An architecture description method for Acknowledged System of Systems based on Federated Architecture

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Abstract. Recently, System of Systems (SoS) approach has been emerged as a solution to achieve a systemwide goal in a large organization by dynamically building a large system with existing constituent systems. In this paper, we present the process of acknowledged SoS architecture description, the essential metadata acknowledged SoS architecture with assessment characters for performance and interoperability among SoS constituent systems.

Keywords: System of Systems; Enterprise Architecture; Interoperability

1 Introduction

As tasks of large organizations in various domains, such as government, transportation and military, become more complex, there have been a lot of solutions that gather several existing systems with interoperability to accomplish their objectives rather than one single system. For example, Missile Defense (MD) system in the military consists of several systems such as sensors, C4I (Computer, Command, Control, Communication and Intelligence) systems and shooters to achieve a common objective that destroys attack missiles in right time and right place. To do so, it is necessary for the military to efficiently design system architecture using information assets such that all constituent systems (CS) work in an integrated and collaborative way. The US Department of Defense Architecture Framework (DoDAF) says Joint Capabilities Integration Development System (JCIDS) defines a collaborative process that utilizes joint concepts and integrated architectural descriptions to identify prioritized capability gaps [1]. But, it is difficult to find the research references on the usage of architecture.

Recently, System of Systems (SoS) approach has been emerged as a solution to achieve a systemwide goal in a large organization by dynamically building a large system with existing constituent systems. According to the US DoD, SoS is defined as a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [2, 3]. There are several types in SoS architectures [3]. Among them, acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS. However, the constituent systems retain their independent ownership, objectives, funding, and

development and sustainment approaches. In a SoS, it is important to identify the critical set of systems that affect the SoS capability objectives and understand their interrelationships. However, there have been few studies to efficiently build an acknowledged SoS.

The goal of this work is to study how to provide the SoS capability analyst, acquisition planner and SoS architect with architecture description approach that concretely and systematically identifies capability gaps for the acknowledged SoS based on Federated Architecture (FA). In this paper, we present the process of acknowledged SoS architecture description, the essential meta data acknowledged SoS architecture with assessment characters for performance and interoperability among SoS constituent systems.

2 Related Works

A System of Systems is a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities [2]. According to [3], Acknowledged SoS have recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on collaboration between the SoS and the system. With the evolution of the understanding of operational capabilities in the US DoD, there is increasing attention focused on the challenges of engineering independently useful systems to work together to meet user needs. As the DoD increases focus on capabilities without changing its system-oriented organization, the number of acknowledged SoS is increasing. User capabilities call for sets of systems working together toward the capability objectives. In many cases, the DoD is choosing to leverage existing systems to support these capabilities [3].

The ‘acquisition’ of systems of systems is somewhat a misnomer since most of the functionality in SoS is already available in fielded systems (which have already been ‘acquired’) or in systems which are themselves in acquisition. The SoS manager and systems engineer work with the owners of the constituent systems to evolve these systems to meet capability needs of the SoS. The current DoD acquisition system is designed for the creation or upgrade of individual systems and the major acquisition milestones and processes are not well matched to the cyclic nature of SoS evolution. In a number of cases, when the investment needed for the SoS is large, an acquisition program has been formed to address these SoS needs, but typically the acquisition program focuses on the new components or major system upgrades needed for the SoS rather than the SoS as a composite enterprise [4].

An Enterprise Architecture (EA) is a high-level architecture or meta-architecture that comprises an organization’s information technology systems (hardware and software), their relationships, and the related processes, functions, groups and people. From a functional perspective, an EA explains how all the IT elements work together as a whole along with the groups and the people of the organization [5].

Federated Architecture (FA) is a pattern which describes an approach to enterprise architecture that allows interoperability and information sharing between semi-

autonomous de-centrally organized lines of business, information technology systems and applications. It provides an approach for aligning, locating, and linking disparate architectures and architecture information via information exchange standards to deliver a seamless outward appearance to users. The US DoD federated GIG (Global Information Grid) Architecture will be based on the semantic alignment of tier level architecture elements with elements of federation high-level taxonomies. Semantic alignment refers to the relationship specified between the meanings of taxonomy elements. The semantic relationships specified between activities will typically include "is equivalent to," "is part of," or "is similar to." [6].

3 SoS Architecture Description Approach

In this section, we propose a process and a meta data model for the acknowledged SoS architecture description approach based FA. The proposed method concretely and systematically identifies the most proper SoS CSs and capability gaps for the acknowledged SoS with current existing legacy CSs. Legacy system architecture data is stored in Federated Architecture Repository and the legacy system architecture data are aligned with federation high-level taxonomies. This approach can specify SoS mission objectives requirements and find proper CSs to satisfy these requirements. The goal of this work is to provide an architecture description approach to SoS capability analysts, acquisition planners and SoS architects.

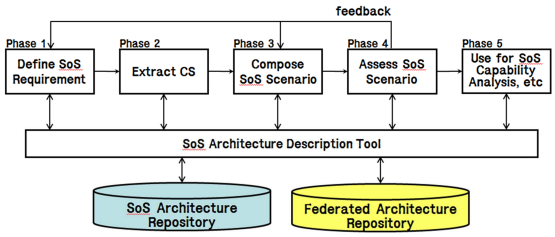

Fig. 1. Process of SoS architecture Description

Proposed description process of the acknowledged SoS architecture is performed by five phases. In the first phase, it specifies SoS requirements that consist of the process of SoS Tasks and their required Performance, and Information exchange requirements among tasks. The requirement specification is stored to SoS Architecture Repository, as shown in Fig.1. In the second phase, proposed method extracts the CS candidates against SoS requirement from FA repository by comparing the SoS Task requirement and legacy system Task semantically. In the third phase, SoS architects compose a scenario with extracted CS candidates proper to SoS Task requirements. The fourth phase is SoS scenario assessment phase that includes CS performance assessment against the SoS Task Performance requirements, Information exchange interoperability and Communication Link interoperability assessment. As a result of the SoS scenario assessment, feedback is allowed to the first or third phase to re-specify SoS requirements or to compose of another SoS scenario with other CS

candidates. This iteration allows architects to get the most proper architecture description. This means that architects can have more proper CSs that satisfy with performance requirements and interoperability against SoS mission objectives with the legacy systems. The result of SoS architecture descriptions also could include insufficient performance and/or not interoperable CS in information or communication links because only legacy systems are used. In the last fifth phase, capability analyst or acquisition decision-maker can make use of SoS description assessments result in order to ameliorate current CS.

Proposed method defines the essential meta data that should be stored in the SoS Architecture Repository and Federated Architecture Repository (see Fig.1).

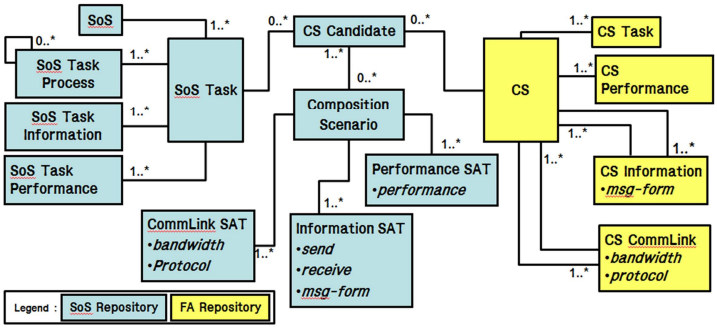

Fig. 2. Essential Meta data Model

The SoS Architecture Repository contains SoS requirement specification data, CS candidates data (extracted from legacy systems in FA repository), SoS scenario (a sequence of selected CS Candidates to support the required SoS Tasks process), and the assessment results of the SoS scenario. The assessment result contains the data whether it satisfies with Performance and Information and Communication Link interoperability requirements or not. Federated Architecture Repository stores meta data for legacy system architecture such as CS task, CS Performance, CS Information and CS Communication Link. These meta data is used for investigating whether the SoS Task requirements are satisfied or not. Fig. 2 shows acknowledged SoS meta data model and Table 1 explains the meaning of essential meta data.

Table 1. Explanation of the essential meta data

Meta data	Description
SoS	Summary and description of SOS. Eg, mission objectives, time point, context, author, etc.
SoS Task	activity or action to complete SoS objectives. It should comply with high-level reference taxonomy.
SoS Task Process	the execution sequence of SoS Tasks
SoS Task Performance	measure and desired value of performance needed to complete a SoS Task
SoS Task Information	A description of the information and their relevant attributes exchanged between SoS Tasks
CS Candidate	A set of the Legacy Systems to support SoS Tasks. SoS composes of a set of Constituent Systems.
Composition Scenario	A set of the ordered pairs {a SoS Task, a CS selected from CS Candidates}

	to support a SoS Task.
Performance SAT *performance*	Whether the performance of selected CS satisfies with the required SoS Task Performance or not (SAT or USAT), SAT = Satisfaction, USAT = Unsatisfaction
Information SAT	Information Satisfaction
send	Whether sending CS have SoS Task Information or not (SAT or USAT)
receive	Whether receiving CS have the SoS Task Information or not (SAT or USAT)
msg-form	Whether message format corresponds with both sending CS and receiving CS or not (SAT or USAT)
CommLink SAT	Weather bandwidth and protocol correspond with both sending CS and receiving CS communication link
bandwidth	Weather bandwidth corresponds with between both sending CS and receiving CS or not (SAT or USAT)
protocol	Weather protocol corresponds with between both sending CS and receiving CS or not (SAT or USAT)
CS	A legacy system stored in FA repository. It is used for investigating the SoS Task requirements.
CS Task	activity or action to complete CS objectives. It should comply with high-level reference taxonomy.
CS Performance	measure and desired value of performance needed to complete a CS Task
CS Information	A description of the information and their relevant attributes exchanged between CS Tasks
CS CommLink	communication medium to exchange CS Information between CSs.

4 Experiment results for Missile Defense SoS Architecture

Table 2. Result data of MD SoS assessment

Assessment Characters	Scenario A				Scenario B			
	U-2	RC-135	AN/ TPY-2	Mistral	DPS Satellite	RC-135	AN/SPY-1D(V)	PAC-3
Detect image Performance								
36000Km altitude	SAT	n/a	n/a	n/a	SAT	n/a	n/a	n/a
10m focal length	SAT	n/a	n/a	n/a	SAT	n/a	n/a	n/a
Detect image-Track Information.								
Image	SAT	n/a	SAT	n/a	SAT	n/a	SAT	n/a
msg-form-corres-sat	SAT	n/a	SAT	n/a	SAT	n/a	SAT	n/a
Ditect image-TrackCommLink								
Bandwidth-sat	USAT	n/a	USAT	n/a	SAT	n/a	SAT	n/a
protocol-sat	SAT	n/a	SAT	n/a	SAT	n/a	SAT	n/a
Detect signal Performance								
6500Km combat range	n/a	SAT	n/a	n/a	n/a	SAT	n/a	n/a
Ditect signal-Track Information.								
signal	n/a	SAT	SAT	n/a	n/a	SAT	SAT	n/a
msg-form-corres-sat	n/a	SAT	SAT	n/a	n/a	SAT	SAT	n/a
Ditect signal-TrackCommLink								
bandwidth-sat	n/a	SAT	SAT	n/a	n/a	SAT	SAT	n/a
protocol-sat	n/a	USAT	USAT	n/a	n/a	SAT	SAT	n/a
Track Performance								
2000Km track range	n/a	n/a	USAT	n/a	n/a	n/a	SAT	n/a
Track-Kill Information								
target priority	n/a	n/a	SAT	USAT	n/a	n/a	SAT	SAT
msg-form-corres-sat	n/a	n/a	USAT	USAT	n/a	n/a	SAT	SAT
Track-Kill CommLink								
bandwidth-sat	n/a	n/a	USAT	USAT	n/a	n/a	SAT	SAT
protocol-sat	n/a	n/a	USAT	USAT	n/a	n/a	SAT	SAT
Kill Performance								
100Km intercept range	n/a	n/a	n/a	USAT	n/a	n/a	n/a	USAT

In this experiment, Missile Defense SoS consists of the four SoS Tasks: Detect launched missile image, Detect signal, Tract the missiles, and Kill the missiles. The SoS Task Performance and Information requirements are also specified in these Tasks. Table 2 shows the assessment results of the scenario A and B by using the assessment algorithm and some weapon systems architecture data. From the result SoS architects can know which scenario is the better SoS architecture. Further, architects can identify the gap between existing SoS and future SoS objective. And then, capability analysts and acquisition decision-makers can plan to resolve the accurate problem point in the current legacy systems capability for the future SoS.

5 Conclusion

In this paper, we presented an acknowledged SoS architecture description approach to enable capability analyst and acquisition planner to assess performance and interoperability characteristics against SoS requirements based on FA repository. Our experiment applied to MD SoS and considered only a few assessment attributes like CS Performance, and Information and Communication Link interoperability. However, the proposed approach can be generally applied to different types of acknowledged SoS architecture description, and can be easily expanded to consider other attributes like CS Services and equipment function level performance.

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