Naval Network-Centric Sensor Resource Management

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Abstract

The benefits of implementing a network-centric Navy lie in the new capabilities made possible by enhanced information sharing between Naval platforms. Foremost is the potential to enable, enhance, and automate dispersed decision-making to support real-time critical mission areas. This paper explores a network-centric paradigm-enabled application: multi-platform sensor resource management.

Sensors in platform-centric Naval Battle Forces are generally utilized and managed to support a single weapon or combat system. The networking of combat systems and platforms creates an information architecture in which sensor management can shift to a Battle Force (BF) focus. In such a network-centric paradigm, individual sensors address the needs of the BF as a whole, overcoming the platform-centric architecture, which constrains sensor use to individual platform's needs. This paper explores design concepts for an automated sensor resource manager that tasks sensors to address BF needs.

Network-centric sensor resource management relies on viewing the BF as a single integrated interoperable combat system of systems, rather than a collection of loosely connected surface, subsurface, and air platforms. Such BF level thinking shifts the focus from legacy stovepipe systems and platforms with little or no collaboration incentive, to optimized uses of resources that transcend platform boundaries and span multi-threat dimensions. This paper explores interoperability problems and root causes associated with legacy Naval BF sensor management and poses solutions and considerations for a network-centric sensor resource manager that functions as part of a BF system of systems.

Network-centric sensor resource management relies on the achievement of BF information superiority. Information concerning the tactical battle space and BF resources (status & capabilities of sensors, weapons, communications, etc.) must be timely, accurate, and consistent across the BF in order to enable optimized sensor command and control. Another enabler is the introduction of higher levels of automation in link management to support optimized inter-platform communications. Additionally, the human interaction with automated decision aids is a critical factor in the design of a BF sensor resource manager. This paper explores a BF-wide

synchronized information database, intelligent link management, and human-machine interactions as necessary enablers for a network-centric sensor resource manager.

This paper makes a case for further study of Naval BF sensor resource management as a viable network-centric application. An analysis is presented which addresses the BF's need for a sensor resource manager. The paper predicts enhancements to the BF based on the adoption of an automated sensor resource manager application into the network-centric Naval BF.

I. Cooperative Sensor Resource Manager Concept

The Naval BF is comprised of surface, subsurface, and air platforms (such as aircraft carriers, cruisers, destroyers, frigates, amphibious warfare ships, surveillance aircraft, fighter jets, and submarines), sensor systems, weapon systems, communication systems, decision nodes (i.e., tactical command centers and planning commands), decision makers, and operators. Historically, the framework of the Naval BF has been based on a platform-centric foundation in which individual platforms acted as autonomous, self-sufficient systems that independently addressed mission areas (such as: theater air and missile defense, surface warfare, undersea warfare, mine warfare, land attack warfare, and information warfare). Collaboration between platforms was limited to addressing tactical missions in real-time or near-real time.

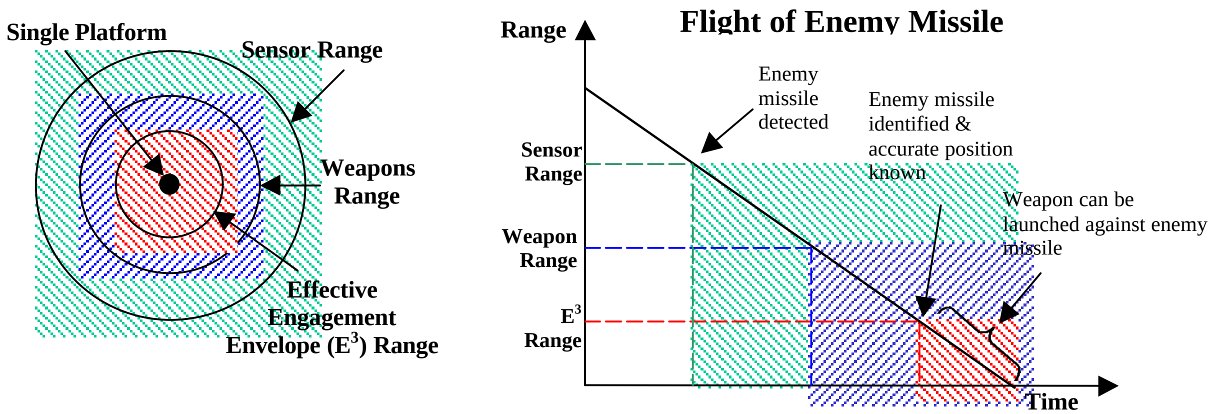

Figure 1 – Not Using BF Resources to Fullest Extent

In the platform-centric Naval paradigm, sensor and weapon resources have not been used to their fullest extent. This is illustrated in Figure 1, in which the concentric circles depict the Effective Engagement Envelope (E3) (the surrounding region in which the platform can fire interceptors at enemy air targets) as smaller than the maximum weapons range and sensor range. Thus, the BF is not reaping the full benefit afforded from its sensor and weapons resources. The graph in Figure 1 shows that the point in time when a weapon can actually be fired (must fall within the E3 reaction time) comes later in the sensor-to-shooter timeline than the time when the weapons launch could have made full use of the weapon's maximum range. Figure 1's illustrations are focused on a single Naval platform, but can easily be extended to a BF where multiple platforms are involved. However, introducing more platforms causes the problems and complexities involved in effectively managing BF resources to steadily increase.

The payoff, or gain in battle space, of having network centric Navy Battle Forces (BF) as opposed to platform centric single ship war fighters is not being realized. The addition of more platforms and subsequently more sensors and weapon systems should afford the BF such benefits as increased detection ranges, improvements in engagements with less resource depletion, and decreases in sensor-to-shooter timelines. However, the additional BF resources are introducing new and greater complexities into the BF problem space, resulting in: information overload, greater decision complexity, a reduced quality and often inconsistent track picture, latencies in response times, and increased competition for resource allocations. The combination of the addition of BF resources and the growing threat environment is causing the BF problem space to grow more rapidly than the payoff space.

This paper focuses on aspects of cooperative sensor resource management—managing BF sensors on disparate Naval platforms from a BF perspective. The Cooperative Sensor Resource Manager (SRM) is envisioned as a command and control system for the Naval Battle Force (BF) that manages sensor resources on multiple platforms (ships and aircraft) in a collaborative manner. The SRM concept involves a set of tightly coupled and networked distributed processors (distributed across BF platforms) that synchronize force-level command and control of sensor resources across the BF.

Automating Sensor Management

Sensor management is a process for improving or optimizing the measurement process in sensor systems. The process of optimizing the control of the measurement process is one of the least developed elements in sensor systems. Some research has been performed to deal with the optimization of detection and tracking functions in isolation of each other. Little research has been performed that takes an overall systematic approach to the composite measurement/ tracking/situation assessment problem. Even less research has been performed that examines solutions to managing sensors on geographically dispersed platforms.

In order to make the case for automating the sensor management function and expanding the function from managing sensors on a single platform to a BF of multiple platforms, the projected system performance of doing so, must be addressed. The following lists projected gains and methods for achieving the gains from automating sensor resource management.

[1] Effective Use of Limited Sensor Resources

- Tailoring different sensor capabilities to different mission needs
- Cueing sensors based on input from other sensors
- Redirecting agile aperture sensors to search in particular sectors or revisit tracks
- Managing modes of multi-mode sensors for different tactical applications
- Controlling scan rate according to information needs

[2] Effective use of Limited Operator Resources

- Limiting operator workload by limiting amount of non-tactical information displayed
- Automating lower level control functions
- Suppressing sensor-specific details from Operator displays and decision-loops
- Easing burden of Operator interfaces without limiting flexibility of human control

[3] Track Picture Advances

- Enabling automated track quality management through sensor optimization

- Recognizing and correcting for track degradation in an automated fashion & in real-time
- Scheduling track updates only as required for maintaining track quality within bounds
- Assigning (& updating) track quality goals based on each track's tactical significance
- Tailoring sensor functions to correct for tracks in dense or obtuse environments
- Handling target maneuvers by using higher-order processing algorithms and techniques
- Improving tracking by adaptively modifying processes in real-time, such as modifying the tracking filter or shortening the target revisit time to minimize model mismatch

[4] Sensor Fusion and Synergism

- Controlling different sensors based on their strengths to cooperatively support overall goal
- Intra-platform and inter-platform cueing of particular sensors based on tracks maintained by other sensors (one sensor detects, while another tracks)
- Minimizing or eliminating active sensing (active radar radiation) by using passive sensors for search roles (while maintaining sufficient tracking accuracy)
- Improving discrimination techniques by optimizing sensor use

[5] Situation Assessment Improvements

- Improving process of situation assessment by automatically shifting from kinematic tracking to generating target inferences (i.e., target intent, etc.) – enabling feedback link between automated situation assessment function and sensors (to improve data collection)
- Efficiently using sensors for tactical needs – managing sensors based on tactically important data collection schemas
- Filling in missing information – using sensors to collect data to confirm tactical inferences (identified detected targets, resolve clustered targets, etc.)

[6] Fire Control Support

- Enabling local and remote sensor data collection tasking based on weapon's needs
- Enabling inter-platform engagement coordination strategies (possibly engagement on remote and forward pass)

Micro vs. Macro Sensor Management

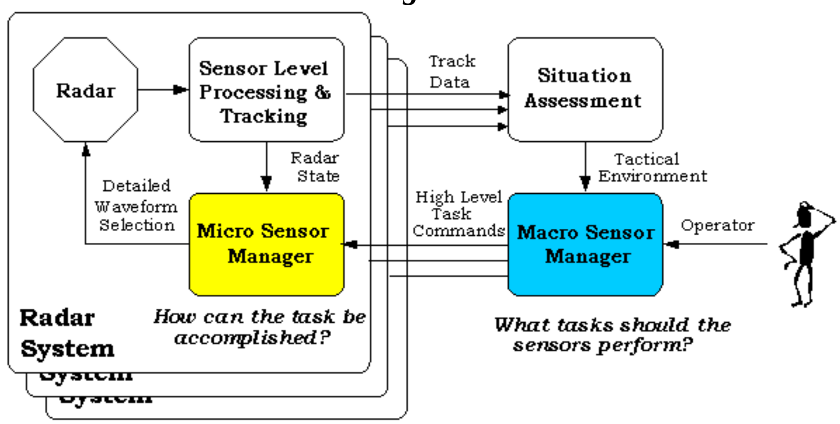

Figure 2 – Sensor Elements

Two aspects of sensor management exist: "macro" management (the determination of WHAT tasks sensors should perform) and "micro" management (the determination of HOW a particular sensor will perform its tasking). This section makes a case for dividing these functions by associating the macro management with each particular sensor and allocating the macro management to the Cooperative SRM system. This allocation simplifies the SRM's difficult task of determining sensor tasking for noncollocated and varying sensors. It also supports the inherent close coupling of the micro management function with the sensors.

Figure 2 illustrates this concept: the sensor system consists of the measurement device (illustrated as a radar) as well as raw measurement-level data processing and a micro-sensor manager that translates macro-level commands into sensor-specific adjustments that fulfill the commands. The sensor elements are shown inside the box marked "radar system". The Cooperative SRM performs macro sensor management functions that determine what tasks each sensor should perform, and avoids determining how each specific sensor will accomplish tasks.

Cooperative SRM Conceptual Design

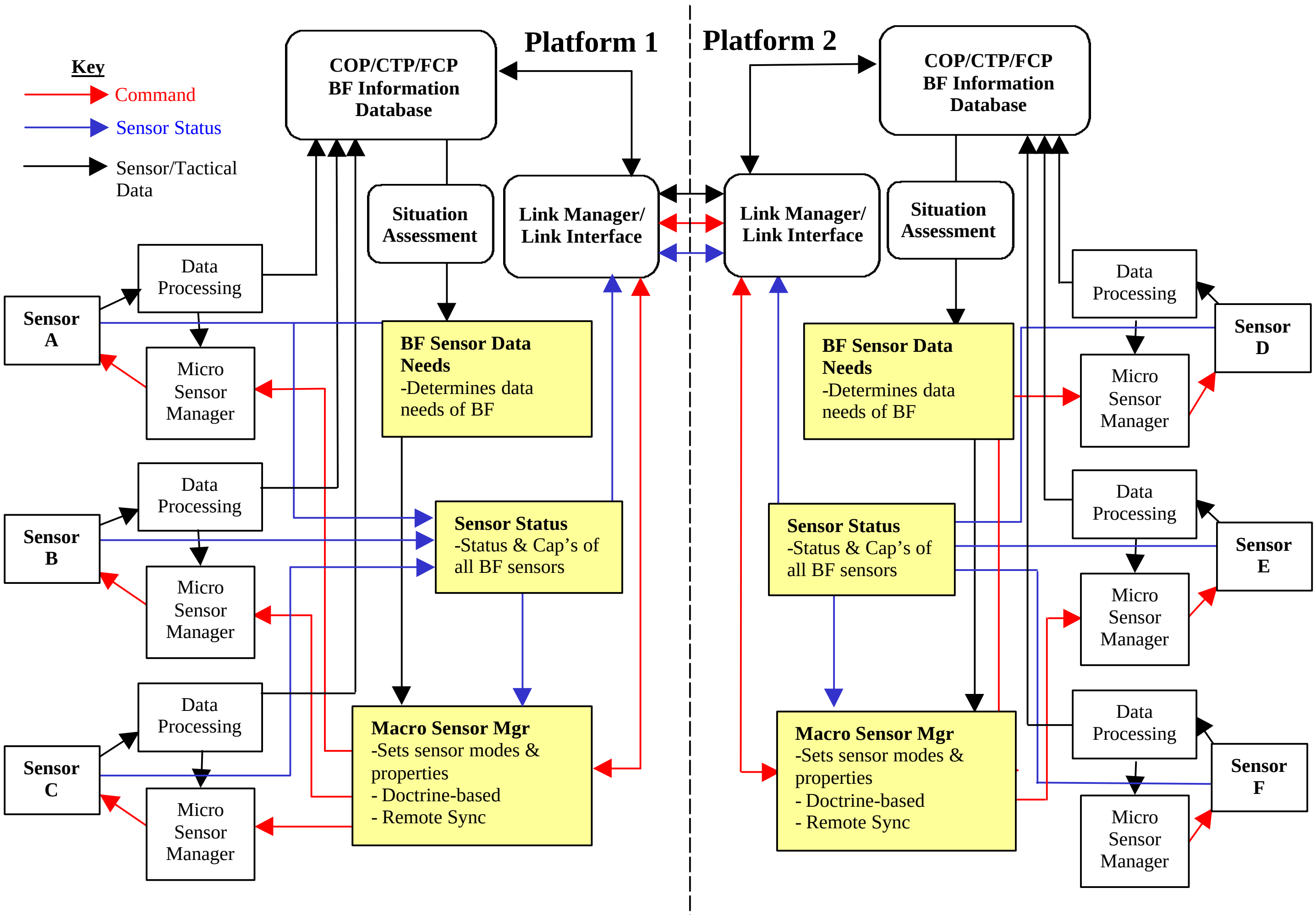

Figure 3 – Automated Cooperative SRM Concept

The SRM's external interfaces must be viewed as a set of interfaces—one on each platform, with the following functionality:
[1] Sending macro-level commands or "sensor tasking" to the sensors – involves routing tasking to correct sensors & ensuring tasking is correctly received

[2] Managing the received sensor data – keeping track of sensor data (& sensor status data)—time-stamping, checking for error, keeping track of error, storing, distributing to all platforms, routing to C4I systems within each platform
[3] Translating information for the various types of sensors -- providing the translation layer that can handle various data types and protocols.

Figure 3 illustrates an example of the SRM functioning on two platforms and interacting with the resident sensors and C4I systems. The SRM has the responsibility to develop macro-level sensor commands. In order to develop these commands, it must keep track of sensor status and determine the sensor data needs of the BF. The concept shown below shows a BF information database, a situation assessment function, and a link manager—all of which are external to the SRM. These elements are addressed later in this paper. Also illustrated are multiple sensors with their associated sensor data processors and micro managers on each platform.

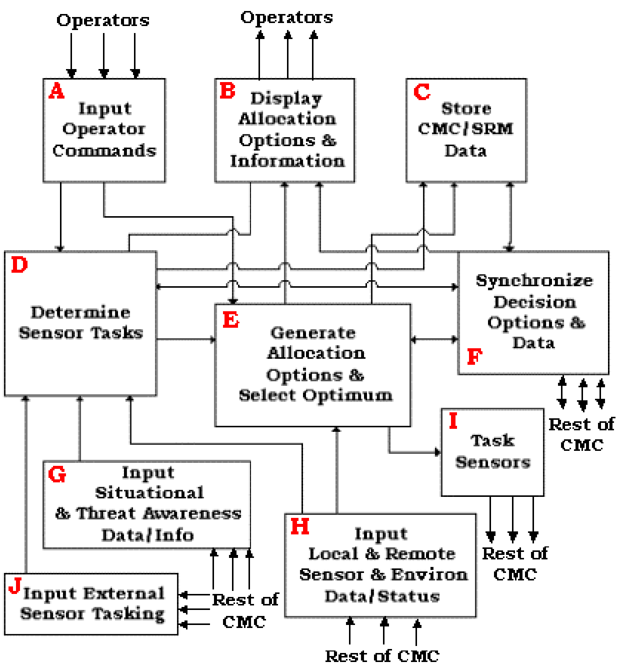

Figure 4 – Example of SRM Functionality

The top-level functionality of the SRM conceptual design is shown in Figure 4. This diagram shows the interfaces between functions A-J. "CMC" in this diagram refers to the Cooperative Management Capability, the parent system that includes an automated link manager, and automated weapons resource manager, as well as the SRM. Besides external interfaces to the rest of CMC and to Operators and the function of storing data, the key functions of the SRM are determining sensor tasks from the situation/threat input and data input; allocating tasks to sensors based on their capabilities, availability and status; synchronizing the decisions among platforms; and tasking the sensors.

II. Existing Challenges to Achieving NCW/Cooperative SRM

This section explores the Naval BF problem space that inhibits the achievement of cooperative sensor resource management and network centric warfare in general.

[1] The shift from platform-centric to network-centric has not completely taken place: network-centric concepts are not "designed-in" to systems yet.

Current Naval systems are not designed from a network centric (multi-platform) point of view. Such network-centric design is necessarily a top down process—starting with a design for Battle Force level and decomposing or allocating force-level requirements to the BF elements (or platforms/systems). The historical approach has focused on the design of each BF element individually and has attempted to achieve interoperability in an "after-the-fact" method by focusing on interfaces between the elements. By not "designing-in" Force-level requirements, network-centric applications such as the SRM are not possible. A force-level vision is necessary to conceive and design the SRM—whose functionality and system boundary spans BF platforms.

[2] The requirements for BF resource management are not specified from a BF-level perspective.

Many naval interoperability problems are the result of problems involving requirements definition and implementation. Requirements for legacy, current, and future systems are not defined from a Battle Force (BF) perspective. The requirements in many cases are incomplete, inadequately or inappropriately defined, and/or stale. The underlying fundamental bases of requirements are frequently misunderstood. Additionally, requirements are not always implemented as intended or as specified and are sometimes not implemented at all. As an example, there are no requirements at the BF-level for sensor resource management.

[3] The Navy's acquisition and program management practices prevent network-centric warfare (and thus BF-level sensor management).

The old saying that too many cooks spoil the broth is exemplified by the way that Naval command and control systems are defined, designed, and procured. Platforms are developed in closed, stove piped environments with the focus on the platform level systems, e.g., ACDS, AEGIS, SSDS MK2. Sensor resource management functionality is embedded in such combat systems and associated sensor systems and is therefore acquired and managed from a platform perspective. Another program management problem involves the process for making changes to requirements and systems. Coordinating the implementation of requirements changes is poorly managed—no organization is responsible for the funding needed to bring about such a process.

[4] Legacy system constraints prevent an evolution to a network-centric Navy.

Legacy system limitations constitute a huge challenge to achieving the collaborative management of BF resources. Many new developments and solutions that might provide improvements are limited or effectively precluded by legacy paradigms, methods, and/or systems. These legacy constraints manifest themselves through: systems that are too expensive to replace or remove; agreements with Joint or Allied forces that prevent their removal; and programmatic "rice bowls" whose survival depends on the continued existence of these legacy system elements. Cooperative sensor resource management is affected by the following legacy constraints:

- Legacy link formats (Link 11, 16, and CEC become data precision bottlenecks for both track and ship position data—causing a huge problem for the fusion of multi-platform sensor data.)
- Legacy use of bandwidth (Does not support sufficient data exchange to achieve shared situational awareness necessary for inter-platform real-time sensor feedback control loops)
- Legacy communication hardware (Limits data exchange speed/accuracy--better technology exists but cannot be used because transition is too difficult (installation across platforms)

- Outdated and multiple combat system baselines (AEGIS Baseline 4 & ACDS Block 0 still in operation— Navy has found it difficult to fund timely retirement/update of older combat system variants, hobbling Force-level resource management capability evolution.)

[5] Existing sensor command and control mechanisms rely too heavily on manual participation.

- Operators have to deal with lower level sensor details than is efficient for making timely and accurate decisions.
- No effective automated decision aids exist for supporting the management of sensors across BF platforms.
- The complexity of missions and operational environment produce a multitude of options and an overload of information, leaving Operators with too much information and too little time to make effective decisions.
- The existing communication architecture does not provide a means of distributing the information (such as sensor status & commands) across the BF to support cooperative sensor resource management and other NCW concepts.

[6] The existing information architecture constrains cooperative BF resource management.

- The existing communication architecture does not provide a means of distributing the information (such as sensor status & commands) across the BF to support cooperative sensor resource management and other NCW concepts.
- The existing infostructure prohibits level 4 data fusion or the feedback loop of fusing data to produce a tactical picture and using information from the picture to re-task sensors to improve the picture in real-time.
- The infostructure relies on disparate C2 processing methods across platforms (due to evolution of various legacy combat systems)—this lack of commonality prevents BF synchronization in terms of shared awareness and collaborative capabilities.
- A lack of standardization in Naval information systems causes complex interfaces; multiple data formats; differences in doctrine, algorithms, & processes; lack of a common BF lexicon; lack of common time/ navigation/data registration standards; etc.
- There is a symbiotic or closely coupled relationship between the command and control of sensor resources and the inherent BF infostructure: the structure of how information flows through the BF poses constraints on how commands and tasks can be executed. As an example, the growth in complexity of the threat space and its environment demands more timely and error-free information sharing among BF decision nodes. The BF framework must evolve in response to this growth.
- Information management throughout the BF has not been considered (or designed) from a network-centric, system-of-systems perspective. For example, databases or track files are designed on a platform or system basis—and as a result, databases are not synchronized and thus data disparities and inconsistencies among platforms exist.

III. Required Enablers for Cooperative Sensor Resource Management

The Cooperative SRM requires the achievement of a network-centric warfare paradigm. Inherent to NCW is interoperability between BF platforms. This section addresses necessary enablers required to achieve the cooperative SRM concept. The first enabler introduced is the establishment of a common, synchronized BF information database. The second enabler described is an automated link manager. Finally, this section addresses higher levels of automation in the Operator's interaction with the Cooperative SRM.

COP/CTP/FCP BF Information Database

The SRM conceptual design was illustrated in Figure 3. An element of this illustration was the COP/CTP/FCP BF Information Database. This element is based on the collapse of the COP, CTP, and FCP into a common database that is synchronized across BF platforms. This concept is integral to the achievement of both information superiority as well as establishing a Cooperative SRM. Information superiority is achieved when the Naval BF gains a superior information position relative to its enemies by establishing and maintaining shared and consistent battle space awareness across the BF. Information in the BF is currently divided into three categories as shown in Figure 5: the Common Operational Picture (COP), the Common Tactical Picture (CTP), and the Fire Control Picture (FCP). Information from all three categories are relevant to the effective and efficient management of BF resources as well as to addressing BF threats and operations.

The COP consists of non-real-time tactical information used for mission planning and force management, such as blue and red Courses of Action (COAs), a priori knowledge of the enemy, and cultural, political, and geographical features. The CTP consists of near-real-time tactical data and information used for cueing and managing BF resources (such as sensors, communications, and weapons). The FCP is the collection of real-time fire control quality data/measurements used to support weapons during launch and in-flight.

The challenge involved in attaining tactical information superiority lies in taking full advantage of the capabilities of the distributed sensors and communication resources to best fulfill the dynamically changing needs of the large set of distributed information users. Without implementing the SRM concept, sensors and other BF resources (links, weapons, etc.) will continue to be managed from a platform-centric perspective, which limits their utility to the BF at large. Additionally, both the sensors and communication links have inherent physics-based bounds that limit their area of coverage and accuracy—and which presents limits that the SRM must work within.

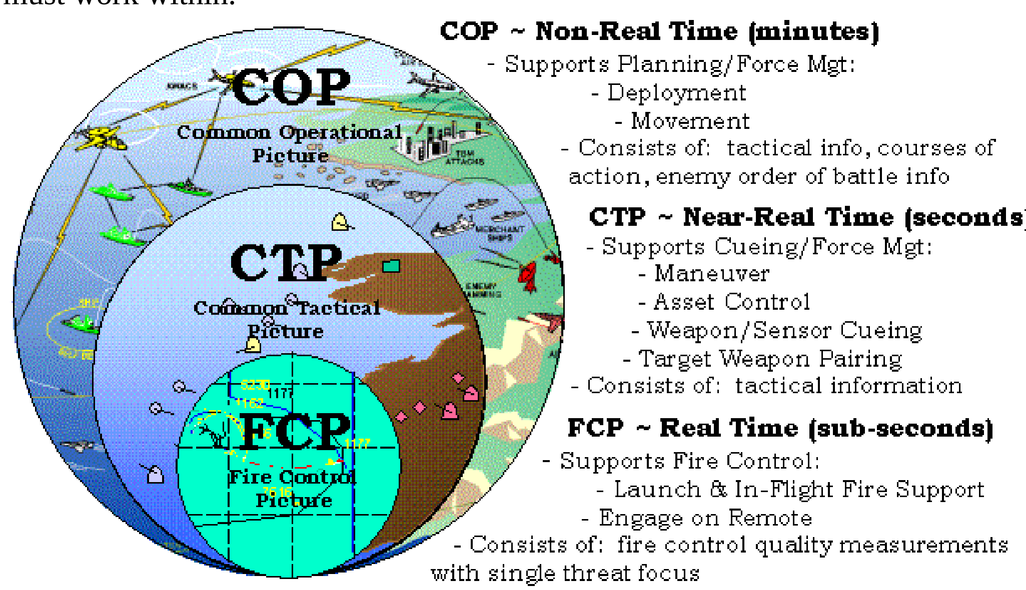

Figure 5 – Three Realms of BF Information

In order to achieve information superiority, the BF must ensure consistency between the three information realms. For example, a decision-maker may detect differences in the location, status, or characterization of a target as it is represented in the COP and in the CTP. This is likely caused by time lateness and observation of different time frames. Since the pictures are updated at different rates, data may be available for the CTP that are not yet available to the COP. Without implementing the SRM, achieving consistency between the information realms is a serious challenge. Thus collapsing the information realms is both an enabler of SRM as well as a result of SRM.

Automated Intelligent Link Management

An important enabler of network-centric sensor management is the automated control of data distribution throughout the BF. Major bandwidth constraints exist due to the physical limitations of the BF's communication devices. These limitations prevent the paradigm of wasteful transmission, or the sending and receiving of all data and information amongst the BF platforms or decisions nodes (which would be a great enabler of cooperative inter-platform sensor control). To most effectively utilize the bandwidth, the BF must intelligently distribute data and information between decision nodes based on the needs of the BF information users, which dynamically change as the operations and missions unfold.

The BF's tactical information users consist of human operators and decision-makers as well as automated C4ISR, combat, and resource (i.e., sensor) management systems that have tactical roles. As missions change in priority and existence during the course of operations, the needs of such BF tactical information users change. For example, during remote engagements, the Cooperative SRM will require interplatform throughput priority for FCP data to support the closing of the fire control loop. Another example is when a user's CTP needs change according to mission priorities, such as the need for higher resolution subsurface tactical data when a subsurface threat is detected.

Automating the exchange of BF information to meet the dynamically changing user needs is key to addressing this challenge. The establishment of an intelligent data distribution capability relies on automation, since the timeframes required to support the distribution of COP, CTP, and FCP are too fast and the amount of data and information is too large to permit a manual solution.

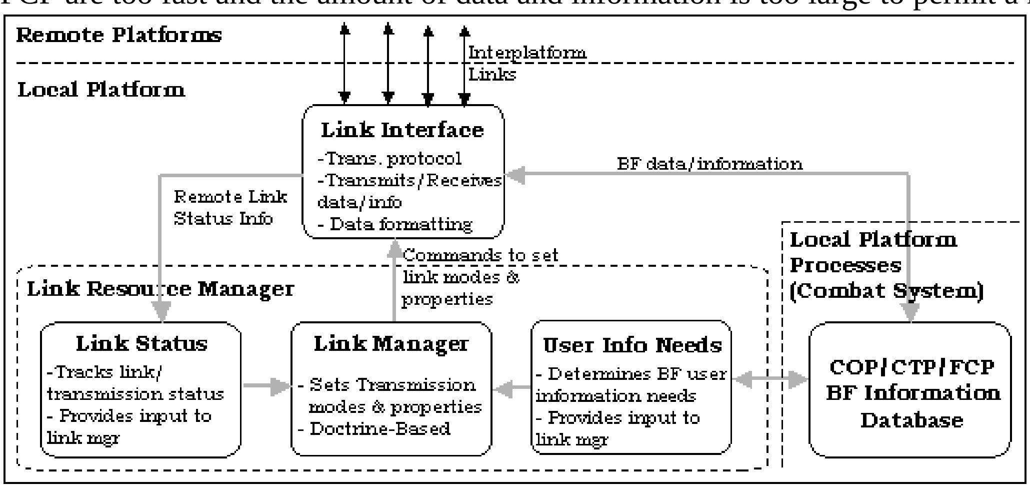

Figure 6 – Intelligent Link Resource Management Concept

The intelligent data distribution concept (as illustrated in Figure 6) is based on an automated, distributed link resource management system that places a smart processor (or link manager) at each decision node or participating platform. Each link manager: (1) determines the needs of the information-recipient users or decision nodes; (2) keeps track of what data and information is available; (3) determines the feasibility of transmission (whether the decision nodes are within transmission distance, whether the communication links can support transmission, whether the transmission will support the user's timeline, etc.); (4) sends commands to other link managers within the BF to control and manage transmissions and transmission modes; and (5) transmits data and information as required.

A possible solution for managing links under such a paradigm would be to establish transmission modes such as one based on the three information realms (COP/CTP/ FCP). As platforms information needs change, the transmission modes change in response. For example, a platform in the midst of an engagement might invoke the "FCP" transmission mode that tailors the information update rate, bandwidth usage, and transmission direction on all remote links that can contribute to the engagement. Figure 7 illustrates a simplified version of this concept. This illustration shows link managers handling a variety of different user information needs during a snapshot in time. The link managers establish link modes that support the information needs, which vary across platforms. In Figure 7, the links are shown in bold that provide data to the platform that requires FCP data. The BF communication architecture would be optimized to support the FCP user's needs as a higher priority than the other platforms during this time period.

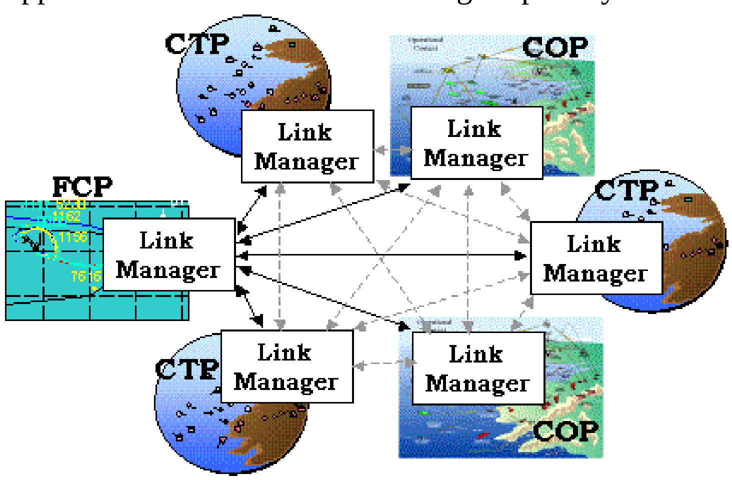

Figure 7 – Intelligent Link Resource Management Concept

Automating the SRM Operator's Interaction

This section addresses methods for managing sensor resources—studying three levels of automated HIL methods as illustrated in Figure 8. In a fully manual HIL system, the human operator performs all decision-making functions without the aid of an automated display. In the semi-automatic sensor system (shown in both Figures 8 and 9), which is most characteristic of current Naval approaches, the machine processes and fuses sensor data and even supports fire control. Yet, in this model, the human controls the sensor. The operator forms an integral link in providing feedback between tracking performance and future sensor behavior. In today's Naval BF, sensor control best fits the semi-automatic model for controlling search volumes and areas.

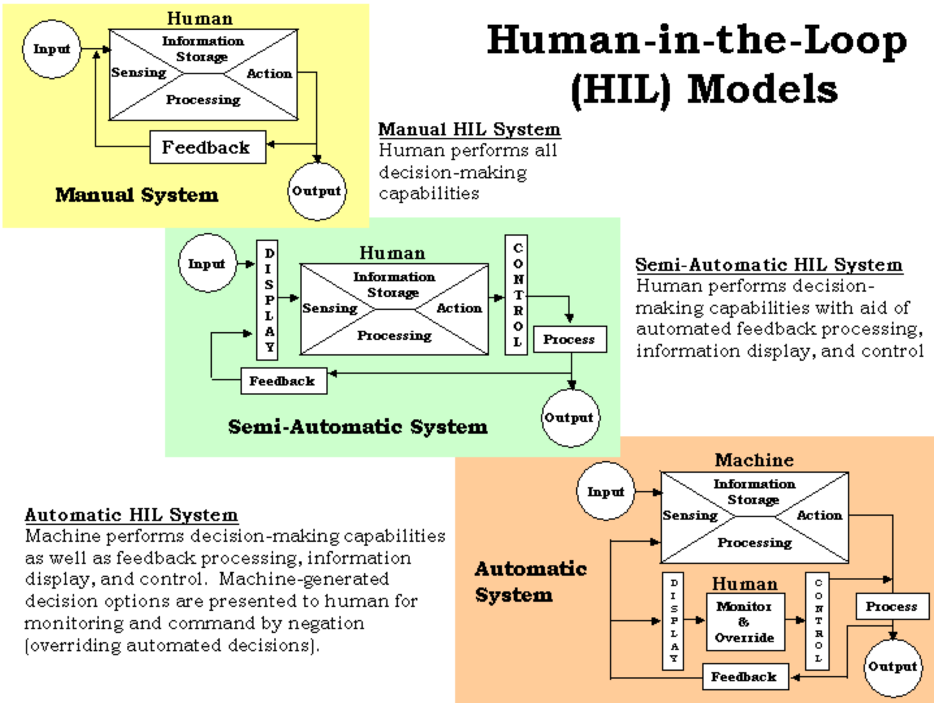

Figure 8 – Human-in-the-Loop Models

In the automatic sensor system (shown in Figures 8 and 9), an automated sensor manager controls the sensor based on inputs from automated processes (such as data association, fusion, and situation assessment) and from the human operator. In this configuration, the automated sensor manager provides the primary feedback to the sensor under the possible guiding input from the Operator. Thus, the automated sensor manager is responsible for controlling future sensor behavior while the operator exercises control by negation. Today's Naval BF uses this model during weapon engagements. The sensor is controlled automatically for cueing and establishing track and providing updates to the interceptor.

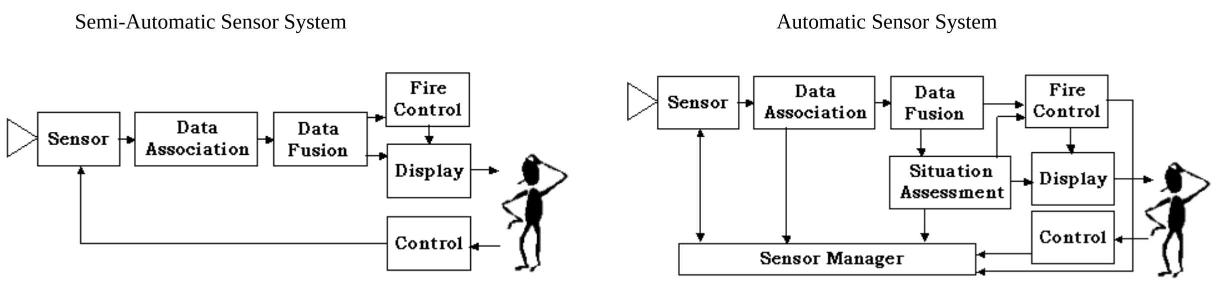

Figure 9 – Semi-Automatic & Automatic Sensor Systems

Clearly as the level & amount of both data and processed information increases, the ability of operators to make decisions decreases. Selecting the correct HIL model (or correct level of automation) is a design imperative. The semi-automatic system is best suited for simpler operational environments that contain fewer and/or slower-moving targets that are easier to track, thus reducing the amount of information that the Operator must deal with and simplifying the Operator's decisions. The automatic system is more costly to develop and maintain—thus it should be employed only when the operational needs and environment dictate—such is the case for the Naval BF with missions such as Anti-Air Warfare. The following benefits that can be yielded from implementing an automated sensor manager are necessary for the Naval BF:

- **Reduced pilot workload –** automated manager alleviates the need for the operator to specify each sensor operation or future behavior. Operator's role can become: override a track's priority, establish degree of allowable active radiation, request special data collection, etc.)
- **Sensor Tasking based on finer detail –** Operator's control ability is based on information shown on display and ability to assimilate information into human decision-making process. This limits the amount, types, and degree of detail of information feeding the sensor control decisions. Automating sensor tasking allows more amounts, types, and finer degrees of detailed information to support the decision-making process. (i.e., humans much better at tactical objectives than making decision concerning the fine details of sensor operation)
- **Faster Adaptation –** automated feedback allows much faster adaptation to the changing environment, i.e., earlier detection of tracking performance degradation.

IV. Payoffs of Cooperative Sensor Resource Management

Realization of the full benefits of BF sensor resources can only be attained through collaborative inter-platform war fighting schemes—or achieving the network-centric paradigm. The BF must be viewed as a single integrated combat system of systems, rather than a collection of loosely connected surface, subsurface, and air platforms. When BF system thinking is adopted, the focus shifts from legacy stovepipe systems and platforms with little or no collaboration incentive, to optimized uses of resources that transcend platform boundaries and span multi-threat dimensions. Achieving a BF system and reaping the full benefit afforded by distributing BF resources on geographically disparate and movable platforms may be possible by dedicating further analysis to the concepts presented in this paper. Further study of intelligent inter-platform data sharing, increased levels of BF automation, and introducing a COP/CTP/FCP shared BF information database, in addition to developing the Cooperative SRM concept in more detail is key to envisioning and eventually achieving the network-centric paradigm.

Expected payoffs of achieving network-centric sensor resource management include:

Increased Battle Space Picture Accuracy – the SRM is expected to increase target track accuracy and improve interoperability problem that inhibit inter-platform picture synchronization.

Decreased Degraded Coverage Zones – the SRM is expected to decrease "degraded" or "no coverage" surveillance zones.

Improved Surveillance Coverage – the SRM is expected to increase the detection range of the BF.

Decreased BF Reaction Time – the SRM is expected to decrease the average BF reaction time (aggregate time taken by BF surveillance, command, control, and communications systems in responding to an attack).

Optimized Economy of Resources – the SRM is expected to better utilize sensor resources an avoid redundancy and non-use by allocating tasks to sensors optimally.

Enabled Innovative Inter-platform Sensor Usage – the SRM is expected to enable new sensor-weapon pairings (i.e., remote engagements), avoid legacy stove-piped sensor-weapon pairings, and inter-platform sensor operations that would otherwise not be possible or imaginable within narrow decision-making time-lines.

The achievement of the Cooperative SRM supports BF interoperability and information superiority. It ultimately results in the ability to make earlier decisions based on more accurate data and faster and more accurate responses to the ever-growing threat space. The Cooperative SRM enables and encourages the collaboration that leads to a single integrated BF system of systems—all of which result in battle space gains.

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