RT-109: Flexible and Intelligent Learning Architectures for SoS (FILA-SoS)

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Research Task / Overview

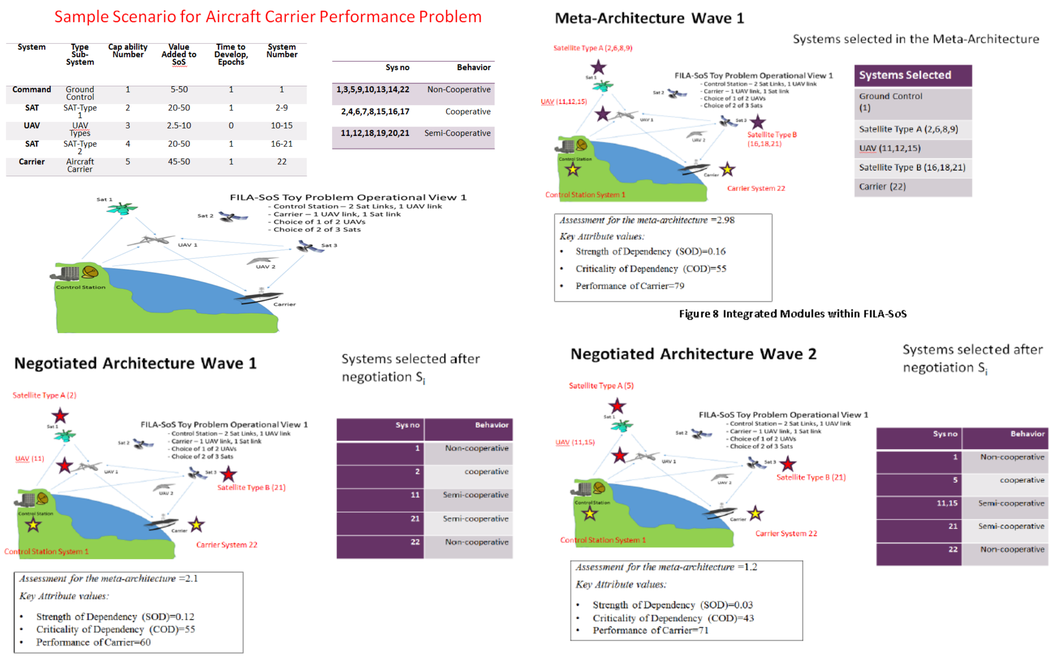
FILA-SoS and the Wave Process address four of the most challenging aspects of system-of-system architecting:

Dealing with the uncertainty and variability of the capabilities and availability of potential component systems; providing for the evolution of the system-of-system needs, resources and environment over time; accounting for the differing approaches and motivations of the autonomous component system managers; optimizing system-of-systems characteristics in an uncertain and dynamic environment with fixed budget and resources

FILA-SoS does so using straightforward system definitions methodology and an efficient analysis framework that supports the exploration and understanding of the key trade-offs and requirements by a wide range system-of-system stakeholders and decision makers in a short time.

Data & Analysis

FILA-SoS has been tested on three notional examples so far the ISR, Search and Rescue (SAR) and the Toy problem for Aircraft Carrier Performance Assessment.



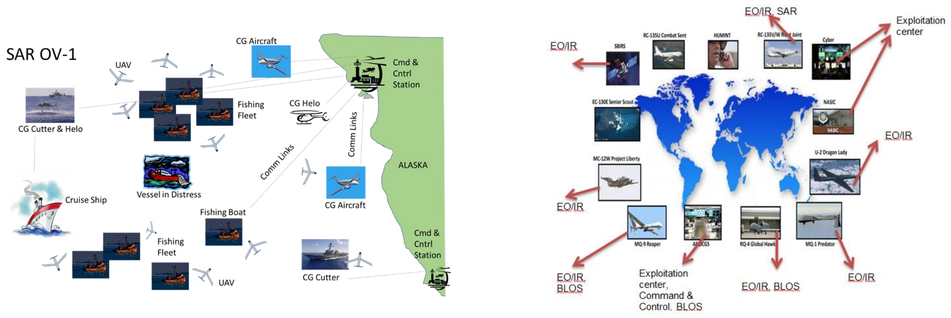


Table 2 ISR domain specific inputs Wave 1

System	Type Capability	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/ interface	Operate $K/hr per system	Time to Develop, Epochs	System Number
Fighter	EO/IR	1	500	0.2	10	1	1
Trainer	EO/IR	1	2000	2	2	1	2-3
UAV	EO/IR	1	50000	0	15	0	4-8
DSP	IR	1	8000	0.1	1	1	9
Fighter	Radar	2	3000	0.7	10	1	10-12
JSTARS	Radar	2	10000	0.1	18	1	13
Theatre	Exploit	3	5000	2	10	1	14-15
CONUS	Exploit	3	25000	0.2	0	0	16
Control	Cmd &	4	10000	1	2	1	17-18
LOS Link	Comm	5	10000	0.2	0	1	19-20
BLOS Link	Comm	5	5000	0.5	3	1	21-22

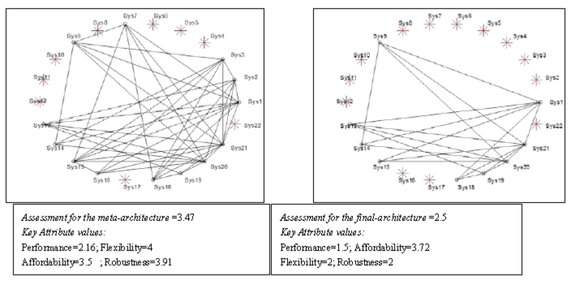
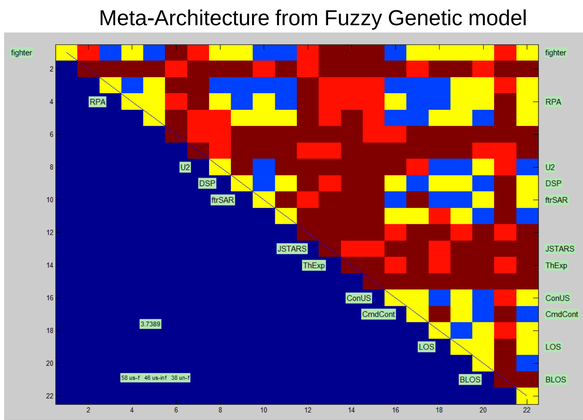


Figure 12 ISR SoS Wave 1 Meta-Architecture (left) and Negotiated Architecture (right)

Meta-Architecture from Fuzzy Genetic model



- 22 total systems
- "Achievable" interfaces are through common comm. links
- Red = Used unachievable interfaces
- Blue = Unused achievable interfaces

Systems highlighted yellow indicate systems that are retained for second wave of SoS development

Table 3 ISR domain specific inputs Wave 2

System	Type Sub-System	Cap ability Number	Coverage sq mi/hr;	Develop $M/ epoch/	Operate n///hr$K/hr per system	Time to Develop, Epochs	System Number
Fighter	EO/IR	1	500	0.2	10	1	1
Trainer	EO/IR	1	12000	0.1	8	1	2-3
UAV	EO/IR	1	8000	0.5	2.5	1	4-8
DSP	IR	1	8000	0.1	1	1	9
Blimp	Radar	2	20000	0.5	12	1	10-12
JSTARS	Radar	2	10000	0.1	18	1	13
Theatre	Exploit	3	5000	2	10	1	14-15
MOBExp	Exploit	3	15000	0.1	0.2	0	16
MOBC2	Exploit	4	12000	1	2	0	17
Control	Cmd &	4	10000	1	2	1	18
LOS Link	Comm	5	10000	0.2	0	1	19-20
BLOS Link	Comm	5	5000	0.5	3	0	21
Mil-Sat	Comm	5	15000	1	5	1	22

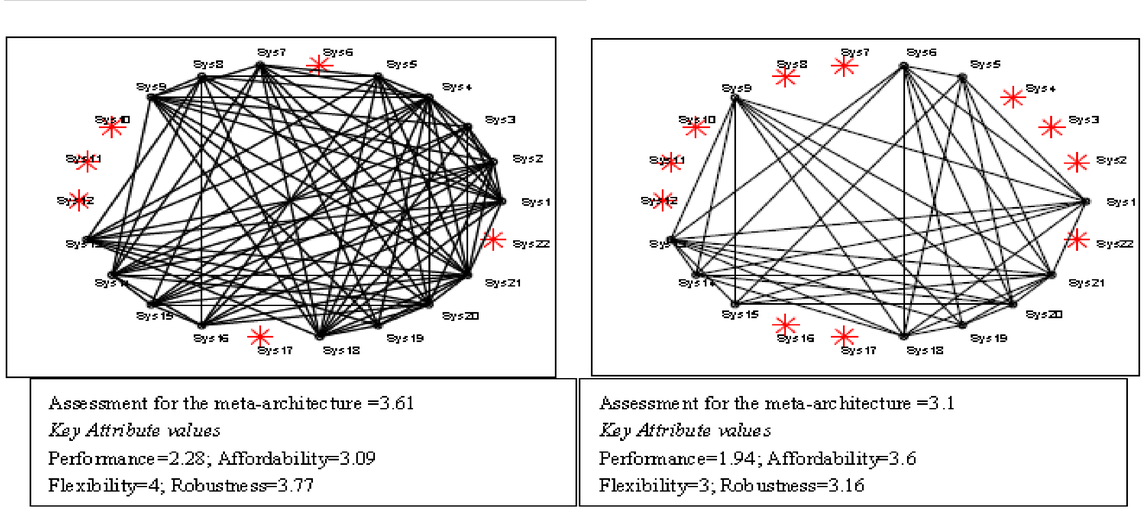


Figure 13 ISR SoS Wave 2 Meta-Architecture (left) and Negotiated Architecture (right)

Goals & Objectives

FILA-SoS Capabilities

Integrated model for modeling and simulating SoS systems with evolution for multiple waves. Models can be run independently and in conjunction with each other. Two model types represent SoS behavior and various individual system behavior. Study of negotiation dynamics between SoS and individual systems

FILA-SoS Value

Aiding the SoS manager in future decision making. Understand emergent behavior of systems in the acquisition environment and impact on SoS architecture quality

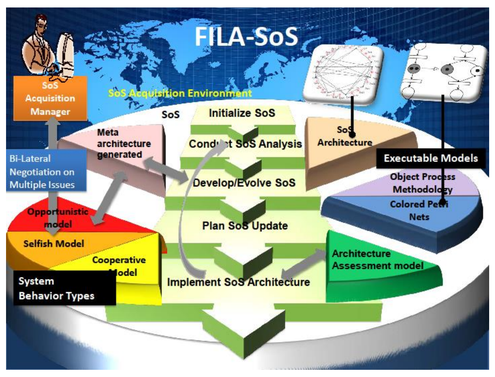
Study the dynamic behavior of different type of systems (selfish, opportunistic, cooperative).

Identify intra and interdependencies among SoS elements and the acquisition environment

FILA-SoS "What-if" Analysis; Model Modularity

Variables such as SoS funding and capability priority can be changed as the acquisition progresses though wave cycles. Simulation of any architecture through colored petri nets. Simulate rules of engagement & behavior settings: all systems are selfish, all systems are opportunistic, all systems are cooperative or a combination

Methodology



Integrated Quantitative Decision Making Model with seven independent modules

- Meta-Architecture Generation Fuzzy Genetic model
- Meta-Architecture Generation Multi-Level model
- Architecture Assessment Model
- SoS Negotiation Model
- System Negotiation Model: Selfish
- System Negotiation Model: Cooperative
- System Negotiation Model: Opportunistic
- Architecture Executable Model
- Overall Negotiation Framework

Meta-Architecture Generation Multi-Level model

Before starting the negotiations between the systems and the SoS architect, the SoS architect can initially select a set of systems that, when negotiated, will result in efficient SoS architecture. The multi level meta-architecture generation model provides an SoS architecture such that each capability is provided by at least one system in the SoS while optimizing SoS three key performance attributes.

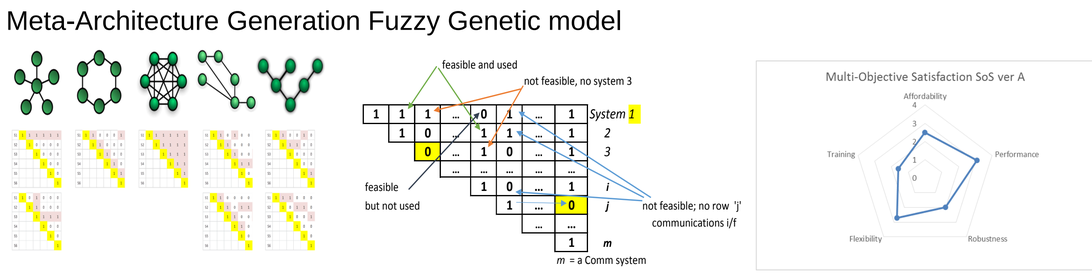
$$
\begin{aligned}
(\text{SoS-A}): \quad & \min \quad TC(\mathbf{S},\mathbf{Y},\mathbf{F}) \\
& \min \quad DL(\mathbf{S}) \\
& \max \quad TP(\mathbf{S},\mathbf{F}) \\
& \text{s.t.} \quad \textstyle\sum_{j\in J} a_{ij}S_j \geq 1 \;\forall i \in I && (4)\\
& y_{jk} + y_{kj} \geq S_j + S_k - 1 \;\forall j \in J, \forall k \in J && (5)\\
& S_j \in \{0,1\} \;\forall j \in J && (6)\\
& y_{jk} \in \{0,1\} \;\forall j \in J, \forall k \in J && (7)\\
& F_j \geq 0 \;\forall j \in J && (8)
\end{aligned}
$$

$$TC(\mathbf{S},\mathbf{Y},\mathbf{F}) = \sum_{i\in I}\sum_{j\in J} S_j a_{ij} c_{ij} + \sum_{j_1\in J}\sum_{j_2\in J} h_{j_1 j_2} y_{j_1 j_2} + \sum_{j\in J} F_j$$ Minimize total cost

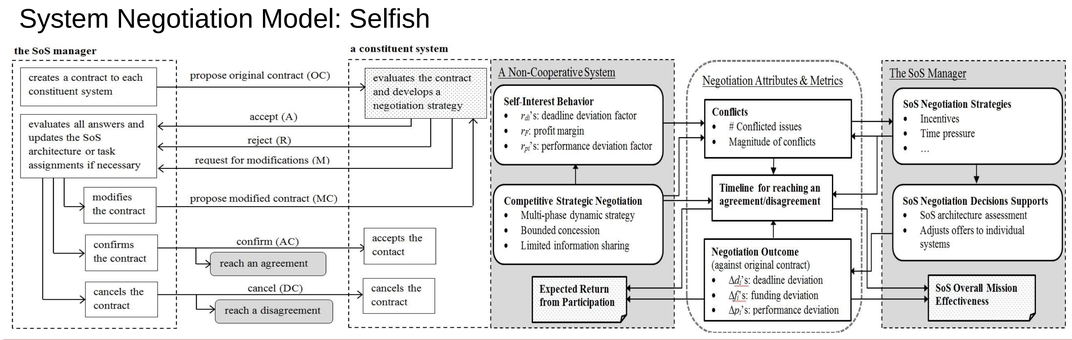
$$DL(\mathbf{S}) = \max_{j\in J}\left\{\max_{i\in I}\{S_j a_{ij} d_{ij}\}\right\}$$ Minimize the deadline

$$TP(\mathbf{S},\mathbf{F}) = \sum_{i\in I}\sum_{j\in J} S_j a_{ij} p_{ij}(F_j)$$ Maximize the performance

Meta-Architecture Generation Fuzzy Genetic model



System Negotiation Model: Selfish



Future Research

FILA- SoS can be used to model of wide variety of complex systems models such as logistics, cyber-physical systems. It provides a test-bed for decision makers to evaluate operational guidelines and principles for managing various acquisition environment scenarios. There is a need to integrate the quantitative models developed as a part of this research that answers, the three-research questions: *What is the impact of different constituent system perspectives regarding participating in the SoS on the overall mission effectiveness of the SoS?; How do differing levels of cooperativeness in participating in the SoS impact the ability and timeliness of a group to agree on a SoS or system architecture? Or impact the ability to effectively use the architecture already in place?; How should decision-makers incentivize systems to participate in SoS, and better understand the impact of these incentives during SoS development and effectiveness?.* This will be achieved through a new FILA-SoS software implementation platform which is user friendly enabling adaptation of the model to other SoS or Cyber Physical Systems and real life implementation. Future research is needed to continue to the build decision making models based on the insights gained in this research for the development of multi-faceted systems that has complex logic with many levels of reasoning in intricate arrangement, demonstrating self-driven adaptability, emergent behavior.

Contacts/References

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