technology evolution add to the challenges. At the same time, systems need to continue to deliver capability whilst operational concepts are being explored and evolved.

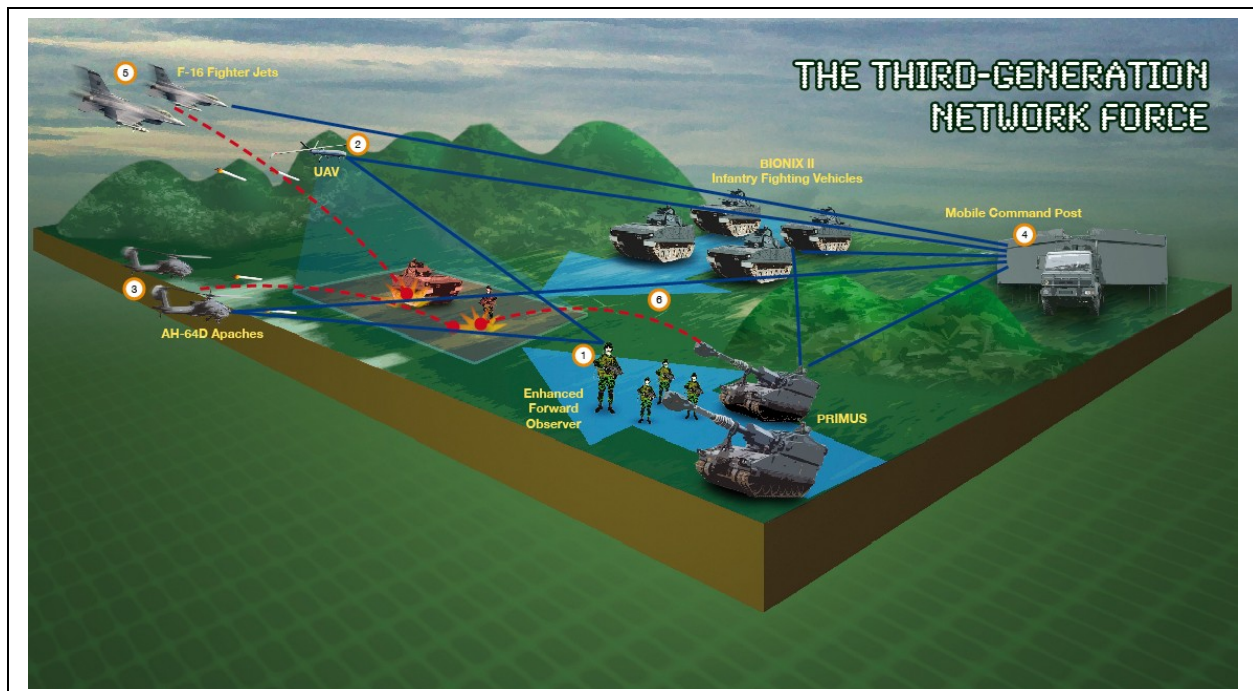


Figure 3. IKC2 Operational Landscape [5]

The Reference Architecture Framework (see Figure 4) is designed to address and manage this complex solution landscape. In order to evolve technical systems while maintaining interoperability and agility amidst this dynamic environment, the problem domain is segregated into multiple sub-domains where each sub-domain is characterised by a set of similar constraints imposed by operational requirements or technology. Within each sub-domain, a set of solution patterns (Reference Architecture) can be designed to enable integration. While we address the problem with different reference architectures in every sub-domain, we achieve overall integration across sub-domains with the Overarching Architecture. Individual project implementations (Target Architectures) can align themselves by referencing suitable Reference Architectures.

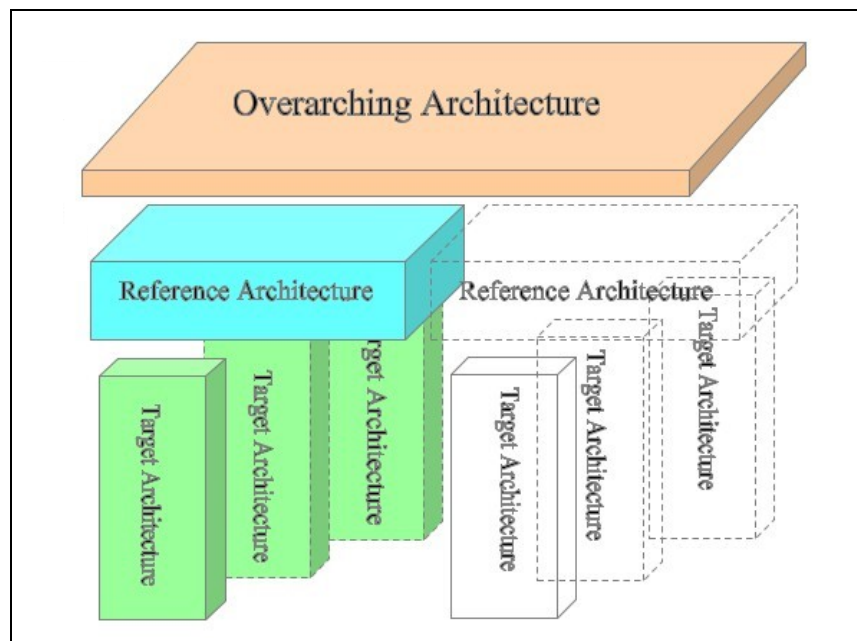


Figure 4. Reference Architecture Framework [4]

Reference Architecture is a set of cohesive, well-tested, and proven template solutions for a class of systems with similar requirements and can be applied to future problems. It consists of design considerations, architecture and solution patterns, technology standards, and reference implementations.

This concept of three levels of architecture types is useful in managing and understanding the complex solution landscape found in the MINDEF and the SAF and provides the following benefits:

- **Reuse.** The alignment of target architectures to sub-domain reference architectures and the SOA alignment at the EBA/EIA ensure that modules developed in one system can be reused in another system, referencing the same reference architecture, whenever there is a requirement. Such reuse is not limited to web services – depending on the reference architectures, system modules, server applications will also be available for reuse through reference architecture alignments.
- **Faster System Delivery Time.** The availability of tested and proven solution patterns from the reference architecture helps expedite the development and delivery of systems. Reuse of

well-tested and proven solutions ensures the quality of the delivered systems.

- **Inter-operability by Design.** The reference architecture ensures that systems referencing the same reference architecture will be inter-operable through employing standard technologies, solutions, and well-defined service and interfaces.
- **Independent Evolution of Sub-domain Architectures.** IT technologies evolve at phenomenal rates, the need to control the diversity and standardise the technologies within an enterprise led to the development of ETA. Yet, technology development is essential for the continuing development of operational capability of the enterprise. The segregation of the enterprise into sub-domains enable the technologies employed within each sub-domain to be evolved taking into consideration impacts within the domain and yet remain fairly independent of the other domains hence enabling the ETA to evolve at a faster pace.

While the Reference Architectures take care of domain alignment and integration, the Overarching Architecture provides the final overall view of the solution landscape and provides a set of solution patterns for the integration across Reference Architectures.

Reference Architecture developments

While the concept of aligning the project architecture or Target Architecture with a set of Reference Architectures is simple, the success of the framework depends on our capability to identify a set of Reference Architectures that are relevant and reliable. To address this issue, we have formulated a two-prong approach.

- **Architecture Studies and prototyping.** We initiated a series of architecture studies on deployed and currently-under-development SAF systems to identify suitable clustering of solutions. These studies look into the deployment environment of the systems, the architecture used for the solutions, the connectivity between the systems, and the similarities between the systems. Through the studies, we have identified potential clusters of solutions where we have initiated separate detailed studies to develop the Reference Architecture and prototype the architecture for those clusters.
- **Domain Best Practices.** With the adoption of the Enterprise Architecture as the Enterprise Compass, we have set-up a governance process where all project teams are required to align the technology and product usage to the enterprise technical standards (ETA) defined and maintained by a panel of domain experts. The project team is required to provide justifications for deviations from the standards. Besides technical standards compliance, the review also covers the network and system architecture to ensure system inter-operability issues and security concerns are being adequately addressed. The review also facilitates the domain experts to further refine the standards and derive suitable domain best practices based on actual project requirements and practices. While such reviews are time consuming, it had facilitated the project teams to learn from the domain experts and for the domain experts to gain the overall pictures of their domains and understanding of the ground issues experienced by the project teams. Through these review sessions, sets of best practices were identified and large architecture patterns had also surfaced. Teams of system architects and domain experts are then formed separately to further develop these best practices and architecture patterns into Reference Architectures.

The Architecture Studies approach is suitable for the identification of Reference Architectures

from the large numbers of inter-connected diverse systems deployed for the SAF. The architecture studies had identified major application clusters – Non-Real-time Command and Control systems, Command and Control systems for Battlefield Management, and Real-time Command and Control systems for various platforms. The operation environments for these clusters are significantly different from the IT environment for the MINDEF community, where relatively homogeneous corporate IT systems had converged over the years through ERP efforts.

Reference Architectures, Service Orientation, and Reuse

The Reference Architecture Framework (see Figure 4) is based on the service oriented architecture concept and supports interoperability across Reference Architectures. The RA Framework will drive the service definitions and approach to ensure coherent build-up of the various architectures.

Individual Reference Architectures will implement services using similar solution patterns using technologies most suited for the intended deployment environment for the architecture. The architecture may be web service based, component based, or based on a set of information sharing messages. The common services will be consolidated into a reuse repository for use across the Reference Architecture domain. Project teams using the Reference Architectures are to document the services that they are reusing or implementing, keeping track of the Operational processes implemented, the Information models used, the implementation technologies, limitations, and down to the actual modules implementing the services.

The service orientation and the alignment with the Reference Architecture will ensure that systems referencing the same architecture will be inter-operable and services will be reusable within the Reference Architecture domain. This brings about two additional benefits to the approach – shorten system delivery time and improved system quality due to reuse of proven solutions.

To facilitate the establishment of Reference Architectures, working groups comprising of system architects from the identified domains were set up. The working groups define, improve, and manage the configuration of the architectures, designs, and template solutions. The working groups also help to review and govern the solution implementations carried by the project teams. The working groups help to keep the Reference Architectures alive and relevant through regular reviews of the solution elements and updates as needed – both of which are critical to the success of the approach.

Based on the implementation approach described above, DSTA developed the reference architecture for non-real-time command and control information systems (see figure 5) i.e. systems where degraded service quality in terms of response time can be tolerated without critical failure. This reference architecture is built upon an SOA infrastructure, and has been designed to allow users to collaborate in a web-enabled user community. Key design considerations also included system reliability and availability, security and reusability of software components. It is three-tier architecture comprising collaborative presentation tier, application tier and enterprise tier.

A common system infrastructure and the security tier support these three tiers. The common infrastructure hosts common support services (e.g. directory service) that can be shared/reused

by systems that reference this reference architecture. The security tier takes care of the various security elements including network infrastructure security, data security, application security etc. The figure below depicts the reference architecture and its key components.

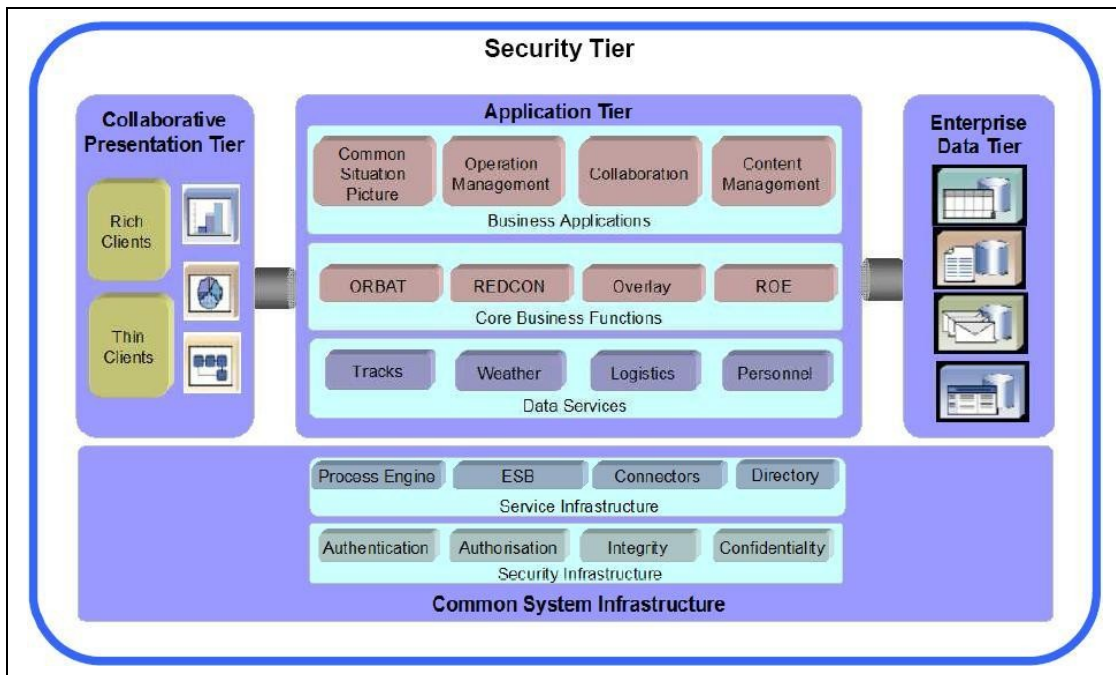


Figure 5. Non-Real-time C2 Reference Architecture

Each of the Reference Architecture must be aligned to an Operational Formulation and SAF Ops Taxonomy. Besides solution patterns, it must establish and maintain a set of business models, information models, service definitions, and technical standards to support the overall EA efforts (see Figure 6).

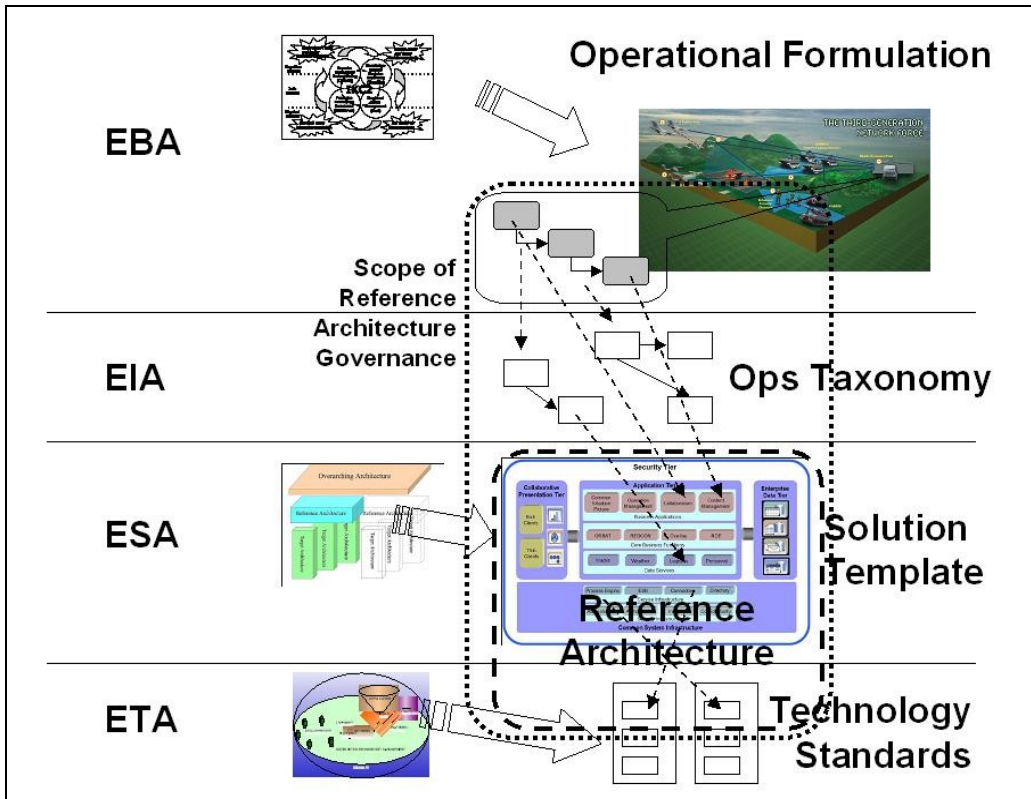


Figure 6. Reference Architecture and EA

How it's all working together – Overarching Architecture

The last crucial element of the Reference Architecture Framework is the Overarching Architecture. With the Reference Architectures focusing on the definition of services within each of the sub-domains, the Overarching Architecture is now responsible for the final integration across all the systems using the Reference Architectures (see Figure 7).

Overarching Architecture is hence an important element in the solution blueprint to achieve the overall objective of IKC2 as defined in the 3rd Generation SAF Vision.

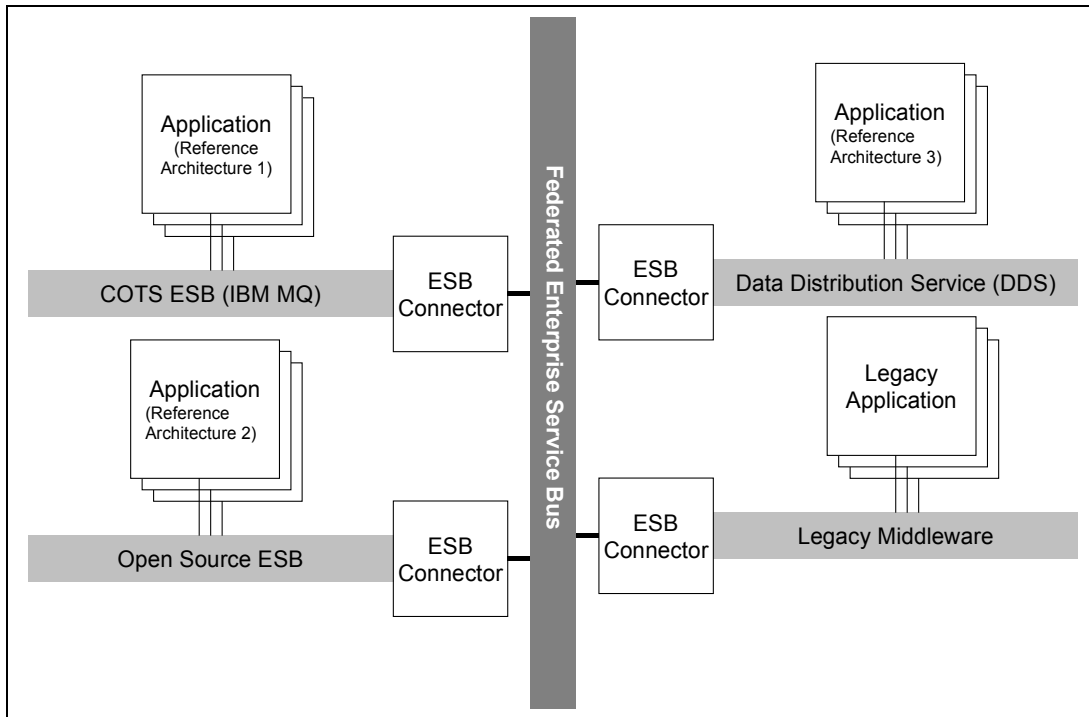


Figure 7. Federated Enterprise Service Bus as the Overarching Architecture

To achieve the objective of integrating across multiple Reference Architectures, the Overarching Architecture needs to maintain a coherent interpretation of Service Orientation across the diverse technical implementations for all Reference Architectures. The implementation solutions will need to match and mediate the service definitions between the clients and service providers, providing the bridging solutions between the difference technology standards, propagating the necessary service management information across the whole enterprise solution landscape. These are the basic functionality of an Enterprise Service Bus, except that in this case, it is used to connect multiple Service Oriented Reference Architectures – hence the name Federated Enterprise Service Bus.

Technically, the Overarching Architecture consists of the following elements (see Figure 8):

- **Network Blueprints.** The Overarching Architecture needs to define the necessary networking blueprints to provide the necessary network connectivity for implementing the IKC2 vision.
- **Networking and Security Solutions.** The Overarching Architecture needs to define a set of standard solutions to provide the necessary network connectivity between systems – such as directional microwave links, satellite connections, or various radio based data connections. Similarly, the architecture will have to specify the necessary security models and solutions for securing each of the operational domains.
- **SOA Governance and Service Development Guidelines.** Service definitions need to be aligned enterprise-wide to facilitate service orchestrations. Governance will need to be put in place to manage and guide the development of the service definitions and to co-ordinate the service access across and within each domain.
- **SOA Connectors.** While each Reference Architecture will implement the defined services

using technologies suitable for the domain, these need to be aligned and matched-up to facilitate orchestration across domains. The Overarching Architecture needs to define and develop a set of SOA connectors to facilitate the integration between the sub-domains.

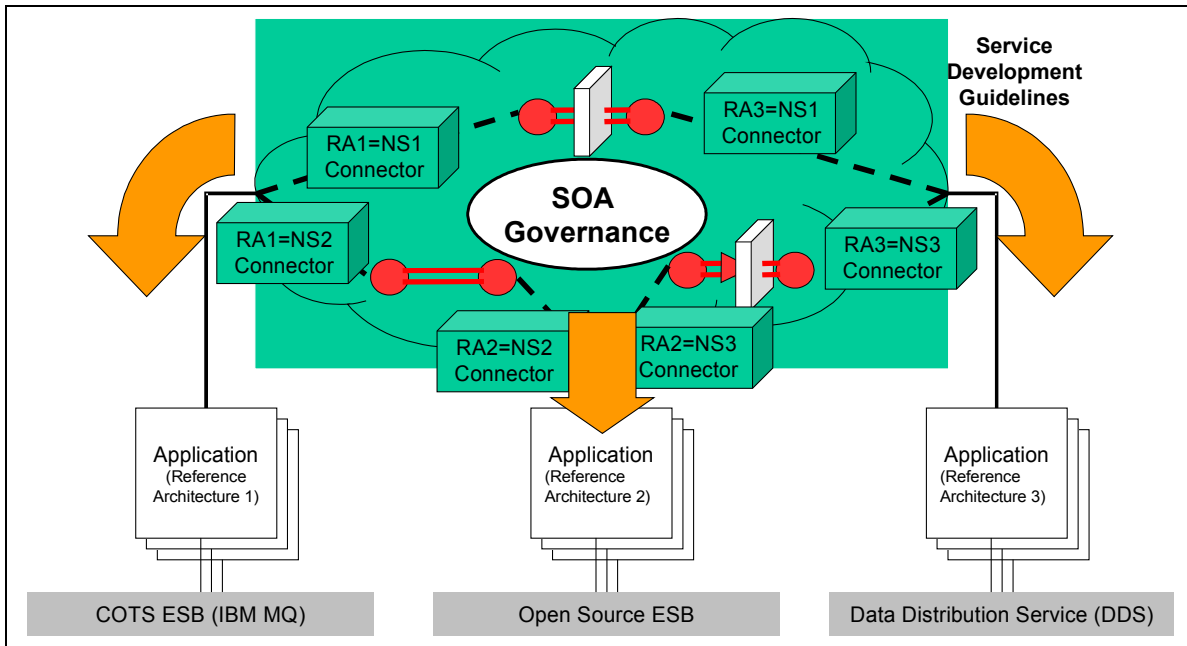


Figure 8. Vision of Federated Enterprise Service Bus

In summary, the Federated Enterprise Service Bus is our current vision of the Overarching Architecture. It meets our security requirements, supports the construction of System of Systems to implement the IKC2 vision, integrates the Reference Architectures, and governance structure and processes can be put in place for the overall architecture (see Figure 9).

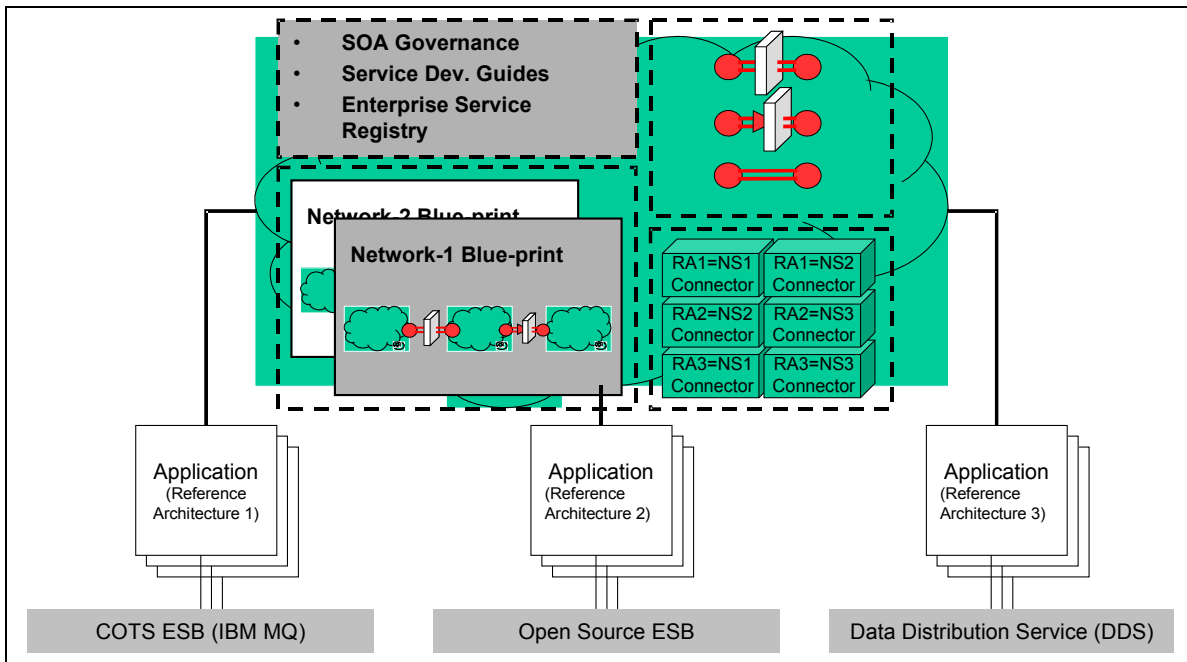


Figure 9. Components of Federated Enterprise Service Bus

Further works

We have developed a framework and the top-level solution blueprint for IKC2 vision for the MINDEF and the SAF based on the service-oriented approach. There is still a long journey ahead of us while we continue to develop the details of the solution blueprint and implement systems according to the blueprint. The needs of the MINDEF and the SAF will continue to evolve with the changing challenges. The solution blueprint will not stay static – the Reference Architectures will evolve with the evolving business needs, technology changes, and new Reference Architectures may emerge. While components of the Federated Enterprise Service Bus will continue to evolve, we believe the basic framework of the architecture will remain stable.

We will continue to explore how the Service Orientation concept can be better exploited to support the Systems of Systems architecting approach. A tighter integration of concept experimentation, System Architecting and the EA approach will also have to be developed. And, there is also a need to develop a framework to continuously evaluate the performance of the System of Systems architecture as it is being defined and implemented as part of the system verification process.

References

1. Lee, Jacqueline et al. 2003. Realising Integrated Knowledge-based Command and Control, Transforming the SAF, *Pointer Monograph*, Singapore Armed Forces.
2. Chang Chai Fung et al. 2007. The Organization Compass – Enterprise Architecture, *DSTA Horizons*.
3. Peake, Robert A. 2000. Enterprise Architecture Strategies, META Group Inc.
4. ISCC NATO Open Systems Working Group. 2005. Architecture Descriptions and Models, *NATO C3 Technical Architecture Volume 2*.
5. Gail Wan, 2008. Operationalising air-land integration, *PIONEER*, Singapore Armed Forces.

Biography

Chai Fung, Chang is Assistant Director (Masterplanning, Enterprise Architecting and Governance). She leads the Enterprise Architecting initiatives in DSTA Masterplanning and Systems Architecting, and is responsible for the establishment and support of the technical governance forum in DSTA. She holds a Master of Technology (Software Engineering) from the Institute of Systems Science, National University of Singapore (NUS). She is also a Certified Enterprise Architect by The Open Group Architecture Framework.

Pong Heng, Tan is currently a principal engineer in DSTA Masterplanning and Systems Architecting (DMSA) programme centre in DSTA. His current work involves the practice of Enterprise Architecture, and focuses on the development of Enterprise Solutions Architecture and Enterprise Technical Architecture for SAF systems. Tan holds a Masters of Engineering in Naval Architecture from the University of Tokyo.

Soh Khum, Tam is currently a senior engineer in DSTA Masterplanning and Systems Architecting (DMSA) programme centre in DSTA. Her current work involves the practice of

Enterprise Architecture, and focuses on the development of Enterprise Solutions Architecture for SAF systems. Tam holds a Masters of Science in High Performance Computation for Engineered Systems from the Singapore-MIT Alliance programme.