

20th ICCRTS: Paper Submission

Title: An Experimentation Framework for Developing Federated Data-Sharing Services Operating in Denied, Disrupted/Disconnected, Intermittent, and Limited-bandwidth (D-DIL) Environments

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Second Alternate Topic: Data, Information, and Knowledge (Topic 3)

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Abstract

Agile network-enabled command and control (C2) requires a distributed-computing infrastructure that supports conceptual model-level and systems-level integration and interoperability (I&I) capabilities. For addressing Information Dominance and Network Centric Warfare (ID/NCW) needs, a mission-driven multi-disciplinary model-based system-of-systems engineering (MBSE/SOSE) approach can help address such conceptual I&I oriented systems-engineering and mission support requirements.

The overall focus of this paper is to provide survey and overview of applicable technologies, reference models, architectures, standards, and available resources, while addressing the practical challenges of implementing a MBSE/SOSE based experimentation framework that focuses on the need for model-level I&I services. As highlighted and discussed throughout the paper, the experimentation framework is to support the development of performance metrics for algorithms and associated methods that address emerging hybrid-cloud (i.e. cloud-to-cloud) data-transport and data-mediation needs. The goal is to provide an assessment capability for a variety of mission scenarios that may include Anti-Access Area-Denial (A2/AD) operating environments where denied, disrupted/disconnected, intermittent, and limited-bandwidth (D-DIL) communications/networking conditions may be anticipated.

For developing a conceptually-integrated MBSE/SOSE approach, the survey/overview is focused towards enterprise architecture and service-oriented architecture (EA/SOA) methods and techniques. Existing EA/SOA resources are to be incorporated and tailored to the extent possible. This level of conceptual I&I, which includes baseline-systems experimentation-support capabilities, helps to facilitate a model-based understanding of the combined interaction of potential sources of degradation (e.g. non-kinetic threats) and end-effects (e.g. D-DIL conditions).

In the near-term, a virtual-networking experimentation framework is being established for providing ongoing cloud-computing MBSE/SOSE experimentation support. The focus of current work is to establish a capability to develop and assess metrics/indicators for data-synchronization services. Such assessment capabilities help ensure timely hybrid-cloud (i.e. cloud-to-cloud) information flows that may span organizational components and a wide range of participating entities. Throughout the paper, footnotes are included to assist readers with more specialized and domain-specific topics.¹

1 Note to the reader: Technical references are enclosed in square brackets and listed at the end of the paper. The superscripted footnotes provide links that help facilitate an introductory understanding of concepts and topics that may be more common in one technology domain but otherwise not familiar or as applicable to the population at large. For accessing links and enlarging graphics as desired or needed, viewing a soft-copy on a large screen is recommended.

1. Introduction and Executive Summary

As previously highlighted for a government-wide inter-agency initiative, called the Information Sharing Environment (ISE), there is a unified cross-cutting objective to provide the right information to the right stakeholder at the right place and time [1].² Such information-sharing capabilities are especially critical for Information Dominance and Network Centric Warfare (ID/NCW) efforts.³

A key consideration for ID/NCW is the model-based design and provisioning of information-sharing services specifically tailored, managed, and optimized to support well-informed maneuvering of geographically-dispersed forces.⁴ Other network-centric initiatives and methodologies share similar characteristics (e.g. network-enabled capability, network-centric organization).⁵ Thus, information and communications technology (ICT) and unified communications are key enablers for providing critical infrastructure components for information-sharing, cognitive support, and related ID/NCW services.⁶

Most recently, ID/NCW services include the incorporation of cyberwarfare and related technologies that address emerging needs.⁷ Within anti-access area-denial (A2/AD) operating environments, a variety of non-kinetic Cyber and electronic warfare (Cyber/EW) threats can degrade the communications/networking capabilities of an ID/NCW ICT framework. Thus, ID/NCW reference models, architectures, standards, and associated ICT frameworks must continue to evolve and adapt to both emerging technologies and emerging threats (e.g. Cyber/EW).⁸

From an Enterprise Architecture and Service Oriented Architecture (EA/SOA) perspective, the U.S. Navy (USN) ID/NCW strategy, roadmap and related documents discuss applicable technology focus areas and respective science and technology (S&T) objectives (STOs) [2-5].⁹ This effort concentrates on a USN ID/NCW technology focus area, identified as "Information Transport and Infrastructure (ITI)" [2].¹⁰ The three ITI STOs are considered particularly applicable: (i) ID-ITI-STO-01: Assured Connectivity and Access in all Operating Environments; (ii) ID-ITI-STO-02: Persistent Network Awareness and Control; (iii) ID-ITI-STO-03: Bandwidth-efficient Communication Capabilities.

2 Information Sharing Environment (ISE; http://en.wikipedia.org/wiki/Information_Sharing_Environment)
ISE home page (<http://www.ise.gov/>)

3 Information Dominance Corps (IDC; http://en.wikipedia.org/wiki/Information_Dominance_Corps)
Network-centric warfare (NCW; http://en.wikipedia.org/wiki/Network-centric_warfare)
NCOW (Network-Centric Operations and Warfare; <http://en.wikipedia.org/wiki/NCOW>)

4 Distributed operations (http://en.wikipedia.org/wiki/Distributed_operations)
Maneuver warfare (http://en.wikipedia.org/wiki/Maneuver_warfare)

5 Network-enabled capability (NEC; https://en.wikipedia.org/wiki/Network-enabled_capability)
Network-centric organization (https://en.wikipedia.org/wiki/Network-centric_organization)

6 Information and communications technology (ICT; https://en.wikipedia.org/wiki/Information_and_communications_technology)
Unified communications (https://en.wikipedia.org/wiki/Unified_communications)
Decision support system (https://en.wikipedia.org/wiki/Decision_support_system)
Augmented cognition (https://en.wikipedia.org/wiki/Augmented_cognition)

7 Cyberwarfare (<http://en.wikipedia.org/wiki/Cyberwarfare>)

8 Reference model (https://en.wikipedia.org/wiki/Reference_model)
Reference architecture (https://en.wikipedia.org/wiki/Reference_architecture)
Technical standard (https://en.wikipedia.org/wiki/Technical_standard)

9 Enterprise Architecture (EA; http://en.wikipedia.org/wiki/Enterprise_architecture)
Service-oriented architecture (SOA; http://en.wikipedia.org/wiki/Service-oriented_architecture)

10 U.S. Navy Information Dominance Science and Technology Objectives, 2014 (last accessed April 2015; http://www.defenseinnovationmarketplace.mil/resources/USN_ID_STO_ED1_2014_DISTA_LR.pdf)

Thus, the information transport and infrastructure (ITI) focus area and respective S&T objectives (STOs) address ID/NCW capability needs for which distributed concurrency control, data/file synchronization, data-transport management (i.e. "data in use", data streaming, traffic flow), and content delivery/distribution networking (CDN) are critical enablers.¹¹

Furthermore, agile network-enabled command and control (C2) requires a distributed-computing ITI framework that is tolerant, robust, and resilient to adverse events that may otherwise cause denied, disrupted/disconnected, intermittent, and limited-bandwidth (D-DIL) communication/networking conditions. D-DIL conditions are especially a concern for time-sensitive mission-tasks executing within contested (e.g. A2/AD) operating environments. In such situations, an emerging diversity and growing number of types of non-kinetic (e.g. Cyber/EW) and kinetic attacks can induce a corresponding variety of different types of D-DIL conditions. To address such emerging threats, there is an emerging need to more explicitly model and understand dynamically-changing types of sources of degradation that can cause different types of D-DIL conditions that impact mission success.

The focus of current work, as described herein, is to survey cloud-based and related distributed-computing technologies, reference models, architectures, resources, and capabilities.¹² Of particular interest are models and resources that can be utilized for incremental continuous-improvement of a persistent converged-infrastructure with standardized generically-defined shared-services.¹³ The goal is to provide a model-based system-of-systems engineering (MBSE/SOSE)¹⁴ oriented approach that can help to better model, characterize, and minimize the operational impact of such ID/NCW and A2/AD related events that can degrade ID/NCW ITI frameworks and cause D-DIL conditions which impact mission performance. Thus, such models, methods, and techniques help to identify, represent, and optimize the respective value-chains and enable performance engineering capabilities that address both functional and non-functional requirements.¹⁵ Application performance engineering is particularly of interest, due to the current focus on methods "to develop and test application performance in various settings, including mobile computing, the cloud, and conventional information technology (IT)".¹⁶

A high-level view of the DoD Information Enterprise Architecture (DoD IEA) is provided in figure 1 (from [6]).¹⁷ As highlighted by the diagram, trusted communication, information-exchange, and NetOps

11 Distributed concurrency control (http://en.wikipedia.org/wiki/Distributed_concurrency_control)

Data synchronization (https://en.wikipedia.org/wiki/Data_synchronization)

Data in Use (http://en.wikipedia.org/wiki/Data_in_Use)

Content delivery network (CDN; https://en.wikipedia.org/wiki/Content_delivery_network)

12 Cloud computing (https://en.wikipedia.org/wiki/Cloud_computing)

Distributed computing (https://en.wikipedia.org/wiki/Distributed_computing)

Computer network (https://en.wikipedia.org/wiki/Computer_network)

Cyberspace (<https://en.wikipedia.org/wiki/Cyberspace>)

13 Continual improvement process (https://en.wikipedia.org/wiki/Continual_improvement_process)

Converged infrastructure (https://en.wikipedia.org/wiki/Converged_infrastructure)

Shared services (https://en.wikipedia.org/wiki/Shared_services)

14 Model-driven engineering (MDE; http://en.wikipedia.org/wiki/Model-driven_engineering)

System of systems engineering (SOSE; http://en.wikipedia.org/wiki/System_of_systems_engineering)

15 Value chain (https://en.wikipedia.org/wiki/Value_chain)

Performance engineering (https://en.wikipedia.org/wiki/Performance_engineering)

Requirement (<https://en.wikipedia.org/wiki/Requirement>)

Non-functional requirement (https://en.wikipedia.org/wiki/Non-functional_requirement)

16 Application performance engineering (https://en.wikipedia.org/wiki/Application_performance_engineering)

17 Department of Defense Information Enterprise Architecture (DoD IEA;
<http://dodcio.defense.gov/TodayinCIO/DoDInformationEnterpriseArchitecture.aspx>)

capabilities are enabled by a persistent infrastructure, such as the Global Information Grid (GIG).¹⁸ Thus, as highlighted by the figures and references, ID/NCW models continue to evolve as they work to incorporate new technologies and address emerging threats (e.g. Cyber/EW). As highlighted by the number of diagrams and views within this paper, view models and their respective architecture frameworks (e.g. DoDAF, TOGAF) are integral to the development of ITI support services.¹⁹

Much progress has been made towards an evolutionary transformation into an operational DoD IEA framework that addresses emerging Cyber/EW threats while supporting ID/NCW capabilities. Within this context of maturing ITI framework capabilities, there are a growing number of fundamental challenges that include both the need for addressing functional requirements for improved functional capabilities, while also addressing the non-functional requirements (e.g. "-ilities") that help to further improve systems-engineering support, responsiveness, and agility.

The STOs, as discussed previously, "provide a basis for harmonizing ID S&T objectives with the other Navy Enterprises to avoid duplicative development" [2]. For incrementally improving and evolving such harmonization capabilities, MBSE/SOSE processes and methods will continue to be a critical enabling technology for ensuring mission readiness and responsive systems-engineering support.

Figure 2 (from [7]), illustratively highlights an example of the types of cloud-based solutions currently being explored and developed for addressing the above discussed ID/NCW capability needs and S&T priorities. A number of other ID/NCW focused efforts and initiatives further illustrate the growing role of unmanned systems (UxS) [8-16].²⁰ In particular, such example efforts highlight S&T ITI challenges associated with developing ID/NCW ITI frameworks that support UxS intensive maritime-afloat and aerial-networking needs within A2/AD operating areas where D-DIL conditions may be encountered.

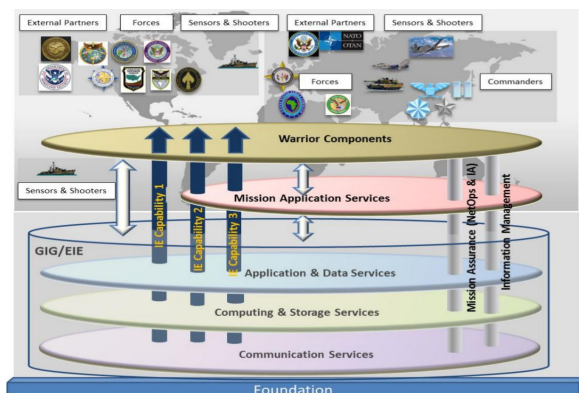


Fig. 1 Illustration of DoD IEA

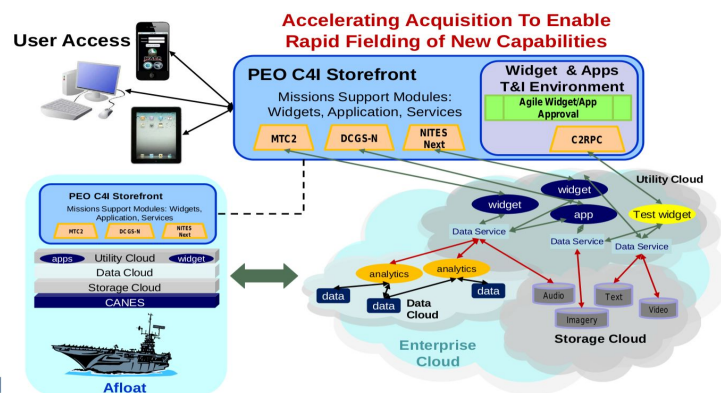


Fig. 2 Responsive SE: Cloud-Based Widgets and Apps

The critical need for ITI oriented research is also highlighted by a recent Office of Naval Research (ONR) initiative, called "Exchange of Actionable Information at the Tactical Edge (EAITE)" [17]. As stated within a description of EAITE, "the S&T challenges are as follows: (i) Ability to distribute

- 18 Information exchange (https://en.wikipedia.org/wiki/Information_exchange)
NetOps (<https://en.wikipedia.org/wiki/NetOps>)
Global Information Grid (https://en.wikipedia.org/wiki/Global_Information_Grid)
- 19 View model (https://en.wikipedia.org/wiki/View_model)
Department of Defense Architecture Framework (DoDAF;
https://en.wikipedia.org/wiki/Department_of_Defense_Architecture_Framework)
The Open Group Architecture Framework (TOGAF;
https://en.wikipedia.org/wiki/The_Open_Group_Architecture_Framework)
- 20 SPAWAR Robotics, home page, acc'd April 2015
(<http://www.public.navy.mil/spawar/Pacific/Robotics/Pages/default.aspx>)

functionality based on mission and information needs without centralized, single-point-of-failure control or dependence upon reachback communications capability; (ii) Algorithms to effectively control information dissemination given competing mission needs, changing network state, and resource availability; (iii) Timely collection and efficient sharing of relevant network awareness in dynamic communication environments (not just local connectivity information); (iv) Effectively adapting to different and heterogeneous underlying network communication connectivity" [17]. Thus, for addressing such S&T challenges, improvements to cross-cutting data-synchronization, data-transport, and data-mediation services are considered critical for the way-ahead.

Figure 3 through figure 5 (from [18]), highlight the type of ITI framework components and respective communication/networking services that are the focus of the current work. Of particular interest are long-haul RF/microwave line-of-sight (LOS) components of land-air-sea links deployed within an area of responsibility (AOR) and operating within a distributed ITI framework (i.e. ad-hoc network of airborne-networking backbone and tactical-edge nodes).²¹ As highlighted by the upper block of the diagram in figure 4, such infrastructure components focus on the "off-board communication links" that support platform-to-platform communication and networking capabilities.

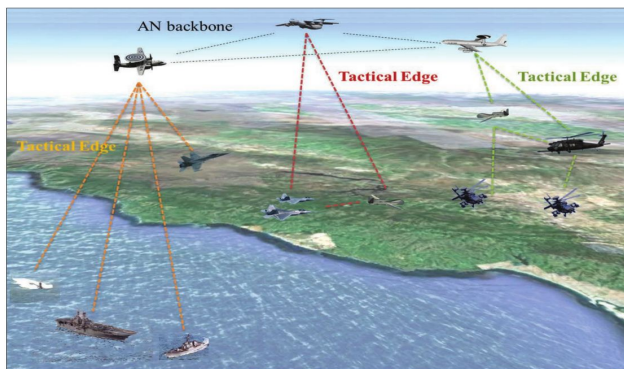


Fig. 3 Airborne-Networking (AN) Architecture: Example

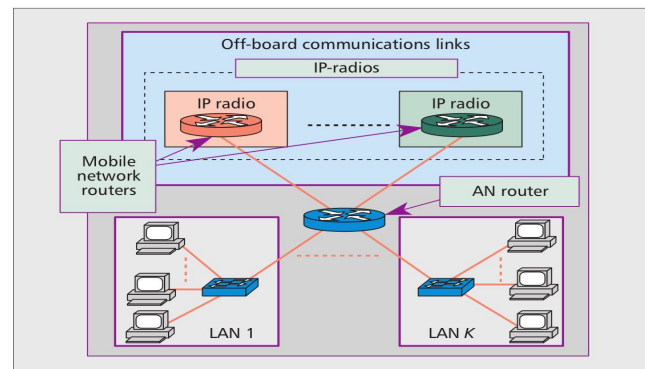


Fig. 4 Airborne Platform Architecture: Example

Figure 5 (also from [18]) illustrates an example of a type of model-based virtual-network experimentation architecture that facilitates assessment of ITI frameworks relative to possible D-DIL related events that may impact and degrade mission-critical information-exchange capabilities. As will be highlighted for other types of resources, there is a need to help accelerate and improve the ability to leverage such resources and accelerate their co-evolution towards a more mature and capable cloud-based ITI framework that addresses S&T challenges and priorities.

Figure 6, from the Joint Communication Simulation System (JCSS) home page, highlights another example GOTS/COTS resource.²² The JCSS tool similarly enables analysis and assessment of expected (i.e. baseline) ID/NCW ITI framework capabilities. As illustrated, JCSS enables stakeholders to assess performance, relative to operational scenarios and expected loads (i.e. traffic generation models).²³

Note that JCSS has limited support for mission scenarios that include potential D-DIL related Cyber/EW events and associated degradation of the NCW/ID infrastructure that may impact ID/NCW operations. Furthermore, I&I and cloud-based ITI framework challenges, as previously discussed, are

21 Area of responsibility (AOR; https://en.wikipedia.org/wiki/Area_of_responsibility)

22 JCSS Home Page (<http://www.disa.mil/Mission-Support/Enterprise-Engineering/JCSS/About-Us>)

Government off-the-shelf (GOTS; https://en.wikipedia.org/wiki/Government_off-the-shelf)

Commercial off-the-shelf (COTS; https://en.wikipedia.org/wiki/Commercial_off-the-shelf)

23 Network traffic simulation (https://en.wikipedia.org/wiki/Network_traffic_simulation)

Traffic generation model (https://en.wikipedia.org/wiki/Traffic_generation_model)

not yet a consideration.²⁴ Thus, the open S&T challenge for how JCSS might best co-evolve with other related resources (e.g. virtual-network M&S). Such ITI oriented challenges are the focus of the work described herein. In particular, this survey/overview and discussion works to address the question of how to best develop a mission-driven experimentation-based S&T framework that includes associated measures of performance/effectiveness (MOP/MOE) metrics/indicators and enables continuous improvement of cloud-based ITI framework services.

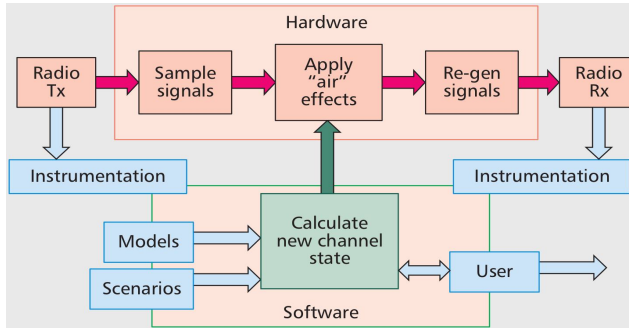


Fig. 5 Virtual-Network M&S Architecture: Example

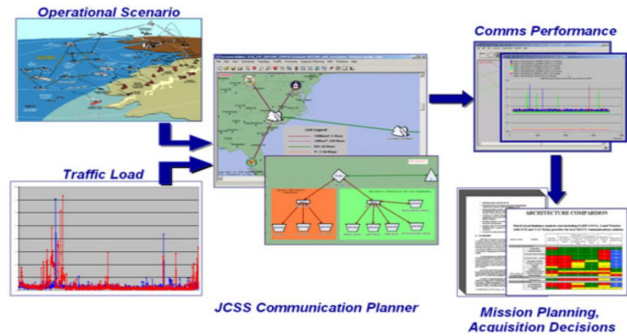


Fig. 6 JCSS: Operational Workflow

As highlighted within figures 1-6 and the following sections, much progress has been made within a range of domains and areas of specialization (i.e. domains of discourse), wherein each separately addresses various aspects of overarching DoD IEA and associated ID/NCW ITI S&T needs.²⁵

The goal is to incrementally leverage the current trend towards virtualization (i.e. abstraction, encapsulation) of system functions.²⁶ This trend towards virtualization is complicated by the variety of types of capabilities and methods that support the decoupling of implementation details from more application-specific and hardware-specific constraints. For example, hypervisors and other types of virtual machine (VM) managers provide the basis for hardware virtualization.²⁷ Network functions virtualization (NFV), which typically includes network virtualization and I/O virtualization, further incorporates software-defined networking (SDN) and related technologies/methods.²⁸ Note that other types of methods/techniques are utilized for virtualizing application and operating-system services.²⁹

Ideally, from a modeling perspective, the payoff of model-based virtualization is twofold: (i) provides an ability to extend configuration management methods and techniques to include dynamic context-dependent reconfiguration, provisioning, and binding of physical resources for the respectively defined virtual entities;³⁰ (ii) enables the definition and use of semantically grounded and correct

24 System integration (https://en.wikipedia.org/wiki/System_integration)

Interoperability (<https://en.wikipedia.org/wiki/Interoperability>)

25 Domain (software engineering) (https://en.wikipedia.org/wiki/Domain_%28software_engineering%29)

Domain of discourse (https://en.wikipedia.org/wiki/Domain_of_discourse)

26 Virtualization (<https://en.wikipedia.org/wiki/Virtualization>)

Abstraction (computer science) (https://en.wikipedia.org/wiki/Abstraction_%28computer_science%29)

Encapsulation (https://en.wikipedia.org/wiki/Encapsulation_%28object-oriented_programming%29)

27 Hypervisor (<https://en.wikipedia.org/wiki/Hypervisor>)

Virtual machine (VM; https://en.wikipedia.org/wiki/Virtual_machine)

Hardware virtualization (https://en.wikipedia.org/wiki/Hardware_virtualization)

28 Network functions virtualization (NFV; https://en.wikipedia.org/wiki/Network_functions_virtualization)

Network virtualization (https://en.wikipedia.org/wiki/Network_virtualization)

I/O virtualization (https://en.wikipedia.org/wiki/I/O_virtualization)

29 Application virtualization (https://en.wikipedia.org/wiki/Application_virtualization)

Operating-system-level virtualization (https://en.wikipedia.org/wiki/Operating-system-level_virtualization)

30 Configuration management (CM; https://en.wikipedia.org/wiki/Configuration_management)

representations.³¹ For example, standards such as the Object Management Group (OMG) knowledge discovery meta-model, have been defined to help address the need for semantic I&I support.³²

Thus, information-exchange standards (e.g. XML, XML Schema) and semantically-grounded reference models (e.g. conceptual schemas, ontologies) can help facilitate the creation and evolutionary development of optimized knowledge representation and reasoning (e.g. RDF, semantic reasoner, OWL) capabilities.³³ Over time, this further enables opportunities for incremental semantic alignment, refactoring and transformation to conceptually interoperable models.³⁴

Ideally, over time, such reference models and respective implementations will minimize unnecessary "conceptual coupling", while supporting a high-degree of conceptual cohesion where there are necessary functional couplings of system services (e.g. application services, platform services, infrastructure services, networking services, data services).³⁵ This type of approach further enables content-centric, information-centric, named-domain networking (i.e. CCN, ICN, NDN) and related emerging capabilities.³⁶ Such conceptual reference models, architectures, and methods, enable continuous model-based optimization, while maximizing system quality attributes (e.g. service assurance, servicability, adaptability, agility, reuse) and minimizing maintenance, sustainment constraints, long-term costs, and undesirable outcomes.³⁷

Two recent project tasks motivate the desire to improve I&I capabilities and co-evolve existing ID/NCW ITI framework resources and components: (i) Recent R&D effort to develop a logical encapsulation of "C2 data-Synchronization Services (C2SS)" for supporting technology transition of data-synchronization algorithms and methods; (ii) Systems engineering efforts working to adopt and tailor rapidly maturing (and evolving) virtualization technologies (e.g. cloud computing, software defined environments, cognitive networks).

Provisioning (<https://en.wikipedia.org/wiki/Provisioning>)

Resource allocation (https://en.wikipedia.org/wiki/Resource_allocation)

31 Semantics (<https://en.wikipedia.org/wiki/Semantics>)

Categorization (<https://en.wikipedia.org/wiki/Categorization>)

Symbol grounding problem (https://en.wikipedia.org/wiki/Symbol_grounding_problem)

32 Knowledge Discovery Metamodel (KDM; https://en.wikipedia.org/wiki/Knowledge_Discovery_Metamodel)

Semantic data model (https://en.wikipedia.org/wiki/Semantic_data_model)

Semantic integration (https://en.wikipedia.org/wiki/Semantic_integration)

Semantic interoperability (https://en.wikipedia.org/wiki/Semantic_interoperability)

33 XML (Extensible Markup Language; <https://en.wikipedia.org/wiki/XML>)

XML schema (https://en.wikipedia.org/wiki/XML_schema)

Conceptual schema (https://en.wikipedia.org/wiki/Conceptual_schema)

Ontology (information science) (https://en.wikipedia.org/wiki/Ontology_%28information_science%29)

Web Ontology Language (OWL; https://en.wikipedia.org/wiki/Web_Ontology_Language)

Knowledge representation and reasoning (KR; https://en.wikipedia.org/wiki/Knowledge_representation_and_reasoning)

Resource Description Framework (RDF; https://en.wikipedia.org/wiki/Resource_Description_Framework)

Semantic reasoner (https://en.wikipedia.org/wiki/Semantic_reasoner)

34 Code refactoring (https://en.wikipedia.org/wiki/Code_refactoring)

Conceptual interoperability (https://en.wikipedia.org/wiki/Conceptual_interoperability)

35 Coupling (computer programming) (https://en.wikipedia.org/wiki/Coupling_%28computer_programming%29)

Loose coupling (https://en.wikipedia.org/wiki/Loose_coupling)

Cohesion (computer science) (https://en.wikipedia.org/wiki/Cohesion_%28computer_science%29)

36 Content centric networking (CCN; https://en.wikipedia.org/wiki/Content_centric_networking)

Information-centric networking (ICN; https://en.wikipedia.org/wiki/Information-centric_networking)

Named data networking (NDN; https://en.wikipedia.org/wiki/Named_data_networking)

37 Continual improvement process (https://en.wikipedia.org/wiki/Continual_improvement_process)

List of system quality attributes (https://en.wikipedia.org/wiki/List_of_system_quality_attributes)

Section two of this paper discusses such previous and ongoing work. This sets the context for the body of the paper (i.e. section three through section seven) that provides an abbreviated survey and overview of related work that addresses common objectives for developing ID/NCW ITI framework capabilities. Thus, these additional sections address the need for awareness and at least conceptual points of reference, regarding such overlapping technologies, reference models, and resources. The goal is to align reference models and standards that have otherwise not been integrated or incorporated into a more general model-based ITI framework that leverages complementary aspects of the functions and services provided by each respective application domain and resource.

Sections three and four review the most immediate opportunity for co-evolving the code-base of the federated data sharing (i.e. content discovery and retrieval) capabilities of the DCGS (Distributed Common Ground System) Integration Backbone (DIB) (i.e. section three) and emerging cloud-computing frameworks (i.e. section four). Much of the code-base for the DIB was recently open-sourced. The open-source version is called the Distributed Data Framework (DDF).³⁸ With a focus on DDF/DIB, sections three and four review federated data sharing, cloud-computing technologies, and example frameworks such as the PEOC4I/SPAWAR tactical cloud - reference implementation (TC-RI).

Thus, sections three and four highlight that the DDF/DIB can be viewed as an open resource which can readily evolve and provide improved cross-cutting hybrid-cloud (i.e. cloud-to-cloud) services that include inter-dependent user-to-user requirements that span across OSI protocol-stack service domains (e.g. session, transport, network, data, physical).³⁹ Of particular interest are transport-layer types of services (e.g. connection-oriented data stream support, tunneling protocols) and transport models.⁴⁰

Such hybrid-cloud services need to include support of distributed mission-specific workflow that spans across separately instantiated cloud-computing domains (e.g. platform-specific private clouds, multi-platform community clouds). From a component-based software engineering perspective, this type of ITI component can act as an adaptive enterprise service bus (ESB) for hybrid-cloud configurations.⁴¹

Within the context of cloud-computing technologies and reference models (section 4), recent developments and trends within the rapid evolution of virtualization technologies are also reviewed. A subsection (section 4.2) reviews the rapid maturity of virtualization for both data/storage and networking functionality. For example, emerging software defined networking (SDN) technologies and standards (e.g. OpenStack/Neutron, OpenFlow) are becoming more widely available.⁴² For wireless networks, network functions virtualization (NFV) tends to naturally incorporate software defined radio (SDR) and cognitive radio technologies.⁴³

38 Distributed Data Framework (DDF; <http://codice.github.io/ddf/>)

39 OSI model (https://en.wikipedia.org/wiki/OSI_model)

Transport layer (https://en.wikipedia.org/wiki/Transport_layer)

40 Connection-oriented communication (https://en.wikipedia.org/wiki/Connection-oriented_communication)

Tunneling protocol (https://en.wikipedia.org/wiki/Tunneling_protocol)

Transport network (https://en.wikipedia.org/wiki/Transport_network)

Spoke-hub distribution paradigm (https://en.wikipedia.org/wiki/Spoke-hub_distribution_paradigm)

41 Component-based software engineering (CBSE; https://en.wikipedia.org/wiki/Component-based_software_engineering)

Enterprise service bus (ESB; https://en.wikipedia.org/wiki/Enterprise_service_bus)

Hybrid cloud (https://en.wikipedia.org/wiki/Cloud_computing#Hybrid_cloud)

42 Software-defined networking (SDN; https://en.wikipedia.org/wiki/Software-defined_networking)

OpenStack/Neutron (https://en.wikipedia.org/wiki/OpenStack#Networking_.28Neutron.29)

OpenFlow (<https://en.wikipedia.org/wiki/OpenFlow>)

43 Software-defined radio (SDR; https://en.wikipedia.org/wiki/Software-defined_radio)

Cognitive radio (CR; https://en.wikipedia.org/wiki/Cognitive_radio)

Dynamic spectrum management (DSM; https://en.wikipedia.org/wiki/Dynamic_spectrum_management)

Thus, the cloud-computing section also reviews the emergence of cloud-based software defined environments (SDE) that enable the creation of reconfigurable cognitive networking models and associated ITI frameworks.⁴⁴ Of critical interest for this effort is the ability to eventually leverage SDE and cognitive network models for enabling adaptive and continuously optimizing distributed-computing ITI framework services. Within the section, examples of such capabilities are highlighted.

For purposes of this paper, SDE and related developments (e.g. cognitive networks) are currently anticipated and planned for future work. The immediate goal is to establish an experimentation capability that focuses on virtual networks of existing resources for which there are opportunities to perform initial experiments that can enable the creation and evaluation of performance metrics that focus on assessing different types of hybrid-cloud data-transport and data-mediation capabilities. While working to develop a hands-on experimentation capability that consists of virtual networks of different types of cloud configurations (e.g. hybrid-clouds), SDE and other types of emerging ITI framework technologies (e.g. cognitive networks) are to be incorporated and road-mapped to the extent possible.

Section five highlights examples of workflow support capabilities that incorporate adaptive ESB capabilities within the context of standardized business rules (i.e. heuristics) and workflow engines (e.g. WS-BPEL Engine), thus enabling integrated workflow and business process management⁴⁵. The incorporation of workflow helps to better identify, represent, and manage key performance parameters (KPPs), from which performance measures and indicators can be developed and utilized for assessing/monitoring the overall quality of service (QoS)⁴⁶. Standardized workflow patterns and task lists (e.g. UJTL/UNTL, METL), as well as, recent M&S standards (e.g. coalition battle management language) are highlighted as example reference models and standards that help to better incorporate mission-execution needs and priorities within this type of mission-support ID/NCW infrastructure.⁴⁷

Section six discusses examples for development and use of distributed computing (e.g. cloud) metrics, indicators and capability assessment models. Due to the current focus and emphasis on cloud-computing frameworks, National Institute of Standards and Technology (NIST) cloud-computing metrics are the primary focus of this section. Within the context of such metrics-oriented models and taxonomies, an example of a "cloud service capability assessment framework" is also highlighted.

Section seven reviews example reference models and related efforts for domains and use-cases that apply to tactical mission-execution and workflow support. The examples include both data-transport related concerns (e.g. response time, latency) and associated metrics. The incorporation of such application-oriented reference-models and standards, helps to assist the process of working through the conceptual integration of the respective models, standards, and mission performance metrics/indicators.

44 Cognitive network (CN; https://en.wikipedia.org/wiki/Cognitive_network)

45 Workflow (<https://en.wikipedia.org/wiki/Workflow>)

Workflow management system (WfMS; https://en.wikipedia.org/wiki/Workflow_management_system)

Business rule (https://en.wikipedia.org/wiki/Business_rule)

Heuristic (computer science) (https://en.wikipedia.org/wiki/Heuristic_%28computer_science%29)

46 Key Performance Parameters (KPPs; https://en.wikipedia.org/wiki/Key_Performance_Parameters)

Performance measurement (https://en.wikipedia.org/wiki/Performance_measurement)

Performance indicator (https://en.wikipedia.org/wiki/Performance_indicator)

Service quality (https://en.wikipedia.org/wiki/Service_quality)

47 Workflow patterns (https://en.wikipedia.org/wiki/Workflow_patterns)

Universal Joint Task List (UJTL; https://en.wikipedia.org/wiki/Universal_Joint_Task_List)

Joint Mission Essential Task List (JMETL) Development Handbook (www.dtic.mil/dtic/tr/fulltext/u2/a331999.pdf)

Battle management language (https://en.wikipedia.org/wiki/Battle_management_language;

http://www.sisostds.org/DigitalLibrary.aspx?Command=Core_Download&EntryId=41767)

Section eight is intended to help communicate and discuss the more long-term aspects of this ongoing ITI oriented research effort. In the near-term, there are a considerable number of S&T challenges associated with co-evolving data-transport capabilities of existing DoD/IC federated data-sharing resources (e.g. DDF/DIB) and emerging maritime-afloat cloud-based ITI frameworks (e.g. TC-RI). While incrementally addressing such challenges, the goal is to more effectively address the need to establish algorithm development and assessment capabilities. Due to the longer term aspects of developing this type of ITI framework, S&T roadmaps are needed to schedule the incorporation of these sorts of possibly more disruptive and transformational technology developments. In principle, the desired MBSE/SOSE approach should anticipate both the near-term, as well as, the longer-term transformation towards more fully virtualized and resilient distributed-computing infrastructures.

Section eight also addresses the need to remain focused on establishing improved experimentation support for performance-metric based assessments of hybrid-cloud data-transport and data-mediation related algorithms. As discussed, this type of logical encapsulation and deployment of algorithmic support-services is not currently available. The goal is to help develop an ITI experimentation framework wherein families (e.g. taxonomies) of algorithms and methods can be readily assessed in terms of mission-execution and workflow support. Ideally, this type of capability can help to continuously improve performance, address emerging challenges, and assess performance over a diverse range of D-DIL types of conditions that may be encountered while operating within A2/AD environments. The current tactic is to focus on co-evolution of existing resources (e.g. DDF/DIB, TC-RI) while working through the development of S&T roadmaps that help facilitate the way ahead.

Section nine summarizes the current status of the experimentation framework effort, within the context of the assortment of S&T challenges reviewed within the body of the paper. This section wraps up with a status report and discussion of the rationale, milestones, and technical details for the incremental co-evolution of existing ID/NCW ITI resources (e.g. DDF/DIB, TC-RI).

Section ten discusses future work and the way-ahead. The remainder of the paper includes sections for acknowledgements, an appendix, and list of technical references.

2. Background: Previous and Ongoing Efforts

Figure 7 (from [19]) and figure 8 (from [20], also in [21]) highlight previous example projects that help illustrate the motivation for the work discussed herein. Although the manned and UxS platforms and sensors may be characteristically different sizes and different levels of fidelity, the goals and objectives of the projects were quite similar, in terms of time-sensitive targeting (TST) and tactical ISR support.

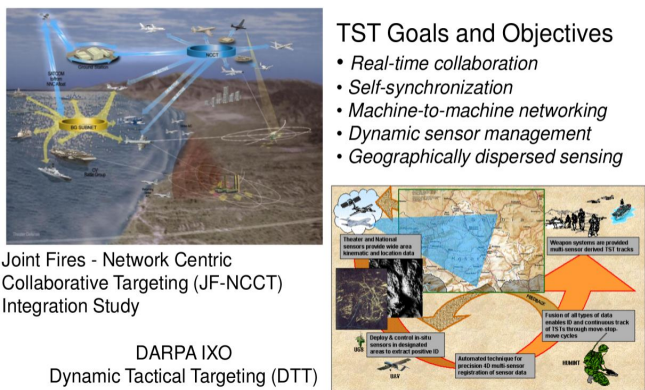


Fig. 7 Time-Sensitive Targeting (TST): Examples (circa 2005)

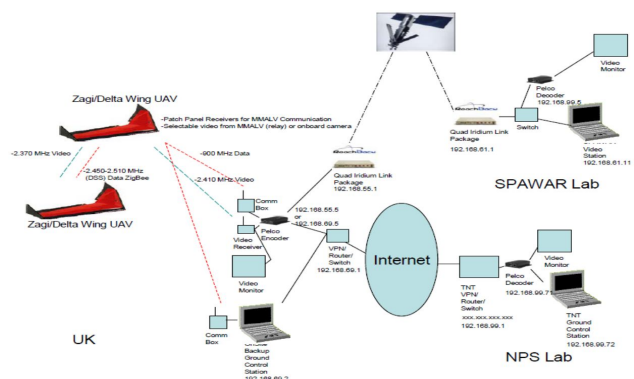


Fig. 8 Network Diagram of Reachback Exp. (circa 2006)

For the Joint Fires - Network Centric Collaborative Targeting (JF-NCCT) integration study, I&I aspects of distributed TST capabilities were of primary concern. From a system-of-systems perspective, the integration study assessed how to best align the Navy led Joint Fires Networking (JFN) net-centric tactical ISR support capabilities with a NCCT type of system.⁴⁸ The Dynamic Tactical Targeting (DTT) effort primarily focused on providing dynamic tactical ISR support at the local forward-area level and longer time-lags (e.g. reachback ashore). For both efforts, improved I&I and NCW support services were developed, demonstrated, and transitioned.

Although the JF-NCCT and DTT efforts had their own specific focus, they shared a common intent⁴⁹ in terms of TST goals/objectives: (i) Enable real-time coordination, collaboration, and orchestration of stakeholders;⁵⁰ (ii) Facilitate self-organization and decentralization (i.e. self-synchronization) for both the human and machine agents;⁵¹ (iii) Support machine-to-machine connectivity and networking to the extent possible;⁵² (iv) Provide dynamic sensor networking and management capabilities;⁵³ (v) Leverage geographically dispersed sensors that could potentially be accessed and utilized for distributed sensor-fusion and related NCW support.⁵⁴ As previously mentioned, non-functional requirements such as architectural modeling, process modeling, and I&I, where also within the scope of these S&T efforts. Joint Task Force (JTF/CJTF) related process-modeling efforts were also performed as separate tasks that relate to the overarching MBSE/SOSE and EA/SOA aspects of this previous work.⁵⁵

During this time period (circa 2005), baseline military doctrine for TST related mission-threads, tactics, techniques, and procedures (TTPs), and standard operating procedures (SOPs) were not available.⁵⁶ Since that time, standardized operational and procedural (i.e. process) focused documentation (e.g. JP 3-60 Joint Targeting) is readily available through the Joint Electronic Library (JEL) and other sources.⁵⁷ Thus, for further improving tactical ISR (e.g. TST) support capabilities, experimentation frameworks can, in principle, readily incorporate such standardized methods and associated measures/metrics/indicators of performance for developing process models (e.g. mission-threads, business logic) that can be evaluated and assessed within the context of possible D-DIL conditions, as may be encountered within A2/AD related scenarios. Ideally, such a framework

48 NCCT (<http://www.comceptinc.com/L3concept/NCCT.htm>; http://www.objectivity.com/wp-content/uploads/Objectivity_CS_L3.pdf)

49 Intent (military) (https://en.wikipedia.org/wiki/Intent_%28military%29)

50 Coordination (<https://en.wikipedia.org/wiki/Coordination>)

Collaboration (<https://en.wikipedia.org/wiki/Collaboration>)

Orchestration (computing) (https://en.wikipedia.org/wiki/Orchestration_%28computing%29)

51 Self-organization (<https://en.wikipedia.org/wiki/Self-organization>)

Decentralization (<http://en.wikipedia.org/wiki/Decentralization>)

Command by negation (http://en.wikipedia.org/wiki/Command_by_negation)

52 Machine to machine (M2M; https://en.wikipedia.org/wiki/Machine_to_machine)

53 Wireless sensor network (http://en.wikipedia.org/wiki/Wireless_sensor_network)

Sensor grid (http://en.wikipedia.org/wiki/Sensor_grid)

Sensor web (http://en.wikipedia.org/wiki/Sensor_web)

54 Sensor fusion (https://en.wikipedia.org/wiki/Sensor_fusion)

Data fusion (https://en.wikipedia.org/wiki/Data_fusion)

Information integration (https://en.wikipedia.org/wiki/Information_integration)

55 Joint Task Force (JTF; https://en.wikipedia.org/wiki/Joint_Task_Force)

Process modeling (https://en.wikipedia.org/wiki/Process_modeling)

Standard operating procedure (SOP; https://en.wikipedia.org/wiki/Standard_operating_procedure)

56 Military doctrine (http://en.wikipedia.org/wiki/Military_doctrine)

Military tactics (http://en.wikipedia.org/wiki/Military_tactics; Naval tactics)

57 Joint Electronic Library (JEL; http://www.dtic.mil/doctrine/new_pubs/jointpub_operations.htm)

incorporates an executable-architecture comms/networking assessment type of capability (e.g. JCSS).⁵⁸

Figure 8 (from [20], also in [21]) highlights an S&T effort that assessed COTS/GOTS global-reachback capabilities that may be readily utilized by miniature/micro aerial vehicle (MAV) platforms.⁵⁹ Much of the focus of this MAV related work has been towards developing interoperable open-source sensor-net frameworks that incorporate sensor-package workbench capabilities [21-22].

A common ID/NCW ITI experimentation framework would have helped facilitate the development of these example variants of TST and tactical-ISR ITI configurations, while also providing an ability to gain additional insights using operationally-realistic analysis capabilities. With emerging ICT and associated ITI virtualization capabilities (e.g. cloud computing, reconfigurable cognitive networks, software defined environments), this type of incremental S&T development, experimentation, and assessment process can become a common standard practice.

Figures 9-10 (from [23]) are diagrams from a previous effort that participated in the updating of DoDAF from a version that predated EA/SOA methods and techniques, to a version (DoDAF 2.0) that more effectively supports service-oriented systems-engineering efforts that incorporate standardized multi-layered (e.g. presentation, business-logic, data) EA/SOA frameworks.⁶⁰ A dashboard view was added to the new version of DoDAF. For commercial EA/SOA applications, this type of standardized widget-based user-interface had become common due to the potential reuse and flexibility provided by variety of standardized widget toolkits, which includes the Ozone Widget Framework (OWF).⁶¹

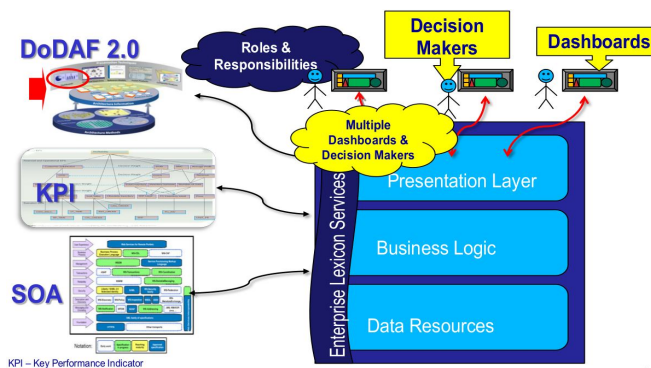


Fig. 9 Standardized Dashboards and Widgets: Example

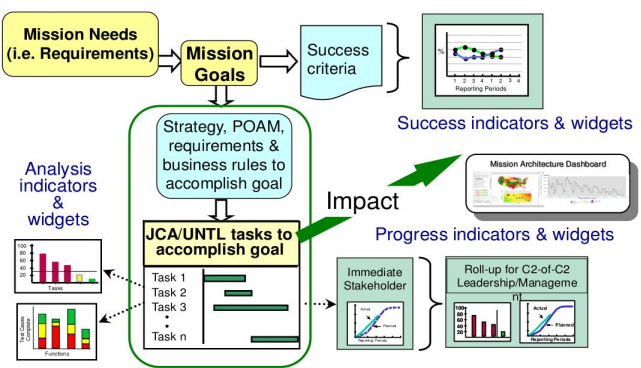


Fig. 10 Standardized Widgets and Indicators: Example

The diagram in figure 9 illustrates how generic baseline performance indicators (e.g. KPIs - key performance indicators), can be associated with standardized baseline widgets to develop mission-specific business activity monitoring resources (e.g. dashboards) tailored to a specific stakeholder context.⁶² Such constructs can, in principle, have baseline default configurations for standardized mission tasks (e.g. UJTL, DoDAF activities), mission essential task lists (METLs), and mission-

58 Executable architecture (https://en.wikipedia.org/wiki/Executable_architecture)
Executable Operational Architecture
(https://en.wikipedia.org/wiki/Operational_View#Executable_Operational_Architecture)

59 Unmanned aerial vehicle (UAV; https://en.wikipedia.org/wiki/Unmanned_aerial_vehicle)

Miniature UAV (https://en.wikipedia.org/wiki/Miniature_UAV)

Micro air vehicle (https://en.wikipedia.org/wiki/Micro_air_vehicle)

60 Multilayered architecture (https://en.wikipedia.org/wiki/Multilayered_architecture)

61 Widget toolkit (https://en.wikipedia.org/wiki/Widget_toolkit; https://en.wikipedia.org/wiki/List_of_widget_toolkits)
Ozone Widget Framework (OWF; <http://www.ozoneplatform.org/>)

62 Business activity monitoring (BAM; https://en.wikipedia.org/wiki/Business_activity_monitoring)

Dashboard (https://en.wikipedia.org/wiki/Dashboard_%28business%29; https://en.wikipedia.org/wiki/Dashboard_%28management_information_systems%29)

scenario event lists (MSELs). This type of mission-representation and execution support capability has continued to mature. A separate section discusses these developments in more detail, while providing examples of resources that can be incorporated into a virtual-networking experimentation framework.

Figure 10 illustrates an adapted version of the generic Goal, Question, Indicator, Metric (GQIM) process that is a variant of the Goal Question, Metric (GQM) methodology.⁶³ The diagram has been tailored to illustrate the applicability to ID/NCW oriented applications. GQM, GQIM, and more recent variants, such as GQM+Strategies, are examples of methods that provide concepts and actionable steps for creating the links between goals, objectives, workflow, and measurement-based decision-making.⁶⁴ Thus, baseline templates can be developed and deployed as stakeholder-specific dashboard elements.

Furthermore, such mission-thread performance metrics and indicators can be dynamically tailored to better reflect and support D-DIL variants of typical mission execution profiles. This type of business-logic based workflow-support capability has also continued to mature. Rule-based management systems (RBMS) are an example where such business-logic can be represented as business-rules.⁶⁵ An example of an operational COTS/GOTS business-rule engine resource (i.e. Drools), is included within a Consolidated Afloat Networks and Enterprise Services (CANES) tool-suite.⁶⁶ Progress towards improved content management, lexicon services, and advanced wiki style user-interface capabilities, has also provided more mature enabling technologies for rule-based approaches [24-27]. Thus, the applicable parameters of MOPs, MOEs, and related performance assessment models can be represented, managed, and dynamically tailored during the execution of the respective mission-threads and scenarios. The development of this type of capability is an ongoing S&T objective of this effort.

Figures 11 and 12 (from [28]) are diagrams from the C2SS effort, a previously discussed project. The first diagram (figure 11) illustrates the concept of using dependency-injection, adapter, and other applicable patterns for in-line insertion and weaving of C2SS aspects and respective functionality.⁶⁷ In principle, this includes the ability to insert context-dependent C2SS functions that help to continuously improve data-synchronization capabilities. Note that aspect-oriented software development and programming techniques/methods were developed to address the need to logically-encapsulate (i.e. virtualize) cross-cutting areas of concern and functionality (e.g. data logging).⁶⁸ For service-oriented architectures/models, this translates into conceptually managing similar types of methods (e.g. data synchronization) that may be associated with a number of different ITI framework services.

Figure 12 highlights the initial focus towards hands-on demonstration of "concurrent distributed updates" (e.g. synchronization of data-sets) for geo-replicated instances of maritime applications (e.g.

63 GQM (<https://en.wikipedia.org/wiki/GQM>)

Goal-Driven Measurement (<http://www.sei.cmu.edu/measurement/tools/goaldriven/index.cfm>)

64 GQM+Strategies (<https://en.wikipedia.org/wiki/GQM%2BStrategies>)

65 Business rule management system (BRMS; https://en.wikipedia.org/wiki/Business_rule_management_system)

66 Drools (<https://en.wikipedia.org/wiki/Drools>)

Rule-based system (https://en.wikipedia.org/wiki/Rule-based_system)

Consolidated Afloat Networks and Enterprise Services (CANES;

<http://www.public.navy.mil/spawar/PEOC4I/ProductsServices/Pages/CANES.aspx>)

67 Software design pattern (https://en.wikipedia.org/wiki/Software_design_pattern)

Dependency injection (https://en.wikipedia.org/wiki/Dependency_injection)

Adapter pattern (https://en.wikipedia.org/wiki/Adapter_pattern)

Aspect (computer programming) (https://en.wikipedia.org/wiki/Aspect_%28computer_programming%29)

Aspect weaver (https://en.wikipedia.org/wiki/Aspect_weaver)

68 Aspect-oriented software development (https://en.wikipedia.org/wiki/Aspect-oriented_software_development)

Aspect-oriented programming (AOP; https://en.wikipedia.org/wiki/Aspect-oriented_programming)

COP).⁶⁹ Thus, the initial focus on consistency models (e.g. eventual-consistency, set reconciliation) and associated algorithms, methods, and techniques (e.g. logical clocks, version vectors, Bloom filters).⁷⁰

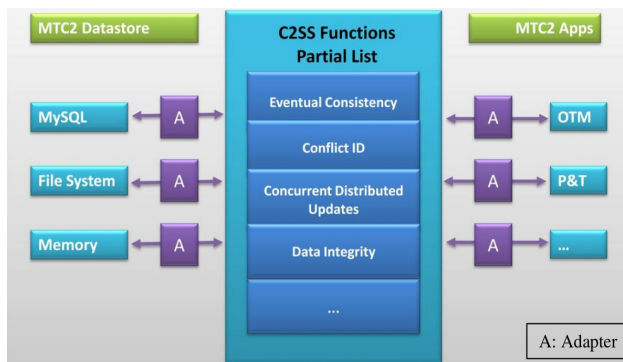


Fig. 11 C2 Data-Synchronization Services (C2SS)

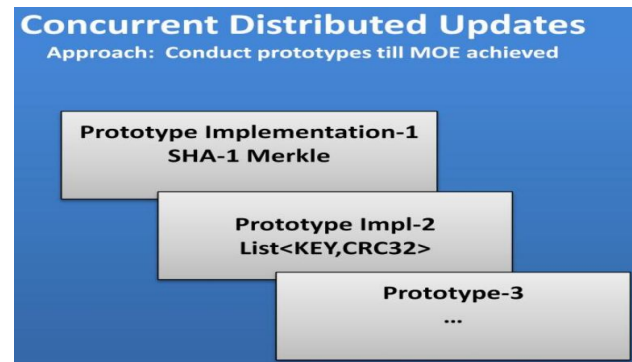


Fig. 12 C2SS Continuous-Improvement: Example

Overall, C2SS types of services are intended to augment existing ITI frameworks with data-synchronization functions that resolve capability gaps and S&T challenges. Due to the open number of possible types of mission-execution environments, different types of solution implementations are anticipated and expected. Thus, as highlighted by figure 12, the definition and use of generic interfaces and abstract methods (i.e. services) hide implementation and context-dependent details, enabling continuous improvement through incremental incorporation of alternative context-dependent variants.⁷¹

The use of such abstractions enables the creation and management of taxonomies of types of services and subcategories of variant implementations. This more agile representation and management of the virtualized abstract representations (e.g. service taxonomies), enables the incorporation of flexible context-dependent methods/techniques for dynamic run-time binding of data and code (e.g. dynamic dispatch, late binding) that best meets the mission-specific needs of the respective stakeholders.⁷²

Figures 13 and 14 are from C2SS working slides that illustrate how functional data paths can be traced from the mission-threads and activities of a given mission-area to the specific widgets that provide the necessary information to the respective stakeholders. This type of mapping of information-support requirements can be utilized for tracing information-exchange requirements of the respective widgets.

Thus, the technical details of the ITI framework dependencies (e.g. physical network topology) can be factored into the logical dataflow constraints (e.g. IERs - information exchange requirements) that are more directly associated with potential operational impact (e.g. total latency, operator response). The work discussed herein, is considered a follow-on effort that works to further address MBSE/SOSE S&T challenges associated with developing this type of mission-driven performance assessment capability. Note that a primary goal of this research is to explore how to best represent and support an ability to

69 Geo-replication (<https://en.wikipedia.org/wiki/Geo-replication>)
Common operational picture (COP; https://en.wikipedia.org/wiki/Common_operational_picture)

70 Consistency model (https://en.wikipedia.org/wiki/Consistency_model)
Eventual consistency (https://en.wikipedia.org/wiki/Eventual_consistency)
Matrix clock (https://en.wikipedia.org/wiki/Matrix_clock)
Version vector (https://en.wikipedia.org/wiki/Version_vector)
Bloom filter (https://en.wikipedia.org/wiki/Bloom_filter)

71 Abstract methods (https://en.wikipedia.org/wiki/Method_%28computer_programming%29#Abstract_methods)
Virtual function (https://en.wikipedia.org/wiki/Virtual_function)
Information hiding (https://en.wikipedia.org/wiki/Information_hiding)

72 Dynamic dispatch (https://en.wikipedia.org/wiki/Dynamic_dispatch)
Late binding (https://en.wikipedia.org/wiki/Late_binding)

assess variants of C2SS algorithms against a representative range of D-DIL conditions that may be encountered within A2/AD environments. In short, the goal is to identify the suite of algorithms and methods that enable the resulting ITI framework to be as reliable, dependable, available, robust, fault tolerant, and resilient as possible, while also supporting an ability to gracefully degrade, if necessary.⁷³

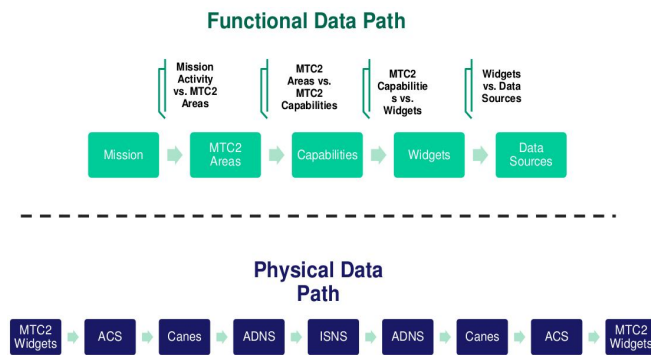


Fig. 13 C2SS: Mission-Driven Data Paths: Examples

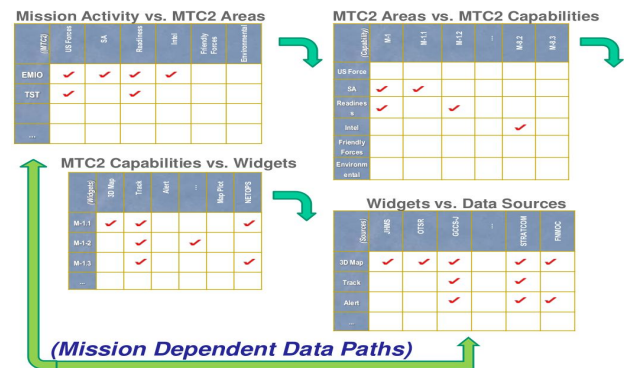


Fig. 14 Dataflow and Data-Path Mapping/Tracing

Figure 15 and figure 16 (from [29]) are diagrams created for a more data-link management oriented project task. Within the context and perspective of the OSI protocol stack, the diagram illustrates RF/microwave LOS comms/networking link-management challenges.⁷⁴ As seen in figure 15, the EA/SOA oriented services stack parallels the comms/networking oriented OSI model (i.e. protocol stack).⁷⁵ Note that due to the focus on "data in motion" and "data in use", an EA/SOA data-layer (data-services layer) for managing "data at rest" (e.g. data persistence) is assumed but not shown.⁷⁶ In terms of mission performance (i.e. operations workflow support) and mission-dependent information-exchange requirements (e.g. MOPs/MOEs), the RF/microwave LOS link-manager is a number of layers removed from the end-user. In other words, there is a need for logical-layer and application-layer support services that enable and augment mission-driven link-management services.

As highlighted within the more detailed block diagram (figure 16), there are a number of logical-layer services that are needed for facilitating mission-driven connectivity management and logical IP-based dataflow management. Thus, within these middleware layers, the respective application-layer tasks, such as Warfighter tasks (e.g. C2, ISR) and mission-support tasks (e.g. data-synchronization, entity management), need to work collaboratively with physical-layer oriented RF/microwave LOS link-management tasks to establish objective and threshold values for link-management MOPs/MOEs that

⁷³ Reliability (computer networking) (https://en.wikipedia.org/wiki/Reliability_%28computer_networking%29)

Dependability (<https://en.wikipedia.org/wiki/Dependability>)

Availability (<https://en.wikipedia.org/wiki/Availability>)

Robustness (computer science) (https://en.wikipedia.org/wiki/Robustness_%28computer_science%29)

Fault tolerance (https://en.wikipedia.org/wiki/Fault_tolerance)

Resilience (network) (https://en.wikipedia.org/wiki/Resilience_%28network%29)

Survivability (<https://en.wikipedia.org/wiki/Survivability>)

⁷⁴ Telecommunications link (https://en.wikipedia.org/wiki/Telecommunications_link)

Data link (https://en.wikipedia.org/wiki/Data_link)

Common Data Link (CDL; https://en.wikipedia.org/wiki/Common_Data_Link)

Tactical Data Link (https://en.wikipedia.org/wiki/Tactical_Data_Link)

⁷⁵ OSI model (http://en.wikipedia.org/wiki/OSI_model)

Protocol stack (http://en.wikipedia.org/wiki/Protocol_stack)

⁷⁶ Data in Use (http://en.wikipedia.org/wiki/Data_in_Use)

Data at Rest (http://en.wikipedia.org/wiki/Data_at_Rest)

Persistence (computer science) (http://en.wikipedia.org/wiki/Persistence_%28computer_science%29)

Persistent data (http://en.wikipedia.org/wiki/Persistent_data)

can most effectively support Warfighter policies and needs (i.e. QoS, IERs).

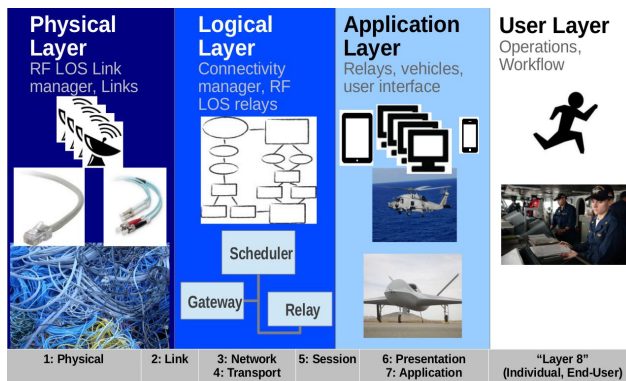


Fig. 15 ISR-Support Services: EA/SOA Layering

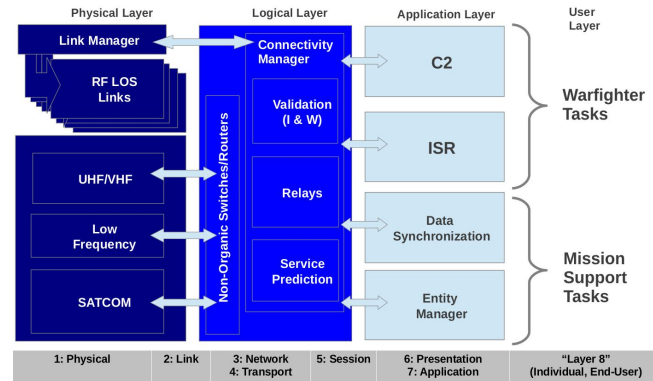


Fig. 16 ISR-Support Services: Systems View

In addition to a number of open technical challenges associated with developing this type of mission-driven RF/microwave LOS comms/networking support capability, there is also an organizational need for collaboratively defining, assessing, and validating MOPs/MOE that quantify the range of associated data-synchronization requirements (e.g. information-exchange latencies). In other words, an incremental MBSE/SOSE process and associated experimentation testbed is needed for developing best-practices (e.g. SOPs) that help to establish mission-dependent objective and threshold values that drive link-management policies and requirements.⁷⁷

As highlighted within figure 16, the logical-layer services are encapsulated into a connectivity-manager that functionally decouples the physical-layer services (e.g. link-manager) from the various application-layer entities (stakeholders) that may concurrently participate within a specific commonly-understood task (e.g. element of the UJTL taxonomy). Using standardized sequencing diagrams, such as Unified Modeling Language (UML) interaction/sequence diagrams, the operational and technical details for how processes need to operate with one another and in what order, can be collaboratively determined and documented.⁷⁸ Figure 17 illustrates how such existing standards (e.g. UJTL, NIEM, UML) can be leveraged for developing an initial RF/microwave LOS link management capability.

Families of possible variations of event scenarios can be generated, relative to a given baseline use-case. Furthermore, for a broad range of possible ad-hoc data-sharing and virtual-teaming situations, naming-conventions, controlled-vocabularies, and standardized information-exchange models (e.g. NIEM, JC3IEDM) enable unambiguous communication relative to a specific mission-task context.⁷⁹ Thus, through the utilization of established standards (e.g. UML sequence diagrams, UJTls, NIEM), mission-task specific information-exchange MOPs/MOE can be determined, assessed, and ultimately validated by collaborative experiments and operational exercises.

⁷⁷ Best practice (https://en.wikipedia.org/wiki/Best_practice)
Standard operating procedure (SOP; http://en.wikipedia.org/wiki/Standard_operating_procedure)

⁷⁸ Sequence diagram (https://en.wikipedia.org/wiki/Sequence_diagram)
UML Interaction diagram (https://en.wikipedia.org/wiki/Unified_Modeling_Language#Interaction_diagrams)
Message sequence chart (https://en.wikipedia.org/wiki/Message_sequence_chart)

⁷⁹ Information sharing (https://en.wikipedia.org/wiki/Information_sharing)
Virtual team (https://en.wikipedia.org/wiki/Virtual_team)
Naming and Design Rules (https://en.wikipedia.org/wiki/Naming_and_Design_Rules)
Controlled vocabulary (http://en.wikipedia.org/wiki/Controlled_vocabulary)
National Information Exchange Model (NIEM; http://en.wikipedia.org/wiki/National_Information_Exchange_Model)
JC3IEDM (<https://en.wikipedia.org/wiki/JC3IEDM>)

Figure 18 is a dataflow diagram for an initial data-collection experiment that worked to document the variability of information-exchange events that represent the types of IERs that are associated with UxS tactical C4ISR scenarios (i.e. CONOPS).⁸⁰ Thus, this type of standardized experimentation process augments and enhances the early MBSE/SOSE lifecycle processes that support model-integration and executable-architecture capabilities.⁸¹ The payoff is collaborative mission-thread analysis, assessment, and validation within the early phases of the respective MBSE/SOSE lifecycle. In other words, the experimentally derived information-exchange statistics facilitate higher fidelity collaboration opportunities that ensure correct system designs are in place before the respective subsystems are built and deployed to an operational EA/SOA/Cloud framework for interoperability testing and validation.

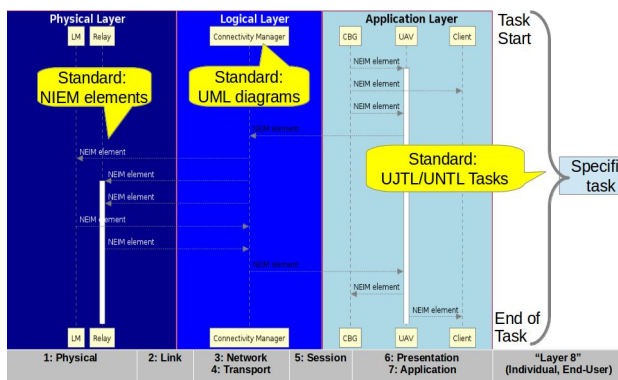


Fig. 17 Task Execution: Example Sequence Diagram

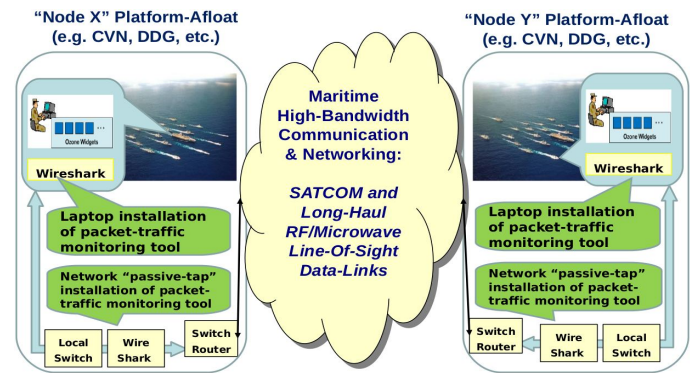


Fig. 18 Platform-to-Platform (P2P) ITI Assessment: Ex.

Most importantly, much needed MOP/MOE estimates can be generated within the respective design phases of the inter-dependent subsystems (e.g. RF/microwave LOS link management, UxS mission-area applications). This type of data-collection experiment was performed for the Trident Warrior 2014 (TW14) experiment. These initial IER related statistics provide a preliminary working baseline for collaborative assessment and validation of mission-driven link-management MOPs/MOEs.

From a standardized task management (e.g. UJTL/UNTL driven workflow) perspective, the IER related information collected at TW14 (e.g. latency distributions for prototypical information-exchange events) helps to identify and assess the parameters and respective objective/threshold values that determine the risk status for a specific mission task (e.g. UJTL/UNTL) or collection of tasks (e.g. METL). This type of task-execution information is critical for the business-logic aspects of battle management and recent development of standardized battle management language capabilities [30-31].

For example, risks due to information-exchange delays (e.g. D-DIL conditions), can be represented and managed at the stakeholder workflow-level of mission-support services. Within the commercial sector, business-rules approaches are another example of this type of management of dynamic work environments. Business rules are especially useful for establishing and managing policies for how to manage situations that are outside normal (i.e. baseline) operating conditions. From a systems design perspective, this type of information is useful for assertion oriented and process calculus methodologies (e.g. design-by-contract, pi-calculus, process calculi) that utilize conditional-execution specifications (e.g. precondition, postcondition, invariant).⁸² Note that business-rules are an example of a type of

80 Concept of operations (CONOPS; https://en.wikipedia.org/wiki/Concept_of_operations)

81 Executable architecture (http://en.wikipedia.org/wiki/Executable_architecture)

82 Assertion (software development) (http://en.wikipedia.org/wiki/Assertion_%28software_development%29)

Design by contract (http://en.wikipedia.org/wiki/Design_by_contract)

Precondition (<http://en.wikipedia.org/wiki/Precondition>)

Postcondition (<http://en.wikipedia.org/wiki/Postcondition>)

event-driven and declarative programming approach towards system design, such as commonly utilized for time-sensitive distributed-control applications and cyber-physical systems.⁸³

3. ITI Resources: Distributed Data Framework (DDF)

Figure 19 (from [32]) illustrates how the Defense Intelligence Information Enterprise (DI2E) is the DoD intelligence mission area element (i.e. component) of the overall DoD enterprise architecture (EA) framework. This highlights the DoD/IC cross-organizational aspects of the DI2E. Note that the diagram further illustrates the role of the Distributed Common Ground System (DCGS) as the federated (i.e. distributed) data-sharing resource between the sensor data producers (e.g. space, airborne, surface/subsurface) and respective intelligence consumers at the various levels of warfare (e.g. tactical, operation, strategic). Within the context of the DI2E, the DCGS Integration Backbone (DIB) enables and supports interoperability between DCGS programs of record (PORs) that respectively support and span across their DoD and IC agencies (e.g. Navy, Marine Corps, Army, Air Force, SOF, IC/NGA).

As discussed in [33] and further illustrated in figure 20 (from [34]), the DI2E provides a "bridge" between ITI frameworks, such as the Joint Information Environment (JIE) and Intelligence Community Information Technology Enterprise (IC ITE) EA/SOA frameworks.⁸⁴ The purpose of the DIB is to facilitate integration and interoperability (I&I) across the individual service (or agency) specific instantiations of DCGS. Thus, the DIB minimizes and helps to eliminate "information silo" or "stovepipe system" types of challenges that have been an issue with federating legacy systems.⁸⁵

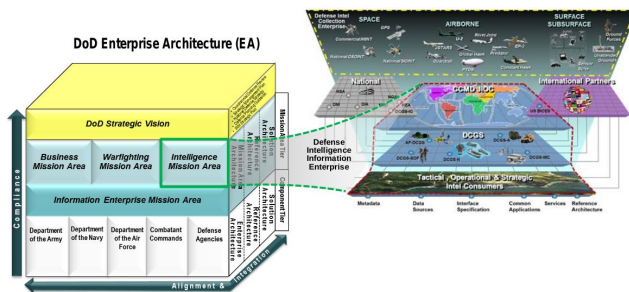


Fig. 19 DoD EA Relationship to DI2E

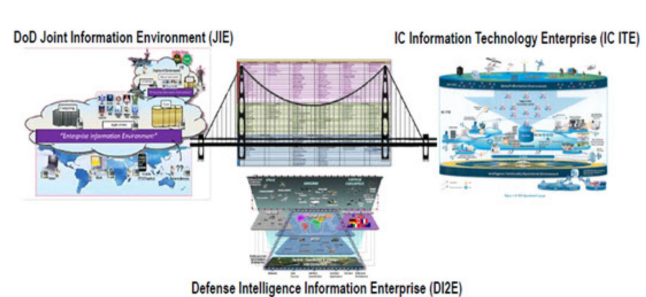


Fig. 20 DI2E: A Bridge Between the JIE and IC-ITE

Figure 21 (from [36]) is a high-level system view of DIB functionality. In 2012, much of the DIB code-base was open-sourced and released as the Distributed Data Framework (DDF). As highlighted, the DDF/DIB provides a common logically-defined interface for a potentially broad range of ad-hoc collections of independently developed and managed resources. As highlighted in figure 21, the

Class invariant (http://en.wikipedia.org/wiki/Class_invariant)

83 Hollywood principle (https://en.wikipedia.org/wiki/Hollywood_principle)

Event-driven architecture (https://en.wikipedia.org/wiki/Event-driven_architecture)

Signal programming (https://en.wikipedia.org/wiki/Signal_programming)

Process control network (https://en.wikipedia.org/wiki/Process_control_network)

Distributed control system (DCS; https://en.wikipedia.org/wiki/Distributed_control_system)

Cyber-physical system (CPS; https://en.wikipedia.org/wiki/Cyber-physical_system)

84 Joint Information Environment (JIE; https://en.wikipedia.org/wiki/Joint_Information_Environment)

Intelligence Community (IC) Information Technology (IT) Enterprise (IC ITE), last acc'd April 2015

(<http://www.dni.gov/files/documents/IC%20ITE%20Fact%20Sheet.pdf>;

<http://www.dni.gov/index.php/about/organization/chief-information-officer-what-we-do>)

85 Information silo (https://en.wikipedia.org/wiki/Information_silo)

Stovepipe system (https://en.wikipedia.org/wiki/Stovepipe_system)

Legacy system (https://en.wikipedia.org/wiki/Legacy_system)

DDF/DIB middleware provides an inter-organizational abstraction-layer that logically decouples the client user-interface (i.e. presentation-layer) from the potentially disparate open number of possible backend data sources. For DDF/DIB clients (top box), a variety of standardized specifications (e.g. DDMS) and interfaces (e.g. OpenSearch, KML) are supported.⁸⁶ On the backend, standardized interfaces and support tools are provided for supporting local metadata cards, card catalogs, and registries that help standardize ingest of user-data and interoperability across DDF/DIB installations.⁸⁷

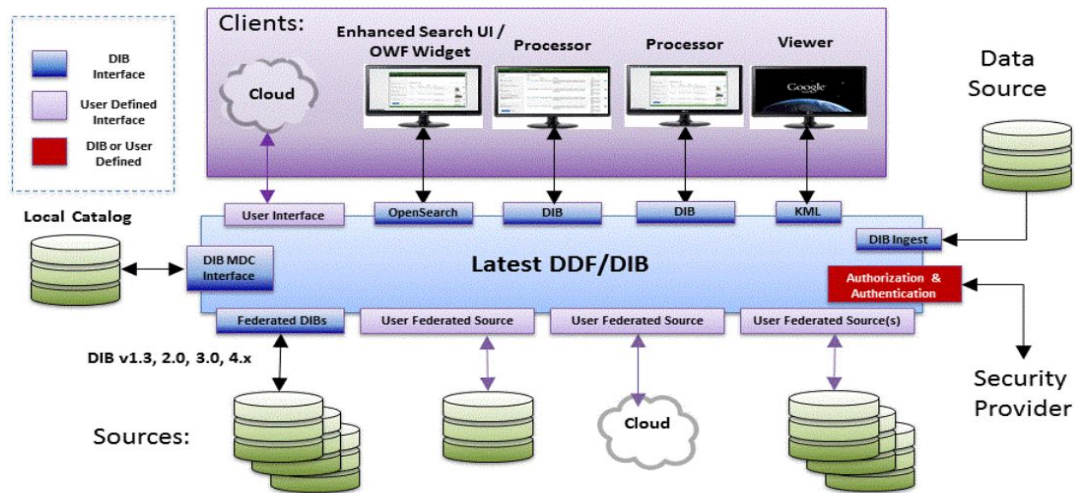


Fig. 21 DCGS DIB Architecture

Thus, out-of-the-box, the DDF/DIB code base provides much of the baseline capabilities for forward-deployed data-transport and data-mediation needs. Furthermore, variants and different types of implementations of DDF/DIB services, will most likely be needed for supporting use of DDF/DIB in more time-sensitive safety-critical mission-tasks. Thus, the opportunity to co-evolve the DDF/DIB to improve operational support and maintain a common architecture that hides context-specific details to the greatest extent possible (e.g. operating environment constraints), while preserving the more abstract representation of the type of data-transport and data-mediation services that are provided.

The inter-organizational network management, provisioning, and identity/access management (IdAM) aspects of DDF/DIB are of particular interest for this effort.⁸⁸ Most specifically, due to the adoption of Internet Protocol (IP) packet-based information exchange, traffic-oriented performance dependencies include a number of factors, such as network congestion, flow control, packet transfer delay, queuing delays, packet delay variation, packet loss, and throughput.⁸⁹ The DDF/DIB helps to bridge and address

⁸⁶ Department of Defense Discovery Metadata Specification (DDMS;
https://en.wikipedia.org/wiki/Department_of_Defense_Discovery_Metadata_Specification;
<http://metadata.ces.mil/dse/irs/DDMS/index.html>)
 OpenSearch (<https://en.wikipedia.org/wiki/OpenSearch>)
 Keyhole Markup Language (KML; https://en.wikipedia.org/wiki/Keyhole_Markup_Language)

⁸⁷ Metadata (<https://en.wikipedia.org/wiki/Metadata>)
 Metadata standards (https://en.wikipedia.org/wiki/Metadata_standards)
 Library catalog (https://en.wikipedia.org/wiki/Library_catalog)
 Index card (https://en.wikipedia.org/wiki/Index_card)
 Metadata registry (https://en.wikipedia.org/wiki/Metadata_registry)

⁸⁸ Network planning and design (https://en.wikipedia.org/wiki/Network_planning_and_design)
 Internetworking (<https://en.wikipedia.org/wiki/Internetworking>)
 Identity management (IdM; https://en.wikipedia.org/wiki/Identity_management)

⁸⁹ Provisioning (<https://en.wikipedia.org/wiki/Provisioning>)
 Taxonomy of congestion control (https://en.wikipedia.org/wiki/Taxonomy_of_congestion_control)

this type of fundamental coupling of the various telecommunications networks with the potentially time-sensitive ID/NCW distributed-operations mission-threads and associated workflow.⁹⁰ With the rapid maturity of virtualization technologies, the DDF/DIB code-base can evolve to help facilitate globally distributed (i.e. hybrid-cloud) converged-architecture data-services, such as typically provided by infrastructure-as-a-service (IaaS) and networking-as-a-service (NaaS) ITI framework components.⁹¹

Figure 22 (from [36]) highlights how the DIB has continued to evolve and mature into an inter-agency federated (i.e. distributed) data-sharing resource that has sustained such operational capabilities for a number of years. As previously noted, the code-base for the DIB has recently been open-sourced as the DDF and is now freely available.⁹² Thus, the DDF/DIB code-base provides an initial data-transport and data-mediation capability that can be adapted and tailored for developing a hybrid-cloud ITI experimentation framework. As highlighted by the green bars within the diagram, DDF has been the core component of the DIB since the release of version 4.0 (March 2012).

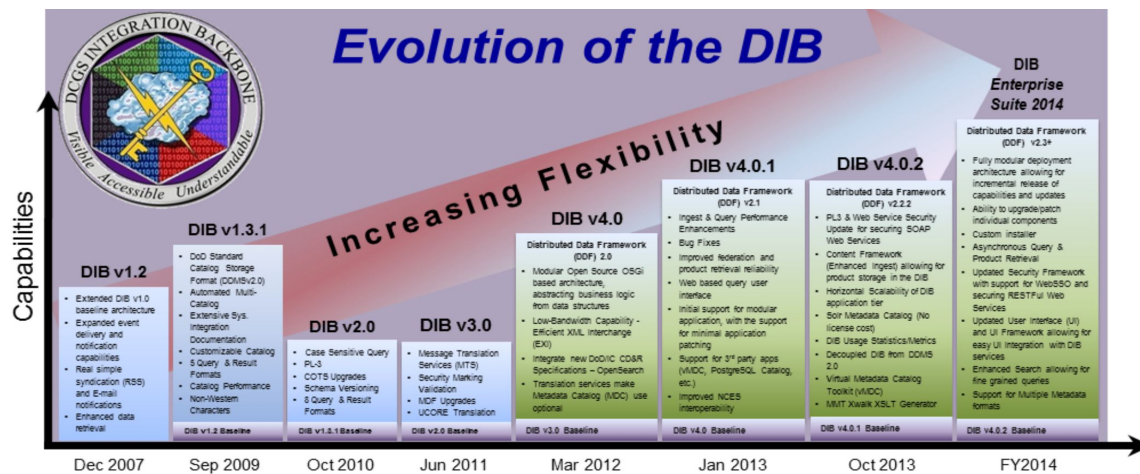


Fig. 22 Evolution of the DCGS Integration Backbone (DIB)

From an enterprise application integration (EAI) and EA/SOA management perspective, this type of evolved and more agile I&I capability augments and extends the role of enterprise systems engineering support and I&I services.⁹³ In principle, methods, techniques, and best-practices of related application domains and disciplines (e.g. operations research/management, industrial engineering, engineering management) can be conceptually integrated and more readily utilized for facilitating continuous performance improvement and incremental development.⁹⁴ Of particular interest is model-level integration of domains that focus on quality, reliability, fault-tolerance, and resiliency (e.g. quality

Network congestion (https://en.wikipedia.org/wiki/Network_congestion)

90 Telecommunications network (https://en.wikipedia.org/wiki/Telecommunications_network)

Demarcation point (https://en.wikipedia.org/wiki/Demarcation_point)

Network-to-network interface (https://en.wikipedia.org/wiki/Network-to-network_interface)

91 Virtual circuit (https://en.wikipedia.org/wiki/Virtual_circuit)

Converged infrastructure (https://en.wikipedia.org/wiki/Converged_infrastructure)

Dynamic infrastructure (https://en.wikipedia.org/wiki/Dynamic_infrastructure)

92 Home page, Distributed Data Framework (DDF; <http://codice.github.io/ddf/>)

93 Enterprise application integration (EAI; https://en.wikipedia.org/wiki/Enterprise_application_integration)

Enterprise engineering (https://en.wikipedia.org/wiki/Enterprise_engineering)

Enterprise systems engineering (ESE; https://en.wikipedia.org/wiki/Enterprise_systems_engineering)

94 Operations research (https://en.wikipedia.org/wiki/Operations_research)

Industrial engineering (https://en.wikipedia.org/wiki/Industrial_engineering)

assurance, reliability engineering).⁹⁵ This includes disciplines and domains that focus on software intensive systems.⁹⁶ Thus, the added interest in the broad range of value-chain and process-improvement focused methods/techniques (e.g. CMMI, Six Sigma, QFM).⁹⁷ A growing number of applicable "body of knowledge (BOK)" references are included within this goal of a more conceptually integrated process that includes conceptual I&I of interdependent best-practices and standards.⁹⁸

The goal is to establish an experimentation-based process and ITI framework, which naturally incorporates relevant knowledge, models, best-practices, and resources. Thus, enabling incremental continuous improvement capabilities that are explicitly mapped/traced to these conceptually applicable professions and domains. This provides a much needed ability to readily incorporate, tailor, and refactor applicable reference models, while creating opportunities to readily cross-leverage, reuse, and adapt applicable architectures, methodologies, models, design patterns, best-practices, and resources.

Figures 23 and 24 (from [37]) further illustrate the functional components of the DDF/DIB architecture. As described in the reference for the figures, "the DIB is a cohesive set of modular, community-governed, standards-based data services focused on enterprise information sharing. DIB provides a common framework to enable the construction of cloud services such as Platform as a Service (PaaS) type of services for data exposure and transformation, and for enabling applications and users to discover and access information from a wide range of distributed sources" [37].

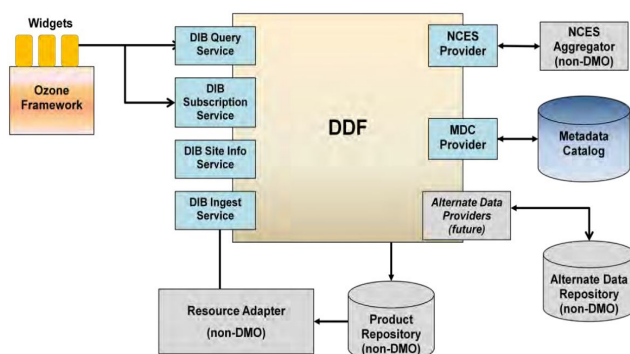


Fig. 23 Distributed Data Framework (DDF)

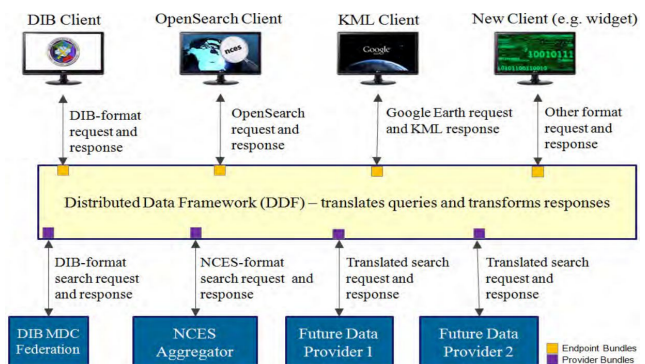


Fig. 24 DDF: Translate Queries, Transform Response

Thus, the DDF/DIB provides an example candidate resource that can be further evolved, refactored, and improved for addressing a variety of emerging hybrid-cloud IaaS/NaaS information/data transport and data-mediation needs. Note that for each separate organizational entity (e.g. Navy, Marine Corps, NGA), distinct cloud constructs (e.g. private/community clouds) are assumed to be defined and instantiated to support the respective ITI related needs (e.g. DaaS/IaaS/NaaS). The focus of the

95 Quality management (https://en.wikipedia.org/wiki/Quality_management)
Reliability engineering (https://en.wikipedia.org/wiki/Reliability_engineering)
Risk management (https://en.wikipedia.org/wiki/Risk_management)

96 Software quality (https://en.wikipedia.org/wiki/Software_quality)
Software metric (https://en.wikipedia.org/wiki/Software_metric)
Software performance testing (https://en.wikipedia.org/wiki/Software_performance_testing)

97 Value chain (https://en.wikipedia.org/wiki/Value_chain; https://en.wikipedia.org/wiki/Value_network)
Value engineering (VE; https://en.wikipedia.org/wiki/Value_engineering)
Business process improvement (https://en.wikipedia.org/wiki/Business_process_improvement)

98 Enterprise Architecture BOK (EABOK; http://en.wikipedia.org/wiki/Enterprise_Architecture_Body_of_Knowledge)
Software Engineering BOK (SEBOK; http://en.wikipedia.org/wiki/Software_Engineering_Body_of_Knowledge)
Project Management BOK (PMBOK; https://en.wikipedia.org/wiki/A_Guide_to_the_Project_Management_Body_of_Knowledge)
Business Analysis BOK (http://en.wikipedia.org/wiki/A_Guide_to_the_Business_Analysis_Body_of_Knowledge)
Data Management BOK (DMBOK; http://en.wikipedia.org/wiki/Data_management)

experimentation framework is to facilitate development of a MBSE/SOSE approach and performance-based ITI framework that bridges the seam and closes the conceptual-model and systems-level I&I gaps. For MBSE/SOSE applications, such gaps typically span across ad-hoc aggregations of an open number of possible private/community cloud instantiations.

As described within the conclusion of an overview of DIB v4.0, "the introduction of DDF v2.0 as part of the DIB v4.0 release represents a major leap forward for the DCGS enterprise community. Not only does DDF enable continued improvements in data-sharing and interoperability, but just as critically it ushers-in a whole new level of flexibility, modularity, and standardization for integrating new data sources, data transformation services, and user-facing interfaces including the Ozone Widget Framework (OWF). The DDF component of DIB v4.0 can form part of the 'connective tissue' between Application Service Providers (ASP) and Infrastructure Service Providers (ISP) by providing a common approach to mitigating the impact of on-going transitions, while at same time maximizing interoperability with the DCGS community and the larger Defense Intelligence Information Enterprise (DI2E)" [37]. This further illustrates the value and payoff for leveraging the DDF/DIB code-base for developing a performance-based MBSE/SOSE experimentation framework that addresses service provider (e.g. ASP, TSP, CSP, ISP) related I&I challenges, such as cloud-to-cloud interoperability.⁹⁹

As further described within the DDF/DIB documentation [36-41], and illustrated in figure 25 (from [41]), DDF/DIB runs on top of a reference implementation of the OSGi framework (e.g. Equinox), which due to being a Java based application, runs within a Java virtual machine (JVM).¹⁰⁰ Being a Java based application, DDF/DIB can be hosted by a variety of operating systems and physical hardware infrastructures (e.g. Windows, Linux, Mac OS, Solaris). Within the DDF/DIB architecture diagram (figure 25), the items within the dotted line represent DDF/DIB out-of-the-box.

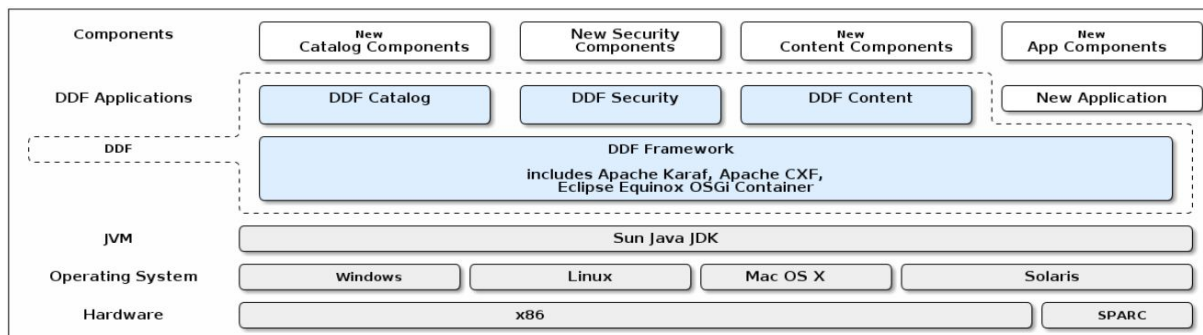


Fig. 25 DDF: Architecture Diagram

As described within the documentation for figure 25, "DDF is a customized and branded distribution of Apache Karaf. DDF could also be considered to be a more lightweight OSGi distribution, as compared to Apache ServiceMix, FUSE ESB, or Talend ESB, all of which are also built upon Apache Karaf.

⁹⁹ Service provider (https://en.wikipedia.org/wiki/Service_provider)

Application service provider (ASP; https://en.wikipedia.org/wiki/Application_service_provider)

Telecommunications service provider (TSP; https://en.wikipedia.org/wiki/Telecommunications_service_provider)

Communications service provider (CSP; https://en.wikipedia.org/wiki/Communications_service_provider)

Internet service provider (ISP; https://en.wikipedia.org/wiki/Internet_service_provider)

¹⁰⁰ OSGi (<https://en.wikipedia.org/wiki/OSGi>)

Equinox (OSGi) (https://en.wikipedia.org/wiki/Equinox_%28OSGi%29)

Reference implementation (https://en.wikipedia.org/wiki/Reference_implementation)

Java virtual machine (JVM; https://en.wikipedia.org/wiki/Java_virtual_machine)

Operating-system-level virtualization (https://en.wikipedia.org/wiki/Operating-system-level_virtualization)

Similar to its peers, DDF incorporates additional upstream dependencies" [40].¹⁰¹

"DDF as a framework hosts DDF applications, which are extensible by adding components via OSGi. The best example of this is the DDF Catalog (API), which offers extensibility via several types of Catalog Components. The DDF Catalog API serves as the foundation for several applications and resides in the applications tier." ... "The Catalog Components consist of Endpoints, Plugins, Catalog Frameworks, Sources, and Catalog Providers. Customized components can be added to DDF" [40].

Figure 26 (from [41]) is a high-level view of the Apache Camel architecture.¹⁰² Apache Camel is an implementation of the patterns (e.g. data-transport, data-mediation) defined within a widely adopted Enterprise Integration Patterns (EIP) book that describes sixty-five design patterns for the use of enterprise application integration and message-oriented middleware.¹⁰³

As discussed in more detail in [42-43], Apache Camel is an open source Java framework that focuses on making integration easier and more accessible to developers. It does this by providing: (i) concrete implementations of all the widely used EIPs; (ii) connectivity to a great variety of transports and APIs; (iii) easy to use Domain Specific Languages (DSLs) to wire EIPs and transports together.¹⁰⁴ Figure 26 shows how these three items map to Camel concepts. To further describe how Camel is organized, the following paragraph provides a short discussion of Components, Endpoints, Processors, and DSLs.¹⁰⁵

As highlighted, Camel enables the explicit definition of a context for Endpoint interfaces. By using URIs, endpoints enable messages to be exchanged (i.e. sent/received) in a uniform logically defined manner. Processors, as defined within Camel, are used to manipulate and mediate messages in between Endpoints. Thus, processors "handle things in between endpoints", such as data-mediation or data-transport (e.g. endpoint-to-endpoint routing). A routing engine utilizes a DSL to wire endpoints and processors together to form routes. Camel is utilized within a variety of EA/SOA frameworks and infrastructure projects (e.g. Apache ServiceMix, Apache ActiveMQ, and Apache CXF).

Figure 27 (from [44]) is a high-level architecture diagram for the Apache Synapse project, which defines proxy services for supporting EIP (e.g. data-transport and data-mediation patterns) functionality.¹⁰⁶ As highlighted by the diagram, Synapse supports the creation of Proxy Services, which allows users to easily create virtual services on the ESB layer to front existing services. Note the more

101 Apache Karaf (https://en.wikipedia.org/wiki/Apache_Karaf; <http://karaf.apache.org/>)
Apache Felix (https://en.wikipedia.org/wiki/Apache_Felix)
Apache CXF (https://en.wikipedia.org/wiki/Apache_CXF)
Apache ServiceMix (https://en.wikipedia.org/wiki/Apache_ServiceMix)
Fuse ESB (https://en.wikipedia.org/wiki/Fuse_ESB)
DDF Upstream Dependencies (<https://tools.codice.org/#DDFArchitecture-AdditionalUpstreamDependencies>)

102 Apache Camel (https://en.wikipedia.org/wiki/Apache_Camel)

103 Enterprise Integration Patterns (EIP; https://en.wikipedia.org/wiki/Enterprise_Integration_Patterns)
Architectural pattern (https://en.wikipedia.org/wiki/Architectural_pattern)
Software design pattern (https://en.wikipedia.org/wiki/Software_design_pattern)

104 Pattern language (https://en.wikipedia.org/wiki/Pattern_language)
Domain-specific language (DSL; https://en.wikipedia.org/wiki/Domain-specific_language)

105 Component (https://en.wikipedia.org/wiki/Component-based_software_engineering#Software_component)
Component (UML) (https://en.wikipedia.org/wiki/Component_%28UML%29)
Communication endpoint (https://en.wikipedia.org/wiki/Communication_endpoint)
Typed communication endpoint (https://en.wikipedia.org/wiki/Typed_communication_endpoint)
Information processor (https://en.wikipedia.org/wiki/Information_processor)

106 Proxy pattern (https://en.wikipedia.org/wiki/Proxy_pattern)
Proxy server (https://en.wikipedia.org/wiki/Proxy_server)
Apache Synapse (https://en.wikipedia.org/wiki/Apache_Synapse)

explicit emphasis and focus on QoS in-line support for addressing the respective requirements (e.g. security, caching, throttling, reliable messaging).

Fundamentally, Apache Camel similarly provides a type of proxy service for implementing EIP functionality, but Camel is not defined, designed, implemented, or managed as such. As stated within [45], Camel and Synapse are different in their architecture and technologies utilized to implement an Enterprise Service Bus (ESB) functionality. In principle, this type of functionality includes the utilization of message mediators and brokers for orchestration as ESB routes.¹⁰⁷ According to [45], such differences require the creation of a separate construct that utilizes and extends enterprise topology graphs (ETG) for developing a common representation that spans the domain specific semantics. This provides an example of the type of I&I resources needed for addressing different types of resources (e.g. Camel, Synapse) that may be utilized across the respective ITI frameworks of individual clouds.

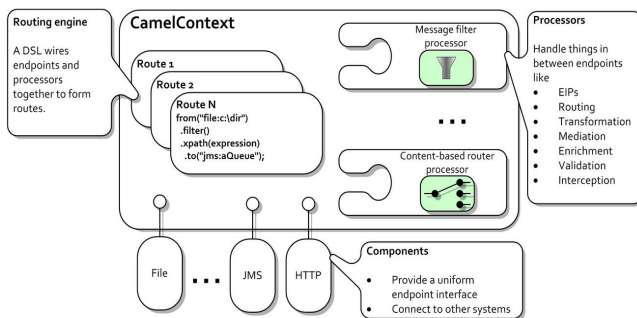


Fig. 26 Apache Camel: High-Level Architecture

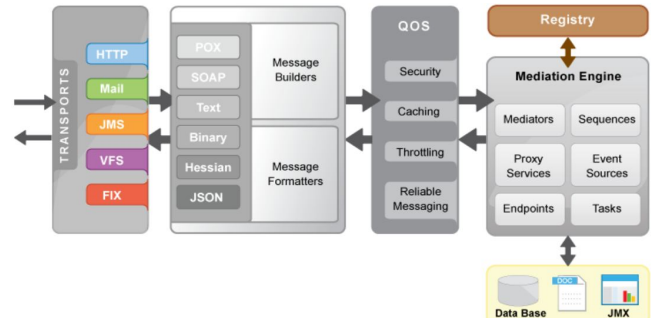


Fig. 27 Apache Synapse: High-Level Architecture

Figures 28 and 29 (from [46]) illustrate a distributed/federated cloud-computing architecture of the Network Implementation Testbed using Open Source (NITOS) effort. As illustrated in the diagrams, NITOS identifies and manages the combined challenges of data-transport (e.g. routing) and mediation (e.g. data mapping and transformation) within the operational context and constraints of wireless networking and mobile nodes.¹⁰⁸ This provides another example of the types of ITI framework variants for which ad-hoc aggregations may need to operate within a hybrid-cloud type of configuration.

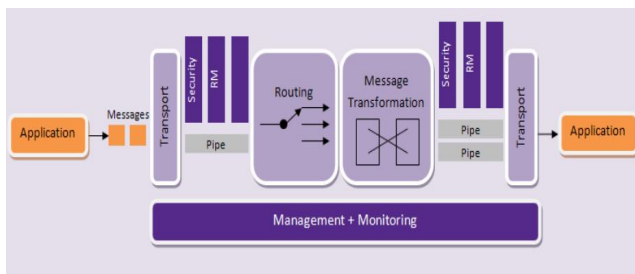


Fig. 28 NITOS: Data-Transport and Mediation

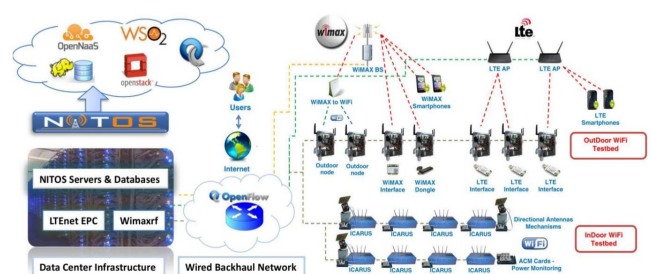


Fig. 29 NITOS Wireless Cloud-Computing: Example

These Apache ESB (i.e. Camel, Synapse) and wireless cloud-computing (i.e. NITOS) examples help to illustrate the value of extending and augmenting DDF/DIB capabilities with more generalized model-based management and support of the respective data-transport and data-mediation services. Other example EIP implementations and related applications further support this perspective [47-48].

¹⁰⁷ Mediator pattern (https://en.wikipedia.org/wiki/Mediator_pattern)

Mediated communication (https://en.wikipedia.org/wiki/Mediated_communication)

Process Driven Messaging Service (https://en.wikipedia.org/wiki/Process_Driven_Messaging_Service)

Message broker (https://en.wikipedia.org/wiki/Message_broker)

¹⁰⁸ Data mapping (https://en.wikipedia.org/wiki/Data_mapping)

Data transformation (https://en.wikipedia.org/wiki/Data_transformation)

4. ITI Resources: Cloud-Computing Models and Standards

Figure 30 (from [49]) illustrates the goal/objective to transition from the current "as is" DoD ITI/ICT framework to a "to-be" cloud-based infrastructure. As illustrated, this entails an incremental process whereby legacy applications and data are consolidated and virtualized. Thus, the incremental transformation to an intermediate "DoD Cloud ready" ITI framework. Figure 31 (from [50]) further highlights the desired end-state where "Access at Point of Need (Mobile, Work, Deployment, Home)" is virtualized and decoupled from particular physical components of the ITI framework.

Thus, depending on the type of operating environment, different types of infrastructure computing components are utilized, such as modular data centers, versus enterprise data centers, versus deployable edge nodes. Optimized secure enterprise networks facilitate the necessary information-exchanges across this potentially global spectrum of heterogeneous computing infrastructure elements that support a broad spectrum of virtual-teaming and mission-execution support requirements.

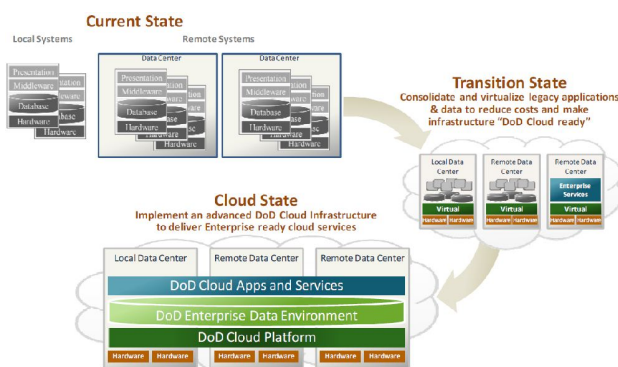


Fig. 30 Roadmap for DoD Cloud Infrastructure



Fig. 31 Enterprise Cloud with Edge Nodes

4.1 Cloud-Computing: Distributed-Computing and Deployment Models

Figure 32 (from [51]) illustrates a taxonomy of distributed computing that includes example variants of different types of distributed computing models. As highlighted, cloud-computing is a type of utility computing. Note the utility-computing variants that may better match forward edge-node requirements (e.g. fog, grid).¹⁰⁹ Thus, the taxonomy highlights a variety of heterogeneous distributed computing models (e.g. jungle computing) that may be applicable to the maritime components (i.e. functional elements) of the DoD ITI framework.¹¹⁰ Other recent surveys have also reviewed the taxonomic characteristics of interconnected cloud-computing environments [52].

Figure 33 (also from [51]) illustrates the variety of types of cloud-computing deployment models. Within the maritime cloud-computing context, each platform deploys a private cloud (e.g. TC-RI). Ad-hoc collections of platforms may have I&I (i.e. hybrid-cloud) support or operate as community-clouds. The specifics of the deployment model for ad-hoc networks of maritime platforms (e.g. battle groups), will continue to be a context dependent decision for which an overarching across-platform ITI framework is yet to be developed. Thus, the need and value for the type of work described herein.

At this time, due to the more traditional and typical data-center type of applications, the utilization and

¹⁰⁹ Fog computing (https://en.wikipedia.org/wiki/Fog_computing)

Grid computing (https://en.wikipedia.org/wiki/Grid_computing)

¹¹⁰ Heterogeneous computing (https://en.wikipedia.org/wiki/Heterogeneous_computing)

Jungle computing (https://en.wikipedia.org/wiki/Jungle_computing)

tailoring of cloud computing has been a primary focus. As distributed ITI technologies continue to mature, other types of distributed-computing models may prove to be best suited for addressing maritime afloat needs. Thus, the need to create a more flexible and agile MBSE/SOSE I&I capability for supporting hybrid-cloud configurations and facilitating the potential evolutionary transformation towards other types of distributed-computing models (e.g. fog computing, jungle computing).

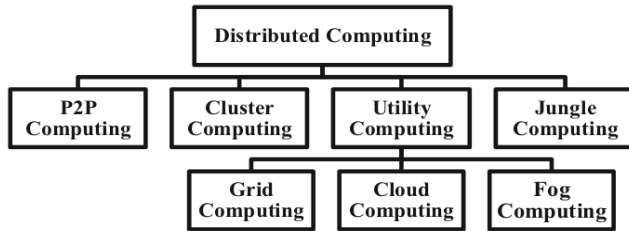


Fig. 32 Distributed Computing Taxonomy

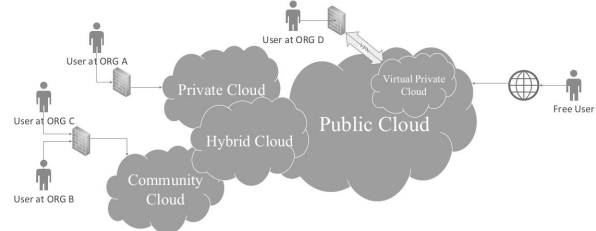


Fig. 33 Cloud Computing Deployment Models

4.2 Cloud-Computing: Example Reference Models

Figure 34 (from [54]) is a high-level view of the NIST cloud computing reference model. For land-based data-centered oriented needs, this is a reference model that has been adopted by a number of organizations, including DoD. As highlighted by the diagram, for supporting the cloud computing "service layers" (e.g. SaaS, PaaS, IaaS), other functional elements are required (e.g. cloud broker, cloud auditor, cloud carrier, cloud service management). For data-transport, the cloud carrier is a critical component. As noted elsewhere, "a cloud carrier acts as an intermediary that provides connectivity and transport of cloud services between cloud consumers and cloud providers. Cloud carriers provide access to consumers through network, telecommunication, and other access devices" [54].

Figure 35 and figure 36 (from [55]) further illustrate the role of the carrier and the inherent cross-cutting dependencies for all cloud providers. For the maritime tactical C4ISR application domain, where each platform has an instantiation of a local private cloud, the off-board communication and networking (i.e. offboard carrier services) are critical ITI components for achieving tactical cloud computing objectives. Such ad-hoc networks of platforms (e.g. battle groups) need to be able to form hybrid-cloud configurations that are robust to A2/AD situations and D-DIL operating conditions.

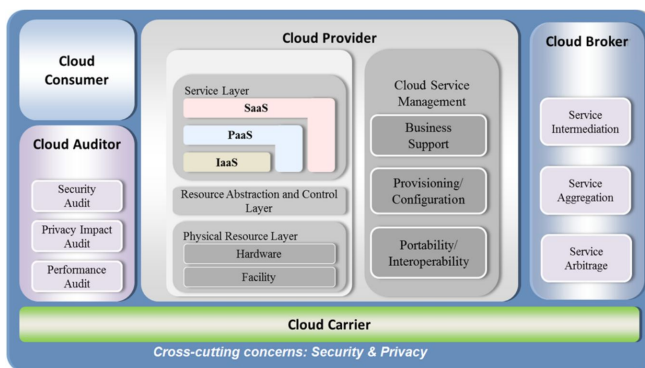


Fig. 34 Cloud Computing Reference Model: NIST Ex.

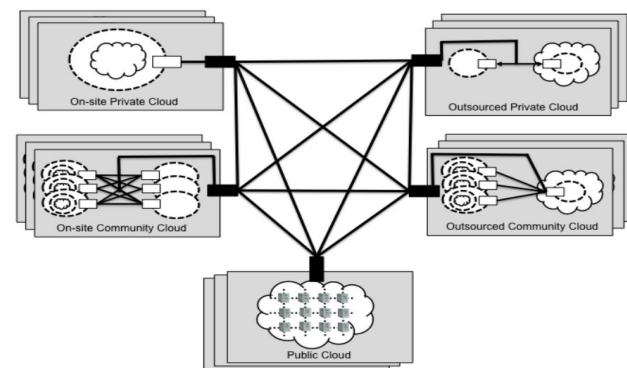


Fig. 35 Cloud Computing: Hybrid Cloud Example

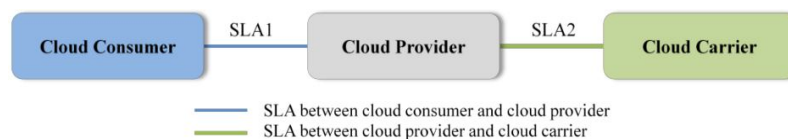


Fig. 36 NIST Standard: Usage Scenario for Cloud Carrier SLA Dependencies

Figure 37 (from [56]) is an example of a vehicular cloud-computing architecture. As highlighted by the block diagram, vehicular-to-vehicular (V2V) and vehicular-to-infrastructure (V2I) communications layer services need to support real-time applications. For unmanned systems (UxS) applications, such time-sensitive and time-critical information-exchange services require the use of more specialized data-transport standards that are typically restricted to embedded-computing applications (e.g. DDS).¹¹¹

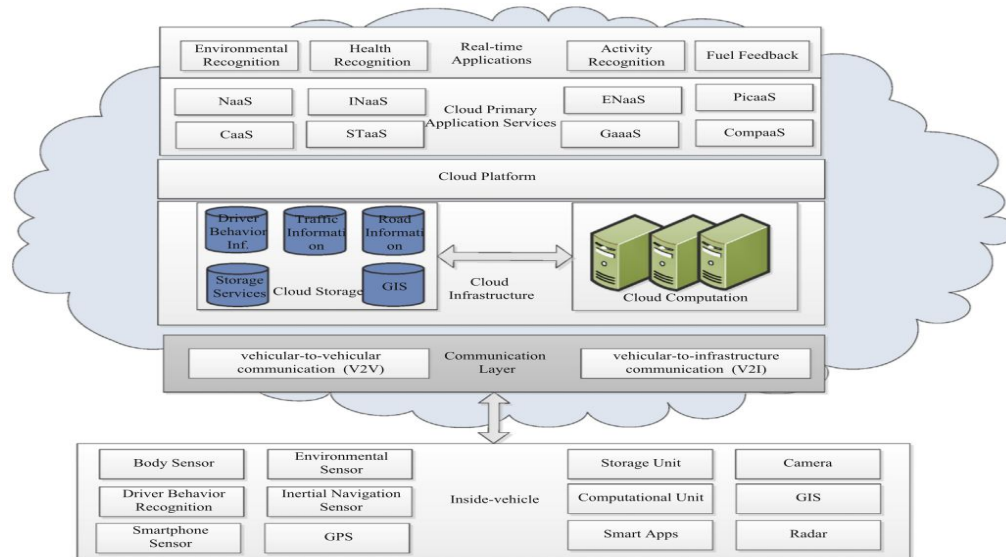


Fig. 37 Vehicular Cloud Computing: Example Architecture

4.3 Cloud-Computing: Evolution Towards Software Defined Environments

Figure 38 (from [57]) is a diagram from a software-defined cloud-computing reference. As highlighted by the example architecture, the control layer plays a key role in admission-control within the application layer. Note that within the control layer, a planner, performance monitor, and energy manager work in concert with both a network-manager and cloud-manager. Figure 39 (from [58]) illustrates the layers of an example software defined networking (SDN) based cloud-computing stack.¹¹² This diagram highlights how virtualization enables the creation of network operating system (NOS) services that utilize SDN libraries and drivers (e.g. OpenFlow) for dynamically configuring and supporting a distributed infrastructure (i.e. data/forwarding plane implementation).¹¹³

Figures 40 through 42 (from [59]) are additional views of software-defined ITI frameworks that are emerging from the rapid maturity of virtualization technologies. Figure 40 further illustrates the type of SDN cloud-computing stack architecture that is introduced in figure 39 and discussed in the previous paragraph. In figure 40, a northbound-interface component within the control-layer, and southbound-interface within the data-layer, are highlighted.¹¹⁴ The northbound interface conceptualizes the lower-level details used by, or within, the lower-level layers of the stack. A northbound interface is used to interface with higher-level abstraction-layers using the southbound interface of the higher level

¹¹¹ Data Distribution Service (DDS; https://en.wikipedia.org/wiki/Data_Distribution_Service)

¹¹² Software-defined networking (SDN; https://en.wikipedia.org/wiki/Software-defined_networking)

¹¹³ Network operating system (https://en.wikipedia.org/wiki/Network_operating_system)

Network functions virtualization (https://en.wikipedia.org/wiki/Network_functions_virtualization)

OpenFlow (<https://en.wikipedia.org/wiki/OpenFlow>)

Routing control plane (https://en.wikipedia.org/wiki/Routing_control_plane)

Forwarding plane (https://en.wikipedia.org/wiki/Forwarding_plane)

¹¹⁴ Northbound/Southbound interface (https://en.wikipedia.org/wiki/Northbound_interface)

component(s).¹¹⁵ The southbound interface decomposes higher-level concepts into more technical concrete device specific terms, enabling the dynamic overlaying of comms/networking services.¹¹⁶

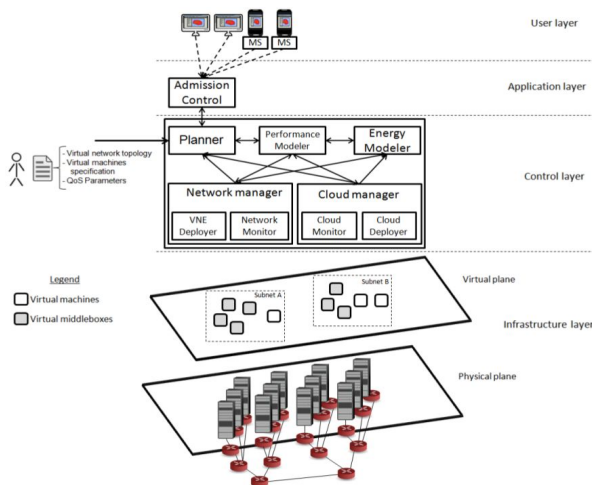


Fig. 38 Software-Defined Cloud Architecture: Example

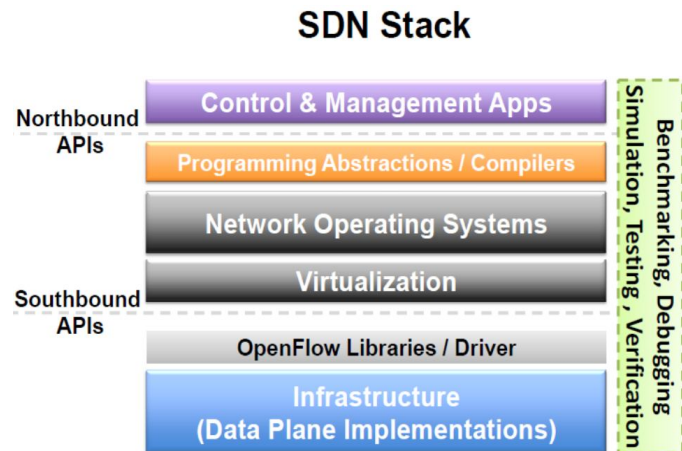


Fig. 39 SDN Cloud-Computing Stack: Example

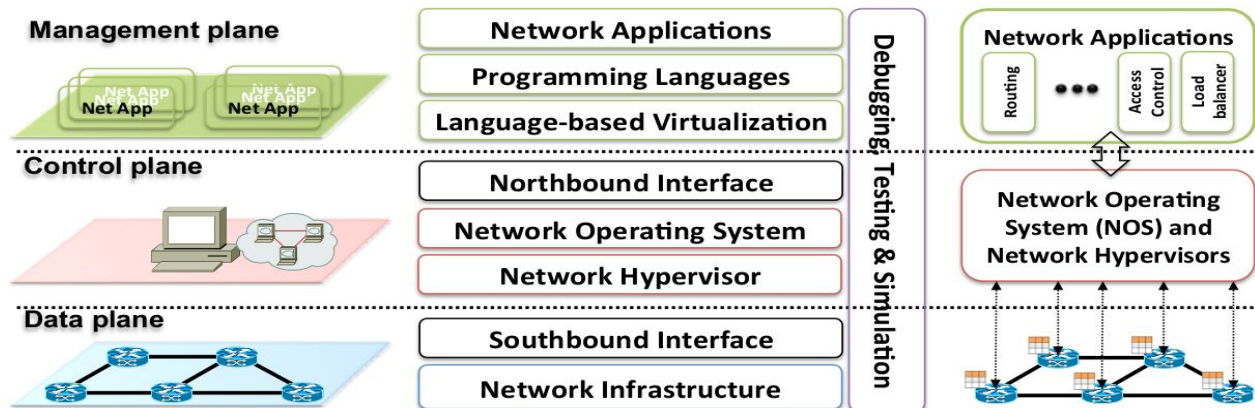


Fig. 40 SDN in Terms of Planes, Function Layers, and System Design Architecture

Figure 41 illustrates how eastbound/westbound interface definitions provide hybrid-cloud I&I capabilities for SDN inter-networking. The example highlights how the definition and use of eastbound/westbound APIs enables interoperability of SDN controller nodes that utilize different implementations of SDN components. Figure 42 is a high-level block diagram of a more fully virtualized software defined environment (SDE) where the business-needs respond to service-delivery operational-level agreements and, subsequently, drive both the "workload definition, orchestration, and optimization" and "software-defined management" aspects of the organizational infrastructure. This in turn drives the dynamic provisioning and configuration of software-defined environments, which rely upon software-defined networking, computing, and storage/data component services.

Figures 43 through 45 are from a recently published introduction to software-defined networking [60]. The high-level block diagram in Figure 43 further illustrates the characteristics of a SDE architecture. Figure 44 is an abstract view of an SDE infrastructure, wherein the available compute and storage resources are interconnected by the networking resources. This abstract view of the resources includes

¹¹⁵ High- and low-level (https://en.wikipedia.org/wiki/High-_and_low-level)

Abstraction (computer science) (https://en.wikipedia.org/wiki/Abstraction_%28computer_science%29)

Abstraction layer (https://en.wikipedia.org/wiki/Abstraction_layer)

¹¹⁶ Virtual network (https://en.wikipedia.org/wiki/Virtual_network)

the pooling of resources with similar capabilities (for compute and storage), connectivity among these resources (within one hop or multiple hops), and additional functional or nonfunctional capabilities attached to the connectivity (load balancing, firewall, security, etc.).

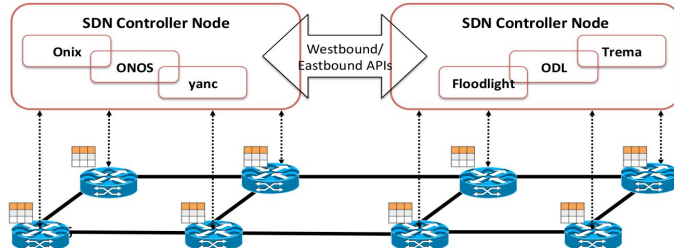


Fig. 41 Distributed SDN Controller: East/West APIs

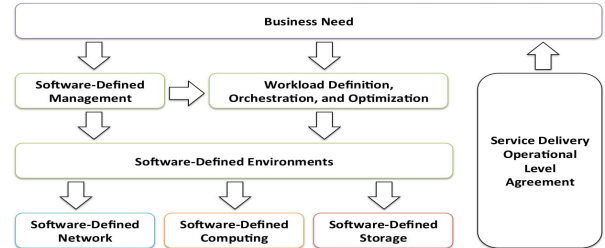


Fig. 42 Software Defined Environment (SDE)

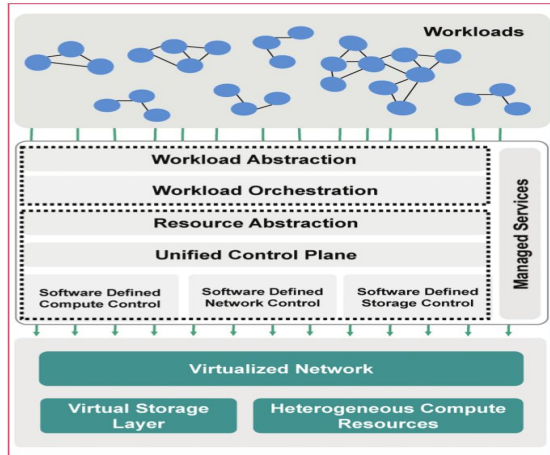


Fig. 43 Software Defined Environment: Ex. Architecture

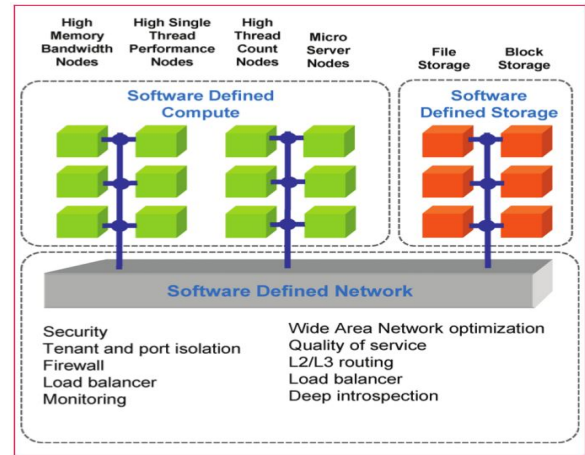


Fig. 44 Capability-Based Resource Abstraction

Figure 45 illustrates the role of continuous optimization, as a value-added service and an integral component of highly virtualized cloud-based ITI frameworks (e.g. SDE). The software quality parameters and key performance indicators (KPIs) help to parameterize the stakeholders (e.g. users) utility functions and drive the optimization process that dynamically manages the virtualized infrastructure. Note that a number of SDE focused books have recently become available. For example a more hand-ons oriented SDE book [61] and other references [62-64] provide additional information regarding more specific SDE and SDN models and implementations of respective frameworks.

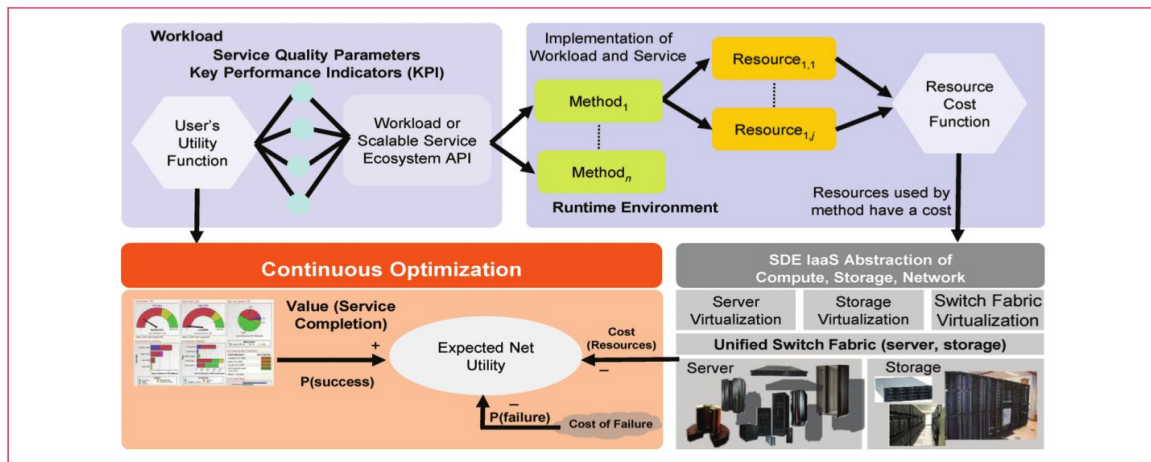


Fig. 45 Outcome-Optimized Framework for Software Defined Environments: Example

5. ITI Resources: Integrated Workflow Support

Figures 46 and 47 (from [65]) illustrate an ESB-based logical architecture that incorporates adaptation and monitoring within the context of workflow management and automation (e.g. BPMN, XPD_L).¹¹⁷ Note that the ESB is working in concert with an "adaptation and monitoring engine (decision mechanisms)" and a workflow execution engine (e.g. WS-BPEL engine). As highlighted in figure 47, adaptation requirements are achieved by monitoring of events that trigger adaptation mechanisms implemented for supporting the respective adaptation strategies.

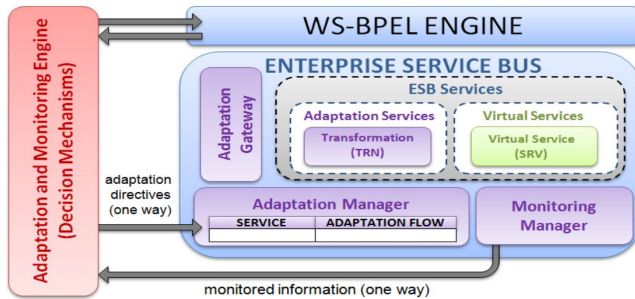


Fig. 46 Adaptive ESB: Logical Architecture

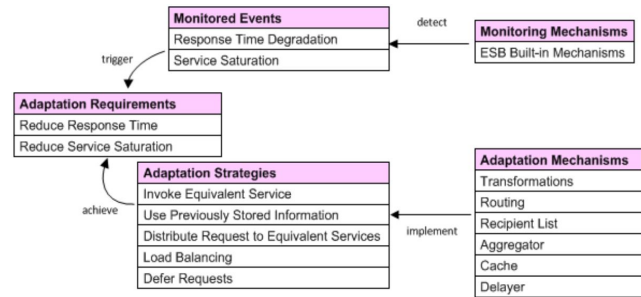


Fig. 47 Adaptive ESB: Strategies and Mechanisms

Autonomic computing and other self-managed architectures tend to address similar QoS issues within a much broader scope than is within the context of EIP focused ESB-based architectures.¹¹⁸ Due to the rapid maturity of such adaptive-workflow capabilities, these are additional areas of work that may provide the flexibility/agility needed to address D-DIL conditions.

Figure 48 (from [67]) illustrates that for process aware information systems (PAIS), as well as other workflow-pattern based collaboration-support and collaborative workflow support systems, there is a spectrum of working environments that span from unstructured (e.g. groupware) to structured (e.g. production workflow) process-flow support requirements.¹¹⁹ For e-professionals, knowledge workers, and associated virtual teaming contexts, this also includes the need for knowledge organization and knowledge management support capabilities.¹²⁰

As noted within the example reference [67], classical workflow management systems offer good process support as long as the processes are structured and do not require much flexibility. Implementing flexible systems that provide the flexibility needed for unstructured environments, is far

¹¹⁷ Event-driven process chain (https://en.wikipedia.org/wiki/Event-driven_process_chain)

Workflow patterns (https://en.wikipedia.org/wiki/Workflow_patterns)

Workflow Patterns, home page (<http://www.workflowpatterns.com/>)

Business Process Model and Notation (BPMN; https://en.wikipedia.org/wiki/Business_Process_Model_and_Notation)

XPD_L (https://en.wikipedia.org/wiki/XPD_L)

¹¹⁸ Autonomic computing (https://en.wikipedia.org/wiki/Autonomic_computing)

Self-management (computer science) (https://en.wikipedia.org/wiki/Self-management_%28computer_science%29)

¹¹⁹ Computer-supported cooperative work (CSCW; https://en.wikipedia.org/wiki/Computer-supported_cooperative_work)

Computer-supported collaboration (https://en.wikipedia.org/wiki/Computer-supported_collaboration)

Cloud collaboration (https://en.wikipedia.org/wiki/Cloud_collaboration)

Collaborative workflow (https://en.wikipedia.org/wiki/Collaborative_workflow)

¹²⁰ E-professional (<https://en.wikipedia.org/wiki/E-professional>)

Knowledge worker (https://en.wikipedia.org/wiki/Knowledge_worker)

Virtual team (https://en.wikipedia.org/wiki/Virtual_team)

Knowledge management (https://en.wikipedia.org/wiki/Knowledge_management)

Knowledge organization (KO; https://en.wikipedia.org/wiki/Knowledge_organization)

Knowledge Organization Systems (KOS; https://en.wikipedia.org/wiki/Knowledge_Organization_Systems)

from trivial. By leveraging workflow patterns, while utilizing a more declarative and functional programming type of approach, the example reference demonstrates that it is possible to balance between support or flexibility.¹²¹ Note that the declarative/functional approach presented in the paper is based on constraints, i.e., anything is possible as long as it is not explicitly forbidden.¹²² Constraint-based models, therefore, implicitly specify the execution procedure by means of constraints: any execution that does not violate constraints is possible.

Figure 49 (also from [67]) is an example architecture for declarative workflow support. As described, "the core of the system consists of the following basic components: Designer, Framework and Worklist. The Designer component is used for creating the so-called constraint templates, to design concrete process models, and to verify these models. The Framework enacts instances of process models. Moreover, it also conducts ad-hoc changes of running instances. While the Framework centrally manages the execution of all instances, each user uses his/her Worklist component to access active instances. Also, a user can execute activities in active instances in his/her Worklist" [67].

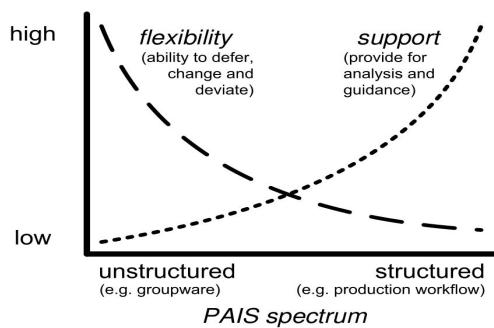


Fig. 48 PAIS: Flexibility-vs-Support

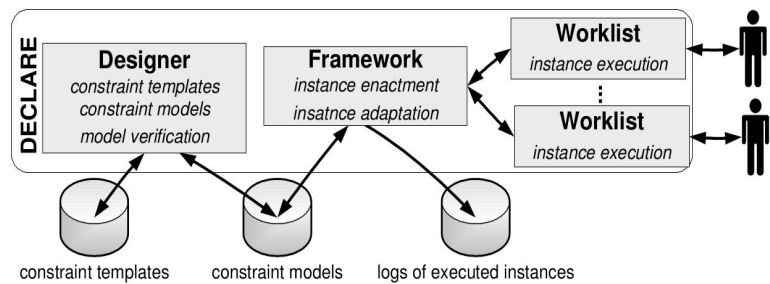


Fig. 49 Declarative Workflow: Example Architecture

As also noted within [67], this type of approach to declarative workflow support has many similarities with rule-based (e.g. BPMS) and other constraint-based process modeling approaches, as previously discussed in the background section. Within a rule-based representation, declared (i.e. specified) process models are executed via execution of rules that trigger each other (e.g. business rules, ECA rule).¹²³ As highlighted for both constraint-based and rule-based systems, for which events and conditions are the focus of concern, event-driven architectures and active databases are the types of approaches that tend to provide the needed balance between flexibility and support.¹²⁴ Note that formal methods have also been developed for supporting this type of declarative workflow support [68]. Overall, the end-goal is to provide an optimized ITI framework that provides support for the worklists of geographically dispersed stakeholders who may be operating during degraded (D-DIL) conditions.

Figure 50 and figure 51 are from a presentation by the Chief Systems Engineer of the Navy [69]. The diagrams illustrate how the Navy mission areas can be decomposed into mission essential task lists (METLs) that can be further mapped into system-agnostic mission threads. The results of this type of process can be readily leveraged for developing PAIS compatible worklists for which associated

121 Declarative programming (https://en.wikipedia.org/wiki/Declarative_programming)

Functional programming (https://en.wikipedia.org/wiki/Functional_programming)

122 Constraint (mathematics) (https://en.wikipedia.org/wiki/Constraint_%28mathematics%29)

Constraint satisfaction (https://en.wikipedia.org/wiki/Constraint_satisfaction)

Constraint programming (https://en.wikipedia.org/wiki/Constraint_programming)

123 Event condition action (ECA; https://en.wikipedia.org/wiki/Event_condition_action)

124 Event-driven SOA (https://en.wikipedia.org/wiki/Event-driven_SOA)

Event-Driven Messaging (https://en.wikipedia.org/wiki/Event-Driven_Messaging)

Event-driven programming (https://en.wikipedia.org/wiki/Event-driven_programming)

indicators can, in principle, be developed using previously discussed methods (e.g. GQIM). Note that system agnostic activity (i.e. workflow) swim-lane diagrams (e.g. SV-5b/6c) provide platform independent models (PIM) for representing system-agnostic mission-threads.¹²⁵

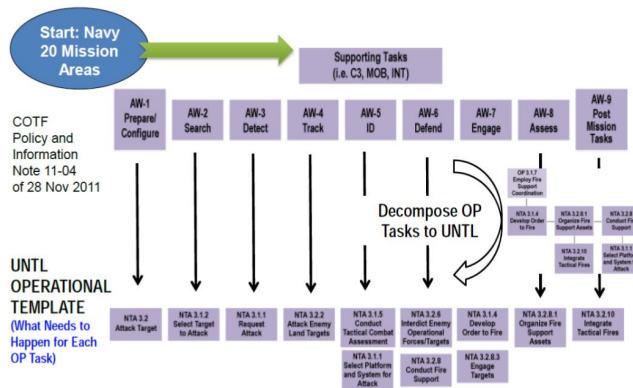


Fig. 50 DON EA: Mission-Thread Development

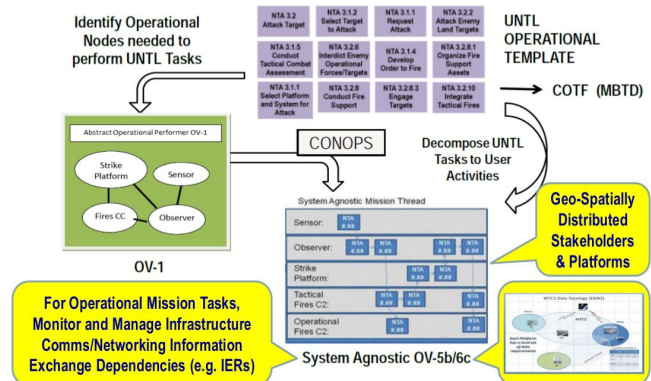


Fig. 51 DON EA: Mission-Thread Development (continued)

Figures 52 through 55 (from [70]) provide a series of example views that highlight a standards development framework (SDF) for a recently certified modeling and simulation (M&S) standard, called the coalition battle management language (C-BML).¹²⁶ Additionally, open-source C-BML resources are available (e.g. OpenBML) and can be readily tailored to the needs of this effort [71-73].¹²⁷

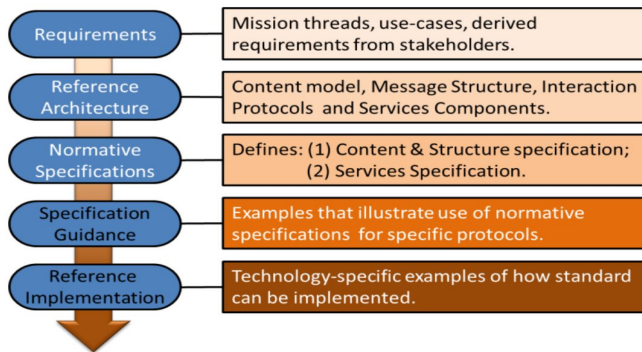


Fig. 52 C-BML SDF: Overview

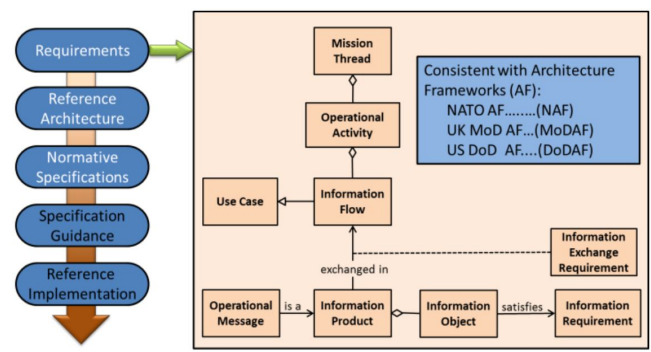


Fig. 53 C-BML SDF: Requirements Model

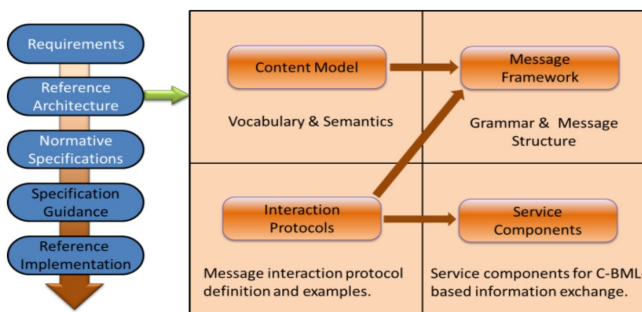


Fig. 54 C-BML SDF: Ref. Architecture

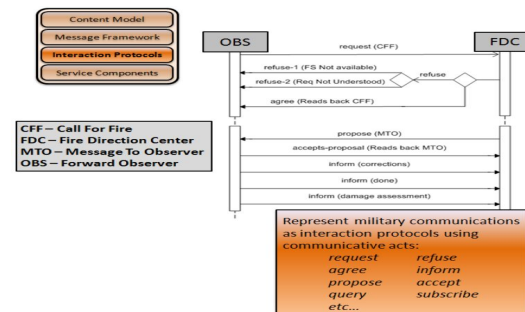


Fig. 55 C-BML SDF: Interaction Protocols

¹²⁵ Activity diagram (https://en.wikipedia.org/wiki/Activity_diagram)

Swim lane (https://en.wikipedia.org/wiki/Swim_lane)

DoDAF Systems and Services View

(https://en.wikipedia.org/wiki/Department_of_Defense_Architecture_Framework#Systems_and_services_view)

Platform-independent model (PIM; https://en.wikipedia.org/wiki/Platform-independent_model)

¹²⁶ SISO C-BML Standard (http://www.sisostds.org/DigitalLibrary.aspx?Command=Core_Download&EntryId=41767)

¹²⁷ OpenBML (<https://netlab.gmu.edu/trac/OpenBML>)

As the figures illustrate, the C-BML SDF can be utilized for developing a model-based approach that incorporates a controlled vocabulary, standardized modeling process, and workflow support capability. This type of approach can incorporate the tracing of military communication events and respective interaction protocols to the corresponding information-exchange requirements, tasks, scenarios, and mission-threads. Ideally, a cloud-based experimentation framework can incorporate this type of capability for developing mission-driven metrics/indicators and continuous-improvement support.

6. Metrics, Indicators, and Capability Assessment Models

Figures 56 through 60 are from the latest (draft) version of a cloud-computing service metrics description document, which has been under development by the NIST cloud computing reference architecture and taxonomy working group [74]. The document presents a Cloud Service Metric (CSM) model that describes the higher level concepts of the abstract metric definitions for a cloud service property. Definitions for abstract metrics contain parameters and rules to express a formal understanding of the property of interest. The CSM model also contains concrete metric definitions that are based on abstract metric definitions. Concrete metric definitions add specific values to rules and parameters that make the metric usable for a given scenario.

Figure 56 (from [74]) shows the relationship between a property and a metric. Cloud services have properties that represent characteristics of the service. The definition and associated data model are important for representing and understanding these properties, as they apply to service capabilities. One way to understand properties is with metrics. The use of a metric through an observation results in measurement results to estimate the property of an element.

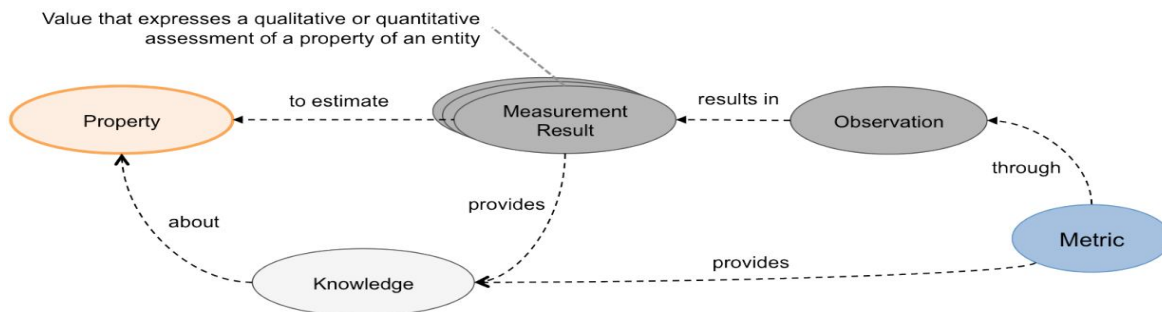


Fig. 56 Entity Properties: Measurements and Supporting Metrics

For more explicitly defining the CSM concept, figure 57 (from [74]) is a UML class diagram that describes and helps to more formally define the metric data model (i.e. class).¹²⁸ The CSM model provides a common standard that captures the information needed to describe and understand metrics. Such metrics are used for gaining knowledge about, and measuring cloud service properties.

Figure 58 (from [74]) displays the process followed to define metrics from different viewpoints and contexts. The CSM model defines the core concepts and elements that constitute a standard of measurement. Specific instances of a subset of these elements are then used to create an abstract metric definition. Then for a given abstract metric definition, implementation metrics are created using instances of another subset of the CSM elements to create concrete metric definitions.

The definition and usage of appropriate metrics with their underlying measures are essential components of the Service Level Agreement (SLA) and Service Level Objectives (SLO), which are

¹²⁸ Class diagram (https://en.wikipedia.org/wiki/Class_diagram)

constituents of the service agreement (SA).¹²⁹ In terms of IT service management (ITSM), metrics are useful for setting boundaries and margins of errors for the service providers to abide by and set their limitations.¹³⁰ For example, metrics are useful at runtime for service monitoring and balancing, or remediation (e.g., financial). Using a standardized set of metrics or metric templates in SAs makes it easier and quicker to define SLAs and SLOs, and to compare them with others.

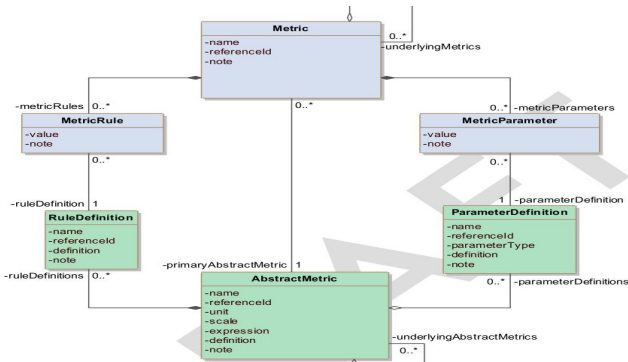


Fig. 57 NIST Draft: Cloud Services Metric (CSM)

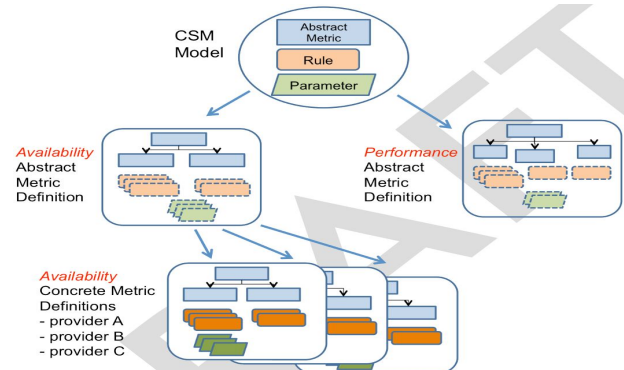


Fig. 58 NIST Draft: Metric Definition Process

Figure 59 (from [74]) illustrates a monitoring use-case where a cloud-customer uses metrics to monitor the status of the services provided, relative to the SLA and underlying SLOs. Figure 60 (from [74]) further illustrates the role of metrics within the context of a scenario (e.g. workflow, mission-task).

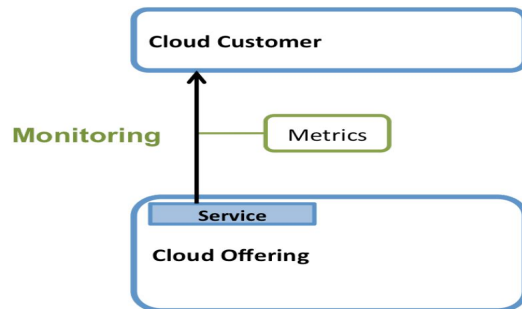


Fig. 59 NIST Draft: Cloud Service Objectives Monitoring

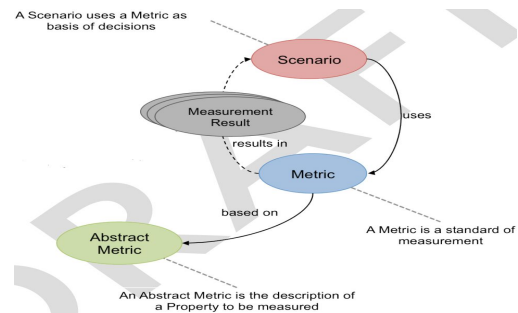


Fig. 60 NIST Draft: Scenario and Metric

As the CSM draft matures and becomes a standard for representing and utilizing metrics, related metrics need to be incorporated into a more unified measurement process and methodology. For example, figure 61 (from [75]) is an example of a wireless-networking focused taxonomy that provides a classification system and data model for wireless-communications oriented quality of service (QoS) metrics that can be incorporated into a unified cloud-based ITI framework.¹³¹ Figure 62 (also from [75]) is an example taxonomy of the types of QoS based enhancements for which QoS metrics can assess the respective contribution to achieving QoS goals and objectives.

¹²⁹ Service-level agreement (SLA; https://en.wikipedia.org/wiki/Service-level_agreement)

Service level objective (SLO; https://en.wikipedia.org/wiki/Service_level_objective)

¹³⁰ IT service management (ITSM; https://en.wikipedia.org/wiki/IT_service_management)

¹³¹ Quality of service (QoS; https://en.wikipedia.org/wiki/Quality_of_service)

Mobile QoS (https://en.wikipedia.org/wiki/Mobile_QoS)

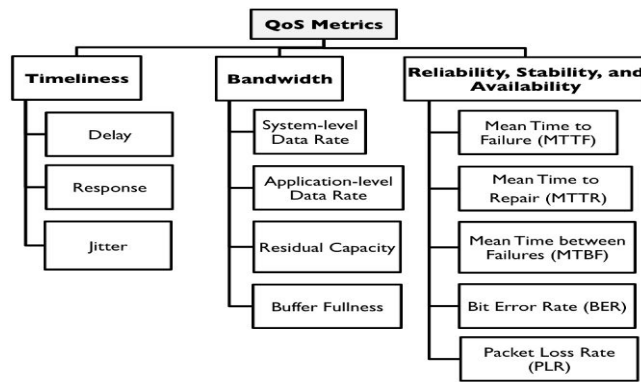


Fig. 61 QoS Taxonomy for Wireless Networks: Example

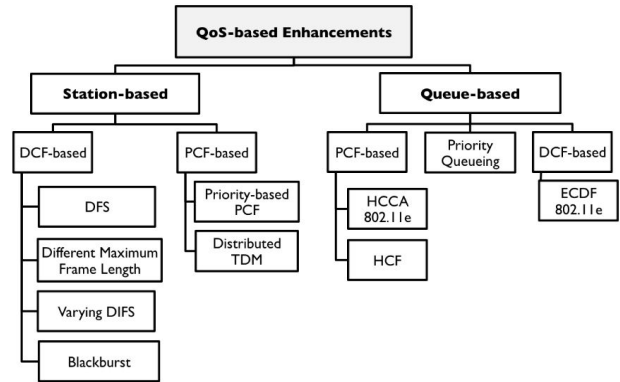


Fig. 62 MAC Layer QoS Enhancement Schemes: Ex.

Figures 63 through 66 (from [76]) are a set of diagrams generated by an effort that is working towards the development of a cloud-service capability-assessment framework. Figure 63 illustrates that much progress has been made towards developing reference models for developing standardized capability assessment frameworks. Note that continuous cloud improvement is an integral element of the process and works closely with cloud-operations oriented activities. As previously discussed, there is a separate MBSE/SOSE I&I challenge associated with how to best incorporate and adapt this type of capability assessment framework for hybrid-cloud data-transport and data-mediation experimentation purposes.

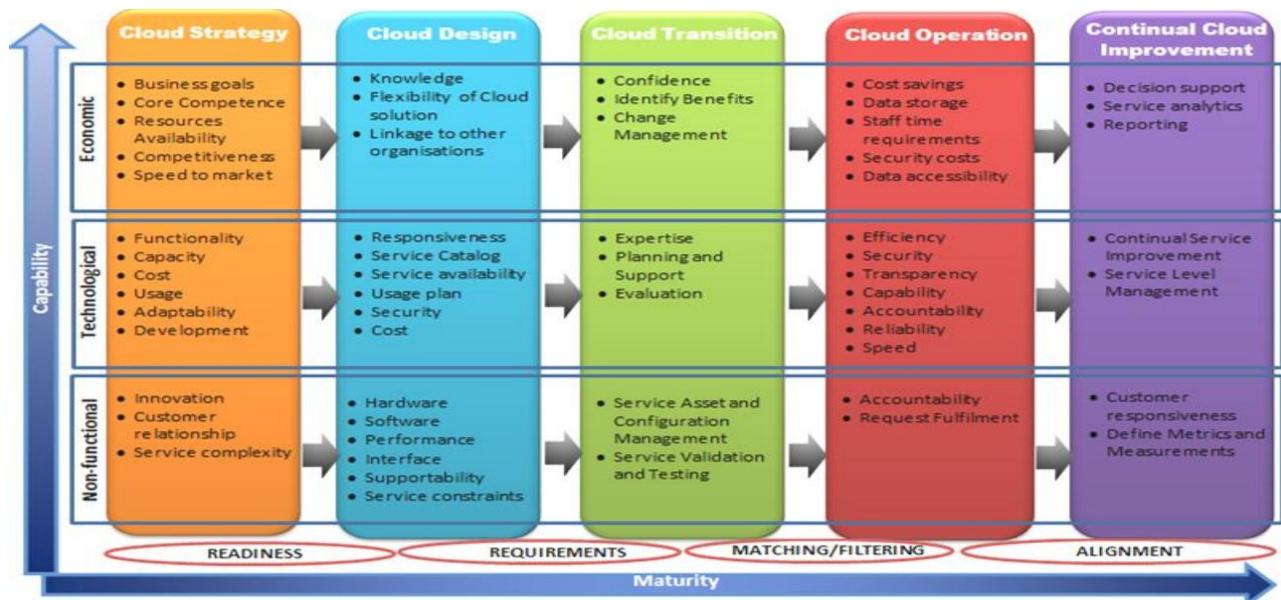


Fig. 63 Capability Assessment Overview

Figure 64 (from [76]) illustrates the taxonomy of the characteristics of the service measurement index (SMI).¹³² Note that the SMI defines a framework and method for the calculation of a relative index, which may be used to compare IT services against one another, or to track services over time.

Figure 65 (from [76]) is a table that summarizes a number of the main components (i.e. elements) which typically need to be considered when assessing a cloud environment. This helps to provide a more well defined structure for an assessment process that measures specific characteristics and best captures the data needed for assessing cloud capabilities. Figure 66 (from [76]) is a diagram that provides an overview of the overarching phases of a typical capability assessment process.

¹³² Service Measurement Index (SMI; https://en.wikipedia.org/wiki/Service_Measurement_Index)

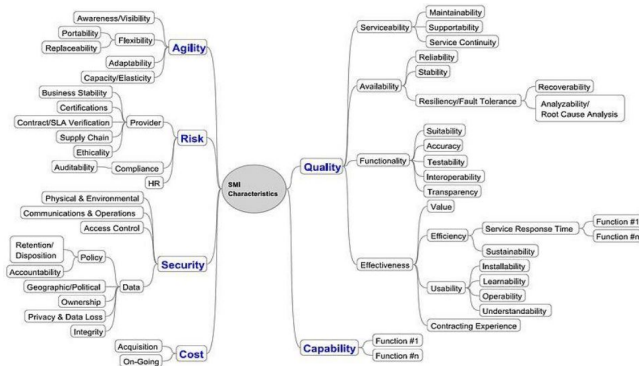


Fig. 64 Service Measurement Index (SMI): Taxonomy

Component	Description
Description	Description of the purpose and use of the process.
Entry criteria	Describe the previous activities and preconditions to successfully carryout the process.
Inputs	Items that are required to conduct the activities (e.g. documents, plans).
Actors	Roles of people to undertake the activities.
Roles	A set of responsibilities, activities, and authorities granted to a person or a team
Activities	Describe the steps to see the process through.
Outputs	Identify what outputs should appear after the activities are executed.
Exit criteria	The results that should be in place in order to conclude the process and responsibilities have been accounted for.
Measures	Define the measures you will collect for the process which will give insight on performance.

Fig. 65 Assessing Cloud Components



Fig. 66 Capability Assessment Overview

As highlighted by the figures, there are many components to the assessment process. These components provide a solid foundation to develop service capabilities through rigorous assessment.

7. Tactical Mission-Support: Example Domains and Use-Cases

Figures 67 through 70 (from [77]) provide example views of a standardized sensor/data fusion model, called the Joint Director of Laboratories (JDL) fusion model.¹³³ Note the role of information management processes, such as resource management and mission management, within the context of mapping, transport, and integration/fusion of information that flows from the sources to the human decision-making activities. Also, note the distinction between explicit-fusion versus tacit-fusion related processes. The end-goal is to improve QoS (e.g. findability, discoverability) and user-experience.¹³⁴

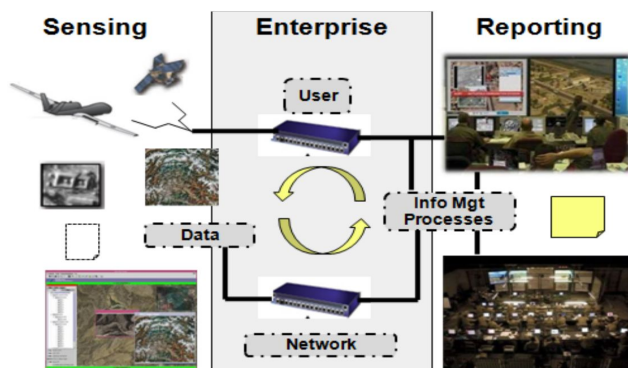


Fig. 67 Information Fusion in the Enterprise

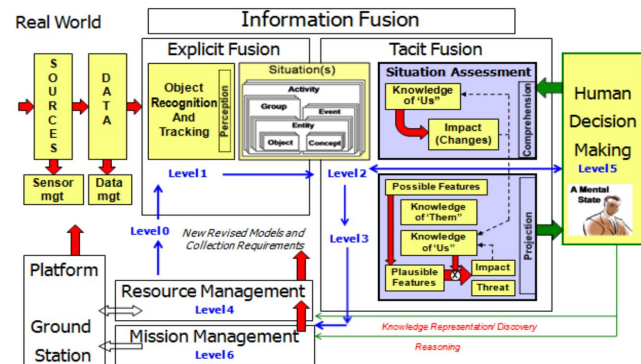


Fig. 68 Info. Fusion Situation Assessment Model

As further highlighted in the example figures, data-mining and other related information services (e.g. information integration, indexing, retrieval, query, question-answer, discovery), play a critical role within the generic use-case model and patterns.¹³⁵

¹³³ Sensor fusion (https://en.wikipedia.org/wiki/Sensor_fusion)

Data fusion (https://en.wikipedia.org/wiki/Data_fusion)

¹³⁴ Findability (<https://en.wikipedia.org/wiki/Findability>)

Discoverability (<https://en.wikipedia.org/wiki/Discoverability>)

User experience (https://en.wikipedia.org/wiki/User_experience)

¹³⁵ Data mining (https://en.wikipedia.org/wiki/Data_mining)

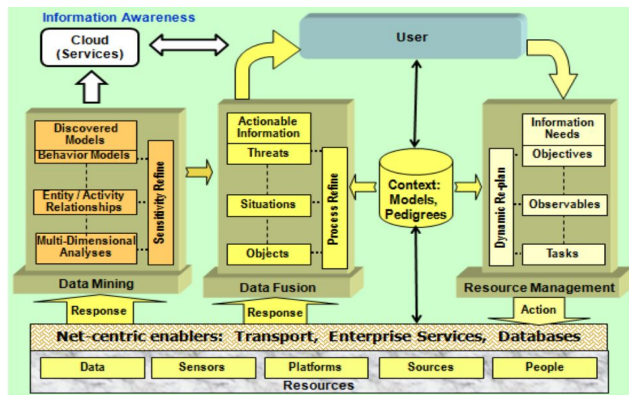


Fig. 69 Information Fusion Enterprise Model

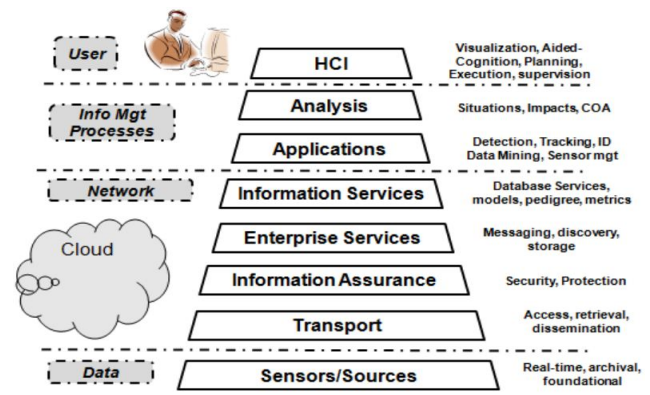


Fig. 70 Layered Information Services

Figure 71 (from [78]) is a table that illustrates the inter-relatedness of metrics that are significant to information fusion and related disciplines (e.g. communications, human factors, ATR/ID, tracking).

COMM	Human Factors	Info Fusion	ATR/ID	TRACK
Delay	Reaction Time	Timeliness	Acquisition /Run Time	Update Rate
Probability of Error	Confidence	Confidence	Prob. (Hit), Prob. (FA)	Prob. of Detection
Delay Variation	Attention	Accuracy	Positional Accuracy	Covariance
Throughput	Workload	Throughput	No. Images	No. Targets
Cost	Cost	Cost	Collection platforms	No. Assets
Stallings 2002	Wickens, 1992	Blasch, 2003	Blasch, 1999	Blasch, Hoffman 2000

Fig. 71 Example Metrics for Information Fusion and Related Disciplines [from Blasch et al. 2004]

Figure 72 (also from [78]) highlights a number of the attributes and subproperties of the respective information fusion metrics. These more use-case focused metrics can help drive the development of performance-based metrics for cloud-computing ITI frameworks.

Timeliness	Accuracy	Confidence	Throughput	Cost
Time to detect	Track uncertainty	Correct ID	Coverage Area	Asset utilization
Track initiation time	Prediction accuracy	Declaration rate	% targets tracked	Revisit rates
Time tracked	Platform error, bias	False alarms	% users needs met	User salary
Plan approval time	Coverage Area	Trust	Number of images	Machine repair costs

Fig. 72 Quality of Service (QoS) Metrics for Fusion Systems: Examples [from Blasch et al. 2004]

Figures 73 and 74 (from [79]) are example views that illustrate how SDN methods have been explored and utilized for helping to manage the timing of a query response as the various stages of the processing pipeline are executed. Note how a query manager interacts with the SDN infrastructure components to address the associated interactions for query-execution support. Figures 75 and 76 (from [81]) illustrate the sequencing of interactions that are required for query execution. This further highlights the role of data-synchronization support and the value of developing a performance-based experimentation framework. The interaction of the query processor with the data sources is a critical dependency that impacts the success of a given query plan.

Information integration (https://en.wikipedia.org/wiki/Information_integration)
Information extraction (https://en.wikipedia.org/wiki/Information_extraction)
Annotation (<https://en.wikipedia.org/wiki/Annotation>)
Subject indexing (https://en.wikipedia.org/wiki/Subject_indexing)
Search engine indexing (https://en.wikipedia.org/wiki/Search_engine_indexing)
Web indexing (https://en.wikipedia.org/wiki/Web_indexing)
Query language (https://en.wikipedia.org/wiki/Query_language)
Query string (https://en.wikipedia.org/wiki/Query_string)
Information retrieval (https://en.wikipedia.org/wiki/Information_retrieval)

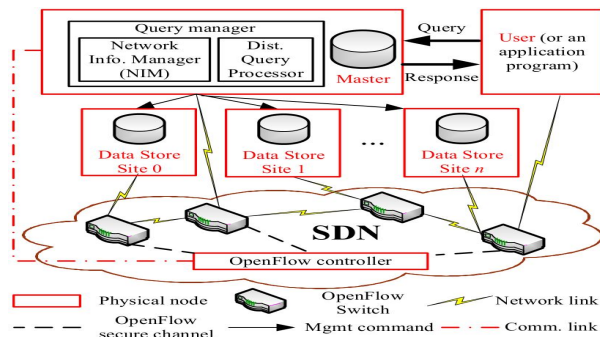


Fig. 73 System Architecture: Example

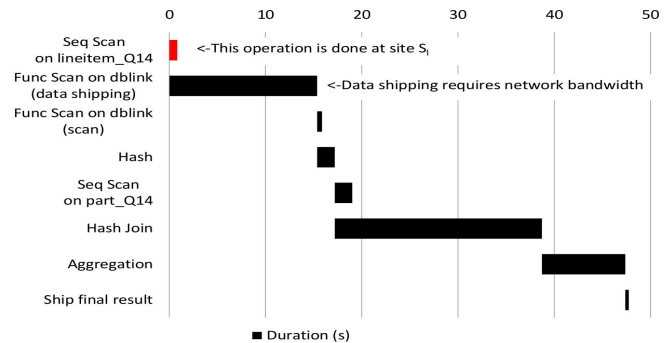


Fig. 74 Example Query-Execution Gantt Chart

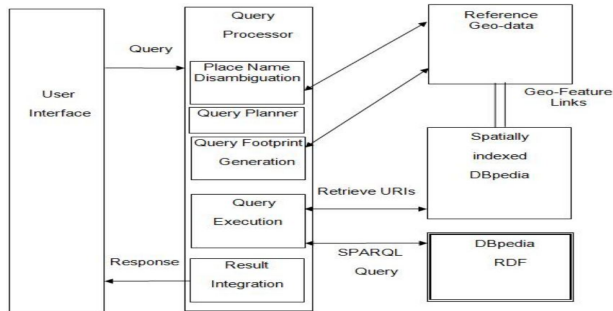


Fig. 75 GIR/QA Systems: Example Architecture

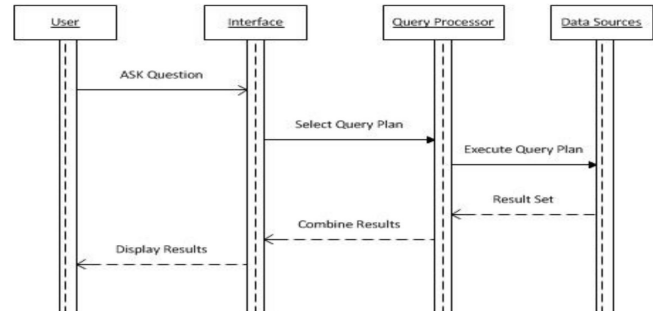


Fig. 76 GIR/QA Systems: Example Sequence Diagram

Other intelligence-cycle oriented methods and techniques, such as the structured geospatial analytic method (SGAM), provide other example use-cases (e.g. information foraging, sensemaking, analysis of competing hypotheses, data visualization) of TST and tactical ISR mission-support services.¹³⁶

8. Discussion

For developing performance-based metrics and associated experimentation support for hybrid-cloud data-transport and data-mediation, the previous sections provided representative examples of the areas of work that need to be addressed. Much of the discussion was from a MBSE/SOSE I&I perspective and position of simply adopting models/methods that are readily available and already proven within their respective application domains (e.g. federated data sharing, cloud computing, workflow, capability metrics/assessment, use-cases). In contrast to the more immediate incremental focus of the previous sections, this section focuses on the long-term end-goals, objectives, and desired outcomes.

The examples provided within the previous sections are meant to communicate the breadth and depth of the current MBSE/SOSE I&I challenges that impact the development of a performance-based experimentation framework that focuses on the development of metrics and indicators for data-transport and data-mediation algorithms. As noted in the previous sections, much progress has been demonstrated within a number of applicable domains. From a more basic perspective, this added knowledge and awareness helps to better inform the development of an experimentation framework.

¹³⁶ Intelligence cycle (https://en.wikipedia.org/wiki/Intelligence_cycle)

Intelligence cycle management (https://en.wikipedia.org/wiki/Intelligence_cycle_management)

Structured Geospatial Analytic Method (https://en.wikipedia.org/wiki/Structured_Geospatial_Analytic_Method)

Information foraging (https://en.wikipedia.org/wiki/Information_foraging)

Sensemaking (<https://en.wikipedia.org/wiki/Sensemaking>)

Analysis of competing hypotheses (ACH; https://en.wikipedia.org/wiki/Analysis_of_competing_hypotheses)

Data visualization (https://en.wikipedia.org/wiki/Data_visualization)

From a more practical perspective, this wealth of related work and rapid maturity of various technologies such as virtualization (e.g. SDE), further complicates the nature of the effort.

Within this section, the goal is to discuss an additional level of complication that relates directly with one of the primary end-goals of this effort. As with the previously discussed C2SS effort, the goal is to logically define different types of functionality for which there is better alignment between the underlying mathematics (and theoretical computer science) and the EA/SOA services that are generically defined. Given this type of highly virtualized architectural structure, different types of algorithms and respective variants can be more readily developed and applied to meet the variety of context-dependent needs that may be encountered within a potentially degraded operating environment.

As indicated within the previous sections, much of the technologies surveyed can incorporate and immediately leverage available models, frameworks, and resources, while also providing the basis for a roadmap for longer lead-time objectives. A key distinction of this effort is the intent to incorporate taxonomies of functions, algorithms, and their generic context-dependent utilization. With this type of more mathematically oriented context, an added objective is to more explicitly incorporate conceptual and abstract models that are otherwise more removed from the engineering and implementation details of ITI frameworks. The end-goal is to at least provide an explicitly defined tracing and mapping of ITI frameworks, from a more mathematical and theoretical computer science perspective. This type of conceptual milestone for MBSE/SOSE enables the ability to more directly work through and further develop the foundational aspects of the respective MBSE/SOSE end-goals.

Figures 77 and 78 (from [82]) visually illustrate the types of taxonomies that can help to define and manage the scoping of different types of algorithms and uses. In this case, the categorization of usage scenarios and associated variants of a family of algorithms, called Bloom filters (BF), are visually depicted. As illustrated, Bloom filters are useful for a variety of applications (e.g. set-reconciliation), where specific types of probabilistic tests of set membership provide a critical benefit. Bloom filters, which can utilize different types of hashing functions and techniques for determining set membership, are a working example and use-case for the more algorithmic oriented end-goals of the current effort.

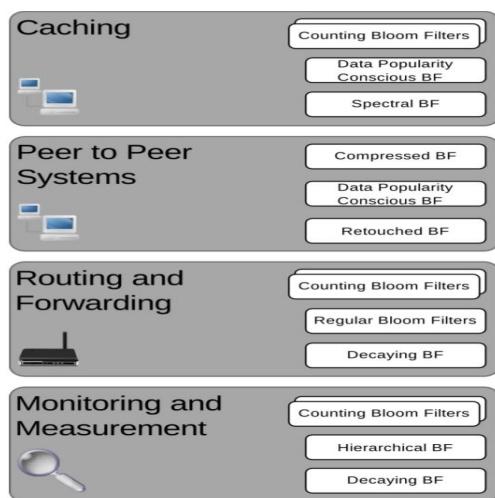


Fig. 77 BF Variants by Usage Scenario

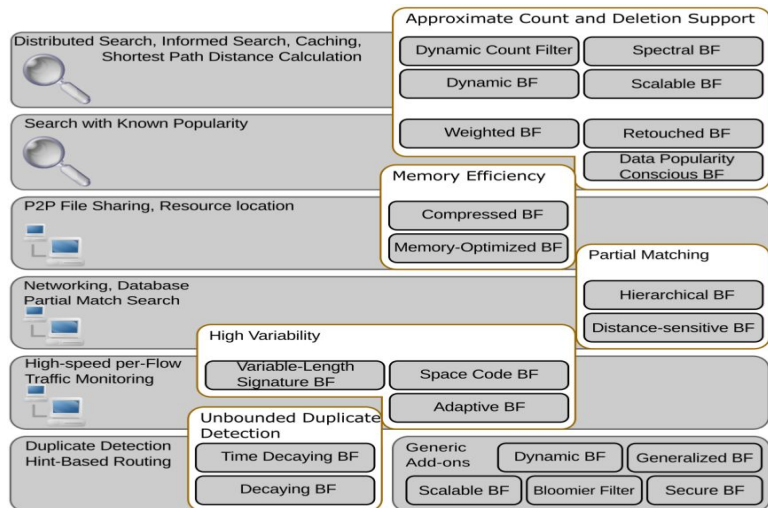


Fig. 78 BF Variants: Summary by Type and Application Scenario

Ideally, an MBSE/SOSE experimentation framework should incorporate and utilize the type of categorizations (e.g. taxonomies, conceptual schemata, data models) illustrated in figures 77 and 78. Such taxonomies, at their high levels of abstraction, can be invariant to specific implementation details as they may apply to either the use-cases (i.e. workflow) or the underlying ITI framework properties.

As highlighted within the previous sections, this type of categorical approach can be quite challenging to align, integrate, and incorporate into a more unified model-based experimentation framework.

Figures 79 and 80 (from [82]) are example taxonomies from an applicable wireless ad-hoc networking context (e.g. MANET, VANET) [82-92].¹³⁷ In this case, classification systems (i.e. taxonomies) are provided for routing protocols and mobility models. Ideally, such taxonomies can be compared and aligned with canonical (i.e. standardized) reference taxonomies that are explicitly represented and managed within a respective experimentation framework. Furthermore, the contextual representation of the interaction between the set-reconciliation algorithms and networking algorithms/services (e.g. routing, mobility models) could be managed and analyzed within their more native mathematical modeling context. Such capabilities are assumed to be driven by workflow-oriented classification systems (e.g. taxonomies, patterns) and standardized models of the respective use-cases (e.g. fusion).

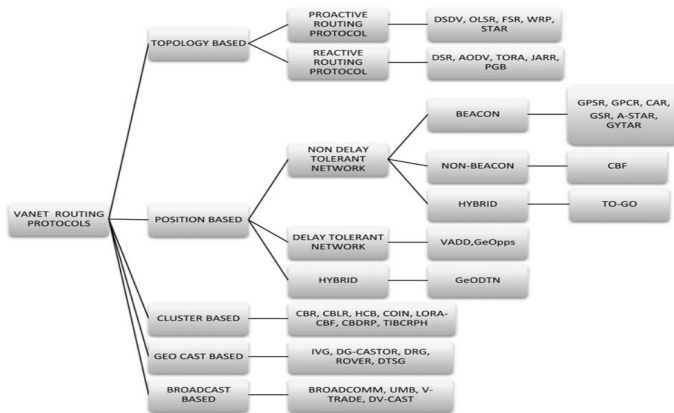


Fig. 79 VANET Routing Protocols: Example Taxonomy

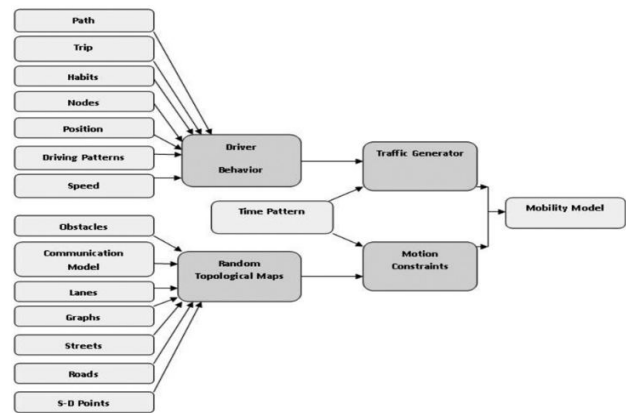


Fig. 80 Generation of Mobility Model: Example

The initial steps are underway for developing this type of virtualization of algorithmic and ITI services capabilities. A virtual network of representative DDF/DIB enabled cloud-nodes will provide a basis and foundation for assessing how to best accommodate and support this type of highly-virtualized performance-metric development and experimentation capability. For initial experiments, recently developed set-reconciliation algorithms [93-94], as well as, recently developed variants of Bloom filters (e.g. multidimensional Bloom filters) and related algorithms are to be utilized as examples of the types of algorithms for which performance-metrics are to be determined and evaluated [95-104]. Also of interest is the incorporation and tailoring of applicable information-exchange standards (e.g. Active XML) for developing more robust/resilient wireless federation of NoSQL data-stores, which includes both RDF triplestore queries (e.g. Rya/Accumulo) and document-centric collaboration using document-oriented databases (e.g. MongoDB, BSON/JSON) [105-110].¹³⁸ The performance metrics and

¹³⁷ Wireless ad hoc network (https://en.wikipedia.org/wiki/Wireless_ad_hoc_network)

Mobile ad hoc network (MANET; https://en.wikipedia.org/wiki/Mobile_ad_hoc_network)

Vehicular ad hoc network (https://en.wikipedia.org/wiki/Vehicular_ad_hoc_network)

¹³⁸ NoSQL (<https://en.wikipedia.org/wiki/NoSQL>)

Apache Accumulo (https://en.wikipedia.org/wiki/Apache_Accumulo)

Resource Description Framework (https://en.wikipedia.org/wiki/Resource_Description_Framework)

Triplestore (<https://en.wikipedia.org/wiki/Triplestore>)

Document-centric collaboration (https://en.wikipedia.org/wiki/Document-centric_collaboration)

Document-oriented database (https://en.wikipedia.org/wiki/Document-oriented_database)

MongoDB (<https://en.wikipedia.org/wiki/MongoDB>)

BSON (Binary JSON; <https://en.wikipedia.org/wiki/BSON>)

JSON (JavaScript Object Notation; <https://en.wikipedia.org/wiki/JSON>)

indicators are to be matched with applicable use-cases (e.g. concurrent distributed updates, federated semantic query/indexing) and scenarios (e.g. content analytics, QA, information retrieval, fusion).¹³⁹

9. Summary and Conclusion

Agile network-enabled C2 requires a distributed-computing infrastructure that is tolerant to D-DIL communication/networking conditions. This is especially the case for time-sensitive mission-tasks operating within A2/AD environments. Under such circumstances, an emerging diversity of Cyber/EW and kinetic attacks can induce a growing variety of different types of D-DIL conditions. Thus, there is an emerging critical need for more explicitly modeling and understanding the different types of dynamically changing sources of degradation that, in turn, can cause different types of D-DIL conditions that impact mission success.

The overall focus of this paper has been to survey the applicable technologies, models, and resources, while addressing the practical challenges of implementing a MBSE/SOSE based experimentation framework that focuses on the need for model-level I&I capabilities. As highlighted and discussed throughout the sections, the experimentation framework is to support the development of performance metrics for algorithms and associated methods that address emerging hybrid-cloud data-transport and data-mediation needs. The goal is to provide an assessment capability for a variety of mission scenarios (e.g. A2/AD) that may include a variety of D-DIL conditions that may be anticipated in such situations.

To the extent possible, available resources are to be utilized and tailored as needed for establishing an initial experimentation-based metrics/indicators development and assessment capability. Sections three and four provided an overview of the DDF/DIB and readily available cloud-computing resources. As covered within the survey, there may be added challenges in terms of the rapid evolution and maturity of virtualization technologies. Thus, a need to determine how to best plan and roadmap different levels and types of virtualization that are to be incorporated within the incremental development process.

Sections five and six reviewed model-based standards and methods for cloud-based metrics, within the context of workflow and mission-execution. As with the case for virtualization technologies, there is an analogous situation where the supporting metrics and workflow models/resources have rapidly emerging developments. The challenge in this case is at least twofold: (i) The model-level I&I challenges for workflow and cloud-computing related performance metrics need to be addressed within their own operations and business-performance context; (ii) The underlying systems-oriented aspects of the ITI framework (e.g. hybrid-cloud infrastructure) needs to be addressed. The combined inter-dependencies of the net-centric operations (i.e. workflow) and respective ITI systems components (i.e. framework) can then be addressed within this operations-versus-infrastructure perspective that is aligned with the type of view models currently utilized for EA/SOA development (e.g. DoDAF).

Section seven reviewed example use-cases that apply to tactical mission-execution and workflow support. The examples included discussion of data-transport related concerns (e.g. response time, latency) and associated metrics. As demonstrated for the examples covered (e.g. data fusion, data mining, federated/distributed query, information foraging, sensemaking), the incorporation of reference models and standards helps to assist the process of working through the conceptual integration of the respective models, standards, and associated mission performance metrics/indicators.

¹³⁹ Semantic query (https://en.wikipedia.org/wiki/Semantic_query)

Question answering (QA; https://en.wikipedia.org/wiki/Question_answering)

Information retrieval (IR; https://en.wikipedia.org/wiki/Information_retrieval)

Section eight discussed the more long-term aspects of this ongoing ITI oriented research effort. In the near-term, there are a considerable number of S&T challenges associated with co-evolving existing DoD/IC federated data-sharing resources (e.g. DDF/DIB) and emerging maritime-afloat cloud-based ITI frameworks (e.g. TC-RI). While incrementally addressing such challenges, the goal is to more effectively address the need to establish S&T roadmaps that incorporate possibly more disruptive and transformational technology development increments. In principle, the desired MBSE/SOSE approach should anticipate both a near-term, as well as, longer-term evolution towards more fully virtualized and resilient distributed-computing infrastructures (e.g. SDE, cognitive networks, resilient systems).

10. Future Work and The Way-Ahead

This technology survey has been motivated by the desire to develop a MBSE/SOSE process that addresses conceptual I&I needs for EA/SOA and related (e.g. SDN) reference models, patterns, best practices, standards, and available resources. In particular, the recently open sourced DDF/DIB and emerging cloud-based ITI frameworks (e.g. TC-RI), are recognized as example code bases that can be potentially co-evolved and tailored to address hybrid-cloud data-transport and data-mediation needs. In particular, there is a need for the development of robust/resilient data-synchronization algorithms tailored to operating in A2/AD environments during D-DIL conditions.

Thus, in terms of an incremental continuous-improvement based MBSE/SOSE effort, the work described in this paper is motivated by a need for establishing a model-based systems integration (MBSI) process that supports conceptual integration and interoperability (I&I) at the platform-independent (i.e. meta-modeling) levels of the MDE lifecycle support process [111]. This type of MBSI process facilitates development of collaborative model-integration and qualification (I&Q) resources and more unified model-integration, qualification, and build capabilities. Complementary work is underway for developing a MBSE/SOSE incremental development process that utilizes and tailors the OMG MDA standards, resources, and tools. The incorporation and use of such methods and techniques into the experimentation framework is also a focus of ongoing and future work.

The role and importance of time-sensitive data-transport and data-mediation services, relative to information-exchange and interaction with unmanned systems (UxS), is another area of future work. For tactical ISR, the impact of D-DIL conditions on machine-to-machine (M2M) and machine-to-human (M2H) interactions are of particular interest. As previously discussed, this effort will continue to work with robotics oriented projects and UxS subject matter experts (SMEs) to further address these types of S&T challenges and associated capability gaps.

Within the technology survey, references to other emerging technologies have continued to surface. In particular, the following three domains are candidates for a follow-up survey: (i) autonomous computing [112];¹⁴⁰ (ii) second generation product-line engineering [113]; (iii) resilient network design and engineering [114-117]. Of particular interest are efforts that have explored the development of resilient autonomous frameworks that provide improved dynamic service level provisioning capabilities.

While conducting this more enterprise oriented survey, efforts that focus on network resilience and engineering resilience systems, were identified. The attached appendix provides examples of applicable work that needs to be further explored. As highlighted, there are well developed reference models and technology development initiatives for which this effort needs to be aligned and integrated.

¹⁴⁰ Autonomous computing (https://en.wikipedia.org/wiki/Autonomous_computing)
Autonomous networking (https://en.wikipedia.org/wiki/Autonomous_networking)

Acknowledgements

The ONR visiting faculty and NREIP/SEAP student internship program has provided a basis of academic outreach that has also facilitated this ongoing multi-disciplinary research effort. Peer-review and suggestions from Scott McGirr, Karl Wiegand, and other colleagues significantly improved early drafts. The authors want to also acknowledge support from the SPAWAR Systems Center Pacific (SSC Pacific) Naval Innovative Science and Engineering (NISE) program. Finally, the authors most particularly thank the program sponsors and respective project managers who have provided continued support. We are especially thankful for the opportunity to develop S&T results into net-enabled operations-support services that address high-priority Warfighter needs and capability gaps.

Appendix: Resilient Systems and Engineering Processes

The example figures and respective diagrams within this appendix are intended to provide a more visual survey of example work within this respective application domain. For more detailed information, the references can be downloaded for more extensive review. The goal is to illustrate the wealth of reference models and related work available for incorporation within an experimentation framework that focuses on robustness and resilience, relative to a variety of types of D-DIL conditions.

The immediate challenge is to determine how to best leverage and tailor available models to the extent possible. A longer term challenge is to determine how to best roadmap and manage the convergence of the models/frameworks in this appendix with the models/frameworks reviewed in previous sections.

In principle, if robustness and resilience are primary concerns for forward-deployed cloud-based ITI frameworks afloat, the examples in this appendix might best be considered a starting point for developing the respective distributed-computing ITI frameworks. A more realistic option is to determine how to best establish an S&T roadmap that supports a co-evolutionary transformation and incremental convergence of existing ITI models and framework resources (e.g. DDF/DIB, TC-RI).

Figure A-1 (from [114]) is an example of a resilience management framework that utilizes a SDN-based network infrastructure. The use of management patterns, resilience management functions, and event monitoring/correlation provide a patterns-based event-driven approach. Also, note that the resilience targets are determined by the respective service level agreements (SLAs). Allowable deviations are a function of the role assigned to a given managed object. Thus, much of the desired or necessary characteristics of the previously discussed data-transport and data-mediation experimentation framework, are addressed within this example resilience management framework.

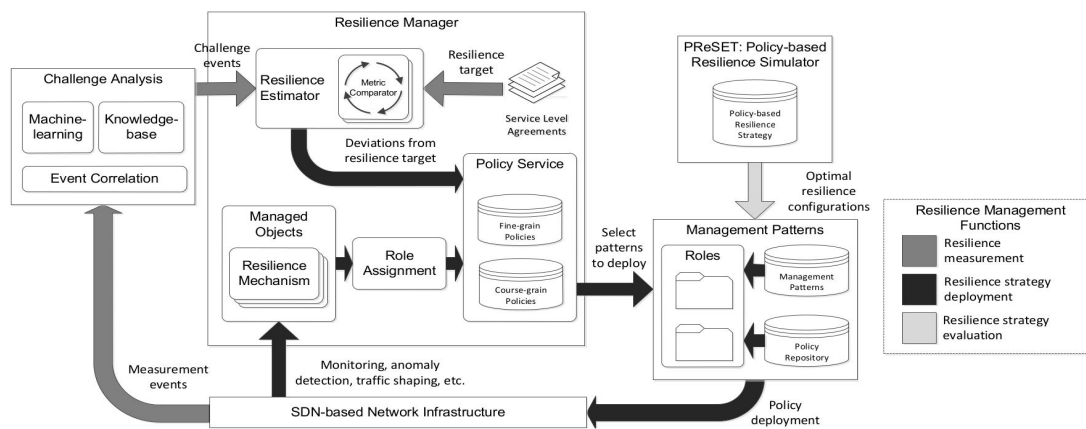


Fig. A-1 Resilience Management Framework: Example

Figures A-2 through figure A-5 (from [115-116]) are high-level views that are available at the ResiliNets architectural framework wiki.¹⁴¹ The example diagrams and associated reference model were generated a number of years ago as part of an early initiative. Figure A-2 (also in [115-116]), is a diagram that provides a view of an example taxonomy and data-model of resilience disciplines (e.g. fault-tolerance, survivability, availability, maintainability/servicability).¹⁴² From a MBSE/SOSE perspective, this is an example of a well developed characterization of the types of the desired features and attributes (i.e. non-functional requirements) of a robust and resilient enterprise framework (EA/SOA, cloud, ITI framework). Thus, ResiliNets provides an example of a well-developed reference model and architecture for developing resilient ITI frameworks. Ideally, much of the conceptual reference model and results from other initiatives, need to be leveraged, tailored, aligned, and mapped into the type of ITI framework needed for addressing D-DIL conditions A2/AD environments.

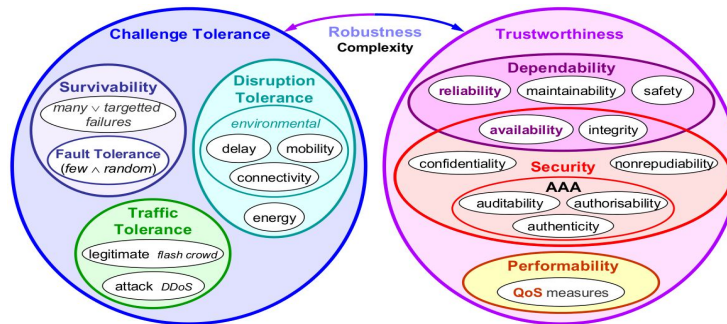


Fig. A-2 Resilience Disciplines: Example Taxonomy

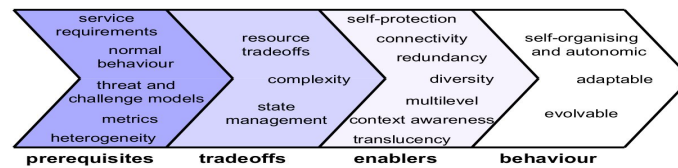


Fig. A-3 Resilience Principles

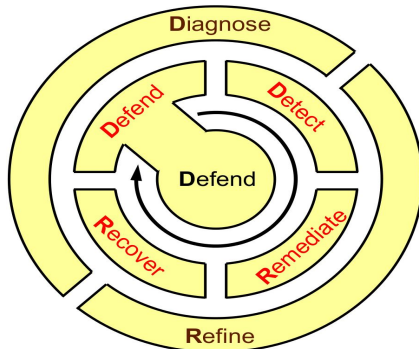


Fig. A-4 ResiliNets Strategy

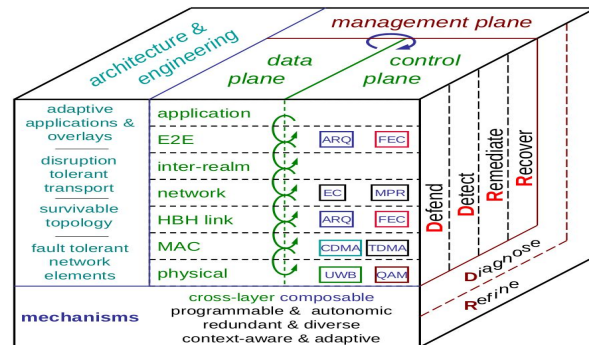


Fig. A-5 ResiliNets: Multilevel Mechanisms

141 ResiliNets Wiki, last access April 2015 (https://wiki.ittc.ku.edu/resilinets/Main_Page)
Highly-Dynamic Airborne Ad Hoc Networking (https://wiki.ittc.ku.edu/resilinets/Highly-Dynamic_Airborne_Ad_Hoc_Networking)

142 Resilience (network) (https://en.wikipedia.org/wiki/Resilience_%28network%29)
Fault tolerance (https://en.wikipedia.org/wiki/Fault_tolerance)
Survivability (<https://en.wikipedia.org/wiki/Survivability>)
Availability (<https://en.wikipedia.org/wiki/Availability>)
Serviceability (computer) (https://en.wikipedia.org/wiki/Serviceability_%28computer%29)
Reliability, availability and serviceability (computing) (https://en.wikipedia.org/wiki/Reliability,_availability_and_serviceability_%28computing%29)

Figures A-6 and A-7 (from [117]) provide an example of an additional challenge. Due to the size of the DoD, there may often be ongoing initiatives and related work that share similar overall objectives and goals. The Engineered Resilient Systems (ERS) initiative is an example of such a case. For ERS, the focus is more towards M&S of platforms (e.g. UxS, surface, aerial) versus tactical C4ISR support. As highlighted by the diagrams and example reference, the data-transport and data-mediation experimentation framework should be in-sync and aligned with such like-minded MBSE/SOSE oriented efforts. Again, ERS is another example of the open challenge of how to at least develop a roadmap for how to eventually achieve this type of virtualized I&I and collaborative-engineering end-goal. In the near-term, the development of performance-based metrics/indicators and an associated experimentation framework, can establish a foundation for a road-map and way-ahead that anticipates and incorporates the types of desired capabilities being developed by ERS and related initiatives.

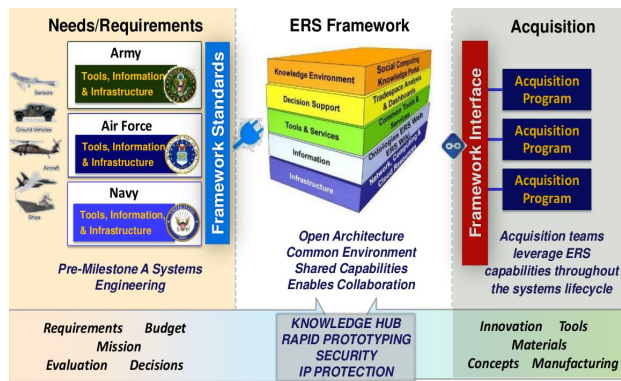


Fig. A-6 ERS Framework Concept

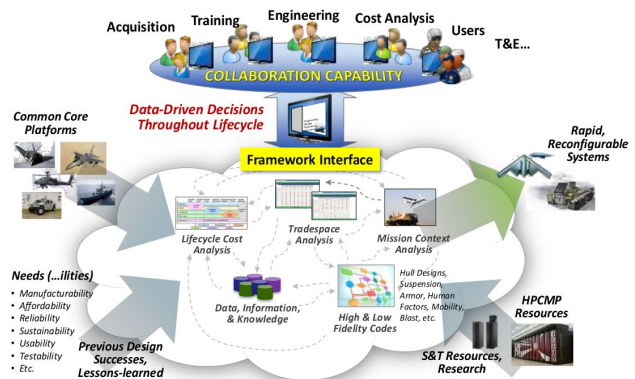


Fig. A-7 ERS Transformation: Data-Driven Engineering

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