Network Models Within ACES

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The APL Coordinated Engagement Simulation (ACES) is being developed to support distributed weapons coordination (DWC) analysis. One key factor affecting the DWC decision process is the quality of the information on which the decisions are based. In ACES, networks facilitate the exchange of situation awareness information to generate a simulated tactical picture and to support the exchange of engagement coordination information. The networks modeled within ACES can be configured to represent the update rates, protocols, and information exchange supported by the current capability of operational systems. However, rather than attempting to emulate the specific behavior of the operational networks, ACES focuses on modeling those network characteristics that create certain behaviors believed to impact engagement coordination such as dual designations and message latency. This article describes the features of the networks modeled within ACES.

INTRODUCTION

Engagement operations depend on a clear tactical picture to support the efficient use of ordnance among firing units and to effectively defeat a raid. Unfortunately, the tactical picture seen in operations today is often ambiguous. Errors in the detection and tracking phase can ripple through the correlation process and affect the clarity of the tactical picture. Correlation is the process whereby contacts or tracks from multiple sensors are associated to a single object; incorrect correlation can result in multiple tracks being reported for the same object, or multiple objects being reported with the same track number. Past engagement coordination analyses have assumed that a single integrated air picture exists, with one and only one track per object. This presents an unrealistic simulated environment in which the impact of an imperfect track picture on engagement operations cannot be determined. The APL Coordinated Engagement Simulation (ACES), which is being developed to support the analysis of weapons coordination alternatives, provides a more realistic simulation environment that is capable of reflecting the ambiguities often present in real-world tactical pictures. An overview of ACES is provided in the article by Burke and Henly elsewhere in this issue.

The units represented in ACES exchange both situation awareness information and engagement coordination information in accordance with the capabilities and constraints of modeled networks. Information exchanged via these networks facilitates the generation of a tactical picture and enables simulation of engagement coordination concepts that require data to be exchanged among potential firing units. Currently, ACES includes representations of two types of networks: (1) the Time Division Multiple Access (TDMA) Data Link (TDL), which captures many of the key features, characteristics, and protocols of Link 16, and (2) the Sensor Based Network (SBN), which simulates high update rate composite track formation, similar to the Cooperative Engagement Capability (CEC).

ACES has been designed not to provide high-fidelity network modeling, but to demonstrate the impact that network performance can have on the situation awareness at each platform and on engagement operations effectiveness. ACES focuses on modeling the communications characteristics that create certain behaviors that impact engagement coordination. Therefore, the data sent across the networks in ACES do not correspond exactly to the message definitions given in the message standard documentation for existing data links. In some cases, not all data identified within a defined message are sent because certain data fields within that message are not used by the model. However, the sizes of the network messages as defined in the message standards are always taken into account when determining how much information can be transmitted across the networks, given the specified bandwidth constraints.

At this stage in ACES development, the TDL is more mature than the SBN. This article therefore provides more detail about the structure and operation of the TDL, while the SBN is discussed at a higher level. Development of the SBN is an objective for FY2002.

TDMA DATA LINK

Architecture

The TDL is a generic representation of Link 16; its characteristics and protocols are based on information found in Link 16 documentation such as the Link 16 operational specification[1] and the Tactical Digital Information Link (TADIL) J message standard.[2] Unit location and status information, as well as engagement coordination information, is exchanged over this network. Processed track reports are also exchanged over the TDL, producing a remote track file (RTF) at each unit. The timing of this information exchange is determined by the TDL network design.

Link 16 architecture features are used in the ACES representation of the TDL network. Link 16 network design is based on a 12-s frame consisting of 1536 time slots, each being 7.8125 ms in length. During development of a Link 16 network, time slots are first allocated to virtual communication circuits called net participation groups (NPGs). NPGs are differentiated by the functions they support. For example, the Surveillance NPG is used for reporting situation awareness and the Engagement Coordination NPG is used to support the exchange of engagement information. Dividing the network into functional groups in this way allows units to participate on only the NPGs that support the functions they perform.

The amount of network capacity given to an NPG is determined by considering priorities, including the number of participants on the NPG, expected volume of data to be reported, update rate of the information to be reported, and relay requirements. Relay is required if messages have to be transmitted over the horizon. The addition of a one-hop relay doubles the number of time slots required to support an NPG. Once network capacity is assigned to the NPGs, NPG capacity is assigned to participating platforms. The number of time slots allocated to each NPG and each unit determines how often a transmit opportunity occurs for that NPG and how much information gets transferred during that opportunity.

As in Link 16, the TDL network architecture contains NPGs, and the timing of the information exchange is determined by time slot allocations. For the TDL modeled in ACES, the timing of the information exchange on each NPG is divided into TDL time steps, that is, the interval in which each unit participating on the NPG gets to transmit at least once. The following paragraphs describe how the TDL time step for each NPG is determined.

Figure 1 illustrates the allocation of time slots to NPGs and units as well as the determination of each NPG's time step. For simplicity, when modeling the ACES TDL network, these slots are assumed to be spaced evenly throughout the 12-s frame; in an actual Link 16 network, however, this may not be the case. Using this assumption makes it simpler to calculate how often a time slot assigned to a specific NPG occurs.

To determine an NPG time slot interval,

$$\frac{\text{Total \# time slots in the network}}{\text{Total \# time slots allocated to the NPG (without relay)}} = n\,. \tag{1}$$

Therefore, every nth time slot will be allocated to the NPG (the result of this division is rounded off for estimation purposes). Since each time slot is a time unit of 7.8125 ms, a transmit opportunity for this NPG will occur every (n) (7.8125 ms).

Note that in Eq. 1 the total number of time slots in the network is divided by the number of time slots allocated to the NPG, *without* relay. This is because n represents the interval between time slots that are allocated to units for the transmission of original data. The relay time slots are allocated to a designated relay platform, which rebroadcasts those data to units located beyond the line of sight.

The length of the time step may be calculated by multiplying the number of seconds between NPG transmission opportunities by the number of transmission

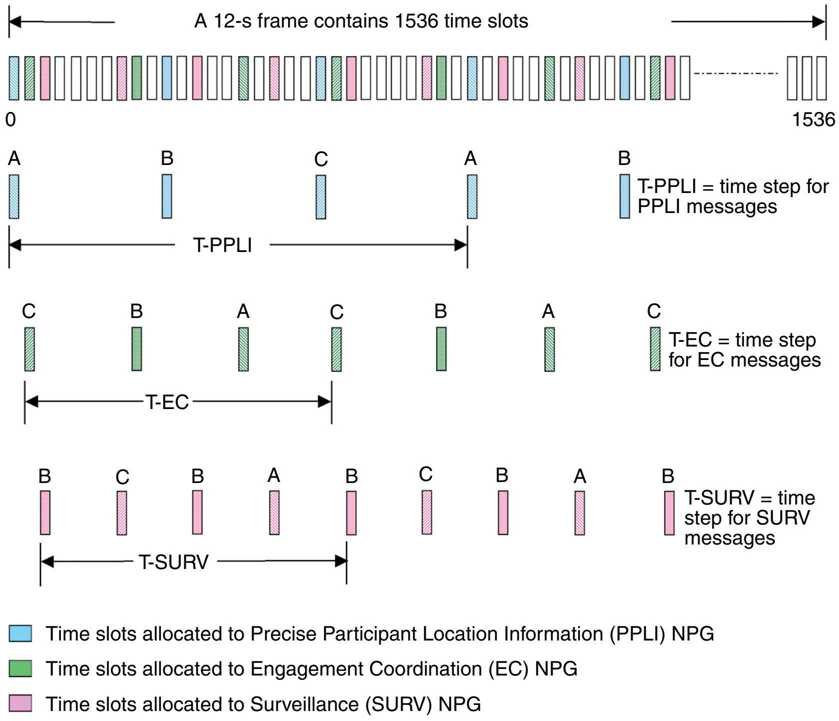


Figure 1. Time step determination for a TDL network.

opportunities needed to ensure that each unit participating on the NPG has transmitted at least once. At the end of this interval, all of the information for that NPG is sent across the network; this method allows ACES to determine the timing of TDL information exchange without getting down to the time slot level.

The information transmitted over the TDL network is separated into groups according to NPGs. For example, track data are transmitted over the Surveillance NPG, while engagement coordination data are transmitted over the Engagement Coordination NPG. Rules dictating when messages should be sent and which unit should send them are based on the rules identified in Ref. 2.

A TDL network may allocate time slot capacity to NPGs that are not of interest to users of the model. Currently, only the Surveillance, Engagement Coordination, and Precise Participant Location Information (PPLI) NPGs are modeled in ACES. Even though the information exchange over certain NPGs may not be simulated, the timing calculations in the model take into account the time slots allocated to those NPGs. The time slots not colored in Fig. 1 represent those that are allocated to NPGs not specifically modeled in ACES and those that are relay slots.

In a TDL network, as in a Link 16 network, there can be different groups of units participating on each NPG (not all units participate on all NPGs), and the unit transmission sequence for each NPG can be different. The example given in Fig. 1 assumes that three units (denoted A, B and C) are participating on each NPG shown. At the end of the time step for each NPG, the information from all three units is sent across the network. On the Surveillance NPG, unit B is given twice as many time slots as either unit A or unit C. Therefore, twice as much information will be sent from unit B at the end of the Surveillance time step.

The track data exchanged over the TDL produces an RTF at each unit; this RTF is one of the sources for the tactical picture. A local-to-remote track correlation process is executed on each unit and results in a series of logical decisions that determine what track data each unit transmits.

Determination of Reporting Responsibility

TDL tracks are correlated to the locally held tracks in an effort to prevent dual tracks from being propagated on the data links. The correlation process itself involves a statistical comparison of values calculated from the state vectors associated with a track and their associated covariance matrices. Each local track may correlate with only one remote track. This correlation process is discussed in greater detail by Bates et al., this issue. Once a local track is correlated to a TDL track, the track quality (TQ) is used to determine which unit has reporting responsibility (R2) for the track.

Each track reported over the TDL is sent with TQ, which is a measure of the reliability of the track data. This value is also calculated on locally held tracks to perform TQ comparisons to determine R2. TQ is an integer between zero and 15. Zero represents a non–real time value (which could be a value sent by a unit that is not a data link participant, relayed by a non–real time system, or associated with track data not derived from an integrated sensor).

TQ is computed by combining the estimated position and velocity errors to form the value

$$B = \sum_{i=x,y,z} \left\lfloor \sigma_{p_i}^2 + \sigma_{v_i}^2 \Delta T^2 \right\rfloor , \qquad (2)$$

where σ_p is the position error in feet, σ_v is the velocity error in feet per second, and ΔT is the time step (defined as 6 s in Ref. 2). These B values are compared with tabulated values in Ref. 2 to determine TQ. In ACES, a function was created to represent the table of TQ values,

$$TQ = \text{Floor}[22.19 - 1.954 * \text{Log}_{10}B], \qquad (3)$$

where “Floor” is a function that rounds the argument closer to zero. This function could potentially return values greater than 15. Because 15 is the highest possible TQ value, the simulation assigns a value of 15 to any computed value greater than 15.

This TQ value is used to determine which unit has R2 for the track. Only the unit that holds R2 for a given track sends data for that track over the link; in theory, this ensures that only one unit is reporting on a track and the best track information is sent across the link. If a unit determines it holds a local track that is not being reported on the link, it assumes R2 for that track and begins reporting it. If a unit determines it has a local track that correlates with a given remote track, it determines who should have R2 based on a comparison of the TQs. For air tracks, a unit must have a TQ at least 2 greater than the value being reported to assume R2. For space tracks (e.g., ballistic missile tracks), the difference is reduced to at least 1 or greater.

Each track reported on the TDL has a unique remote track number (RTN), given to it by the unit that originated the track report. When a unit correlates its local track to a remote track, it assigns that track’s RTN to its local track. When a unit assumes R2 for a track, it keeps the same RTN originally reported to ensure continuity in the track reporting. Figure 2 illustrates the decision chain that results from the track correlation process.

If tracks have the same TQ, R2 goes to the unit with the higher unit number. In accordance with Link 16 rules, a unit may also assume R2 for a track if the unit holds local data on the track but has not received a remote report on that track for a specified time period.

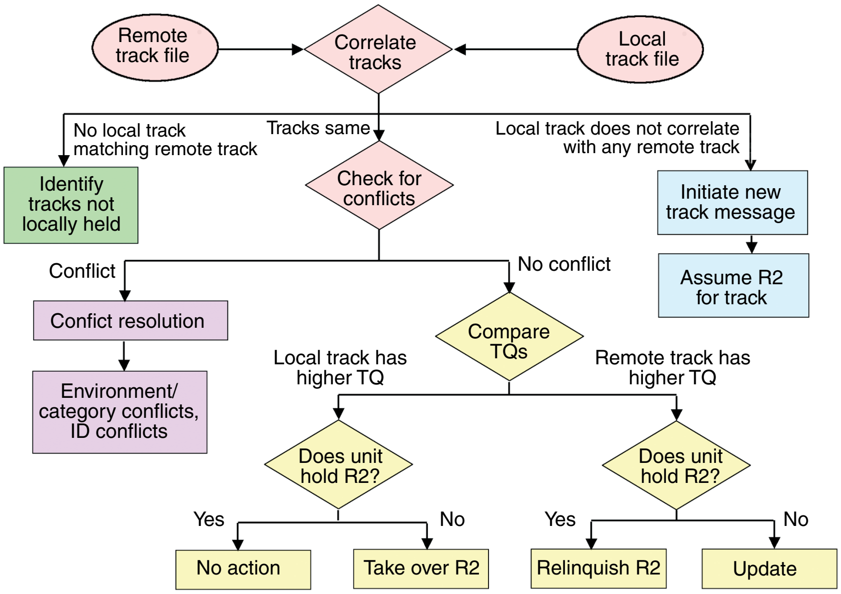


Figure 2. Correlation-related decision chain for the TDL.

The correlation process can also help detect and resolve track identification and category conflicts that may cause confusion in the tactical picture. ACES does not currently resolve these conflicts because categorization and identification functions have not yet been implemented; all tracks are assumed to be hostile space tracks. However, future versions of the model will have the capability to resolve such conflicts.

SENSOR BASED NETWORK

While the TDL is designed to simulate a broadcast data link network, the SBN is designed to simulate a point-to-point sensor netting network. The SBN supports the exchange of sensor data from multiple sources to form composite tracks. SBN architecture, timing, and information exchange are based on the concepts and methods employed by CEC.

The SBN represents a network, such as CEC, in which high data rates are achieved by employing a pairwise multiple access scheme. This type of network relies on directional antennas, which allow one unit in the net to transmit data to a second unit, while a third unit in the net is simultaneously transmitting data to a fourth unit, as illustrated in Fig. 3. In the figure, unit A1 sends data to unit A2, while unit A4 sends data to unit A3. This process continues until all of the units in the net have transmitted data to every other unit within the net located within the network’s effective range.

In some instances, units may be located beyond line of sight; in these cases, a relay is required for the data to reach their destination (as in the case with TDL). In Fig. 3, units A1 and A3 are too far away from each other for direct data exchange to occur. Therefore, units A2 and A4 act as relays to exchange information between units A1 and A3.

Each set of pairwise transmissions takes place within a period of time called a “frame.” This is different from the TDL frame discussed previously. The time step ACES uses to transfer SBN information is defined as the interval in which all units on the SBN net have the opportunity to transmit their data to every other unit on the net (the same rationale as used in TDL). At the end of this interval (denoted T_{SBN} in Fig. 3), all of the SBN information is sent across the network.

Currently, only track states are transmitted across the SBN, but the implementation of this network

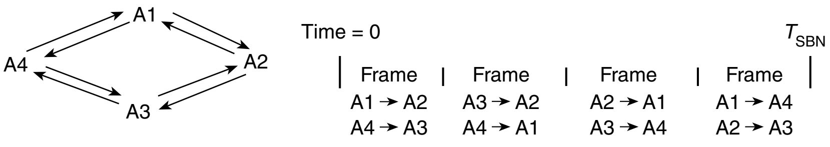


Figure 3. Time step determination for an SBN.

will allow other types of information, such as engagement coordination data, to be sent. ACES does not send measurement data to each platform via the SBN. Instead, platform tracks with errors are transmitted, and then on each platform all the information provided in those track states is fused into a single track. This corresponds to the intent of ACES to model the behavior of the network as it impacts engagement coordination, rather than to emulate specific characteristics of operational systems (e.g., CEC). Each track has its own composite track number (CTN), which is used by all units on the network to denote that track. Every platform on the SBN maintains a composite track file (CTF) using this CTN.

SBN composite track management is illustrated in Fig. 4. When a unit receives data on an existing track from the network, it updates the data for that track being held in the CTF. If the local sensor data do not correlate to any of the composite tracks, those local data are assigned a new CTN and are transmitted across the network to the other units during the next SBN cycle. If the local sensor data do correlate to an existing target in the CTF, the appropriate CTN will be assigned to those local data. If the local sensor data have a CTN assigned, those local data will be sent to other SBN units and added to the existing composite track data for that target.

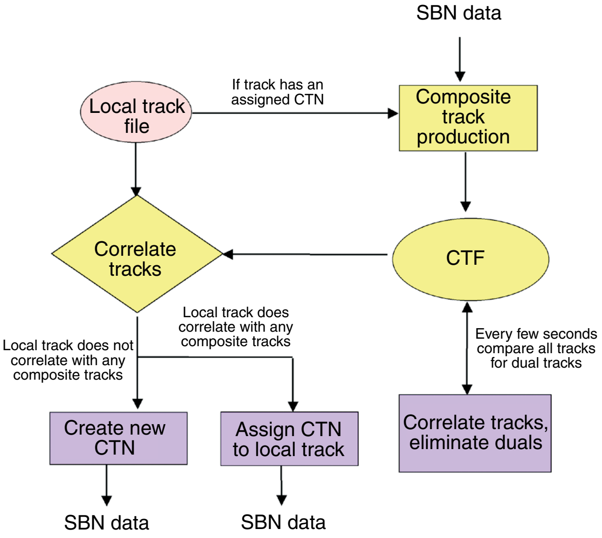


Figure 4. SBN composite track management process.

Each SBN unit will periodically attempt to correlate each track in the CTF to the others to verify that there is only one composite track for each object, eliminating dual tracks. All platforms employ identical algorithms to maintain the same CTF for all SBN participants (unlike TDL, where each platform will employ its own algorithms to meet the R2 processing rules).

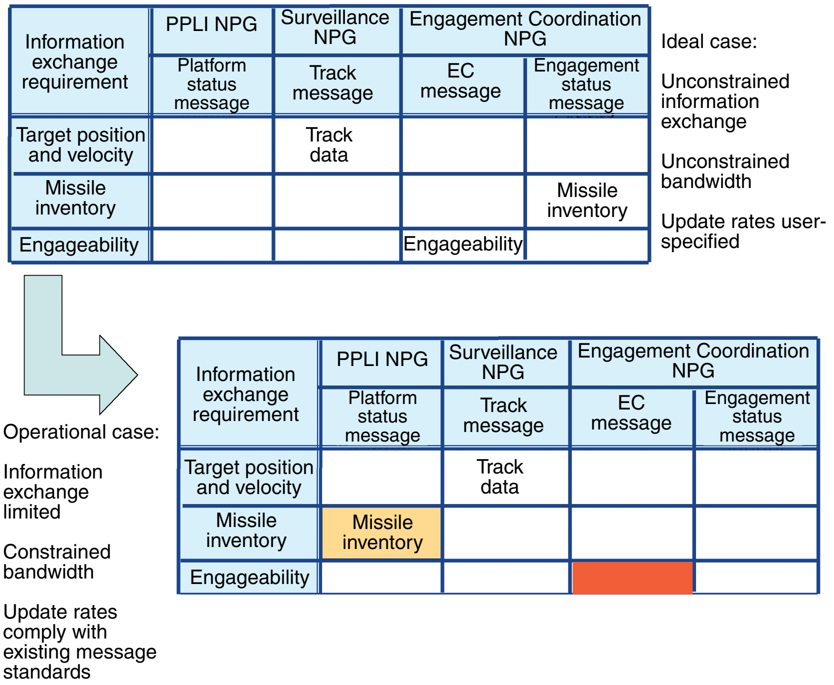
FLEXIBILITY OF NETWORK MODELS

The networks in ACES can be modeled at a variety of different levels. Both the TDL and SBN can be modeled so that all desired information is exchanged with minimal latency, representing the ideal case. These networks can also be modeled to reflect the current operational characteristics of the systems on which they are based. Operational limitations may be imposed, including restricting information exchange to current message standards, constraining bandwidth, and constraining specified update rates. ACES also provides the flexibility to model the networks at levels between ideal and operational. For example, a case may be run in which the bandwidth is constrained but update rates are faster than those specified.

To illustrate the flexibility of network modeling in ACES, consider the example shown in Fig. 5, which focuses on the information being exchanged over the TDL during engagement coordination. The information exchange requirements shown are information items that need to be sent to support a distributed engagement coordination concept (see the article by Shafer et al., this issue).

In the ideal case, no limits are placed on the type of information that can be exchanged over the networks, and this information is transmitted with no constraints on bandwidth or update rate. If the networks were modeled to reflect current operational capability, however, engageability data could not be sent over the TDL, as the current message standard for Link 16 (the system on which the TDL is based) does not support those data. Missile inventory would be sent in the platform status message over the PPLI NPG, as defined in the message standard. Because the units participating on the PPLI NPG would likely be allocated fewer time slots than those participating on the Engagement Coordination NPG, inventory information will be transmitted less frequently. Introduction of bandwidth constraints and adherence to specified update rates may result in higher latencies during information exchange.

The networks in ACES currently run under the assumption that there is perfect connectivity. However, network connectivity may degrade because of factors such as atmospheric propagation effects or jamming.



Information exchange requirement	PPLI NPG	Surveillance NPG	Engagement Coordination NPG	
	Platform status message	Track message	EC message	Engagement status message
Target position and velocity		Track data		
Missile inventory				Missile inventory
Engageability			Engageability	

Ideal case:

Unconstrained information exchange

Unconstrained bandwidth

Update rates user-specified

Information exchange requirement	PPLI NPG	Surveillance NPG	Engagement Coordination NPG	
	Platform status message	Track message	EC message	Engagement status message
Target position and velocity		Track data		
Missile inventory	Missile inventory			
Engageability			🟥	

Operational case:

Information exchange limited

Constrained bandwidth

Update rates comply with existing message standards

Figure 5. Networks within ACES can be modeled to reflect the ideal case, the operational case, or levels in between.

Future versions of the model will provide the capability to run the networks under conditions of degraded connectivity, adding another degree of flexibility and reality to the networks.

FUTURE ANALYSIS USING ACES

The modeling of the networks within ACES allows for the exploration of how certain network characteristics can impact engagement coordination. For specified engagement coordination schemes, aspects of network performance can be examined to determine the most critical requirements for success. These aspects include the type of information that must be exchanged, the timeliness with which that information must be exchanged, and host system implementation of network rules and protocols.

The flexibility of the network modeling can also support future analyses that focus on information exchange. This model can be used to explore whether upgrades or modifications are needed to the current operational use of existing systems. For example, ACES can help identify whether new messages or higher update rates may be needed to support certain engagement coordination concepts. ACES can also be used to explore the differences between applying a data link system vice a sensor netting system to support these concepts.

Analyses such as these are critical to determining network requirements to support engagement operations. By providing a realistic, flexible simulation environment able to support this type of analysis, ACES stands out as a unique capability that will be valuable as engagement concepts are explored in the future.

REFERENCES

[1] Navy Center for Tactical Systems Interoperability, *Link 16 Operational Specification OS-516.2, Change 2* (3 Mar 2000).

[2] Department of Defense Interface Standard, Tactical Digital Information Link (TADIL) J Message Standard, MIL-STD-6016A (Apr 1999).

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