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THE FUTURE OF C2

OPERATION OF MULTIPLE LINK 16 TERMINALS CONNECTED TO A SINGLE HOST

by

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Abstract:

Link 16 is the backbone tactical datalink system for exchange of related surveillance, weapons coordination, and air control information. The standard for Link 16 operation is a single terminal. Until recently no platform employed more than one Link 16 terminal. The United States (US) military standard and North Atlantic Treaty Organization (NATO) standard organizations have not developed documentation for operating multiple terminals from a single command and control (C2) unit. The issues and proposed implementations are covered in this paper. The closest document available to define the remote C2 host with multiple connections was developed by the US for Joint Range Extension (JRE). The JRE document addresses beyond line of sight exchange of Link 16 information. The JRE standard was not adopted by NATO and there are no plans for a comparable document. The lack of a JRE or remote standard in NATO for C2 operation impacts US systems that are trying to achieve interoperability.

Some of the issues that must be resolved include source track numbering for the host and the terminals, routing of data, control of duplicate data to and from multiple terminals, remote initialization, remote keying of the encryption devices, network design, network operation and management, and data forwarding. The paper also provides insight into how large C2 systems plan to interact in a coalition environment.

Link 16 network design and management requires new and creative initiatives when operating with multiple data paths. Secure voice is a problem when data is sent over multiple paths. Can the non-C2 platform receive the secure voice transmission from multiple terminals on different time slot blocks? Network design has many issues to resolve.

Link 16 operation when multiple terminals are connected to a single host impact US, NATO, Allied, and Coalition datalink operations. The issues must be identified and addressed. The paper will start that process.

INTRODUCTION

Link 16 is a tactical datalink system designed for military platforms (aircraft, missile defense, ships, and ground command elements) to exchange related data within the battlespace. Aircraft are classified as either command and control (C2) units (like E-3A and E-2C) or non-C2 units (fighters, tankers, strike/attack, and helicopters). The data exchanges include surveillance, information management, weapons control, aircraft control, fighter-to-fighter, and electronic warfare. Link 16 is used to provide warfighters with the capability to transfer real time tactical information among surveillance and weapon systems in digital format in accordance with established rules and messages. The real time exchange of information provides fire control precision information in support of weapons engagement and delivery as well as increasing situational awareness and warfighter effectiveness. The Department of Defense has designated Link 16 as the standard datalink for tactical communications.

Normal operation of a platform is with a single Link 16 terminal. When these platforms are deployed and in a combat or potential conflict area, there are large numbers of platforms with plenty of potential relay units to distribute the line-of-sight (LOS) restricted data. The use of Link 16 is expanding with the use of the Joint Range Extension Application Protocol (JREAP) that can extend the tactical battlespace throughout the world. JREAP defines a protocol that can be used over satellite or terrestrial systems to exchange Link 16 data messages. A number of new users of Link 16 do not have continuous access to airborne platforms for relay and do not have satellite or other non-LOS links to platforms. The new users have vast land areas and few, high altitude Link 16 capable platforms available. The proposed solution for providing connectivity over the wide areas is placing Link 16 terminals at strategic locations throughout the operational areas and connecting all of the terminals to a single Command and Control (C2) capable system. The primary use of this connectivity is between large ground C2 elements and airborne fighters (non-C2). Several existing ground C2 systems are implementing Link 16 with multiple terminal configurations. These C2 system implementations will have similar capabilities to the systems defined below.

LOCATION AND PHYSICAL SECURITY

A Link 16 terminal is normally part of a platform configuration. The terminal is in the airplane, ship, or weapons control area. The physical security is related to the security of the platform. For multiple terminal operations, the Link 16 terminal may be collocated with sensors like remote deployed radars or in strategic locations near the top of a mountain. The location must meet the physical security requirements for a Link 16 terminal that possesses cryptographic equipment and keying material including protection and monitoring. Having to man locations at the top of a mountain is impractical. Electrical power is also an issue. Ensuring power is available is a critical component of the location. Power is required for the Link 16 terminal and the associated equipment connecting the terminal to the C2 host including the communications link and the computer providing interfacing and monitoring services. Approvals and certifications are required by the appropriate agency for cryptographic, TEMPEST, and physical security (e.g., National Security Agency (NSA) for cryptographic).

PRECISE PARTICIPANT LOCATION AND IDENTIFICATION

Precise Participant Location and Identification (PPLI) is a Link 16 message that is used by units to transmit complete location, identification, and limited status information. PPLI contains unit location information and its navigational accuracy. For identification PPLI contains platform information, call signs, IFF data, and numerous activity status indicators (e.g., airborne, mission commander, C2, flight leader, emergency, bailout, etc). The PPLI is also used for air navigation and timing. PPLI also has dedicated time slices. Each Link terminal that is active on the network sends a PPLI message based on the platform type.

The problem occurs with having multiple terminals owned by a single C2 unit. Each terminal has a location as does the C2 unit. If the C2 unit's location is used for every Link 16 terminal, the air navigation solution is incorrect and the locations of the Link 16 terminals are unknown. If the Link 16 locations are used, the location of the C2 unit is unknown. The United States (US) platform solution is based on the JRE standard documentation, which requires an Indirect PPLI providing the C2 units location and status indicator data, be sent in the surveillance portion of the time slices. Each Link 16 terminal sends its PPLI in its dedication time slice and the Indirect PPLI of the C2 unit is sent on a surveillance time slice assignment. NATO, the United Kingdom (UK), and France (FR) have very unique requirements. UK/FR interpretation is that the land C2 unit is the same type of platform as the Link 16 terminal and sends a Land Point PPLI in the surveillance time slices. Many US and other national platforms do not process platform type PPLI that are received in the surveillance time slices. One problem is that NATO/UK/FR standards groups have not accepted the new definition of the Indirect PPLI that was designed for use in JRE systems that is the ideal solution for a single C2 host and multiple terminal configurations.

CRYPTOGRAPHIC KEYING

Multiple Link 16 terminal operation requires getting the cryptographic keys into terminals that are displaced from the C2 host and in possibly unmanned locations. Not only do you need the capability to get the cryptographic keys to the location, the Link 16 terminal must be secured to cryptographic rules and requirements. The distribution, monitoring, and control mechanisms must be approved by the appropriate agency (e.g., NSA, SECAN (Military Committee Communications and Information Systems Security and Evaluation Agency), or appropriate national organization). The ability to remotely set the crypto load to zero when physical barriers are illegally penetrated is mandatory. The control and access to the crypto keying device at the initiation location must be defined and approved.

REMOTE INITIALIZATION

Remote initialization is providing data to a Link 16 terminal that defines its operational parameters and allocates its bandwidth. This capability is the least complex of the issues as the data is not classified and can be routed over a standard communications link. The network management system or the cost C2 can distribute the data to each terminal for insertion into terminal memory. The data can also be modified by the network management system if required.

NETWORK DESIGN AND SPECTRUM APPROVAL

Getting approval for operating Link 16 networks requires submission of the design to the national organization that is tasked with aviation regulation and safety (e.g., Federal Aviation Administration (FAA), Civil Aviation Authority (CAA), …). The spectrum or frequencies that Link 16 uses is owned by aviation organizations for operation of navigation aids. The design of Link 16 networks requires ensuring the navigation aids will not be disturbed or interrupted. Although Link 16 does not use specific navigation aid frequencies, excessive amounts of high power radio frequency (RF) pulses near these frequencies is restricted, making Link 16 network designs limited to a certain number of pulses. Link 16 network operation has a lot of restrictions when operating under peacetime rules. For example, it is difficult to get a network approved to use Link 16 wideband voice (16 kilobits per second (kbps)). Sharing of the time slices (called multi-netting) is also restricted because it permits more than 100 percent of the RF pulse allotment to be available to the network.

The design of Link 16 networks is very complicated and further makes the approval process complicated. Without going into details, a number of issues arise with using multiple Link 16 terminals over large areas.

Will the local aviation agency allow more than one Link 16 terminal to use the same time division assignments? Use of the same time division assignments is prohibited by the FAA in the US. This restriction prevents simultaneous multiple network number use and contention mode (similar to carrier sensed multiple access with collision detection).

Will neighboring countries require their agency also approve networks that use Link 16 terminals within a certain distance from their border? For operation in Europe, each country may require network approval or have a central European Union (EU) agency provide approval for all networks.

Will different country agencies have a common or unique set of rules and guidelines for approval? Currently, many EU countries have independent local aviation agencies with vastly different rules. As more countries are exposed to Link 16, the rules may become more common or the opposite may occur. The primary countries that currently operate Link 16 systems include the US, UK, and FR and each have very unique requirements.

NETWORK OPERATION AND MANAGEMENT

Network operation and management (NOM) relates to the ability to dynamically reconfigure the network design after it has been loaded into Link 16 terminals. The network management system must have the ability to monitor the network to determine when loading problems are occurring and to redistribute the available bandwidth in an efficient manner. Additionally, it is good if the network management system is able to add and remove Link 16 units from the network. Finally, the network management system is the primary network monitoring system and the only component that determines the best routing of addressed messages.

For small numbers of Link 16, the capability provides minimal benefit. For large area systems with many terminals, the NOM capability is critical to efficient operation and to efficient management of the limited bandwidth. Maintaining the knowledge of bandwidth changes for large numbers of Link 16 terminals is complex and new capabilities are required. (A lot of the complexity can be reduced by use of a Link 16 terminal capability called Time Slot Reallocation (TSR). The TSR function can redistribute bandwidth for two data segments (e.g., surveillance and air control) with intervals as low as 6 seconds. NATO does not currently use TSR.)

SECURE VOICE

Secure voice has two issues. When operating in 16 kbps mode, most of the Link 16 network bandwidth is used for secure voice. When operating in 2.4 kbps mode, the quality of the sound is poor. In large, land based systems, only 2.4 kbps voice is available. The second issue is directing the data to and from a Link 16 terminal. The voice data can arrive from multiple terminals so software must be available to select the first received packet and delete the others. Outgoing secure voice can be routed, but it must maintain a connectivity matrix to determine the best Link 16 to use. The software required to determine the best terminal is complex.

TIME REFERENCE

Link 16 requires a common time reference. Link 16 networks are synchronized to a common time reference in order to maintain its rapid frequency hopping, jam resistant capability. Getting all of the ground Link 16 terminals on the same time is easy as long as the Global Positioning System (GPS) is operational. If GPS is disabled, the Link 16 terminals need to have an alternate time standard available that all of them can use. Using a time standard at the C2 host and providing it to each terminal by the communications system may be one solution. Having a high-accuracy ground-based time standard at every location is another alternative that is the best but most expensive solution.

DUPLICATE DATA AND ADDRESSED ROUTING

A major issue relates to the possibility of more than one of the ground terminals exchanging messages with a platform. If an airborne platform is flying very high, it may have line of sight to two or more ground-based Link 16 terminals. During this situation the communications systems from the Link 16 terminals to the host C2 system routes duplicate or multiple copies of messages that are received in the same time interval by multiple terminals. Because Link 16 track data on moving entities is extrapolated, the first received message is the most accurate as it has the least extrapolation error. Additional software must be developed to remove the duplicate messages. On the transmission of messages, the broadcast messages go to every terminal. Addressed messages are broadcast or routed to the Link 16 terminal with best connectivity to the addressed unit. The use of a single terminal reduces bandwidth use but increases the complexity of the routing software. The addressed message routing requires knowledge of the Link 16 terminals receiving data from the addressee. Additional software must be developed to remove the duplicate messages and provide routing if required. For small numbers of Link 16 terminals, the added complexity and monitoring does not add a lot of benefit. A duplication time window can eliminate extra copies of received messages as receive time slices for the same data cannot be sent in adjacent time slices.

ELECTROMAGNETIC INTERFERENCE

As many Link 16 terminals are located with other powerful RF producers, electromagnetic interference (EMI) must be evaluated and resolved. As many Link 16 terminals are being located near airports and air navigation radars, co-sight interference to and from Identification Friend or Foe (IFF), Tactical Air Navigation (TACAN), and radar systems is very probable. EMI issues with IFF and TACAN must be resolved. EMI tests are required by cognizant authorities.

POSSIBLE SYSTEM CONFIGURATION

SMALL US LINK 16 TERMINAL SYSTEM

One solution is to deploy a two Link 16 terminal configuration that is named TWO for convenience. TWO is connected to a large, ground C2 system similar to those developed by Thales Raytheon Systems (TRS).

The Link 16 terminals are located at existing radar locations on near opposite ends of the protected area (100-200 mile separation). The radar site provides physical security.

The C2 host sends an Indirect PPLI message and each Link 16 terminal sends a Land Point PPLI.

The cryptographic keying and remote initialization requirements are met by extending an existing capability. The solution has a one-time NSF approval, but it will not be approved for other systems.

Link 16 networks are designed by US organizations meeting US usage standards. TWO uses the same network assignments for both Link 16 terminals.

Remote initialization and network operations and management are performed by the Interim JICO (Joint Interface Control Officer) Support System (JSS) until the JSS under development is completed, approved, and certified.

Secure voice is not required but its implementation may be added at a later date.

TWO has a time standard available at each location if GPS is lost.

The C2 host detects the duplicate messages based on it being within a time volume of receipt of the first message. Special routing for addressed messages is not required as data always goes to both terminals.

Each site is inspected for EMI and all problems are being resolved.

LARGE US MULTIPLE LINK 16 TERMINAL SYSTEM

The Link 16 US (LUS) terminal deployment architecture is evaluated, tested, and deployed under contract to a US service organization. LUS is also connected to a large, ground C2 system.

LUS deploys 20-30 Link 16 terminal locations. The terminal locations are military bases, radar sites, FAA sites, and sites operated by contracted companies that are responsible for their physical security.

The C2 host sends an Indirect PPLI using the data forwarding capability of the Link 16 terminal interface system in accordance with MIL-STD-6020 for data forwarding and MIL-STD-3011 for JREAP.

The cryptographic keying requirements must meet the latest NSF approved system.

Remote initialization and network operations and management are performed by the Interim JICO (Joint Interface Control Officer) Support System (JSS) until the JSS under development is completed, approved, and certified.

Link 16 networks are designed by US organizations meeting US usage standards. Final decisions on network assignments for each of the Link 16 terminals are under review.

Secure voice operation is under evaluation.

LUS may or may not have an alternate time standard decision approved.

Exact methods for determining duplicate messages and addressed message routing need to be finalized.

Link 16 terminal locations will complete EMI testing and all problems are resolved.

LARGE NON-US MULTIPLE LINK 16 TERMINAL SYSTEM

The Large Non-US Multiple Link 16 Terminal (LMLT) system has a terminal deployment architecture based on NATO standards and/or other national documentation. The LMLT may or may not require approval by NACMA (NATO Air Command and Control Management Agency), the organization responsible for developing NATO systems. LMLT is connected to a large, ground C2 system and uses large federations of Link 16 terminals (> 15) covering large geographical regions.

The Link 16 terminal locations are at radar sites, near airports, and near military facilities that are responsible for their physical security.

The LMLT host plans to send a Land Point PPLI message as does each Link 16 terminal.

Remote terminal initialization and network management are provided by a non-US network management and control system.

The cryptographic keying requirements are approved by SECAN.

Link 16 networks are designed by NATO and host country organizations meeting their usage standards. Final decisions on network assignments for each of the Link 16 terminals are decided by NATO or the host country approval organization.

Secure voice operation may be an option but probably too complex for a large area.

LMLT uses the common time solution provided by the communication system as the time standard at every location is cost prohibitive.

Duplicate messages evaluation and addressing by terminal are planned.

Link 16 terminal locations complete EMI testing and all problems are resolved.

MEDIUM-SIZED NON-US MULTIPLE TERMINAL SYSTEM

The Medium-sized Non-US Multiple Link 16 Terminal (M2LT) system has a terminal deployment architecture based on NATO standards and/or other national documentation. The M2LT may or may not require approval by NACMA (NATO Air Command and Control Management Agency), the organization responsible for developing NATO systems. M2LT is connected to a large, ground C2 system and uses approximately 5-15 Link 16 terminals covering a modest geographical region.

The Link 16 terminal locations are at radar sites, near airports, and near military facilities that are responsible for their physical security.

The C2 host sends a Land Point PPLI message as does each Link 16 terminal.

The cryptographic key control organization, key management, and key distribution methodology are submitted to SECAN or NSA for approval.

Remote terminal initialization and network operations and management are provided by a local Data Link Management System.

NATO or the national organization builds their own networks with approval by the governing organization.

An alternate time standard decision is optional based on need and funding availability.

Duplicated messages are detected and removed. Addressed messages are evaluated for routing at the datalink interface component of the C2 host.

Link 16 terminal locations meet EMI requirements and all problems are resolved.

CONCLUSION

Multiple Link 16 terminal operation with a single C2 host has a number of issues that must be resolved. Many of the systems that are under development or near deployment are creating unique solutions. Proposed solutions to Link 16 problems require the development of a common solution for all multiple Link 16 terminal users. The large ground C2 systems defined above have different solutions and capabilities. These systems will have interoperability problems to resolve.

Multiple Link 16 terminal operations as defined above is only one solution for getting a Link 16 path between a large, ground C2 system and airborne units. Creating unique solutions without approval of the US and NATO Link 16 standards organizations is risky. Skipping the organizations that approve the technical and operational aspects of Link 16 systems including developing standards will lead to non-interoperable systems.

A NATO standardization agreement (STANAG) for multiple Link 16 terminal operations needs to be developed to ensure all Link 16 systems are interoperable. The development process for the JREAP document, Military Standard 3011, should be used as a guide and reference. More involvement by the datalink technical organizations is required to prevent the deployment of single platform use Link 16 capability.