14TH INTERNATIONAL COMMAND AND CONTROL RESEARCH AND TECHNOLOGY SYMPOSIUM (ICCRTS)

"C2 AND AGILITY"

TOPIC 9: C2 ARCHITECTURES AND TECHNOLOGIES

COMPOSING ADVANCED C2 NETWORKS USING THE TACTICAL COMPONENT NETWORK

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Abstract

As new and disparate sources of sensor data such as unmanned platforms and net-enabled joint assets are integrated into the battlespace with existing capabilities, novel sensor network architectures will be needed to support emerging concepts of operations and leverage maximum advantage from the newly available information. Ideally, network design should be flexible enough to allow assets to enter and leave the net without disruption to the network, remain anonymous, contribute data of differing quality and generally remain independent from the performance and behavior of the network as a whole.

Since inception in the 1980s, collaborative sensor networks have offered tremendous benefits over conventional tactical data links. An *advanced* sensor network provides even more powerful advantages. The Tactical Component Network (TCN) is an advanced sensor network that provides increased flexibility by adding multiple network capability, enabling joint, coalition, and multi-level interoperability and managed data exchange between independent community of interest networks.

TCN is a DoD-licensed software framework conceived and designed to create a complete collaborative information environment founded on highly capable and scalable advanced sensor networks. Ships, aircraft, ground units, space elements and C2 nodes create optimal situational awareness through exchange and synthesis of sensor and related planning and command information.

1 INTRODUCTION

As new and disparate sources of sensor data such as unmanned platforms and net-enabled joint assets are integrated into the battlespace with existing capabilities, novel sensor network architectures will be needed to support emerging concepts of operations and leverage maximum advantage from the newly available information.[1] Ideally, network design should be flexible enough to allow assets to enter and leave the net without disruption to operations, remain anonymous, contribute data of differing quality and generally remain independent from the performance and behavior of the network as a whole.

As the availability, variety and capability of sensors has increased over time, the means to leverage the tactical information they provide into more effective force-wide capability has evolved as well. The ability to establish and maintain track with individual sensors presents challenges, even when multiple sensors are linked via conventional tactical networks. Since inception in the 1980s, collaborative sensor networks have offered numerous benefits over conventional tactical data links. Logical extension of sensor netting capability with current software system design approaches allows composition of advanced sensor networks that provide even more powerful advantages.

As an off-the-shelf Department of Defense asset, the Tactical Component Network (TCN) provides an extensible software framework for distributed, real-time sensor collaboration and an infrastructure for the development, integration and test of components within a distributed sensor network. In the original license agreement, Missile defense agency states:

> “As the commercial world enters into the age of “Virtual Information Technology (IT)” based on hundreds of billions of dollars in wired and wireless infrastructure, it is up to the U.S. Military to manage its own infrastructure to accomplish missions faster than “threat speed”. The requirement for Virtual IT in the mission of the Missile Defense Agency is even more pronounced with an operational force structure distributed across hundreds of miles or more operating as part of a multi-Service and coalition force. A large scale TCN® has the potential for providing this capability while capturing all the unique environmental constraints, ruggedization, and extreme requirements for data throughput, security and speed.”[2]

Full-use special license rights to the TCN software were acquired by DoD in 2007. The purpose of this paper is to describe a concept for this DoD-owned asset to be leveraged in the composition of a highly flexible and capable tactical C2 network in a notional Joint Air and Missile Defense environment. The advantages that can be realized by implementing TCN include an off-the-shelf capability to conduct simultaneous integrated air and missile defense composite tracking, multiple echelons and community of interest networks, and increased extensibility of operational C2 networks.

By implementing advanced sensor networks, the warfighter can achieve extensibility of the operational architecture, flexibility to configure segmented networks according to mission requirements, and efficiency in both bandwidth and cost that provides incentives for service and community participation.

2 BACKGROUND – EVOLUTION OF TACTICAL NETWORKS

Just as Horatio Nelson's use of visual communications was a revolutionary advantage in the conduct of naval warfare, the combination of radio communications and electronic detection capabilities (particularly radar) via tactical data links (TADL) provided huge advantages to the warfighter. Groups of assets were provided access in real-time or near-real-time to the full, combined tactical picture. This allowed improved reaction times, extended battlespace, more reliable command and control, and the ability to operate effectively beyond line of sight.[3] Such an architecture is described by Figure 1, and an notional operation view is presented in Figure 2. Several communications systems have been developed over many years to support TADL communications, or the near-real-time exchange of data among tactical data systems. Each such system is specified by hardware/software characteristics (e.g., waveform, modulation, data rates, transmission media, etc.) as well as by message and protocol standards.

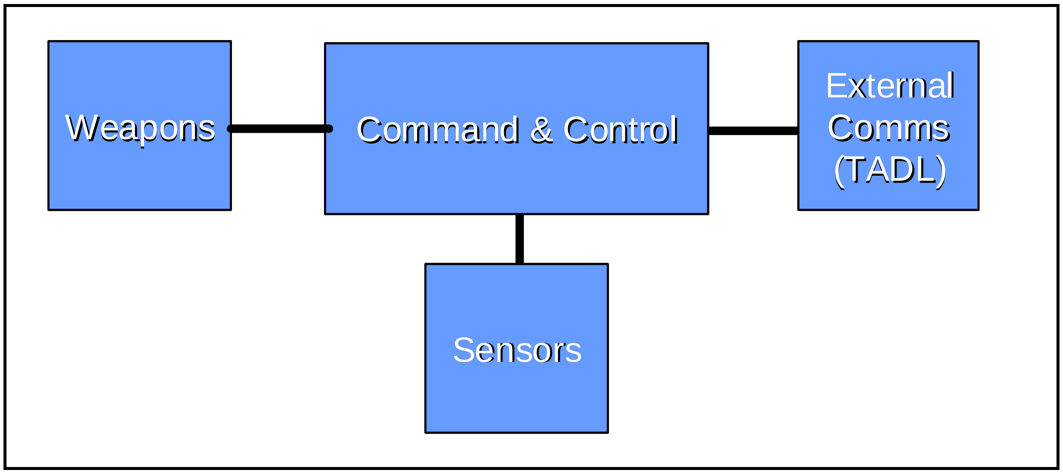


Figure 1 Conventional Tactical Data Link Configuration

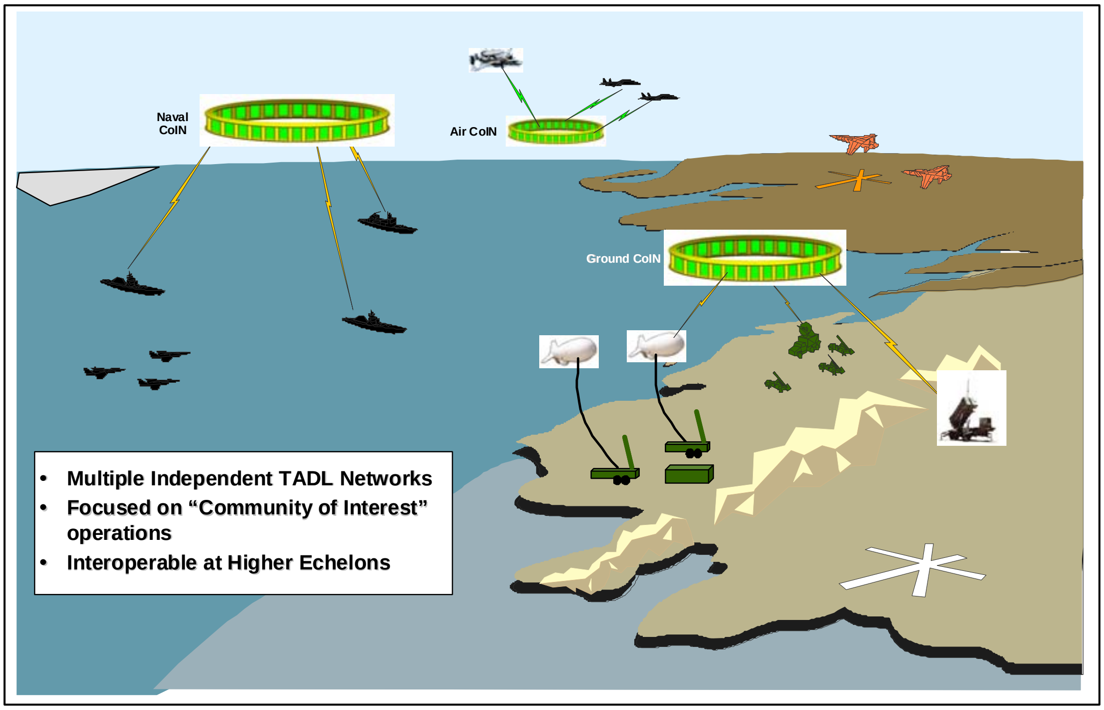


Figure 2 Operational view of conventional tactical data link

As tactical data links proliferated and were extended, new technical and operational challenges were recognized, including the ability to maintain a consistent and correlated track picture, especially air tracks that may be closely spaced, maneuvering, passing through sensor coverage gaps, and other challenges to radar tracking in general. In these conventional tactical data links, each unit develops a track from onboard sensors and then attempts to correlate that local track with received remote tracks. The challenges of mitigating navigational differences and sensor alignment among participating platforms results in dual tracks, track swaps, or miscorrelation.[4]

Collaborative sensor networks, by exchanging sensor measurement data (versus tracks), form single, composite tracks developed from common data through identical processing algorithms. Sensor netting was developed to integrate force-wide sensors and combat systems to counter both aircraft and increasingly capable and stealthy missiles. The Cooperative Engagement Capability (CEC) is a successful example of a collaborative sensor network. It interfaces existing surveillance sensors, weapon and command/ decision computers, navigation inputs, fire control sensors, and identification friend or foe processors to support a virtual force-wide distributed combat system.[5] A simple block architecture is described by Figure 7 and a corresponding notional architecture operational view is shown in Figure 4.

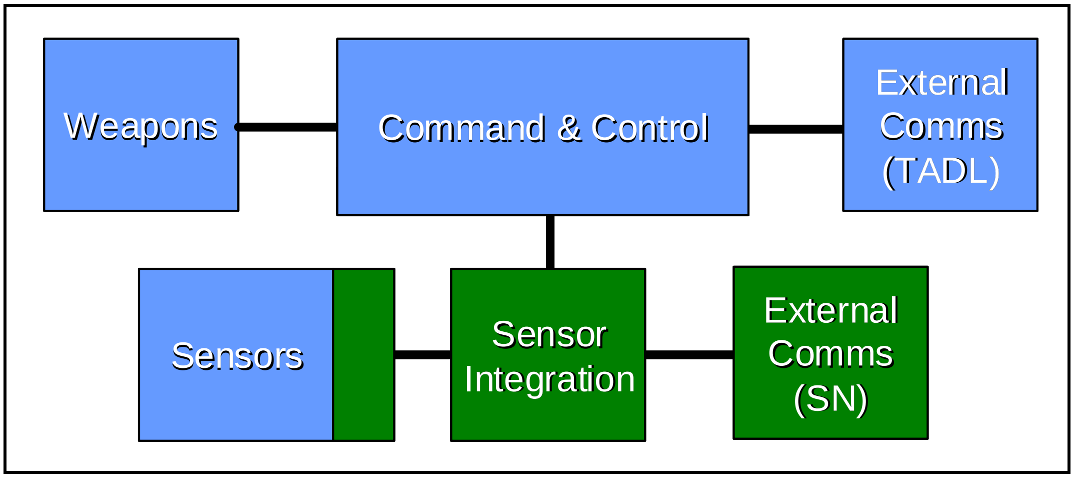
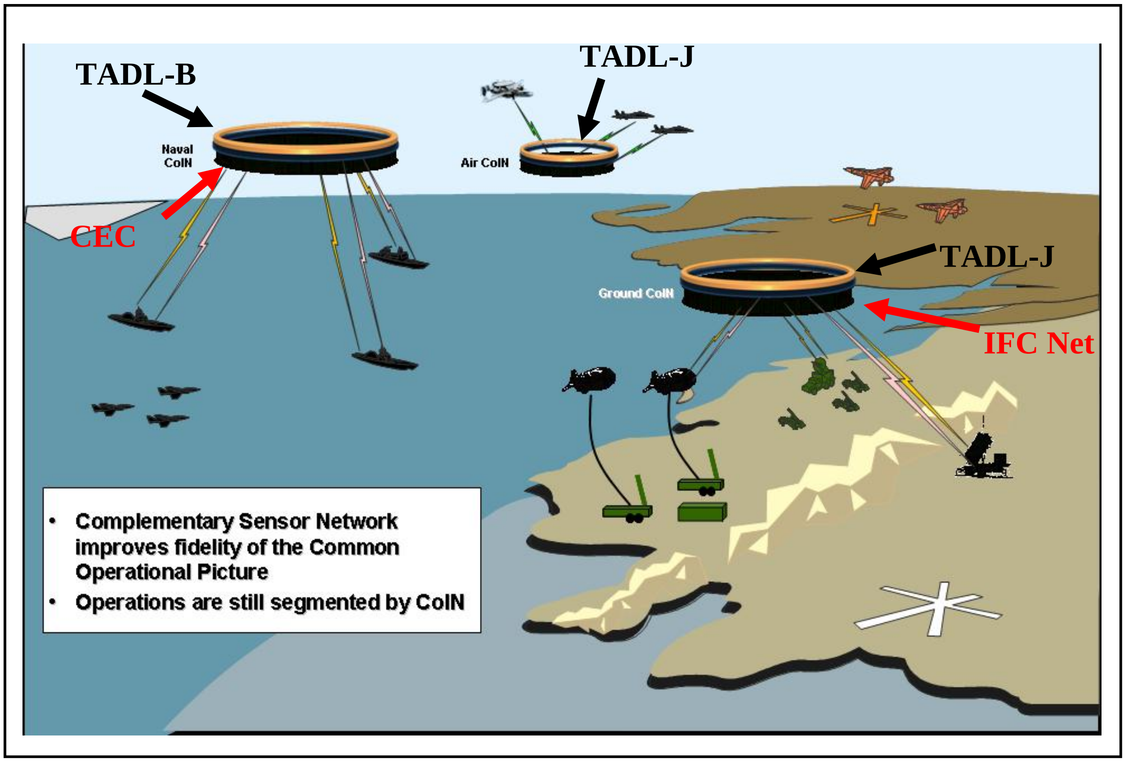


Figure 3 Collaborative Sensor Network Configuration



- Complementary Sensor Network improves fidelity of the Common Operational Picture
- Operations are still segmented by CoIN

Figure 4 Operational View of a Collaborative Sensor Network

Collaborative sensor networks have offered tremendous benefits over conventional tactical data links, but require invasive (and by result, expensive) integration into host systems. The large bandwidth required to distribute all available sensor measurement data requires a highly capable (and expensive) communication infrastructure. By adopting alternative architectural approaches and leveraging advances in the flexibility and open design of current computing and networking systems, an advanced sensor network can be designed to allow maximum extensibility, bandwidth efficiency, and lower implementation cost while retaining the benefits of the sensor netting concept.

An *advanced* sensor network makes use of more flexible computing technology, and provides even more powerful advantages that can be extended from currently employed sensor netting capabilities. The Tactical Component Network (TCN) software enables construction of an advanced sensor network that provides increased flexibility by adding multiple network capability enabling joint, coalition, and multi-echelon interoperability and managed data exchange between independent community of interest networks. An advanced sensor network can be implemented as an extension of a more inclusive Joint network architecture, integrating with existing sensor networks and providing interface with existing tactical data link networks and command and control networks. A logical diagram of an advanced sensor network is shown in Figure 5. The corresponding operation view of an advanced sensor network is depicted in Figure 6.

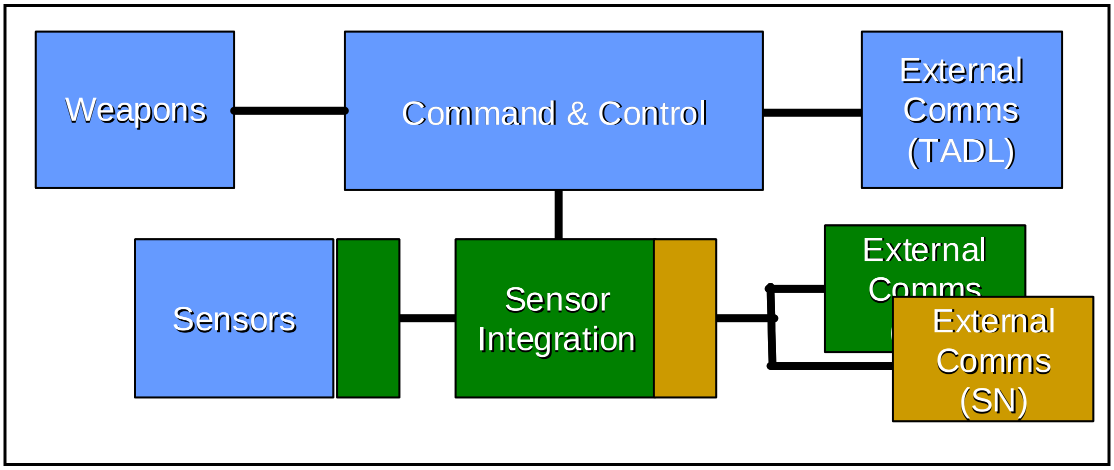
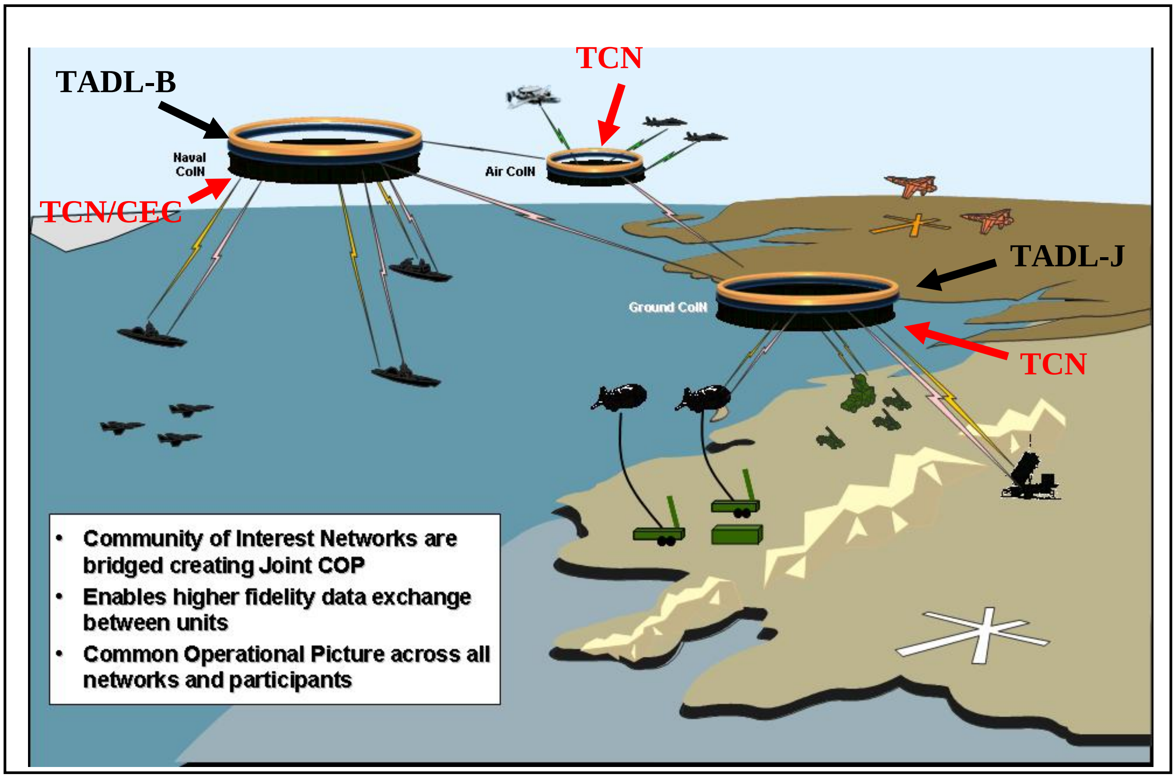


Figure 5 Advanced Sensor Network Configuration



- Community of Interest Networks are bridged creating Joint COP
- Enables higher fidelity data exchange between units
- Common Operational Picture across all networks and participants

Figure 6 Operational View of an Advanced Sensor Network

3 DESIGN GOALS FOR TACTICAL SENSOR NETWORKS

Examining decades of tactical network design experience, certain crucial attributes can be identified that enable the maximum utility to be achieved from designing a generic tactical networking framework. The tenets of design addressed by novel design approaches in TCN can be summarized as cornerstones of tactical sensor networks:

- Network participants must maintain physical and functional independence. A change to- or addition of any network element should not force change at any other element(s) in the network. As networks grow to include more elements and a greater diversity of element participants, joint acceptance, life cycle, acquisition, and certifications should not be impacted. All element-specific processing must be performed at the originating elements and not at the recipients to eliminate coupling between elements that can lead to the need for one or more element(s) to change due to a change by some other element.
- Information exchanged on the network must support and be responsive to the needs of the network users. The network should meet widely differing user data requirements, while minimizing or eliminating extraneous, redundant and otherwise unnecessary network exchanges. In such a network, data is exchanged based on stated mission-defined goals. Exchanges are made collaboratively and within the context of information provided by all contributing elements.
- Network extensibility must be minimally impacted by the number of network participants. The network should be capable of including a wide array of participants in networks of various topologies. The ability to distribute processing requirements to the network edges eliminates limitations on information input due to computational complexity growth and allows the use of low cost PC's and operating systems. A design and operational challenge with tactical-edge networks is finite bandwidth and low throughput rates at points within the system. An advanced sensor network must effectively function within existing make optimal use of available bandwidth and account for artifacts induced by limitations of the communications network.
- The network communications structure must seamlessly include all communications systems acting in concert. Existing available communications system such as The Data Distribution System (DDS), Joint Tactical Information Distribution System, (JTIDS), Multi-Function Information Distribution System (MIDS), Situation Awareness Data Link (SADL), Enhanced Precision Location and Reporting System (EPLARS), etc. must collectively form the travel paths for data between networked elements. The network structure must accommodate the differences in communication systems throughput in a seamless and fully interoperable manner. The communications device(s) used at any point in the network should be selected according to the needs of the user.

- The sensor network must support multiple levels of exchange security while maintaining needed concurrency. Inclusion of coalition elements requires elements or groups of networked elements be able to control access to their information without undermining legitimate user needs.

These attributes were identified through extensive experience and lessons-learned designing and implementing sensor networks. Designing a tactical sensor network with these attributes in mind allows tremendous flexibility and capability improvements over other existing technologies. The constant thread through these attributes is maximum flexibility in integration, information exchange, and operational configuration. By using object oriented and open architecture concepts to allow functional components and participating nodes within the framework to remain functionally and logically independent, the objective network achieves flexibility, affordability, and effectiveness.

4 OVERVIEW OF TCN

In 2007, TCN special license rights (full design and source code access) were acquired by the Department of Defense as a proven-performance, low-cost, open architecture solution for sensor networking. TCN provides an architectural framework that addresses the cornerstones for collaborative sensor networking described above. TCN design is based on a software building-block approach. A combat or mission system architect can define specific functional objects to meet operational requirements and network them and supporting objects together as building blocks for more complex tactical structures. These blocks are integrated through collaboration-enabler and portability applications which ensure component independence. The objective is a framework, based on common components, which can be easily tailored to meet unique system and mission requirements. The foundation elements of TCN provide the method by which these objects, components in TCN, are connected to meet the overall operational requirements for a system. ."[6]

TCN is an architectural concept realized in a set of software functions which interact in a publish-subscribe construct. The functional components can be categorized into four areas:

- Element components – those physical resources resident in the host system that are to be integrated into a network, usually one or more sensors and one or more communications devices.
- Adaptive components – software elements of a TCN implementation which integrate host resources into the network, normally developed by the host system developer. Each sensor or communications device is interfaced with an element server tailored to the characteristics of the individual system, and conforming to published TCN requirements, including the open, common application protocol interface (API). TCN adaptive components have been developed and operated for a variety of sensors as well as communications capabilities ranging from low-bandwidth systems to complex software defined radios.

- Foundation components – those elements of the TCN software that are common among all segments in the objective network and required to meet mission objectives.
- Mission applications – components that integrate desired functionality to tactically employ the network resources. Examples of mission applications are visualization capability, resource management tools, planning tools, battle management, or threat evaluation and weapon assignment.

A notional individual node in a TCN implementation is shown in Figure 7.

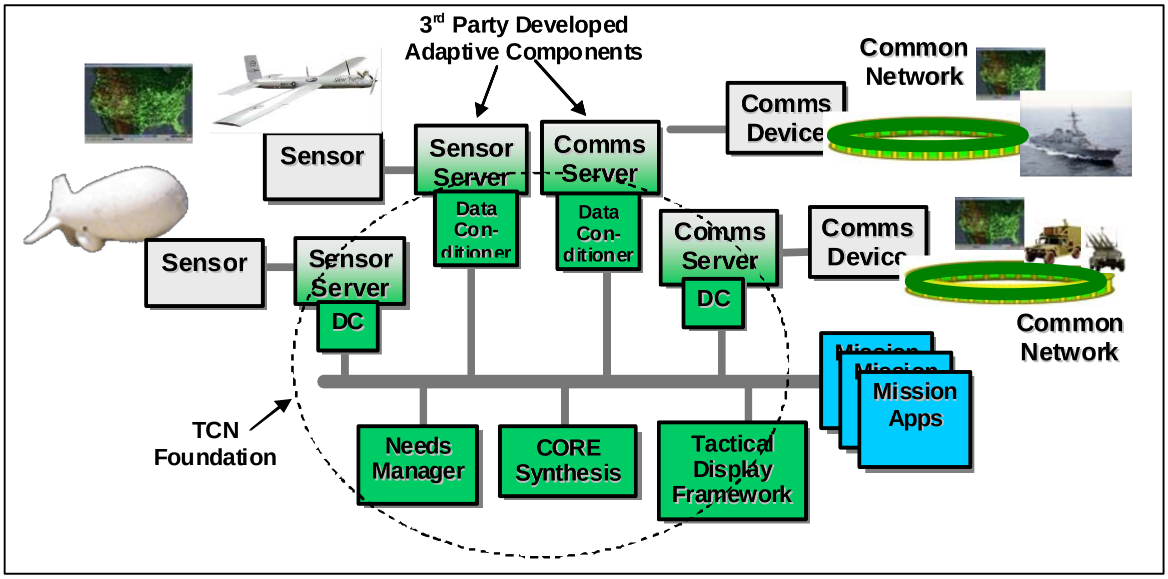


Figure 7 - TCN Segment

Element resources remain entirely in the domain of the host system, and are integrated through adaptive components to allow complete functional independence and minimal, if any, impact to host systems.

Adaptive Components are defined by development requirements and interface documentation that is part of the TCN product package. The adaptive components are:

Sensor Element Server

- Performs processing optimized for the specific sensor
- Depending on what the sensor provides, it may manage correlation, association, and tracking for the local sensor
- Provides the data conditioner with associated measurements (AMRs) or new tracks
- Developed by the element owner to leverage domain knowledge and maintain technical control

Communications Element Server

- Formats messages for communication medium
- Performs communication device interface and management
- May perform functions associated with encryption devices

TCN foundation components are the functional software modules which are common among all segments in a TCN-enabled architecture. The principal foundation components are:

Data Conditioners

- Provide a standard interface for exchange of sensor information with element servers
- Perform needs/accuracy-based data distribution
- Accumulate and distribute associated measurement reports to other components
- Perform sensor data alignment functions
- Provide divergence cues to the element server for divergence processing

Current Observation Related Estimate (CORE) Synthesis. CORE is the TCN message format for track information exchange within the TCN foundation.

- Fuses CORE data with the network track state into a Fusion Algorithm Combined Track (FACT) for use by element servers, data conditioners and mission applications. FACT is the format for a composite track representation coming out of the TCN foundation
- Manages local distribution of TCN data

Report Need Manager

- Maintains Report Need requests from local data users
- Manages local and network distribution of Reporting Need requests

Mission Applications are optional software components which are integrated into the TCN architecture to perform mission-related functions. Examples of a mission application would be a visualization capability to display the TCN composite track picture and interface any desired operator controls, or a C2 capability such as threat evaluation or sensor resource management.

5 TCN UNIQUE DESIGN CHARACTERISTICS

TCN provides an architecture for an extensible, evolvable, multi-level access, collaborative sensor track process that creates a distributed track state database from multiple radars or other multi-dimensional sensor position and rate measurements. The sensors and track data sources may be co-located at a single site or geographically dispersed. These measurements are processed and resulting information is exchanged over one or more distribution networks. There are several unique features that distinguish TCN as an advanced sensor network. These can be mapped into the design goals for a tactical sensor network as described in Section 3.

Component Based Open Network Architecture (Network participants must maintain physical and functional independence). The de-coupled component structure is designed so host systems of existing elements need no modification for new elements to use and contribute to network data. For new systems to be capable of operation with existing sensors in a TCN-enabled network, the new system is integrated through element servers designed against common requirements specifically to support the host system. Interaction is defined via a generic application protocol interface, ensuring adherence to data encoding standards. By making third-party development of the adaptive components, the TCN approach additionally garners the benefit of allowing system "owners" to integrate into a TCN capability without disclosing critical or proprietary design information.

Processing at the Source (Network extensibility must be minimally impacted by the number of network participants). A geodetic registration solution is developed at each sensor element data source by the associated TCN data conditioner. Data is distributed in a common (Earth-centered) coordinate frame, and sensor specific metrics are provided in a sensor independent form. Operationally, since distributed track data is registered and processed at the source, participating segments can join or leave a TCN-enabled network without disruption to the overall network operation.

Intelligent Data Distribution (Network extensibility must be minimally impacted by the number of network participants). The TCN architecture provides the capability for data exchange to create a track picture in a common frame of reference for all data sources and data users in a set of data distribution networks. Each data user states the level of kinematic rate accuracy needed for each track according to track identity, type, category, status, geographic location or other doctrine. The minimum amount of data required to support the stated accuracy need is distributed. By managing the amount of data distributed per track to meet stated tactical requirements, use of available communications bandwidth in the network is optimized. The addition of new sources and users does not affect the computational complexity for the existing network components for a given number of supported tracks – bandwidth requirements change with track population rather than the number of participating nodes observing the tracks or using the data.

Multiple forms of information exchange (Information exchanged must be responsive to the needs of network users)   TCN supports the concurrent exchange of various forms of track update information. Based on the capability of the host sensor to provide track updates in any of several forms, TCN will support the exchange of associated measurement reports, variable length "tracklets" or accumulated individual measurements on a single track, or full track states with associated covariance. TCN exchanges track update information within an architecture or network using a message format that can accommodate various levels of fidelity, including single updates or accumulated measurement data.

Concurrent Multi-Domain Operation (The sensor network must support multiple levels of exchange security while maintaining needed concurrency). The open, component based architecture of TCN and the ability to compose TCN segments operating on multiple communications networks allows network designers and managers to segment mission-oriented community of interest networks (COINs) which contribute and use track data from a common network track database maintained collectively by the network. Information exchange between COINs or network segments can be managed or filtered based on any attribute associated with individual tracks, which could include classification, identification, geographic position, or predicted impact point, as a few examples.

Communications Neutrality (Seamlessly include all communications systems acting in concert). The TCN design explicitly accounts for the wide variety of existing communications systems and to accommodate new systems that may be available in the future. TCN has been demonstrated with many communications devices spanning a wide range of sophistication and bandwidth capacity, from the Cooperative Engagement Capability (CEC) Data Distribution System (DDS) to VRC-99 and other low-bandwidth radios. This ensures that the performance of the network is determined by the communications capability and is not constrained by the TCN framework.

The algorithms used in the TCN foundation enable networks to meet otherwise unattainable specifications for network size and track capacity, accuracy, and concurrency. TCN also provides a greater flexibility in the selection of appropriate data distribution equipment by driving bandwidth requirements down to the realm of commercial radios. Where track accuracy improvement is constrained to single sensor performance, filtering methods such as covariance intersection can be applied.

The novel approaches used to develop TCN as an advanced sensor network enable the major benefits of extensibility, flexibility of network design and scalability.

6 BENEFIT OF IMPLEMENTING AN ADVANCED SENSOR NETWORK

Composite tracking

As with the Cooperative Engagement Capability and other composite tracking technologies, TCN uses a collaborative sensor construct to aggregate individual detections and updates to create and maintain continuous, accurate tracks throughout the network. Because the source of track information may be coming from multiple view angles and be based on different frequencies or even phenomenology, the best information available on a track within the network is at least as high in quality as the best sensor viewing the object, and substantially better in cases where multiples sensors can view the track.

During the history of employment of tactical data networks, challenges of establishing a common operational picture from multiple sources, diagnoses and solutions for the root causes of tracking challenges such as dual tracks, identification conflicts, track continuity and picture commonality were documented studied. The quest for a single integrated picture has become a target of substantial investment by the Joint acquisition decision-makers and spawned a large technical community. This arena of study and development encompasses Joint Interoperability, composite tracking techniques and technologies, and identification technologies among other areas.

Collaborative sensor networks such as the Cooperative Engagement Capability were a leap ahead in the ability to establish composite tracks from multiple sensors and provide real-time fire control quality data on demand. Additionally, efforts in the Joint community have produced standards for interoperability and technologies to allow existing and emerging tactical systems to adapt into a global community of contributors and consumers of a single integrated air picture. These advances came at some cost, both in dollars and technical design flexibility of system developers.[7]

Implementation of an Advanced Sensor Network necessarily must not allow regression from the standards set and the capabilities achieved by existing programs and technologies. However, one of the design goals of TCN is flexibility of interface and concept of operation for both legacy and developing systems, resulting in considerable lower implementation timelines and costs.

Extensibility and flexibility in network composition as described below allow the conformity of systems using this approach to established standards of interoperability. The capabilities of individual contributing tracking sources is preserved, as source-specific or even adaptive correlation techniques and technologies are encompassed in the open architecture design. To achieve a common tactical picture based on composite tracks, a common correlation engine is employed within the network infrastructure to locally establish, maintain and manage common network tracks at each participating node. These composite tracks are composed of multiple forms of data exchange, from sensor measurement data up to full track states with covariance, depending on what the contributing sensor provides. Within the network foundation infrastructure, variations on a common form of track update allows interoperability among participating units providing varying track formats.

TCN includes a foundational component that combines local and remote track updates as they are received to produce a common representation of tracks. This function is performed identically at each node, varying with inputs from the local sensor and resynchronizing the track representation across the network as required to maintain the stated accuracy goal. To address range/ azimuth correlation among multiple contributors, TCN uses well-established collaborative tracking techniques appropriate to the classification of the track. Performance has been assessed positively relative to SIAP issues of track commonality and continuity, including under stressing conditions such as with converging or diverging tracks, sensor gaps, and tracking closely-spaced objects.

Extensibility

The principle benefit garnered by implementing an advanced sensor network is the extensibility of the architecture. This entails not only the ability to add new elements, but to easily incorporate legacy systems including communications, sensors, and command and control systems. This also means the ability to build on extant capability via open interfaces with new functions. This is accomplished with several facets of the overall design approach.

Maintaining physical and functional independence of components through a component-based open architecture ensures legacy systems can be incorporated by use of adaptive interfaces. Participants can operate in the same data environment regardless of native communications or processing capability. Units that are “disadvantaged” due to lack of connectivity to more capable networks (lack of tactical data link capability, for example) can access the same tactical data as other participants in the network to the extent their host communications systems allow.

This was demonstrated with TCN in the US Pacific Fleet when non TADL-equipped ships of an amphibious ready group were provided the capability to maintain an accurate representation of the battlespace track picture over both line-of-sight and beyond line-of-sight using standard naval communications networks. The near real-time picture of the battlespace provided operational commanders the ability to make more timely and effective decisions than were previously possible. Disadvantaged units gained increased situational awareness by sharing sensor information and by receiving the local picture from remote units. Connectivity with other tactical data link networks including units with sensor netting capability was also possible with this network design.[8]

Likewise, the requirement in design for communications neutrality ensures that systems can be integrated into the network using the communications systems that are available rather than imposing requirements or specific communications solutions.

Sensor network architecture that requires a specific form of information exchange is also an impediment to extensibility. An advanced sensor network supports multiple forms of information exchange, including sensor measurement as well data track data and fully characterized track state data, by distributing registration and processing to the source and normalizing information format within a common, open and extensible message set.

Another important factor contributing to extensibility of advanced sensor networks is the allowance for (or reliance on) third-party development of adaptive components. This mitigates natural resistance of system developers to allow invasive integration requirements to impact proprietary system designs. Custom design of adaptive components such as sensor servers and communications servers allows robust integration of systems and capabilities without driving changes to those systems or incurring technical risk. Additionally, by avoiding a design approach that requires modification of host systems, time-consuming and expensive recertification of operational systems can be minimized.

Network Design Flexibility

Another notable feature of an advanced sensor network is the design flexibility to meet operational mission requirements. Multiple community of interest networks (CoINs) can be composed as contiguous parts of a larger global network within which a common perception of reality is maintained. The definition of a community of interest network is a collection of platforms connected via a network construct to meet a shared objective. A mission application would be implemented at the node to allow intelligent distribution of common interest track data between the two networks.

Within and across multiple CoINs, a common operational picture is developed and maintained. The COP is the critical enabler of Joint integrated layered self defense. It enables Joint command authorities to take full advantage of available information gathered from all sensor resources and improves multiple mission integration and execution. It enables improved threat detection and track, weapon inventory management, fratricide avoidance, mission planning and numerous other vital command and control functions.

Yet implementing this concept produces another level of technical and operational challenges. Although there is clear benefit to maintaining a common basis for tactical information and management, diverse mission specific requirements demand diverse instantiations of the picture. Services and communities within the services all fight differently, yet need to maintain interoperability with each other. Joint operations require not just interconnectivity, but a means by which multiple missions are each supported according to specific needs.

This challenge of Joint operations extends not only horizontally across operators with specific missions and methods, but vertically across multiple echelons of command. A strategic-level commander needs an entirely different type of information and presentation than an operator controlling a weapon for a self-defense engagement, yet a reliable system of command and control demands that both pictures be derived from a common understanding of reality. A network software infrastructure that supports a complex network topology allows participants with diverse operational network requirements to effectively operate within independent CoINs yet remain logically connected to other forces. Such an architecture is notionally depicted in Figure 8.

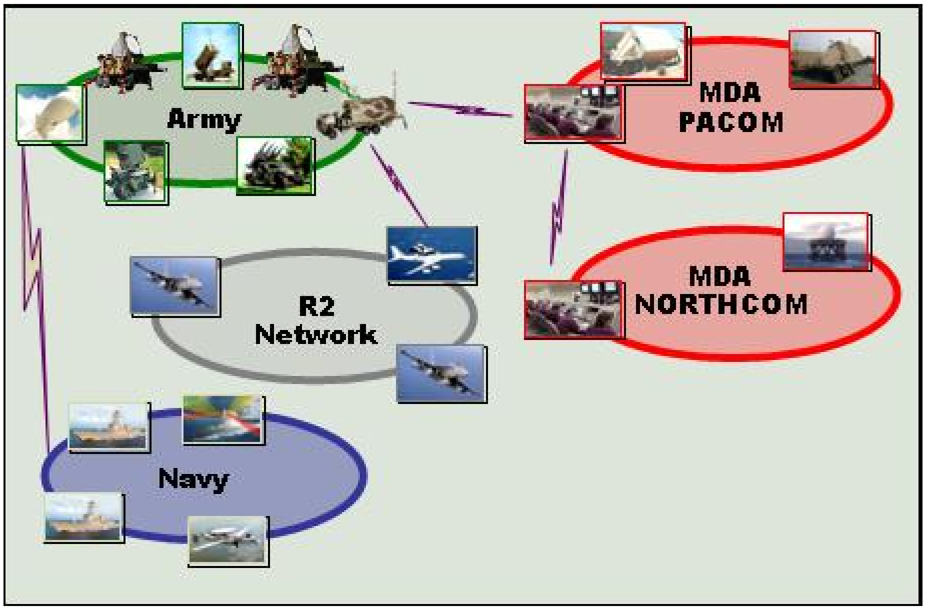


Figure 8 Notional Network Architecture

The example implementation described shows four TCN-enabled community of interest networks depicting common tactical pictures tailored to a specific mission. Also depicted is a bridge to a Link 16 network, which is accomplished by “telling-in” link data using a multi-source integration capability. The example depicts a notional deployment in a littoral region with an elevated sensor system, ground-based air defenses, a Navy carrier battle task force, and connectivity to regional combatant command authorities for missile defense. With the ability to match network topology to specific concepts of operations, multiple inter-related mission-specific networks can share the same basis for a common operational picture. Tactical data can be shared as dictated by doctrine and the concept of operations to allow a contiguous tactical network across missions such as air and missile defense, ground and maritime operations, military and civilian air control and others.

By allowing composition of interoperable segmented networks, operators and operational commanders are able to appropriate levels of situational awareness and support mission requirements without driving unnecessary or onerous information exchanges.

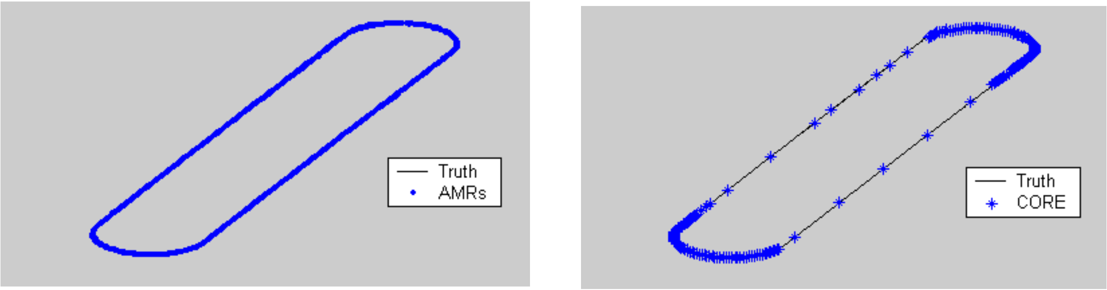
Scalability and Efficiency

Managing information exchange to optimize consumption of available computing resources and communications bandwidth is a design driver for an advanced sensor network. With ever-increasing number of contributing sources of tactical data, and with rising volume of data being exchanged, increases in communications bandwidth does not always keep pace with operational demands. Using available bandwidth as efficiently as possible involves minimizing the exchange of irrelevant and redundant data, while fully supporting mission requirements. Scalability demands that bandwidth usage should be driven by the track environment and mission requirements, and not by the number of network participants. By moving processing out to the source, establishing common objectives for information quality within community of interest networks, and by segmenting CoINs to support levels of data exchange required by specific missions, an advanced sensor network allow targeted, goal-oriented use of available bandwidth.

First, processing at the source is an approach to network design that allows for track and sensor metric information exchange in a sensor-independent format, and removes the need to exchange host reference information. This approach also allows nodes to enter and leave the network without disruption. TCN uses an Earth-centered, Earth-fixed coordinate frame to pre-register data at the source, eliminating the need to exchange source-specific information. Providing sensor metrics in a sensor-independent form enables addition of new elements without impact to existing components.

Secondly, using a goals-oriented paradigm for data exchange minimizes the transmission of irrelevant and redundant information. With in a CoIN, accuracy (or other measurable attribute) levels are established, and participants communicate the required accuracy level per track. The network as a whole reacts to meet the stated requirement with the minimum information exchange required to achieve the required accuracy. This requirement can be specified for individual tracks by operator action or by doctrinal logic (track attribute, geographic region, track behavior, etc.).

An example of the different exchange approaches is shown in Figure 9, where the track updates are shown for an aircraft flying a race-track pattern. On the right plot, sensor measurement data is exchanged each time there is a track update at any node on the network, demanding equally high bandwidth at in all portions of the track trajectory. The plot on the left uses the goal oriented approach, and varies the frequency of network track update as the aircraft maneuvers. A straight line trajectory requires less frequent network exchange to maintain a network track within stated error constraints, while the turn sections of the pattern show more frequent exchange to maintain the accuracy goal. Extension of this approach to a complete composite track picture drastically reduces the amount of bandwidth required.



Full exchange of track update data

Goal-oriented exchange of track update data

Figure 9 Track update frequency comparison

Figure 10 shows a capture of a data plot comparing a full sensor measurement data exchange with a goal-oriented exchange that manages accuracy within a specified threshold. The upper left window shows the accuracy values of the network track relative to the locally held track. The saw-tooth pattern occurs as the network track is extrapolated, and then an update is triggered by the accuracy goal threshold. The lower panel compares the bandwidth use between the goal-oriented exchange (green line) and the bandwidth use if exchanging all sensor track updates (red line). This demonstrates scalability by showing the constant level of information exchange as driven by the constant track population versus the increasing level of bandwidth consumed by exchanging increasing quantities of information by multiple network participants exchanging updates on the same object.

Figure 10 Comparison of Goals-Oriented Track Data Exchange vs Full AMR Exchange

Scalability is also served by maintaining the physical and functional independence of participating components. The ability to be “radio-agnostic” means that access to the benefits of the network picture are limited only by host systems’ available communication capability rather than a network-required standard communications interface.

These three major attributes – extensibility, design flexibility, and efficiency/scalability – are what characterize an advanced sensor network. These capabilities designed into a tactical framework allow integration of new data sources without compromising interoperability with existing legacy forces. Most new sources bring the ability to sense and report large quantities of data, either through persistent coverage or higher fidelity track data. Elevated sensors, powerful forward-deployed sensors and unmanned platforms are just examples of currently available or planned sources of tactical data that can be integrated into sensor networks. Implementation of advanced sensor networks forms the foundation of high fidelity tactical knowledge, supporting precision engagements as well as situational awareness.

7 IMPLICATIONS

The ability to connect multiple echelons and multiple mission specific CoINs enables creation of a Joint architecture that serves all levels of command and all missions with at single integrated picture. The joint architecture shown in Figure 11 shows the sensor netting capability as the sensor information foundation of a net-enabled common operational picture. In turn, net-enabled capability ensures extensibility of the tactical benefits of the advanced sensor netting architecture into non- and near-real time domains for broader command and control and battle management functions. A TCN-enabled tactical networking and sensor netting capability is currently under evaluation by multiple Joint communities to be integrated into a broader, net-enabled, service-oriented and data-centric architecture. This objective architecture would make true net-enabled interoperability a reality.

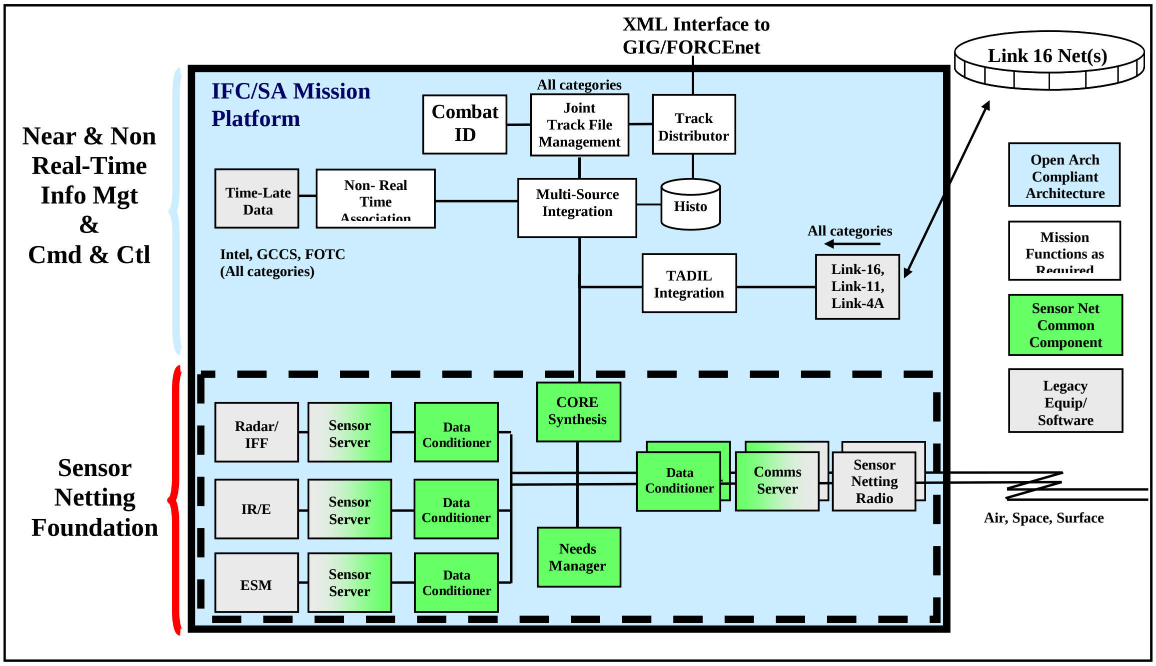


Figure 11 Joint Integrated Architecture with TCN

Using TCN as the foundational Single Integrated Air Picture technology enables the architecture to work with existing air picture networks while sharing identification and associated attributes across the composite network. With this foundation, higher-order C2 concepts can be realized, including network-based precision cueing and sensor resource management, forming the basis for a Joint integrated fire control capability.

In December 2006, Raytheon's Integrated Defense Systems sector demonstrated an environment called Joint Fires or JFires which demonstrated a hardware-in-the-loop system constructed on a TCN foundation. The demonstration created a multi-theater, multi-service Single Integrated Air Picture (SIAP) capability to conduct integrated fire-control engagements by the Army's Surface Launched Advanced Medium Range Air-to-Air Missile, and the Navy's Standard Missiles-2 and -3 and Evolved SeaSparrow Missile against simulated cruise- and ballistic-missile threats. The demonstration was based on government-developed scenarios taking place in areas of responsibility for the Pacific and Northern commands and involved more than 50 sensor nodes and monitored thousands of weapon tracks, both friendly and hostile.[9]

As advanced sensor networks such as the JFires environment are designed and demonstrated, key questions arise concerning concepts of operations. Once the ability to visualize and analyze operational scenarios with advanced sensor networks in place is presented to members of the Joint community, a universal reaction has been to conceive questions about concepts of operations that would have previously been rhetorical. Issues of force lay-down, network design, resource management, and data exchange policy are just a few of the areas of operational consideration that arise once the ability to effectively exchange tactical data among all mission areas and levels of command is realized.

8 SUMMARY

Continuing the evolution of tactical networks to the capability provided by an advanced sensor network yields tremendous operational benefits. As much of a quantum leap of capability was represented by both tactical data links decades ago, and by collaborative sensor networks that tightly link air defense sensors into virtual distributed combat systems; advanced sensor networks provide the next leap of capability to the battlespace. The advanced sensor network allows extension of the most potent informational capabilities to a large number and variety of participants through open generic interfaces, efficient data exchange constructs, and the flexibility to compose network architectures to support all missions based on a common perception of reality. With key tenets of extensibility, flexibility and scalability, an advanced sensor network construct provides not only increased capability to a broader swath of participants, but a new environment for command and control innovation.

The Department of Defense has invested in the acquisition of TCN as an enabling technology. There are immediate benefits that can be realized in the areas of Joint interoperability, achievement of a single integrated air picture, and extension of a common tactical situational awareness picture across the full spectrum of missions and command echelons. An advanced sensor network with a myriad of potential benefits and new capabilities is possible by levering the DoD investment in TCN.

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