Scaling Model-Based System Engineering Practices for System of Systems Applications: Analytic Methods

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http://www.ndia.org/events/2017/10/23/20th-systems-engineering-conference

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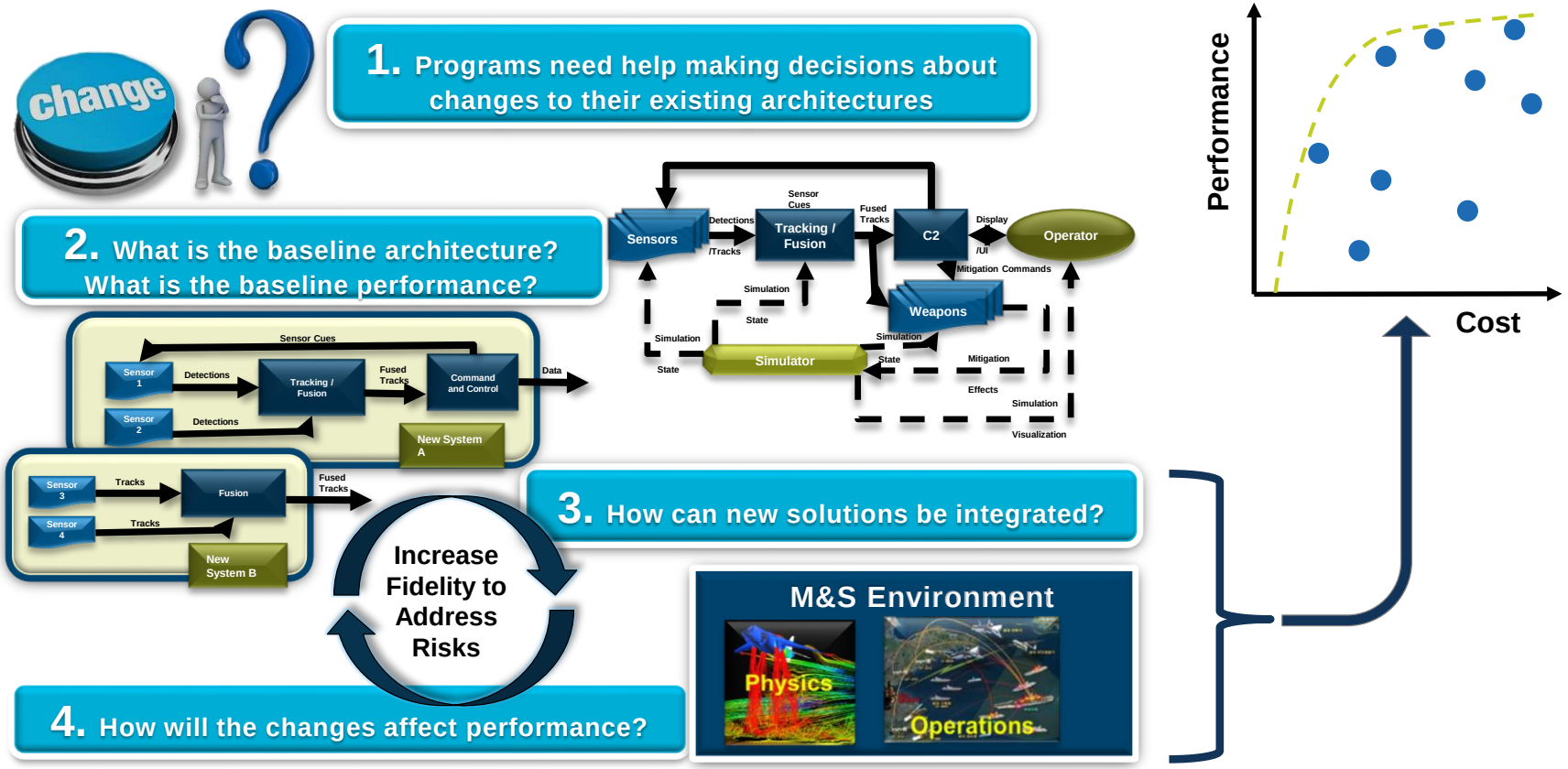
Motivation



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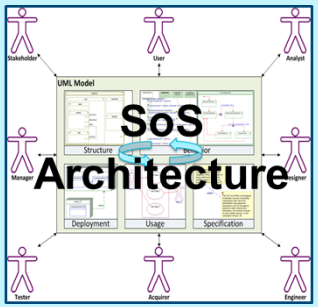
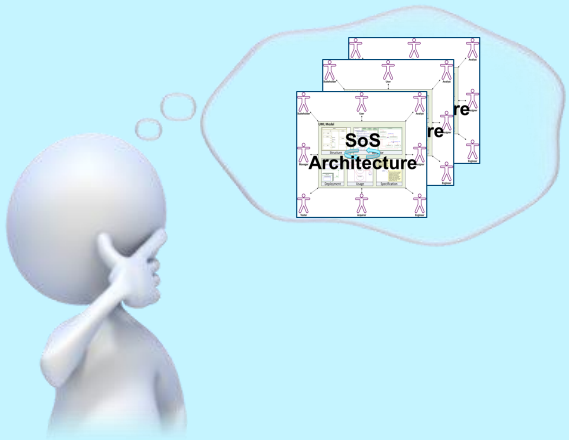
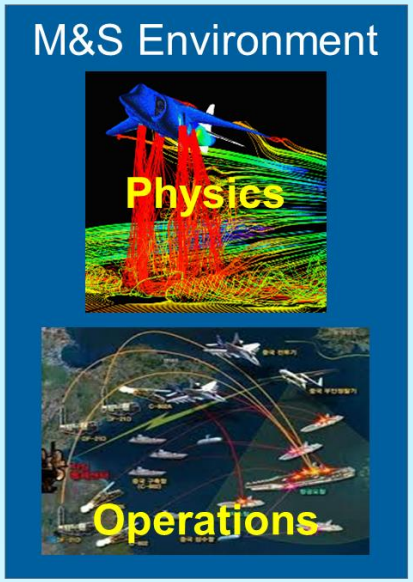
As-is for Evaluating Architectures

SoS Analysis of Alternatives



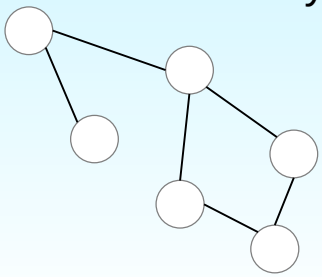




Establish baseline SoS architecture

Generate SoS architecture alternatives

SoS graph abstraction and network analysis



MIP contribution: inform prioritization of alternatives using lightweight analytics

Detailed evaluation with M&S environment

Informed architecture selection

Robustness Metric (Algebraic Connectivity Value)

- **Represents average difficulty of isolating a node**
  - Second smallest eigenvalue of a Laplacian Matrix
- **Inputs:**
  - Degree Matrix
    - Diagonal matrix that contains the number of nodes adjacent to a given node

$$D_{ij} = \begin{cases} d_i & \text{degree of component } i \text{ when } i = j \\ 0 & \text{otherwise} \end{cases}$$

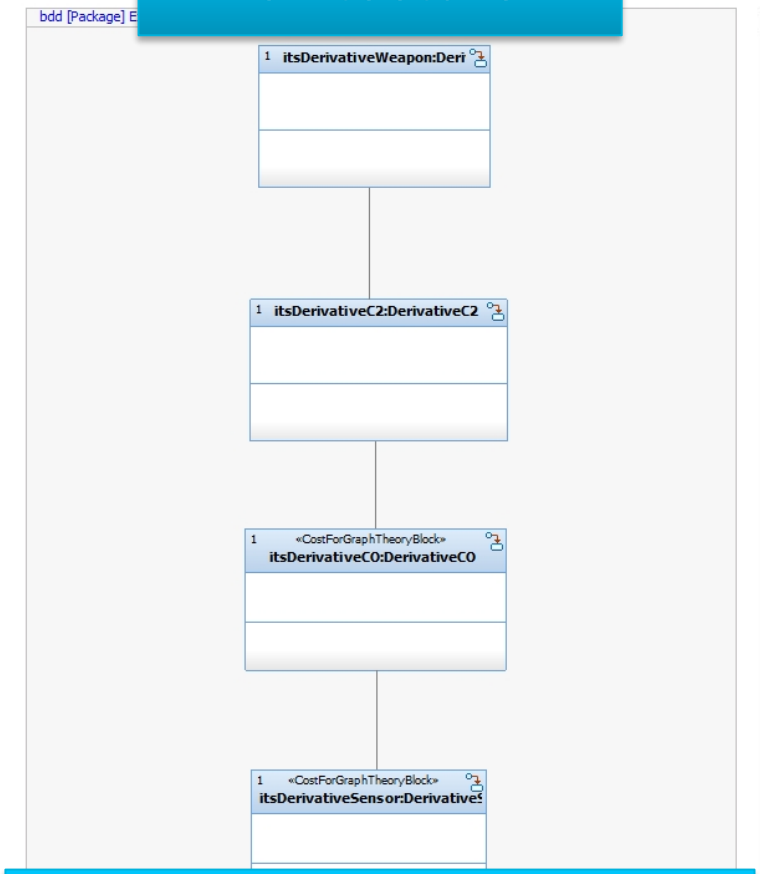
  - Adjacency Matrix
    - Symmetric matrix that contains a 1 if two given nodes are adjacent and 0 otherwise

$$A_{ij} = \begin{cases} 1 & \forall[(i,j)|(i \neq j) \quad \text{and} \quad (i,j) \in \Delta] \\ 0 & \text{otherwise} \end{cases}$$

Reference: H. Mehrpouyan, B. Haley, A. Dong, I. Y. Tumer, and C. Hoyle, "Resiliency analysis for complex engineered system design," *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, vol. 29, no. 01, pp. 93–108, Jan. 2015.

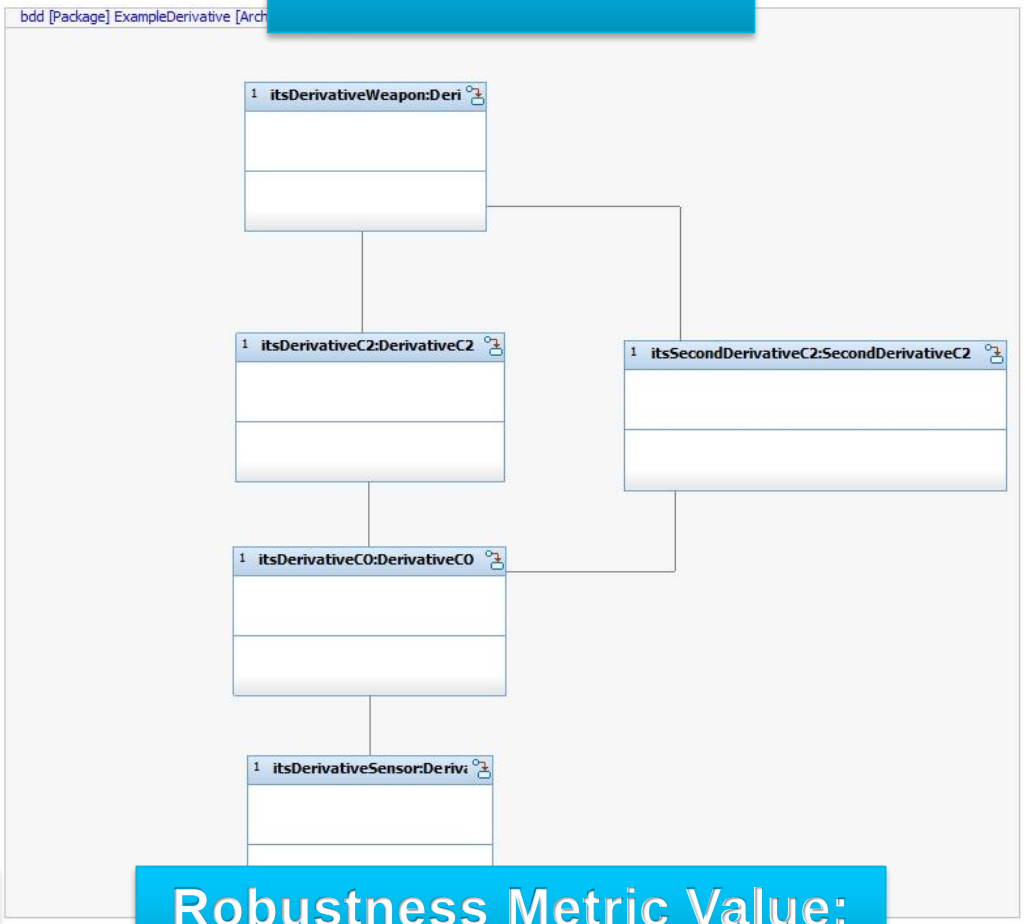
Identifying Robust SoS Architectures

Architecture 1



Robustness Metric Value: 0.5858

Architecture 2



Robustness Metric Value: 0.8299

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Multi-layer Architectural Analysis

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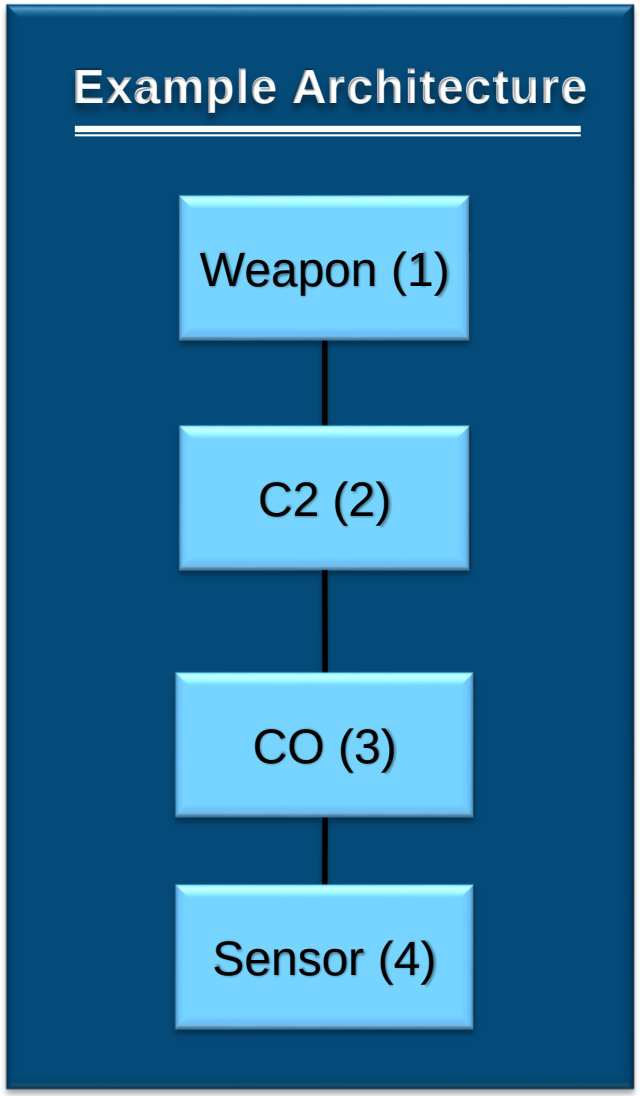
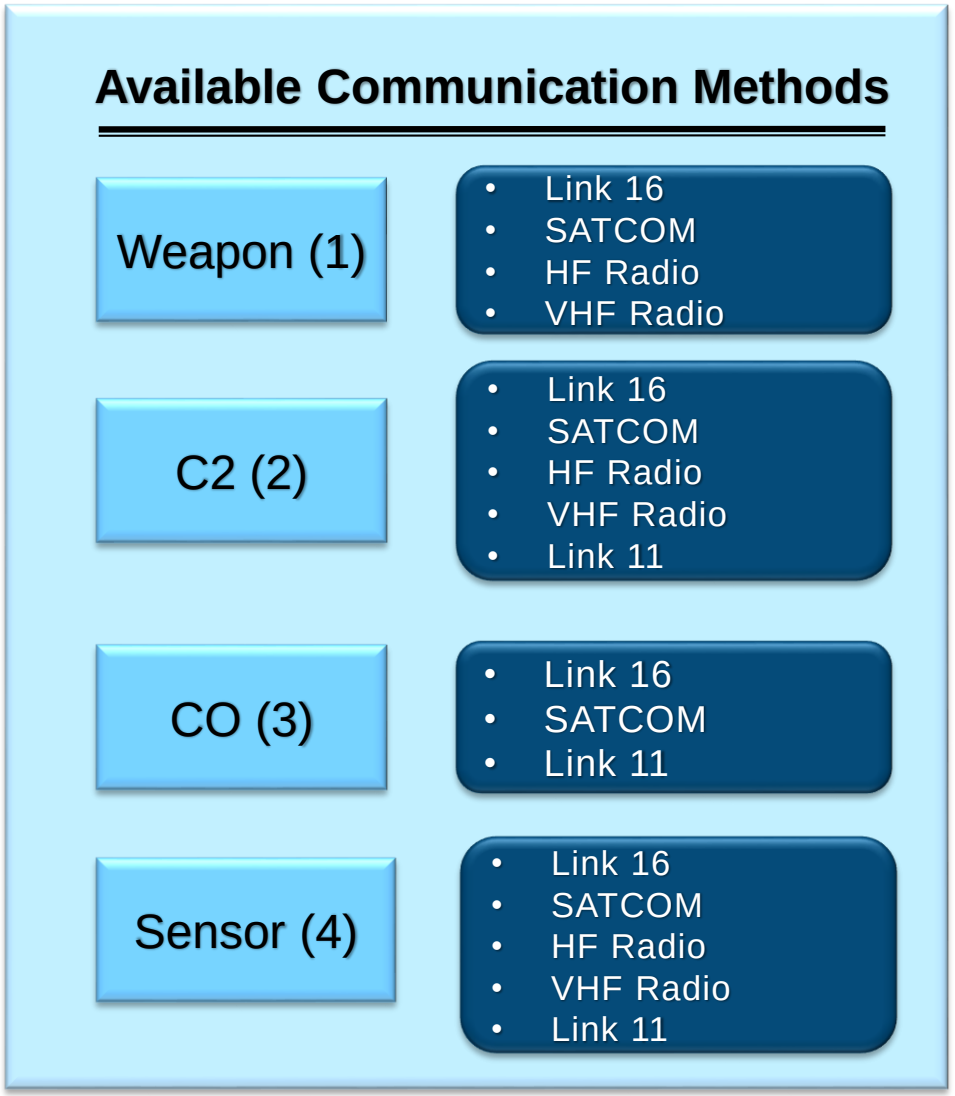
Example Architecture





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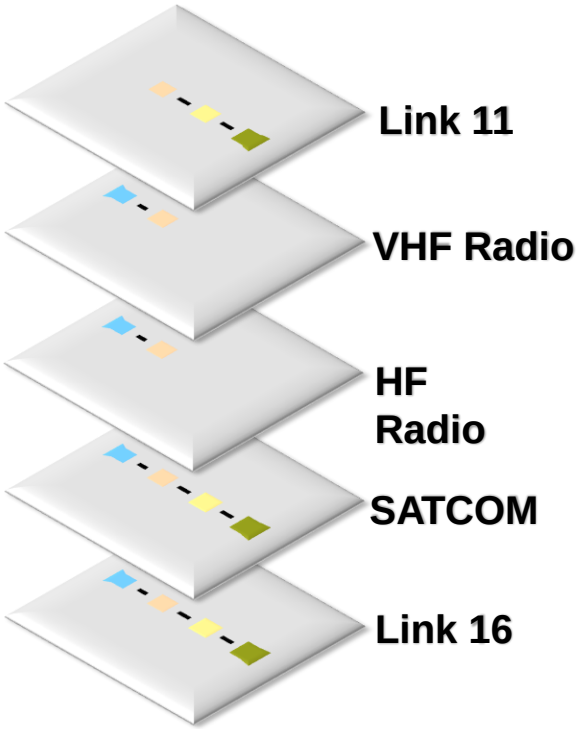
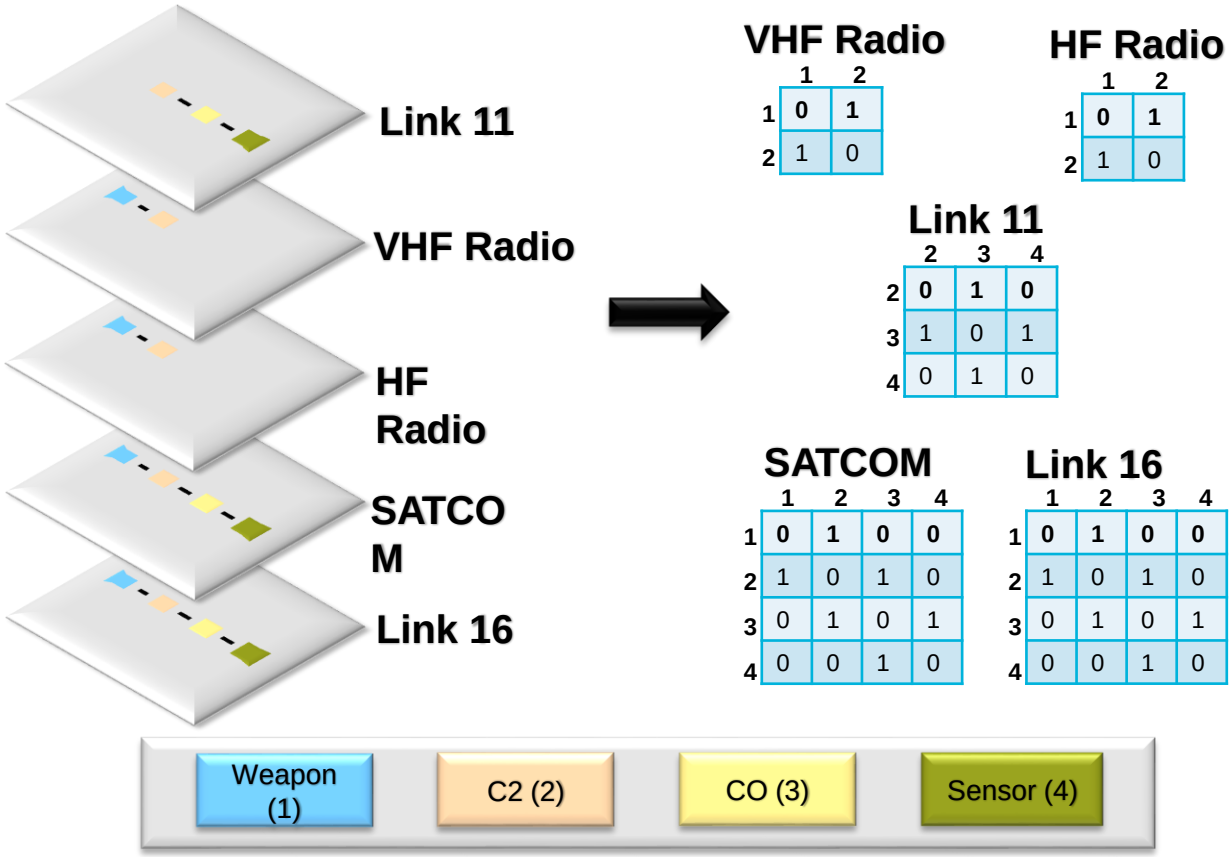
Mapping Architecture to Multilayer Graph – Intralayer Graph Representation



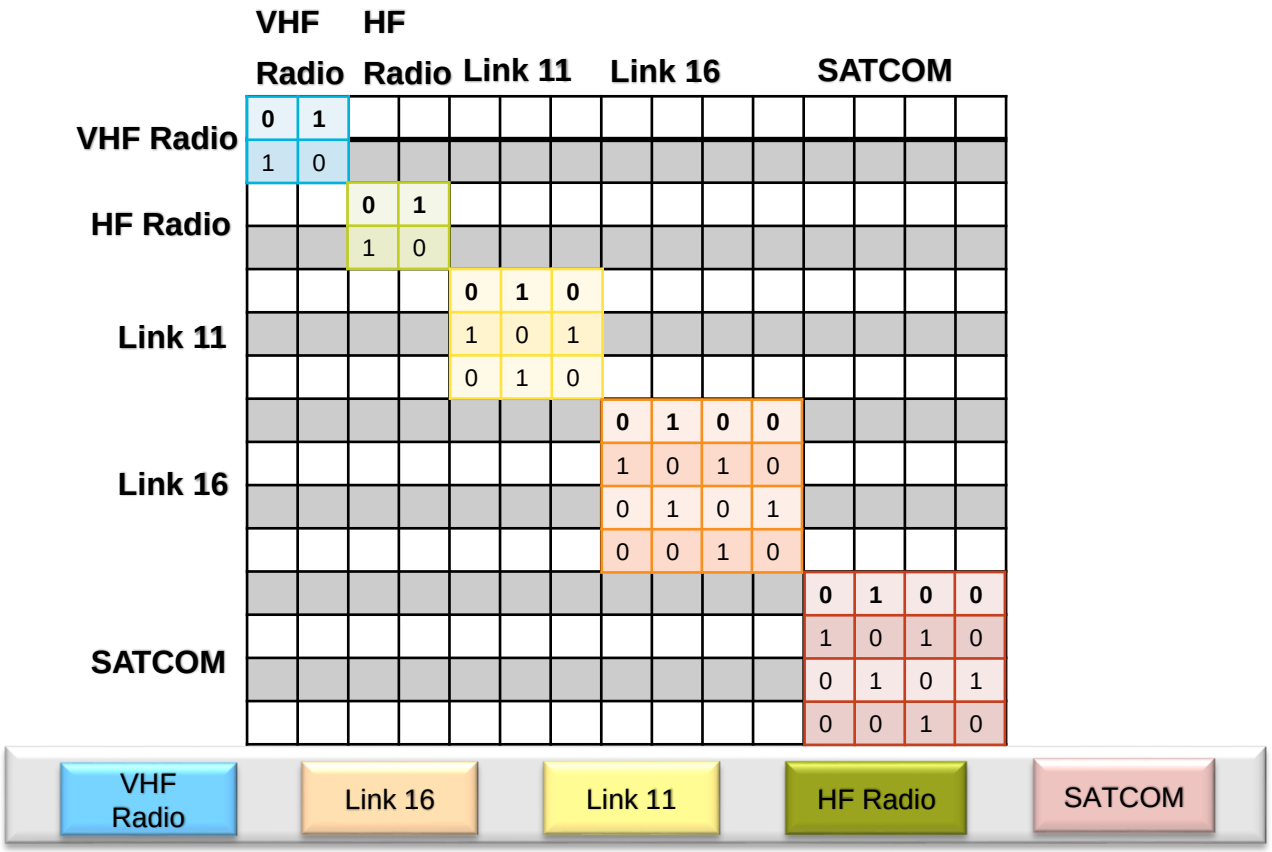
Available Communication Methods

Weapon (1)	• Link 16 • SATCOM • HF Radio • VHF Radio
C2 (2)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11
CO (3)	• Link 16 • SATCOM • Link 11
Sensor (4)	• Link 16 • SATCOM • HF Radio • VHF Radio • Link 11

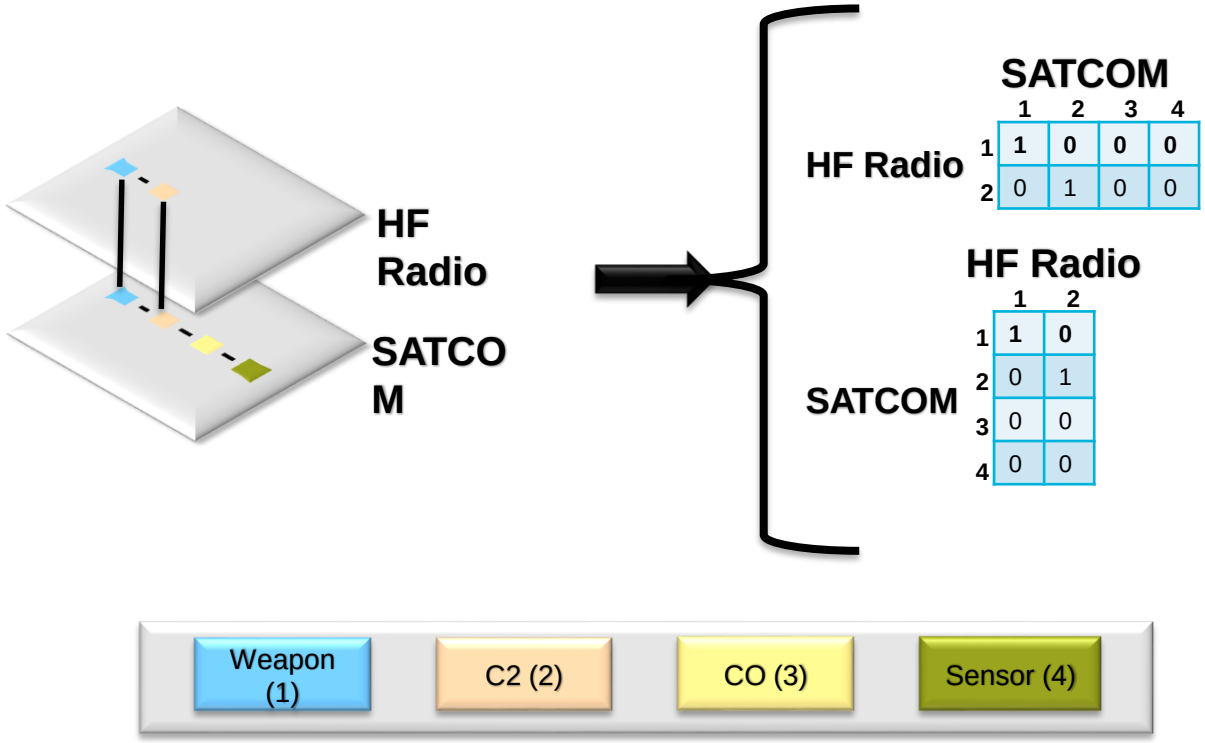
Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation



Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation

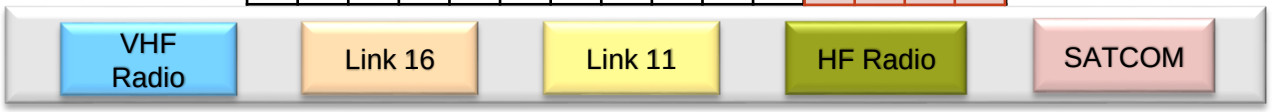


Mapping Architecture to Multilayer Graph – Interlayer Matrix Representation



Mapping Architecture to Multilayer Graph – Adding Interlayer to Intralayer in Matrix

	VHF Radio		HF Radio		Link 11			Link 16				SATCOM			
VHF Radio	**0**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**
	1	0	0	1	0	0	0	0	1	0	0	0	1	0	0
HF Radio	1	0	**0**	**1**	0	0	0	1	0	0	0	1	0	0	0
	0	1	1	0	0	0	0	0	1	0	0	0	1	0	0
Link 11	0	0	0	0	**0**	**1**	**0**	0	1	0	0	0	1	0	0
	0	0	0	0	1	0	1	0	0	1	0	0	0	1	0
	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
Link 16	1	0	1	0	0	0	0	**0**	**1**	**0**	**0**	1	0	0	0
	0	1	0	1	1	0	0	1	0	1	0	0	1	0	0
	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0
	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1
SATCOM	1	0	1	0	0	0	0	1	0	0	0	**0**	**1**	**0**	**0**
	0	1	0	1	1	0	0	0	1	0	0	1	0	1	0
	0	0	0	0	0	1	0	0	0	1	0	0	1	0	1
	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0



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Summary

- **Results**
  - Developed a scalable rapid analysis capability for MBSE software tools
  - Identified a proxy for resilience that can be measured using lightweight analysis techniques
  - Tested the analysis method on notional architectures and compared the results with a low fidelity operational modeling and simulation tool
- **Lessons Learned**
  - Detailed analysis will have to accompany the graph theoretic analysis to account for operationally critical architectural components
  - Based on the domain the optimal graph theoretic value may vary