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

1. Programs need help making decisions about changes to their existing architectures

2. What is the baseline architecture? What is the baseline performance?

3. How can new solutions be integrated?

4. How will the changes affect performance?

M&S Environment

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As-is for Evaluating Architectures
SoS Analysis of Alternatives

Establish baseline SoS architecture

Generate SoS architecture alternatives

MIP contribution: inform prioritization of alternatives using lightweight analytics

M&S Environment

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

Identifying Robust SoS Architectures

Architecture 1

Robustness Metric Value: 0.5858

Architecture 2

Robustness Metric Value: 0.8299
Multi-layer Architectural Analysis
Example Architecture

Available Communication Methods

- Link 16
- SATCOM
- HF Radio
- VHF Radio

Example Architecture

Weapon (1)

C2 (2)

CO (3)

Sensor (4)
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

- Link 11
- VHF Radio
- HF Radio
- SATCOM
- Link 16

VHF Radio

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HF Radio

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SATCOM

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Link 16

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Weapon (1) C2 (2) CO (3) Sensor (4)
Mapping Architecture to Multilayer Graph – Intralayer Adjacency Representation

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Legend:
- **VHF Radio**
- **HF Radio**
- **Link 11**
- **Link 16**
- **SATCOM**
Mapping Architecture to Multilayer Graph – Interlayer Matrix Representation
Mapping Architecture to Multilayer Graph – Adding Interlayer to Intralayer in Matrix

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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