Intelligent Content-Aware Data Prioritization and Synchronization across Disconnected, Intermittent, Limited (DIL) Networks

Approaches and Considerations

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Typical Problem Areas for Afloat C4I

- Dynamic and Ad-Hoc inter-platform information exchanges over Disconnected, Intermittent, and Limited (DIL) network (SIPRnet)
  - Evolving topology and mission ➔ *Highly variable bandwidth demands*
  - Data generation can exceed available bandwidth ➔ *Cannot guarantee adequate resources for all generated data to be exchanged*
  - Unreliable connections ➔ *No implicit assumption that shared data will be fully replicated as intended*

- Information objects have varying degrees of relevance to the user at different times ➔ *Systems should act to focus communications resources where they are most needed*

- Decision-makers rely upon the quality and completeness of shared tactical information ➔ *Systems should provide assurance of the integrity of the shared tactical information*

Unmanaged Data Poses Risk to Mission Success
Undersea Warfare Decision Support System

The Common Tactical Picture (CTP) is defined as providing *situational awareness* with such *timeliness and accuracy* that would *facilitate an overt action* on the part of a commander up to and including *engagement with weapons.*

**Operational Need**

Provide an ASW Common Tactical Picture *Across the ASW Enterprise* which:

- Increases Situational Awareness
- Reduces Operator Workload
- Enables Improved Mission Planning, Search Execution, ASW Track Management and ASW Battle Management

**References:**
- ASW Command and Control (C2 Study)
- Naval Warfare publication (NWP &NTTP) 32-1
- Fleet Exercise Results (VS-06, VS-07, USWEX)
- Submarine combat Systems APB-06 Capabilities Letter
- Anti-Submarine Warfare (ASW) Initial Capabilities Document (ICD)
- Global Anti-Submarine Warfare (ASW) Concept of Operations (CONOPS)
- OPNAV N6 Modernization Requirements Letter for AN/UYQ-100 USW-DSS
ASW C⁴I Game Changer

- Joint Undersea Superiority Study
- Anti Submarine Warfare Initial Capability Document (C⁴ for ASW)
- CNO Vision for ASW Superiority, May 2009

ASW C⁴I Transformation

- Metrics Based Planning and Execution
- Improved Sensor Search Effects
- Real Time CSG Synchronization
- Automated ASW Sensor Data Exchange
- ASW Sensor Contact Correlation and Fusion
- Shared Tactical Decision Aids on USW Common Tactical Picture

Current Operations

USW DSS Improvements
USW-DSS Data Exchanges

- Data exchanged between DDGs, CGs, CVNs, IUSS*, and ashore command sites:
  - Track / Contact Data
  - Tactical Decision Aids (TDAs)
  - Sensor Performance Data (measured noise and reverb)
  - Search Plans
  - Tactical Status and Orders
  - Administrative Data (Force Management and Versioning)

- Comms via SIPRnet today; other paths under evaluation for future systems

* IUSS Information exchanges are a subset of those listed here
USW-DSS Current Approach

• JCIDS-level requirements for USW-DSS B2 to establish and maintain a **common USW tactical picture** between connected platforms
  
  – Topology is managed hierarchically and implemented automatically to provide consistency
  
  – Data is exchanged peer-to-peer to maximize reliability and minimize critical nodes

• USW-DSS B2 employs **prioritization of data by type** to cope with DIL network
  
  – When bandwidth limits are reached, priority is given *en masse* to certain data types over others

• Some data exchanges use periodic **synchronization mechanisms**
  
  – Reconciliation still dependent on data-type priority hierarchy
Roles and Status of Composition Membership

Geographic Extent of Shared Data
Filters out extraneous geospatial data

Selected Platform Details
Prioritization by Topic
High/Med/Low Priority and BW Caps for each

Bandwidth Cap
Total BW limit

BW Plots over Time
Color Coded by Type

Instantaneous Values
Pie charts and values
Data Exchange Challenges - Causes

• Applications contribute to the overall bandwidth, but:
  – Applications may be unaware of the total available bandwidth for the system
  – Applications may be unaware of the bandwidth incurred by other applications
  – Applications may be unaware of the bandwidth incurred by *their own* data
  – Total system bandwidth can vary based on comms performance and other systems
  – BW limits/schemes that do not account for all factors will suboptimize the system

• Different data components from any one source are generally not *uniformly important* to the human user, and can vary in importance based on:
  – Mission priorities
  – Absolute relationships (location, threat category, time, speed, etc)
  – Relative relationships / comparisons with other data objects (range, LLOA, etc)
  – What is present on a peer (acceptable latency or thresholds for differences in shared information)

*Is Every Update of Every Object in One Type *Always* More Important than Any Update of Any Object in Another Type?*
Data Exchange Challenges - Effects

• Operator can prioritize between data types, but can only affect *incurred bandwidth* by removing shared content or subtracting platforms

\[(\text{Orig}_{\text{rate}} \times \text{num}_{\text{platforms}}) > \text{bw}_{\text{avail}} \Rightarrow \text{Congestion}\]

• Under constrained bandwidth, some data will not be exchanged \(\Rightarrow\) Reduced Effectiveness

• Data priority is applied in rigid, over-broad groupings \(\Rightarrow\) Stratified

Simple, Static Prioritization Schemes Limit Potential
USW-DSS Data Prioritization Research

• **Synchronization State** ($S_S$ or Data Validity) can be calculated for each remote platform
  
  – *Determined as a function of % accuracy, latency characteristics, and mission relevance*
  
  – *Manage communications to maximize $S_S$*

• Each data object should be able to be prioritized and managed independently by the system

• Data objects should be able to co-mingle in priorities between data types to maximize $S_S$

Measure Sync Quality and Maximize with an Objective Function
Key Features of an Improved Approach

• Affect / control the rate of data production
  – Prevent saturation
  – Improve system ability to respond to network conditions

• Evaluate data objects individually
  – Quantify operational significance at the object level
  – Prevent stratification by type when BW is constrained

• Provide synchronization metrics
  – Give users an understanding of (and confidence in) the integrity of the shared tactical picture
  – Metrics should be intuitive, easily comprehensible
USW-DSS Candidate Approach

• Centrally manage all cross-platform information exchanges
  – Enables intermingling of data types in priority through a coordinated knowledge of bandwidth availability and need
  – Consideration: avoid architectural constraints requiring bilateral code changes wherever possible

• Dynamically prioritize traffic to maximize an objective function
  – Quantify the state or quality of the shared situational awareness
  – Manage transmissions (data object + remote endpoint pairs) individually
  – Focus on those transmissions that most contribute to the objective function
USW-DSS Candidate Approach

• Assign each data object a discrete value that relates each shared object to a mission criticality (across all data types) ➔ Tier Value
  – Dynamically update as parameters change
  – Tier profile to be customized by Warfare Commander and disseminated by the system
• For each locally produced \{data object, destination platform\} pair, track the remote state of that object using timestamp ➔ State Matrix
• For each entry in the State Matrix, calculate a (continuous) Urgency ➔ Urgency Matrix
  – a function of tier, time-latency, displacement error, categorization error, other criteria
• Rank-order the Urgency Matrix by highest priority ➔ Transmission Priority Vector (TPV)
  – Remove transmissions for known unreachable units
• Select highest priority bytes from the TPV to each destination platform
  – Not to exceed outgoing capacity of the source, incoming capacity of destinations
  – BW capacity based on last packet(s), with configurable default values and maxima
• Provide a parallel periodic synchronization using similar object-level priorities

Under Development using USW-DSS Build 2 as Demo System
Prototype Objectives

• Demonstrate that a given Synchronization State can be obtained with reduced bandwidth
• Demonstrate that for a fixed bandwidth, an improved Synchronization State can be obtained
• Demonstrate that improved operator control over data exchange priorities is possible
• Demonstrate that improved operator awareness over the state of shared tactical information is possible
Effective But Coarse-Grained and Reliant on Human Intervention to Modify Settings when BW is Constrained
Classic Feedback Loop

Enables System Response Faster Than A Human Could Respond
Intelligent Data Prioritization

Available Real-Time Commander Actions

Δ Tier Profile

Data Type 1
  Δ Shared Data Set

Data Type 2
  Δ Shared Data Set

... Data Type N
  Δ Shared Data Set

Available Real-Time User Actions

Assign Tier

Calculate Urgency
  By {object, dest} pairs
  Consider latency, error, etc

Estimate Remote State

Real-Time System Actions

Output Queue

Dest’n A

Dest’n B

Dest’n N

Transmission Status

Sync Query Response

Δ Shared Data Set

Feedback Loop and {Object, Destination}-Level Prioritization Enable More Granular, Automatic, Objective-Oriented Data Prioritization
Conclusion

• Systems with no data prioritization capability risk mission accomplishment or require significant operator intervention

• Systems with coarse-grained data prioritization approaches provide a certain measure of control and ensure the flow of certain types of data under adverse network conditions

• An approach which emphasizes synchronization goals at a system level and adapts to changes in data content, mission relevance, and network conditions can exceed the performance of today’s generation of C4I systems
Questions