ANALYSIS OF IMPORTANCE OF TACTICAL DATA LINK (TDL) IN MILITARY DOMAINS IN 21ST CENTURY

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Abstracts: Military planning, decision-making, and command and control now necessitate large and expanding amounts of data. National security organizations must increase their ability to rapidly communicate and use massive amounts of information/data in order to improve situational awareness and support increasingly complicated military operations. Furthermore, this information/data is frequently gathered from geographically scattered devices. Tactical data links were created in accordance with particular specifications to facilitate sophisticated data exchange for military engagements. Military operators typically employ tactical data links (TDLs) to communicate important information that is optimized to meet the mission goals of TDL-equipped assets and their associated Information communication Requirements (IERs). The number of interconnected units and systems can be dramatically increased with multi-link operations. As a result, the complexity of the Joint Data Network (JDN) grows, necessitating careful network planning and administration. Link 16 and Link 22 are the most recent and advanced tactical data link networks. Both second-generation data lines were developed to address the shortcomings of first-generation data links. Link 22, for example, was created to replace Link 11. Among other things, it allows for Beyond Line of Sight (BLOS) communication. It was meant to work in more connected environments, complementing Link 16 and enhancing C5ISR capabilities. It is an analytical paper that forecasts the future growth of TDL in military domains and its extensive use in both battle space and business in the twenty-first century.

Key Words: Processing, integration, system architect, RF, TDL, MADL, ICT, Link 11, Link 22, LOS, BLOS, NATO, XMPP**,** JADO, C5ISR, SDR

Introduction

Command and control (C2) are very important for modern military forces. The C2 is a very important part of the success of military actions in the services or joint environment. On the other hand, C2 in military operations rests on keeping communication clear and steady. Commanders want to know things like, "Where is my enemy?" and "What is the enemy's plan?" Where's the ship of my enemy? Where is my attack plane from the enemy? Where is my opponent's tank? Who is the bad person? Where is the goal? In fact, all the information systems are driven by the way that new defense systems are linked together. Now, we have RPVs (Remotely Piloted Vehicles) with electro optical and infrared (IR) sensors. These are different things that hover over the fight space and can send back a lot of data in real time. What do we do with a lot of important and large data? How do we give them out? So, at the moment, most of the contact in the military is done through computer networks, which can be attacked. Again, quantum computing is a field that is growing quickly and has the ability to change how we solve problems that are too hard for traditional computers to handle. So, the whole method of communication will change in the future. Command, Control, Communication, Computer, Cyber, Intelligence, Surveillance, and Reconnaissance, or C5ISR, is a popular term these days. Sharing tactical information, intelligence, or data to help the Military Decision-Making Process (DMP) through a safe and secure communication link makes the best use of the Tactical Data Link (TDL) System necessary.

TDL is a communication standard that employs multiple data channels for the transmission and exchange of tactical data between armed forces. It provides a secure network for military communications. IDM, Link 11, AFAPD, Link 16, Link 22, SADL, JREAP, VMF, and SIMPLE are examples of tactical networks. The network can be chosen based on the requirements of the application and the TDLs developed primarily by the United States and the North Atlantic Treaty Organization (NATO). For instance, Link 16 is utilized for LOS communication. Situational awareness is achieved using SADL. Link 22 is utilized for BLOS communications applications. Through TDL's secure communication, military personnel are able to make accurate decisions in life-or-death situations. Again, this useful high-tech technology integrates readily with a variety of military systems, thereby enhancing their capabilities. Therefore, the defense industry witnessed a surge in the replacement of traditional military communications systems with these real-time, secure links.[1]This aspect will drive TDL market expansion during the next decade. As we all know, the COVID 19 pandemic crisis has resulted in transit limitations

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and the closure of various production facilities for an extended period of time. These factors contribute to a slow growth rate between 2020 and 2022. TDL market growth, on the other hand, will accelerate in the post-COVID era and in the current global geopolitical environment.

TDLs are systems that transmit exchange and process tactical data/information in real time according to standard message formats and communication protocols[2]. They enable combat units that serve the same tactical purpose but are geographically dispersed to form a cohesive tactical community[3]. Today, many systems can work on more than one link at the same time, which gives a more complete picture of the situation. Some systems are called Forwarders or Gateways, and they can move information from one data link to another. Now, combat groups with connections to tactical data links can share intelligence and weapon resources in the tactical community to achieve the same tactical goal, making them more effective in battle[4],[5]. Tactical data links have been used increasingly widely in the military. They can be used to quickly understand combat situations through the transmission of information between combat units, helping to control the overall battle situation.[6] Tactical data links are an important means of transmitting information, but the communication channel is complicated during the transmission process, and the reliability of the data transmission is considerably affected by the surrounding environment.[7] It is therefore critical to ensurethe accuracy of the data while transmitting at high speed in a complex environment.[8]TDLs are standardized digital communication links that were created to allow parties to exchange tactical information using secure transmission protocols and bearer characteristics. TDLs are secure, ECM-resistant, high-capacity communication lines that provide real-time tactical situational awareness and extended connectivity to centralized assets that are beyond line-of-sight (BLOS).

TDL systems are quickly becoming an essential component of modern military operations. It has the unique capacity to transport massive amounts of data quickly; it can manage data communication in critical environments while maintaining dependability and data security. As a result, a wireless hybrid network may be an effective complement to its radio frequency (RF) equivalent. Wireless system co-development can improve system performance in terms of data throughput, dependability, and redundancy for TDL, ensuring its optimal use in military communication systems. Furthermore, it can significantly contribute to secure data sharing within military services, paving the path for C5ISR. Again, efficient localization is critical in many modern applications of Unmanned Ground Vehicles (UGVs) and Unmanned Aerial Vehicles (UAVs), contributing to increased control, safety, and power economy, among other things. The ubiquitous 5G NR (New Radio) cellular network will open up new possibilities for improving the localization of UAVs and UGVs.[9]As we all know, modern armed forces have a lot of interoperability problems with data protocol, data encryption, transmission policy, hardware and software interface protocol, and heterogeneous hardware and software, and standardization of systems or systems (SoS) has become a must. With the use of standard, secure transmission links, any modern military, including those of many developing nations, may be able to close the gap. It's an analytical study mostly based on secondary sources that try to figure out how important TDL is for modern military operations and how widely it's used in real battle places like land, air, sea, space, and underwater as well as business in the 21st century. It also tries to predict how much it will grow in the future. This paper will also talk about the basics and functions of radio frequency and tactical communication, the development of different TDLs and what they can do, the background and chronological development of digital communication and TDL, the system architect of a TDL, the hardware and software that can be used with a TDL, the trend of the TDL market, the growth forecast for the TDL market, the future development of TDL, etc.

ITU, Basic of Radio Frequency (RF) and Tactical Communications

The International Telecommunication Union (ITU) is a specialized United Nations organization that drives innovation in information and communication technologies (ICTs) in collaboration with 193 Member States. ITU is dedicated to linking the world. Information and communication technologies are used in practically every aspect of modern life, including commerce, culture, and entertainment, as well as at work and at home. Today, there are billions of mobile phone subscribers, nearly five billion television viewers, and tens of millions of new Internet users each year. Hundreds of millions of people utilize satellite services around the world, whether they are getting directions from a satellite navigation system, checking the weather forecast, or viewing television from remote locations. Every day, millions more people utilize video compression in mobile phones, music players, and cameras.[10]The International Telecommunication Union (ITU) is a specialty branch of the United Nations that works with 193 Member States to push for new ideas in information and communication technologies (ICTs). ITU works to connect people all over the world. Information and communication technologies are used in almost every part of modern life, including business, society, and entertainment, as well as at work and at home. There are billions of people who use cell phones, almost five billion people who watch TV, and tens of millions of new Internet users every year. Satellite services are used by hundreds of millions of people all over the world, whether they are using a satellite navigation system to find their way, checking the weather report, or watching TV from far away. Millions of people use video compression on their cell phones, music players, and cameras every day.[11]ITU frequency bands include VLF, LF, MF, HF, VHF, and UHF. The radio spectrum is an essential component of the much larger electromagnetic spectrum, which includes not only radio waves but also light, infrared, ultraviolet, and other forms of radiation. Different wavelengths and frequencies indicate that the signals have different properties and can be utilized in a variety of ways, including long-distance radio communication, point-to-point radio

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communication, radio links that are more secure because they do not travel as far, satellite communications links, and many others.[12] Electromagnetic wave spectrum showing where the radio spectrum is located has been shown in figure 1 below.

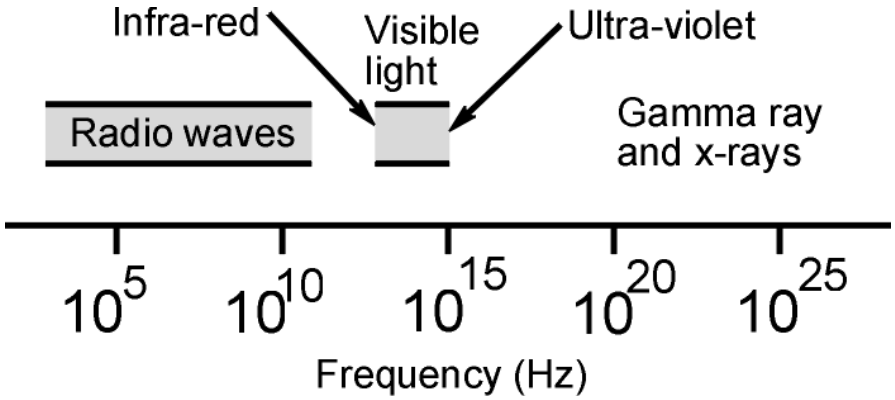

Figure 1: Electromagnetic wave spectrum showing where the radio spectrum is located[13]

Different frequencies and spectrum regions may be better suited to one type of radio use than another. These are terms such as LF, MF, HF, VHF and UHF, EHF, and so on, and they represent areas of the radio spectrum or radio frequency spectrum that most people are familiar with. The International Telecommunication Union (ITU) is a multinational body that governs radio spectrum utilization. However, in order to readily refer to different areas of the radio spectrum, the ITU divided the radio frequency spectrum into twelve distinct bands, which are not only numbered 1 to 12 but also given names.[14]The band designations were established when wavelength was the method for measuring the position of the signal in the spectrum; the radio spectrum is depicted in Figure 2 and Table 1 below. As frequency is used today instead of wavelength, the band boundaries are at points equal to 1 x 10n. For instance, the HF portion of the electromagnetic spectrum extends from 100 meters to 10 meters or 3 to 30 MHz These frequencies are specified by the ITU Radio Regulations. There were only nine bands originally, but as usage and prospective usage of the radio spectrum expanded, there are now twelve bands. These ITU frequency bands serve as the fundamental definitions of the various regions of the radio frequency spectrum and are accepted and utilized globally.

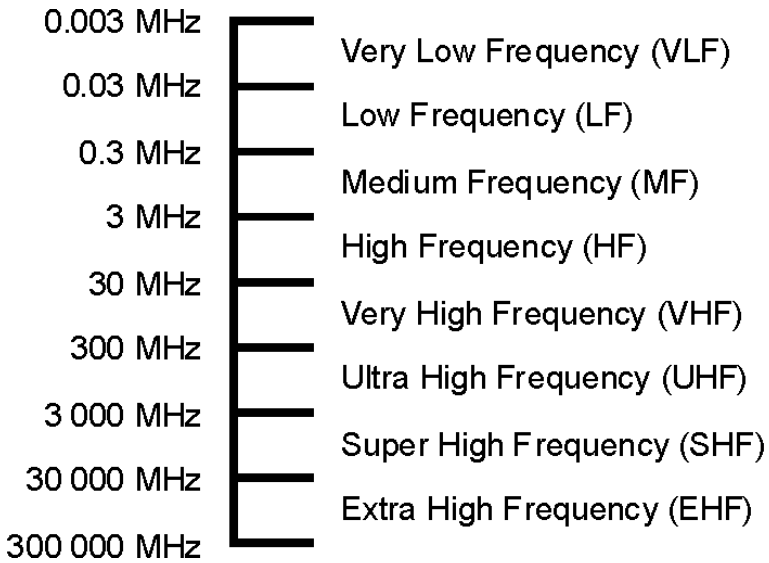

Figure 2: The radio spectrum with RF[15]

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BAND NAME	ABBREVIATION	ITU BAND NUMBER	FREQUENCY	WAVELENGTH
Extremely Low Frequency	ELF	1	3 - 30 Hz	100000 - 10000 km
Super Low Frequency	SLF	2	30 - 300 Hz	10000 - 1000 km
Ultra Low Frequency	ULF	3	300 - 3000 Hz	1000 - 100 km
Very Low Frequency	VLF	4	3 - 30 kHz	100 - 10 km
Low Frequency	LF	5	30 - 300 kHz	10 - 1 km
Medium Frequency	MF	6	300 - 3000kHz	1000 - 100 m
High Frequency	HF	7	3 - 30 MHz	100 - 10 m
Very High Frequency	VHF	8	30 - 300 MHz	10 - 1 m
Ultra High Frequency	UHF	9	300 - 3000 MHz	100 - 10 cm
Super High Frequency	SHF	10	3 - 30 GHz	10 - 1 cm
Extremely High Frequency	EHF	11	30 - 300 GHz	10 - 1 mm
Tremendously High Frequency	THF	12	300 - 3000 GHz	1 - 0.1 mm

Table 1: ITU radio spectrum bands with their names, wavelengths and frequencies [16]

As we know that, Radio frequency (RF) is the oscillation[17] rate of an alternating electric current or voltage[18] or electromagnetic field[19] or mechanical system in the frequency[20] range from around 20 kHz to 300 GHz. It is roughly between the higher limit of audio frequencies[21] and the lower limit of infrared frequencies.[22] These are the frequencies at which energy from an oscillating current can radiate off a conductor into space as radio waves.[23] Actually, they are used in radio technology, among other uses and different sources specify different higher and lower bounds for the frequency range. Basic diagram of RF (radio frequency) wireless technology has been shown in figure 3 below. RF propagation occurs at the speed of light and does not need a medium like air in order to travel. RF waves occur naturally from sun flares, lightning, and from stars in space that radiate RF waves as they age.

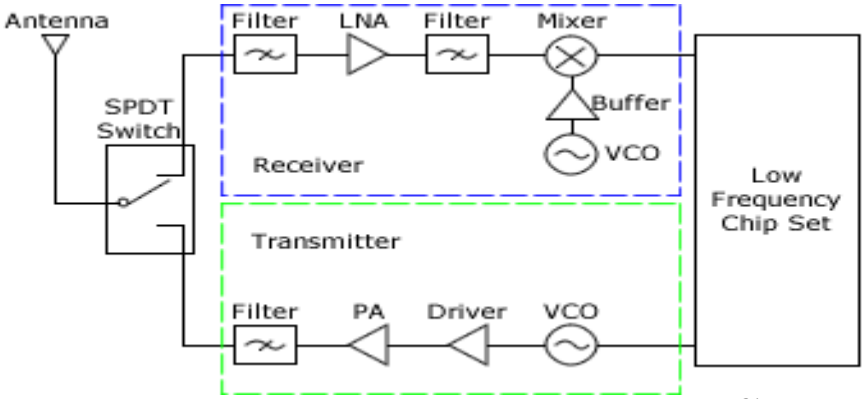

Figure 3: Basic diagram of RF (radio frequency) wireless technology [24]

Tactical communications are basically military communications[25] in which data or information of any kind, especially orders, command and military intelligence,[26] are conveyed from one control, person, or place to another upon a theatre of war, particularly during the conduct of battle. Such communication includes any kind of delivery of information, whether verbal, written, visual or auditory, and

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can be sent in a variety of ways. Nowadays, this is usually done by electronic means. The earliest way of communicating with others in a battle was by the commander's voice or by human messenger. In ancient time, a runner would carry reports or orders from one officer to another. Once the horse was cultivated messages could travel much faster.A very fast way to send information was to use drums, trumpets or flags.[27] Again, telegraphs helped theater commanders to move large armies about, but commanders face many complicacies in a changing battlefield.[28] At the end of the 19th century the dissimilar units across any field were immediately joined to their commanders by the invention and use of the radio.[29] In initial stage, the radio could only broadcast tones, and messages were sent via Morse code.[30] The first field radios used by the United States (U.S.) Army saw action in the Spanish American War in 1898 and the Philippine Insurrection in 1899–1902.[31] At the same time the field telephone has developed and made commercially feasible. This caused a new signal occupation specialty to be developed like lineman.[32]

As we know that, if we broadcast our plans over radio waves, anyone with a similar radio can listen to the same frequency and can know our plans. After World War II,[33] due to advances in electronics, it allowed for electronic scrambling of voice radio. Actually, during the war operational and strategic messages were texted and encrypted with ciphers too complex for humans to crack without the assistance of a similar, high-tech machine; as it happens by the German Enigma machine.[34] However, after computer science advanced, tactical voice radio could be encrypted, and large amounts of data could be sent over the airwaves in 'quick bursts of signals'[35] with more complex encryption.[36] Before the electronic age, it was much harder for forces to talk to each other. Messages had to be sent by messengers on horseback or on foot, which took time depending on how far the messenger had to go. Long-distance communication improvements helped the commander on the battlefield because they could learn about any outside force or factor that could affect the way a fight was fought.[37]In tactical communication, the major concerns are the network stability, network redundancy and network security (SRS). A stable network is relatively easy to achieve where communication nodes are distributed in end-to-end structure, for example LAN network using Optical or Ethernet connection, which is practicable in land based data sharing.

On the other hand, maritime platforms like warships mostly function as mobile Ad-hoc Network (MANET), where there is no end to end network infrastructure[38]. The same is true for air elements, whose constantly shifting positions at high velocity expose the network to constant connection and disconnection. Even land/army elements become mobile on the battlefield, and tactical communication within the nodes is frequently disrupted. Consequently, network redundancy is a significant challenge in military communication, and in particular tactical communication. Radio communication networks, such as VHF/UHF for limited range and HF for long distance, are frequently insufficient to support tactical communication. Satellite Communication (SATCOM), despite its expense, has gained popularity as a network redundancy solution. In environments with no end-to-end network infrastructure, the incorporation of a hybrid communication system employing Disruption/Delay Tolerant Network (DTN) architecture could therefore be advantageous.[39,40] The DTN architecture is useful in environments where there is no end-to-end network infrastructure. The ability to forward messages to recipient nodes, taking advantage of node mobility, makes the DTN approach compatible with filling the gaps left by conventional networks[41]. However, all digital tactical communications systems[42] usually have few basic components; those are:

- A Data Source. This could be a sensor system like radar or a human operator entering command and control instructions or manual observations.

- A Data Processing and Display System. This collects coordinate information from the data source(s) and makes sure it meets the standards for release to the tactical About Synthesis offers services in military systems, training, systems and software engineering, technical management, and a wide range of other fields. Our new products and unique support and consulting services make us the first choice for both large and small businesses. The company was started in 1988, and its main goal is to solve common industry problems by combining technical knowledge with easy-to-use software applications. When it gets information, it saves it in local databases so that other integrated systems can use it. It is expected to have a user interface where the tactical communications system's settings can be changed.

- Cryptographic System (optional). The data being communicated is encoded by the cryptographic system, and in some circumstances, pseudo-random transmission characteristics (such as frequency hopping) are also introduced to increase resistance to jamming.

- Communications System. A modem, a radio transceiver, and an antenna are common components of radio frequency systems. The radio transceiver and antenna are obviously unnecessary for landline systems.

- Message set. In order to facilitate the sharing of parametric data, modern digital tactical communications systems use a standard set of messages.

On the other hand, a digital tactical communication system might support the following:

- Single direction data transfer (simplex).

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- Two-way data transfer, but transfer in only one direction at any time (semi-duplex).

- Simultaneous two-way data exchange (duplex). Three basic types of connectivity are used.

- Point-to-point. A dedicated link between a pair of units, normally only issued between fixed Command and Control (C2) posts, or from C2 posts to a missile command post.

- Broadcast. Here, a single instrument will transmit data that will be simultaneously received by multiple participants. This is also a simplex transmission by definition, as the data transfer from the broadcasting unit to the recovery unit is unidirectional.

- Networked. This permits all units in the network to communicate with one another. Each transmitting unit can broadcast information to all other units on the network that have the right cryptographic keys, or it can address information to a specific unit, as in a point-to-point link. Data communications between fixed ground locations are supported by media land lines. These can be dedicated copper wires, although they are most commonly fiber optic cables. They are usually part of a multi-route pocket switching network. Satellite Communications (SATCOM) are increasingly being utilized to assist tactical communications, particularly with the emergence of man-portable devices capable of locating, connecting to, and remaining locked in to non-stationary satellites. Radio is most likely the most commonly used medium for tactical communications. Modern radios are dependable, portable, powerful, and simple to encrypt. Military tactical communications radios typically operate in the HF to SHF frequency bands designated by the International Telecommunications Union (ITU), with some very low frequencies used for submarine communications. VHF, UHF, and SHF are limited to line-of-sight (LOS), while some higher frequencies have shorter ranges due to atmospheric water absorption. HF has BLOS capabilities and can be used over great distances or in mountainous terrain, however it is also vulnerable to ionosphere effects.

TDL Standard and Example/Names Used

There are numerous varieties of tactical data links, with Link 6, Link 11, Link 16, and Link 22 being among the most common. Using a data link standard, a TDL provides communication via radio waves or cable among the nations of NATO. All military C3 systems transmit, relay, and receive tactical data using standardized TDL.[43]TDL is often referenced by the standards used; a brief overview has been given blow. However, many of the key TDL specifications are necessarily classified, as well as there is plenty unclassified information to give a clear understanding of TDLs.

- Link 1:NATO data link between Air Defense Main Control Centers. It is a Tactical Data Exchange for Air Defense, which is simply a ground link and point-to-point communication. Link 4 is an S-series TDL from the first generation.

- Link 4: Ground to Air Data Link. It uses for the Control of Military aircraft;basically point to point communication.Link 4 isfirst generation, S/R seriesTDL.
- Link 6: Missile Base to Control Centre Link. It'sa SAM Automatic Data Link; basically point to pointcommunication. Link 6 is first generationTDL.

- Link 7: ATC/Defense Link. It's a TDL for ATC; basically point to point communication. Link 7 is first generationTDL.

- Link 10:Ship to Ship Link. It'sa MaritimeTactical Data Exchange; basically broadcast communication.Link 10 is second generation, M seriesTDL.

- IJMS: ECM Resistant Communication System (ERCS). It's an Interim JTIDS/MIDS Message Specification TDL, which is essentially broadcast communication. Link 16 has already supplanted the Interim Data Link Standard. IJMS is a second-generation TDL from the M series.

- SADL: Situational Awareness Data Link. It is a Situational Awareness Data Link, which is essentially a form of broadcast communication. EPLRS will provide A-10s and F-16s with air-to-ground and air-to-air data link capability. SADL is a TDL of the second iteration, K/J series.

- Link 11:Fast Automatic High-Frequency Link. It's a Maritime Tactical Data, which is basically a way to send out a message. Link 11 is a M series TDL from the second generation. Link 11 is the first TDL that is still used. Ralph Benjamin worked at the UK Admiralty Surface Weapons Outfit (ASWE) in the 1950s and 1960s to make TDL. After that, NATO took it up and made it a standard. It works over HF and UHF at a set speed and sends 24-bit messages in a 30-bit payload. It can use either half-duplex

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communication or a broadcast mode between two nodes. In a half-duplex, a "roll call" from a controlling server lets each member of the network send at the same time.

- Link 14:Slow Semi–Automatic Link. It'sa Maritime TDL; basically broadcast communication.Link 14 is second generation, D/MS/E seriesTDL.

- Link 16: High capacity, ECM resistance, multifunctionality, and TDMA connectivity. It is ECM Resistant Tactical Data Exchange, which is essentially broadcast communication. Link 16 is a J series third-generation TDL. Link 16 is a more complex and modern TDL that is primarily used for aviation communication. It works in a specific UHF band and uses TDMA to share a single fixed-frequency channel. In addition to the basic TDL short structure messages, Link 16 provides voice, text messaging, and image sharing.

- Link 22: NATO Improved Link 11. It's being made to replace Link 11, and the plan is for it to do basically the same thing. Link 22 is a J series TDL from the third generation. Link 22 is an updated version of Link 11 that focuses on the navy. It uses the features of Link 16, so it can also be an upgrade path for computers that use Link 16. Link 22 was made by the NATO Improvements to Link 11 (NILE) program, and NILE is what most people call it. Key things about Link 22: It works with Link 16 and supports J-Messages.

    - It can operates over HF and UHF, fixed speed and fixed frequency
    - It used a Dynamic TDMA (DTMA) approach for members of a network
    - It allows nodes to join a network (late network entry)
    - It can support multiple interconnected networks (a Super Network) and relay between networks.
    - Here messages can be directed to a list of nodes, all nodes on the network, or all nodes on the super network
    - Here error correction is possible
    - It resilient to node loss
    - Here messages have priority
    - Congestion management, giving preference to higher priority messages
    - Message creation time and perish-ability (when message is no longer valid)

Most Prominent and Adaptable TDLs around Globe

Link 11. Link-11 is a data link with a half-duplex configuration that employs the M-series message format. It has been utilized across multiple platforms and nations throughout its history. The system operates in either roll call or broadcast mode. Roll call operation employs a Net Control Station that queries each participant, also known as Pickets, in order to stimulate their data transmission. This cycle is replicated according to the NCS configuration through a polling sequence. In broadcast mode, a single source can send a single data transmission or a series of individual data transmissions. Link-11A operates in the HF and UHF channels and offers both BLOS and LOS range flexibility. Link-11B is a ground-to-ground implementation of a subset of the message catalogue for the M-series. This point-to-point link employs serial transmission and is commonly referred to as Serial Link-11.

Link 11 is a netted, half-duplex digital data link and used by NATO nations and particularly the U.S. military to exchange digital tactical information between land-based, airborne, and seaborne platforms. This digital data link allows ships, shore installations, and airplanes to exchange radar track information and written messages. Link-11 is the same as the Tactical Digital Information Link A (TADIL-A) used by the United States Armed Forces and is also known as MIL-STD-6011. Link 11 operates on two frequency bands. Such as: one in the HF band and another in the UHF band. It has a ground wave range of up to 300 nautical miles in the HF band and a sky wave range of 1,000 nautical miles. It can cover a line-of-sight within the range of 20 to 30 nautical miles for ship to ship connections and 150 nautical miles for ship to air connections in the UHF band. The link 11 system employs QPSK modulation and can broadcast packets of up to 30 bits in length, with 6 bits of error correction and 24 bits of encrypted payload data. The Link 11 network may operate at two different data rates. Such as: 75 frames per second (2250 bps for UHF) and 45 frames per second (1364 bps for HF). A Link 11 network can accommodate up to 61 members in the ships, submarines, aircraft, and shore facilities at the same time. The system is generally in roll call mode, controlled by a Net Control Station (NCS). The following portion of this page concerns roll call mode. Link 11 has been replaced by Link 22 Tactical Data Link, which boasts significant enhancements in capability, such as the ability to host up to 125 users and reach data rates of 4kbps for an HF network and 12 kbps for a UHF network. However, Link 11 is scheduled to remain the primary naval tactical data link for another ten years until being gradually superseded by Link 22 in 2024.[44]A Link 11 network is made up of a Network Control Station (NCS) and a number of Picket stations or Participating Units (PU). The NCS is a part of the link 11 architecture. It acts as a common control station that lets people connect to the net and keeps operating rules for the net in place.

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Link16. Link-16 specifies the J-series message format, which has been optimized for use with the MIDS/JTIDS TDMA architecture. Link-16 employs a time slot structure and can operate up to 127 nets at the same time using discrete frequency hopping patterns. Link-16 relies heavily on network design. IDLs (formerly known as NDLs) are required to supply terminal initialization parameters that satisfy platform IERs and contribute to overall mission objectives. Surveillance, EW, Mission Management, weapon assignments, and air control, as well as speech, text, and imagery, are all supported by the J-series messaging format. These messages are organized into Network Participation Groups (NPGs) based on their role and assigned to participants as transmit, receive, and relay for the accompanying data. Links 16 units send Precise Participant Location Identification (PPLI) messages to establish their position and provide critical status updates that improve overall situational awareness. The architecture promotes network survivability, while the time slot relay improves range flexibility, widening the area of data distribution. channel 16 is an encrypted, jam-resistant TDL network used by the United States and NATO Allies to enhance situational awareness among scattered battle forces by information exchange via a shared communication channel. This permits command and control centers to generate Common Operating Pictures (COPs), which allow allied forces to electronically observe the battlespace, identify threats, and acquire targets.[45]

Link22. Link 11 is followed by NATO Improved Link Eleven (NILE), which is also known as Link 22. Link 22 is meant to make up for what Link 11 didn't do well by making it easier for Air, Land, Surface, and Subsurface units to share combat data using HF and UHF waveforms. Link 22 is made to work with and support Link 16 by having a flexible and dynamic network architecture and an automatic way of managing the network. It has better LOS and BLOS capabilities, so units can join directly even if they are 1000 Nm apart. Link 22 units can work in both HF and UHF networks, so they can join to multiple networks at once. This lets subnetworks be set up to meet data exchange and connectivity needs.

Joint Tactical Information Distribution System (JTIDS).JTIDS is a protected, high-capacity, ECM-resistant communication system that operates in the UHF frequency between 960 and 1215 MHz (L-band). Its design is based on a node-less TDMA architecture and uses 51 discrete frequencies with rapid frequency hopping. When fitted with a high-power amplifier, these terminals are typically referred to as Class II or Class IIH.

Multifunctional Information Distribution Systems (MIDS).MIDS is a small terminal constructed to US and NATO specifications. With over 10,000 terminals in use, the MIDS terminal families cover a wide range of platforms, services, and nations. Block Upgrades and Block Cycle upgrades are used to sustain service life and functional improvements. MIDS is in the process of transitioning to Block Upgrade 2, which includes Crypto Modernization, Frequency Re-Mapping, and Enhanced Throughput. These changes improve security, frequency clearance flexibility, and raise the quantity of usable data within a given time slot from a maximum of 12 data words to 40+ words, depending on mode.

Joint Tactical Radio System. The JTRS terminal is a 4-channel radio that can be programmed by software for Link 16, TACAN, and advanced networking modes. JTRS is often used in the MIDS-J configuration. It can handle CMN4 and CCR, which lets it receive data from 4 nets at the same time and makes it much easier to receive data sent in the contention access mode.

Joint Range Extension.JREAP Application Protocol JREAP provides multiple methods for exchanging BLOS data. The message structures and protocols are defined by MIL-STD-3011C / NATO STANAG 5518. JREAP is utilized in three distinct protocols: JREAP-A – Multiple terminals share the same JREAP media and send data when queued by the Network Controller. JREAP-A employs an announced token-passing protocol for communications in half-duplex mode. JREAP-B - Utilizes a synchronous or asynchronous point-to-point full duplex mode, over secure telephone lines, SHF SATCOM, or other point-to-point media connections. JREAP-C – utilizes TCP/IP or UDP network protocols over any secure IP media connection that is compatible.

Situational Awareness Data Link (SADL).SADL makes it easier to connect the digitalized battlefield through the EPLRS radio, which allows contact from fighter to fighter, from the air to the ground, and from the ground to the air. Since EPLRS is part of FBCB2, friendly troops can get information about where an airplane is. Participants in SADL can communicate with Link-16 through gateways and can join the Link-16 network as Indirect PPLIs.

Variable Message Format (VMF).VMF is platform neutral and uses the K-series binary variable message format. As a result, standards are required to define the message headers that are appropriate for specific bearers. The VMF message format is a bit-oriented digital information standard with variable message length that allows combat units at different organizational levels to exchange data. Because the message structure is flexible, VMF can transmit only the information needed, making it a feasible alternative for bandwidth-constrained applications.

Background and Chronological Development of Digital Communication and TDL

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Data or digital communications, including data transmission and data reception, is the transfer and reception of data in the form of a digital bit-stream or a digitized analog signal transmitted over a point-to-point or point-to-multipoint[46] communication channel.[47] Examples of such channels are copper wires, optical fibers, wireless communication using radio spectrum, storage media and computer buses.[48] The data are represented as an electromagnetic signal. Such as: an electrical voltage, radio wave, microwave, or infrared signal.[49] A data link is a means of connecting one location to another[50] for the purpose of transmitting and receiving digital information or data communication.[51] It can also refer to a set of electronic assemblies, consisting of a transmitter and a receiver and the interconnecting data telecommunication circuit.[52] These are governed by a link protocol enabling digital data to be transferred from a data source to a data sink.[53] There are at least three types of basic data link configurations that can be conceived of and used as follows.

- Simplex communication is a communication channel that sends information in one direction only. For example, in TV and radio broadcasting, information flows only from the transmitter site to multiple receivers.[54] Simplex communications, usually meaning all communications in one direction only.[55]
- A half duplex (HDX) method lets you talk both ways, but only in one direction at a time. You can't talk in both directions at the same time. A two-party system like a walkie-talkie is an example of a half-duplex system. To make sure that only one person is talking at a time, you have to say "over" or another term that has already been chosen.[56] A good analogy for a half duplex system would be a one lane road that allows two way traffic or that traffic can only flow in one direction at a time.[57] Again, HDX communications, meaning communications in both directions, but not both ways simultaneously.[58]
- Duplex communications are capable to communicate in both directions simultaneously.[59] A duplex communication system is a point-to-point system made up of two or more connected people or objects that can talk back and forth. Many communication networks use duplex systems so that two connected parties can talk to each other in both ways at the same time or so that equipment in the field can be monitored and changed from a distance.[60] Full transmission capacity is available in both directions as send and receive functions are separate.[61]

In civil aviation, a data link system usually known as Controller Pilot Data Link Communications[62] and that is used to send information between aircraft and air traffic controllers. For example, when an aircraft is too far from the ATC to make voice radio communication and radar observations is possible. Such systems are used for aircraft voyage across the Atlantic and Pacific oceans. One such system, used by Nav Canada and NATS[63] over the North Atlantic, as they uses a five digit data link sequence number confirmed between air traffic control and the pilots of the aircraft before the aircraft proceeds to cross those oceans. This system uses the aircraft's flight management computer to send location, speed and altitude information about the aircraft to the ATC. And then, ATC can send messages to the aircraft regarding any necessary change of course. In unmanned aircraft, land vehicles, boats, and spacecraft, a two way (either full-duplex or half-duplex) data link is used to send control signals, and to receive telemetry.[64] Multiplexing is a way of combining numerous analog or digital signals into one signal over a common media in telecommunications and computer networking. The goal is to share a limited resource, namely a physical transmission medium. Code is a system of rules used in communications and information processing to convert information, such as a letter, word, sound, image, or gesture, into another form, sometimes reduced or secret, for communication over a communication channel or storage in a storage media. Communications security is the discipline of keeping unauthorized interceptors from accessing intelligible telecommunications while still sending content to intended receivers.

TDL are secure wireless communication links used by US armed forces and NATO nations to exchange information on the battle field (Land, Air and Sea). In fact, the basic concept of TDL is to exchange standardized short messages over a shared communications channel, in particular UHF and HF Radio.[65] A core function is to share location information of friendly and hostile mobile units using information from radar and other sources. This tracking function is central to TDL, and leads to the service being commonly referred to as tracks.[66] TDL systems can be used as three distinct functions as follows.

- Message Format. The base of such format is a fixed structure message, although some TDL specifications do much.

- Message Catalogues. Definitions of such messages is to support a range of functions, including Precise Participant Location Information (tracking), network management, surveillance, weapons coordination, electronic warfare support, status and information management.

- Protocols to operate over the various link. These are detailed and complex protocol specifications.

Soldiers need to know exactly what is going on during an operation so they can make decisions that are correct and on time. Choices can determine whether someone lives or dies. So it is very important to be able to share information safely. Because of our TDL skills, this is possible. During ongoing activities, our cutting-edge, flexible, and secure data system sends information that is accurate and reliable about the situation.[67]TDL enables the command to issue directives electronically to the frontline, reducing pilot and troop strain

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and ensuring detail accuracy. TDLs are long-distance, high-capacity wireless transmission lines that connect nodes for data transmission and reception. They are used to establish secure wireless communications between two radios that are separated by a significant distance.[68]

Again, Common Data Link (CDL) is a secure military communication protocol used by the United States. The United States Department of Defence created it in 1991 as the military's basic procedure for images and signals intelligence. CDL runs at data speeds of up to 274 Mbit/s in the Ku band. CDL enables full duplex data sharing. CDL enables full duplex data sharing. Common data link (CDL) Interface Boxes (CIBs) transmit, receive, synchronize, route, and simulate CDL signals. The Tactical Common Data Link (TCDL) is a secure data link that the United States military is developing to deliver secure data and streaming video communications from airborne aircraft to ground stations. The TCDL can accept data from a variety of sources, encrypt it, multiplex it, encode it, transmit it, de-multiplex it, and route it at high speeds.[69]It has a narrowband uplink that is used to handle both the payload and the vehicle and a wideband downlink that is used to send and receive data. Again, the TCDL sends and receives Ku band signals using both antennas that point in one direction and antennas that can point in any direction. The TCDL was made for unmanned aerial vehicles (UAVs), like the MQ-8B Fire Scout, as well as non-fighter situations with crew. The TCDL sends radar, picture, video, and other sensor data at speeds between 1.544 Mbit/s and 10.7 Mbit/s over distances of up to 200 km. It is also hoped that, in the future, the TCDL will be able to handle the higher CDL rates of 45, 137, and 274 Mbit/s that will be needed.[70]

Today, one of the most critical operational situations for all armed forces is having faster and more accurate information on the exact positions and conditions of their forces-troops on the battlefield than the enemy forces. HavelsanDoob, for example, is a suitable Command and Control Information System (C2IS) capable of ensuring situational awareness for fast and accurate information sharing on the battlefield, generating an operational picture through operational planning, and facilitating the critical decision-making process.[71] It has designed for effective management and protection of their troops to be ensured, while high performance is provided for the operations to be carried out with minimum damage and success. It has easy installation and user-friendly interface. Its constant communication and reporting process to the headquarters improves the situational awareness in all units.

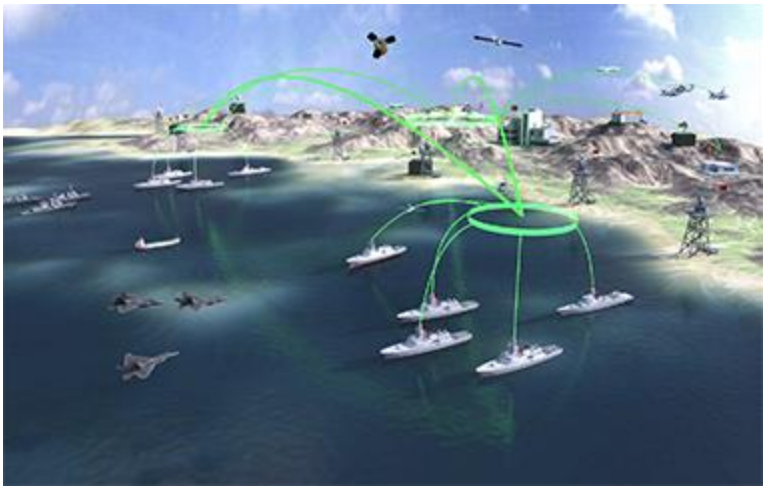

Figure 4: Example of C2IS capable of ensuring situational awareness on battlefield[72]

TDL is still one of the most important ways for military devices that are spread out over a large area to share information. Link 16 is the TDL that NATO and many other military units use the most. Even though Link 16 was put into use for the first time in the 1990s, it and its different parts have been constantly improved, making sure that it will still be useful in the future. Link 22, also called NILE, is the latest TDL built to replace Link 11. It is now being used. Mainly, marine systems are planning to use Link 22 because it can connect systems that aren't in direct line of sight (BLOS). When different TDLs are used, it becomes important to send data between them so that the right data is available at the right time. Management of data sharing is an important part of making sure that the different TDLs don't get too busy. For instance, the JCSys team has been working in the international TDL area for a long time and is made up of experts who are known around the world by users and customers. The team has a lot of information and experience about how TDLs work and how to run and manage them.[73]

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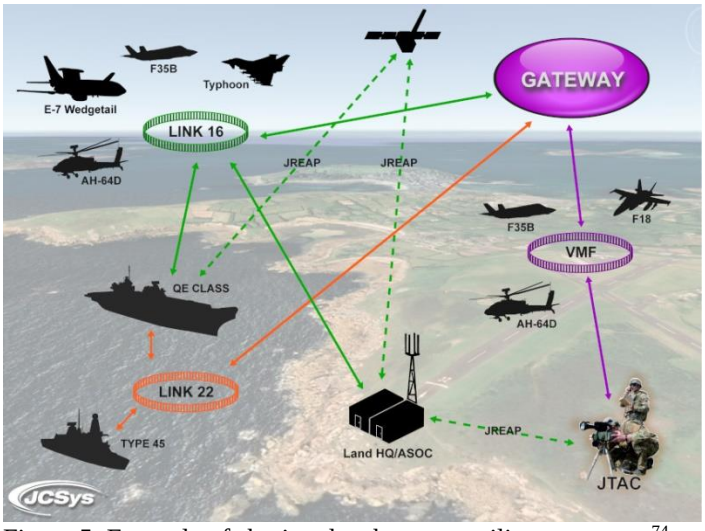

Figure 5: Example of sharing data between military systems [74]

Interoperability is the capacity of assets to provide services to and receive services from other assets using common standards to facilitate effective data exchange and system operation. Interoperability is a crucial aspect of the entire TDL life cycle, affecting multiple levels, including RF, data, protocol, and the Human Computer Interface (HCI). These levels characterize the physical transfer of messages, the message itself, compliance with defined protocols, and the correct display and interpretation of information by receiving operators. The implementation of message formats at the bit level has a direct effect on the precision and accuracy of the data exchanged. Understanding and administering the capabilities and limitations of each TDL-equipped platform requires accurate documentation of each platform's bit level implementation.[75]

TDL Hardware and software

TDLs hardware and software make up TDLs system. TDL's hardware consists of numerous components, including the radio itself, the RF generator, and the intelligence that is moved across that radio over the waveform in a network-centric style. They are governed by MIL regulations. According to Marty McDonough, President and CEO of Tactical Communications Group (TCG), 'Link 16 is constantly being enhanced.' The capacity to transfer pictures into the cockpit of an F-15 Strike Eagle or an F-18 Hornet via advanced digital data links is an example of Link 16's cutting-edge technology. In addition, has the ability to create a Weapons Data Link (WDL), which allows Link 16 to be used over the airways to guide smart weapons after they have been released from the delivery platform. Marty McDonough, on the other hand, formed TCG in 1994 as an R&D section of Dynamics Research Corporation (DRC). Marty worked as an Airborne Intelligence Analyst in the U.S. Air Force. He has also worked for the NASA as an Intelligence Analyst.[76] He also said, 'Some people say the Link 16 system is really a Cold War 'artifact'. Actually Link 16 is 35 year old technology. It's a very complex, tiny, secure system. But the system has been plagued by costs around US$ 1 million apiece in the early days. The cost has come down drastically, but there are only three sources of those radios at this time; ViaSat in California, a consortium of BAE and Rockwell Collins, and a European consortium called EuroMIDS.'

There are a lot of data links, like Link 16, which we talked more about, as well as Link 11 and Common Data Link (CDL). CDL is more of a way to send wideband or high-demand information, live video, and other things. But we no longer use teletypes that can type 24 words per minute! Today, TDL can help keep an eye on the fight space in one way or another as threats change and troops need to stay in touch. It is very important to get that processed data into the right hands and in front of a Strike Force as soon as possible. Even though Link 16 is 35 years old, it is sometimes called an "artifact" of the Cold War. It's a very small, complicated, and safe device. But initially, each part of the device cost about $1 million. The price has gone down a lot, but there are still only three places to get these radios: ViaSat in California, a group made up of BAE and Rockwell Collins, and a group called EuroMIDS in Europe.

Today, TDL improve situational awareness and accelerate the decision-making process, making them essential to facilitating information advantage at every level. Despite the proliferation of multiple data sources, gateways, and broadcasting mediums, Link 16 or Link 22 TDLs continue to be the resilient bearers of choice on the battlefield, with their utility in connecting government and civilian agencies growing. Few TDL solutions (such as Metrea or ASTi) have designed and delivered Link 16 (or Link 22 in the future) solutions to a diversity of Air, Land, and Maritime users/customers.[77] They usually combine the expertise of their TDL software and systems engineers with the operational experience of expert personnel to deliver innovative, modified solutions that provide cost-effective capabilities to the users/customers.[78]They provide entire end-to-end TDL solutions, from original needs to TDL terminal and ancillary provision, platform installation, certification, and commissioning. Excellent modular connection software solutions that address minimal size, weight, and power constraints.A good TDL system need to be fulfill few requirements; like: multi link planning tools for complex

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systems; cost-effective walk on walk off Link systems; suite of end-to-end test, evaluation, verification, and validation tools including Link terminals; synthetic link capabilities to support the Live Virtual Constructive training environment; link basic software interfaces into platform mission systems and dismounted user devices; multi TDL training and consultancy services, after sale service and technical support system,[79] etc.

Next couple of paragraph will be discussed about the basic TDL software.[80]The U.S. Navy, Air Force, Army, Marine Corps, and other joint Services continue to integrate TDL capabilities into their platforms. As a result, it is not surprising that simulation requirements for this established TDL continue to increase. There are numerous aspects to the modelling of TDL, but the fundamental concept remains that data is transmitted over a radio frequency link, and in many cases uses the same transmitter and receiver as audio communications. Therefore, it makes sense to utilise the same system that manages voice for data transfer. The fundamental TDL interface software permits the transmission of host-origin data via radio model objects and correct reception based on fundamental radio characteristics. Using this strategy guarantees that this behaviour is supported in both local and networked environments.[81] Again, Elsis PRO Link 22 DLP is the most lightweight customized implementation.[82] It is a software based formatter/deformatter plug-in with or without tactical user interface, dedicated for C2/C3/C4 and other variations of command and control systems like C5ISR. Curtiss-Wright's TCG LinkPRO is another standards-based, high fidelity, software-only, multi-link, TDL processing engine that improves tactical communications, reduces the time, risk, and expense of TDL integration, alleviates interoperability issues, and lowers lifecycle maintenance costs for military forces and other organizations worldwide.[83]LinkPRO ensures reliable communication between all link participants by supporting a variety of terminals, radios, and communication protocols such as Link 22, Link 16, Link 11, SADL, VMF, and JREAP. Key Features of this software are:[84]

- Multi-link message processing capability
- Has embedded, software-only, TDL train
- Has full-featured API
- Has IP based host connectivity
- Low level protocol off-loading capability
- Dynamic message routing capability
- Has automatic R/C, R2, and message responses
- Multiple Terminal Control capability
- MIDS JTRS, STT, TTR, LVT-1, 2, and 3
- JREAP, VMF, SADL
- Use Windows or Linux

As a result, LinkPRO has employed for TDL processing, tactical communications, and TDL integration. This multi tactical data link solution is adaptable to any tactical host. Such as: a stand-alone system with a full-featured API or embedded into a host mission software suite made possible by flexible IP-based host connectivity. LinkPRO can be found in command-and-control solutions all across the world. Hardware needs are modest in this case. COMM tact, on the other hand, has launched the Phoenix series of real-time broadband data link solutions, which are intended to enable mission-critical wireless communications for multi-domain military operations.[85]The data links are readily integrated with platforms such as UAVs and UGVs, providing ISR and tactical engagement missions with dependable, high-performance broadband video and data connectivity. Phoenix SR (short range), MR (medium range), and LR (long range) are three variants optimised for link ranges up to 250 km (150 miles) that comprise the Phoenix multi-platform solution. It provides a point-to-point as well as a point-to-multipoint link, acting as a real-time communication relay to surmount line-of-sight issues arising in complex areas and field tasks.[86] The Phoenix has ideal size, weight and power (SWaP) parameters, and advanced error correction techniques and algorithms that enable reliable and robust full-duplex wide-band communications. The system supports two options for tactical combat ground units. Such as:

- RVT: Its enables the combat unit to receive real time data and video from an aerial platform.
- ARVT: Its enables the combat unit to receive and transmit data and video, facilitating control of payloads

The Mini Tactical Command and Surveillance Data Link (MTCSDL) is an advanced digital data link device that is cheap, uses little power, is light, and has a wideband. The system is made to work with mini and small UAVs, observation helicopters, and UGVs, among other things. The MTCSDL is a digital device that can support either a full duplex or a half duplex (TDD) link. Both the uplink and the downlink channels can support forward error correction, AES encryption, and anti-jamming. The link has a transceiver that is small, light and uses little power. This is needed for small robotic aerial vehicles. The Ground Data Terminal (GDT) has a patch antenna, an Omni antenna, and a modem all in one box, which makes it easy to take and quick to set up. The uplink channel of the system is used for command and control, while the downlink channel is used to send video, telemetry, and other possible input data.[87] However, IMC Industries is a worldwide leading provider specializing in state-of-the-art RF modules, microwave components and data link communication systems for defense, and civilian applications. IMC's products supply cutting-edge solutions for aerospace, ground, and maritime platforms and each tailor-made configuration is suited for MIL-STD requirements and a variety of user/customer needs.

TDL System Architecture (For Example Link 11 and its Future)

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A Link-11 network consists of a Network Control Station (NCS) and a number of Participating Units (PU) or picket stations. The NCS is a participating unit in the link 11 architecture and that act as a common control station and permits access to the net as well as maintains net operational discipline.[88] Figure 6 below depicts the fundamental on-board system architecture of the Link-11 system. Each unit is equipped with a data terminal set (DTS), computer for the Tactical Data System (TDS), encryption hardware, and radios for communicating with other units. The following is a quick explanation of each part:

- **Tactical Data System (TDS).** It is in fact a computer and has the capacity to receive data from sensors, such as radar, navigation systems, and operators. It can collect the information in digital data bases. The TDS computer features a memory buffer that stores incoming and outgoing messages. This computer manages a database which consists of information on enemy position fixes, tracks, information on own PUs, vessels, aircraft, sonobuoys, etc. The key functions of the TDS include supplying tactical digital information to the net participants, retrieving and processing incoming digital tactical information received from other net participants, managing the display functions for the operator, performing track updates on contacts, and replying to operator inquiries.

- **Encryption Device:** It is a device which has the capacity to encrypt data from the TDS computer when transmission occurs and sends it to the DTS (as shown below in figure, transmission). When the PU is receiving, encrypted data is received from the DTS, then decrypted and sent to the TDS computer (as shown below in figure, receiving).

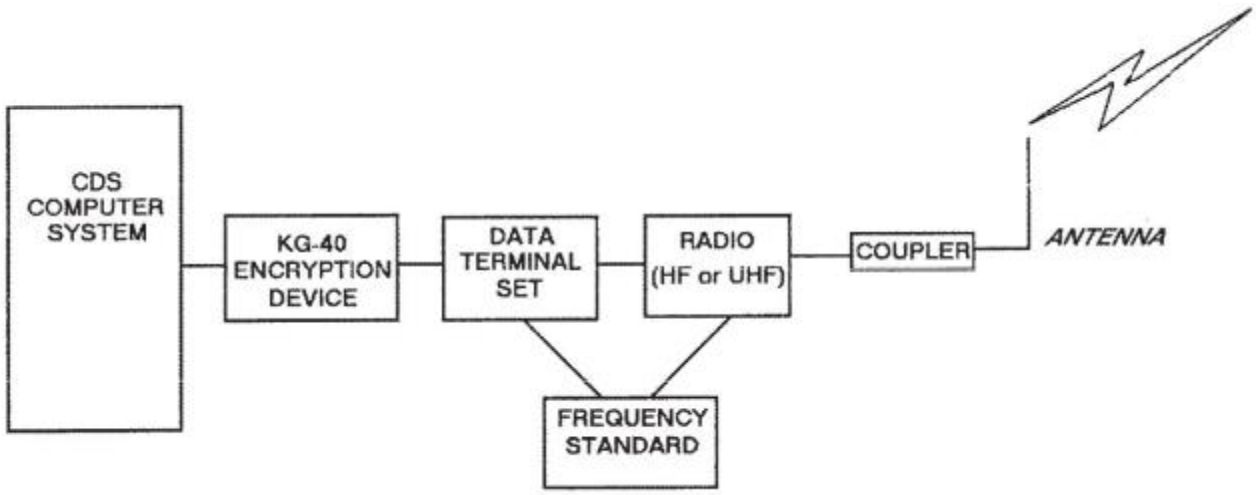

Figure 6: Onboard system architecture of the Link 11[89]

- **Data Terminal Set (DTS).** The data terminal set (DTS) is the heart of the Link 11 system that acts as the system modulator/demodulator (MODEM). The TDS computer sends 24 bits of data to the DTS via the encryption device. The DTS adds 6 bits of data (known as hamming bits) for error detection and correction. Now, the 30 bits of data are phase-shift modulated into 15 audio tones. These 15 data tones and a Doppler correction tone are combined to generate a composite audio signal, which is then sent to either the UHF or HF radio equipment for transmission. While receiving, the DTS receives the composite audio signal from the radio and separates the 15 data tones and the Doppler correction tone, demodulates the 15 data tones into 30 data bits, ensure the 6 hamming bits for errors, and sends 24 bits to TDS computer via the encrypted device. DTS's normal mode of operation is in the half-duplex mode when it can either transmit or receive. The key functions of the DTS include error detection and correction, audio signal generation, link protocol control; NTDS (Navy TDS) interface control, and digital/analog conversion.[90] Link 11 offers the following six modes of DTS operation:
  - **Net Synchronization:** This mode of operation permits the terminal of each picket station to synchronize its internal timing to that as used by the net control station (NCS) terminal. When the task force is formed, the picket stations inform the NCS of their readiness to establish link operations. Upon establishing communication with all picket stations, NCS transmits Net Synchronization.
  - **Net Test:** This mode of operation is used to confirm connectivity between the Link 11 units. Upon completion of the Net Test, all picket stations report their status information to the NCS. After that, the NCS directs all PUs to switch to the Roll Call mode and initiates link operations.
  - **Roll call mode:** This is the normal mode of Link 11 operation that provides full utilization of force area surveillance and tracking capabilities. In the roll call mode, one unit operates as the NCS, while the other units operate as the picket unit. The NCS initiates the roll call by addressing and transmitting an interrogation message to a specific PU that then responds by

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transmitting its data. The NCS then call up the next PU address for interrogation.[91] The roll call mode is used to provide all PUs with continuous, near real time exchange of tactical information.

- **Broadcast:** In this mode, one PU will continuously send a series of short broadcast messages to all the members of the net. Once manually initiated, the transmission will continue to be sent automatically until the operator stops it manually. **Short Broadcast:** In this mode, a picket station or the NCS sends a single message to all members of the net. The data transmission is initiated by the operator and is terminated automatically when the computer has finished sending the DTS data.
- **Radio silence:** This mode allows a unit to receive Link 11 data but does not allow the unit to transmit data. This mode is typically used just prior to joining an active net in order to sync its TDS with the NCS.

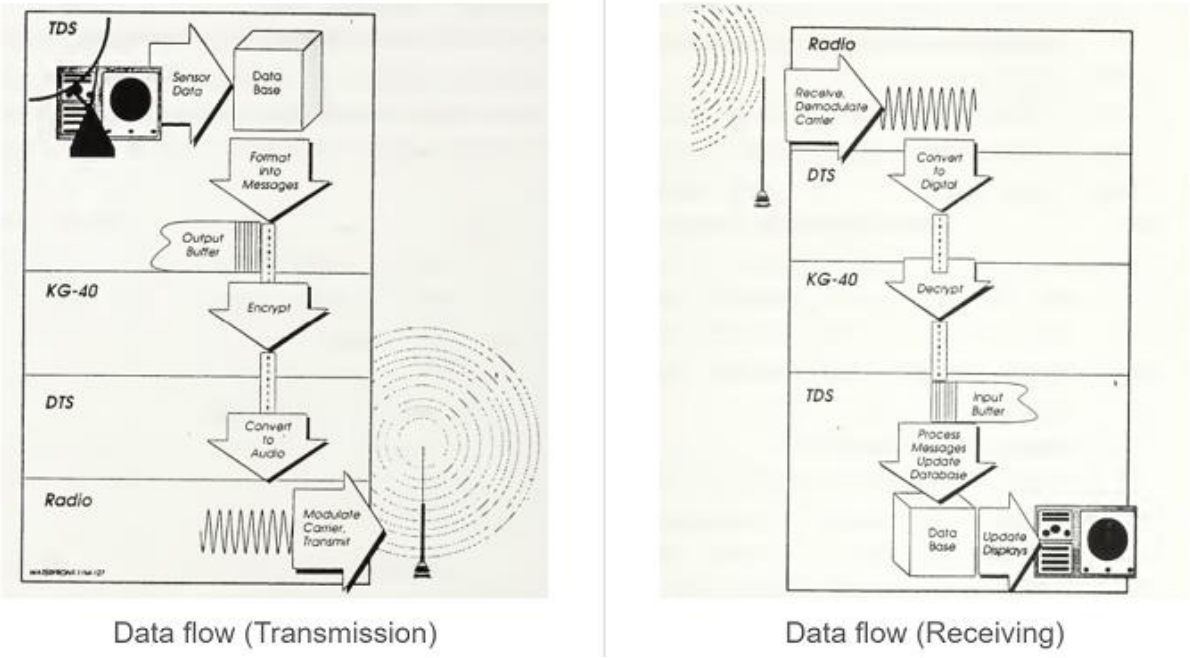

Figure 7: Transmission and receiving data flow of the Link 11[92]

- **Radio HF or UHF.** Link 11 uses two frequency bands like, a HF band and another in the UHF band. In the HF band, it has a ground wave range of up to 300 nautical miles and may reach a sky wave range of 1000 nautical miles. In the UHF band, it can cover the LOS range of 20 to 30 nautical miles for ship to ship connections and covers 150 nautical miles for ship to air connections. The link 11 system uses Quadrature Phase Shift Keying (QPSK) modulation and can broadcast packets of 30 bits length, with 6 bits of error correction and 24 bits of payload data and that is encrypted. As we know that, QPSK is a form of phase modulation technique, in which two information bits and combined as one symbol are modulated at once; selecting one of the four possible carrier phase shift states.[93] The Link 11 network can operate at two different data rates, the fast data rate operates at 75 frames per second (2250 bps for UHF), and the slow data rate operates at 45.45 frames per second (1364 bpsfor HF). Up to 61 participants like, ships, submarines, aircraft, and shore facilities and can be hosted on a Link 11 network at any one time. The system normally operates in a roll call mode under the control of a NCS.

Link 22 is anticipated to succeed Link 11 in 2024. Link 22 is an encrypted digital TDL and that operates in the HF and UHF frequency bands. It was devised by NATO to facilitate the secure exchange of information between all allied forces like, air, ground, and sea. Link 22 supports LOS and BLOS communication connections up to 300 nautical miles in the HF band. It provides a secure means of communication between allied forces.[94] Link 22 is even able to operate in bad transmission conditions and provide a stable communication link at lower data rates. It is based on a distributed architecture, so even if a specific unit fails, the network will continue to operate.[95] Link 11 had some problems, so the Link 22 program was made to replace it, and make it easier for allied troops to work together, and fill in the gaps left by Link 16. Again, Link 22 is also known as NILE, and which stands for NATO improved Link 11. However, Link 11 is being replaced by Link 22 TDL, which has a lot more capabilities. For example, it can handle up to 125 participants and get data rates of 4 kbps for an HF network and 12 kbps for a UHF network. Link 22 gives allied troops a way to talk to each other that is safe. Link 22 can even work when there isn't a good signal and still provide a safe way to talk at lower data rates. It is based on a distributed design, which means that even if one part stops working, the network will still work.[96]

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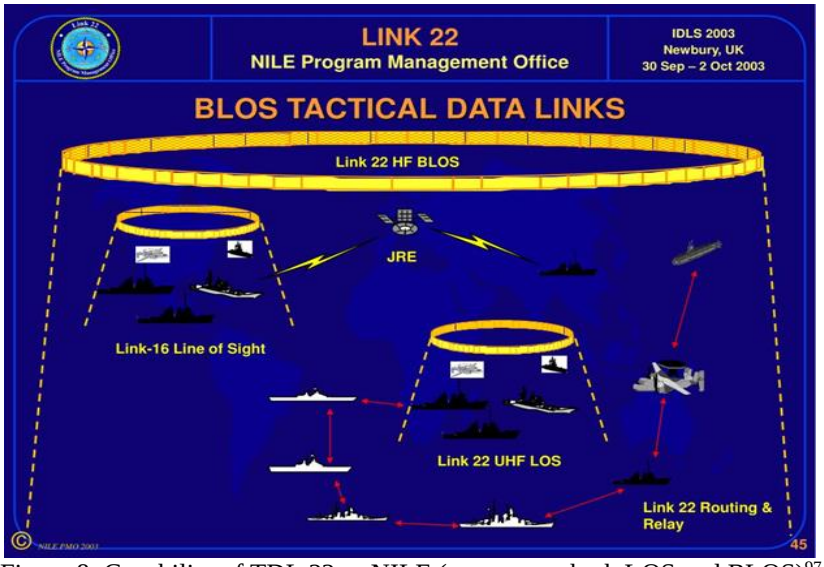

Figure 8: Capability of TDL 22 or NILE (encompass both LOS and BLOS)[97]

It is expected that, Link 11 will remain the chief naval tactical data link for another ten years; it will be gradually replaced by Link 22 from about 2024. Renowned company like Lockheed Martin, are committed to helping the Department of Defense of U.S. and its allies act with greater comprehension and decisiveness than ever before.[98] There are seven countries that use Link 22 and those are: Canada, France, Germany, Italy, Spain, United Kingdom, and United States. Spain replaced the Netherlands to become the 7th country and the U.S. is the host nation.[99] However, in future, every military forces (army, navy, air, marine, space) will be deter rapidly evolving threats across all domains like, land, air, sea, space, and cyber.[100]Joint All-Domain Operations (JADO) integrates platforms, sensors, weapons, and joint all-domain command and control (JADC2) systems with radical innovation to provide a complete picture of the battle-space and enable prompt, decisive action.[101]A Multi-Link battlefield scenario for joint operations in 21st century has been shown in figure 9 below.

Figure 9: Multi-Link battlefield scenario for joint operations in 21st century[102]

Relation of TDLs with C5ISR, XMPP and HF Radio

C5ISR. The broader context for TDLs is Command and Control (C2) which is a part of NATO and national command, control, communication, computers, cyber, intelligence, surveillance and reconnaissance (C5ISR).[103] However, for the most formidable and supper power nation on earth, C5ISR systems depend on secure, timely, and error-free communications among US forces. Data Intelligence (DI) engineers provide both Test & Evaluation (T&E) and standards development support to a variety of US Navy, US Army, and Joint C2 systems.[104] The other key communication technology for C2 is Message Text Formats, as part of the TDL framework. C2 Systems must support the MTF (Message Text Format) protocols.[105] TDLs are generally considered to be utilized on closed networks in which all nodes are connected. C2 systems will typically have a larger reach, and the XMPP considerations pertain to supporting C2 systems with nodes outside the TDL. However, the Basic function of TDL for Command and Control (C2) defines the

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requirements for a Joint Tactical Information Distribution System/Multifunctional Information Distribution System (JTIDS/MIDS) Unit (JU) to participate on a Link 16 interface and is subdivided into two additional subfunctions, namely, defining the requirements for a Joint Tactical Information Distribution System/Multifunctional Information Distribution System (JTIDS/MIDS) Unit (JU) to participate on Terminal: This sub-function defines the message requirements for JU participation on a Link 16 interface for the terminal. This sub-function defines the JU host message requirements for supporting the friendly position and status, as well as the message exchange capabilities.[106] For a C2 platform, basic functions are:[107]

- Platform Situational Awareness;
- Network Management;
- Air Surveillance;
- Surface Surveillance;
- Subsurface Surveillance;
- Land Surveillance;
- Space Surveillance;
- Ballistic Missile Defence Operations;
- Electronic Warfare;
- Weapons Unit;
- Air Controlling Unit;
- Command;
- Surface-to-Air-Missile (SAM) Controlling Unit;
- Unmanned Aerial Vehicles (UAV) Controlling Unit;
- Network Enabled Weapon Controller;
- Network Enabled Weapon In-Flight Target Update Third Party Source.

XMPP. eXtensible Messaging and Presence Protocol (XMPP) is the NATO standard for chat and presence. Now question arise, how XMPP can be used to support TDL. For operation over a tactical network it makes sense to utilize optimized TDL protocols. However, TDL information can also be useful in the strategic domain. XMPP provides a flexible high performance mechanism for switching and sharing short messages, and which might be useful for TDL services. There are two integration approaches. Many XMPP services are provided for human users exchanging short text messages, and often using Multi User Chat (MUC) rooms.

- **Gatewaying TDL and XMPP.** The first integration approach is to convert between (binary) TDL messages to XMPP text messages. NATO's experimental work on this approach to integrate between J Messages using JREAP C and XMPP messages led to Isode.[108] However, since 2002 Isode has been developing and supporting commercial off the shelf (COTS) client and server software for secure messaging and directory systems by consideration of XMPP and TDL. NATO's method is based on the Networked Interoperable Real-time Information Services (NIRIS), which is integrated with XMPP. NIRIS is a middleware application and that offers situational awareness data to specialized functional area systems. TDL services may include free text messages. It's only natural to convert these to XMPP, so that TDL users can talk with XMPP. Again, users and TDL messages can be shared in MUC rooms. TDL communications can also be converted into human-readable representations. This could be useful for providing easy human monitoring of TDL data. This could be useful for low-volume data streams that can be easily comprehended by humans. While this strategy could be utilized for information application management, the second appears to be preferred.

- **Using XMPP as a TDL Transport.** The second strategy is to utilise XMPP to transport binary TDL messages. XMPP messages consist of XML stanzas that can transport any payload, not just text messages. It would be simple to encapsulate TDL communications inside of an XMPP stanza. This complements TDLs employing native transport and facilitates TDL interconnection. The benefit of this encapsulation method is that any TDL message can be readily transported over XMPP and extracted for processing by a system capable of handling TDL messages. This provides a highly flexible approach to the distribution of messages, notably for the many TDL-provided system monitoring activities. This approach has the advantage of being able to utilise a distributed messaging infrastructure, which enables TDL distribution to interested parties who are not physically connected to the TDL network. This can facilitate strategic locations and access to TDL information across domains. Another potential advantage of XMPP transport for TDL is the use of XMPP PubSub. XMPP includes a publish-subscribe capability, also known as PubSub. PubSub is a building element for other applications and is not directly used by humans; therefore, its capabilities and benefits must be demonstrated.[109] In this publish subscribe mechanism, TDL messages would be routed to an XMPP PubSub node. Systems interested in some or all of these messages could subscribe to the node with an appropriate filter, and that would enable the node to be sent messages of interest. This provides a flexible mechanism for wide and selective rapid distribution of TDL. This filtering can also be used to constrain traffic on networks of limited bandwidth.

TDL over HF Radio. One of the NATO Standards for Data Application over HF Radio is STANAG 5066. The STANAG 5066 HF link level protocol is used by most military apps that use HF. As we all know, STANAG 5066 is a NATO standard for using HF radio to run data apps.

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STANAG 5066 works with an HF modem and gives data program a way to use and share an HF modem. It gives applications the core data link services they need to work well over HF radio, and it defines a protocol that makes it easy to keep the applications and modem/radio levels separate.[110]STANAG 5066 enables applications to share an HF link and makes efficient use of the HF layer. HF systems are both expensive and large. Because the quantity of RF noise inhibits receiving when a radio is broadcasting, HF systems normally work half duplex. Physical separation is required to run duplex or multiple HF channels. On land, this is simple, as transmit and receive stations are often positioned many kilometres apart. This separation can also be accomplished with caution on big movable units, such as a huge ship. This is not feasible for small mobile units. Because of size and separation restrictions, it is often preferable to have applications share a single HF channel. STANAG 5066 is intended for application multiplexing. Link-11 and Link-22 each describe their own high-frequency link protocols. This means that TDL cannot share an HF channel with other apps using existing standards. For data exchange over an HF Channel, three main designs exist: CSMA (Carrier Sense Multiple Access), WTRP (Wireless Token Ring Protocol), and TDMA (Time Division Multiple Access).

For TDL use of an HF channel, it makes sense to use TDMA and, in particular, the strong protocol of Link-22. It is a fair and strong way to do things. For general use, the best choices are HF, CSMA, and WTRP. But CSMA works best in networks with few users, while WTRP works best in networks with many users. When TDL needs to share a channel with other apps, it would make sense for it to use a good solution that can be used for many different things. TDL data, on the other hand, usually needs to be sent quickly, so it is possible that it would be given a high priority so that it is sent before applications. This choice and other factors like maximum transmission time would rely on the overall application and quality requirements. Again, HF surface waves travel a long way past where you can see them, especially over water. This makes it a good way for a military task group to share the channel and talk to each other. This set-up usually has good propagation, so it would make sense for TDL and other apps to share these HF links. HF Sky-wave, on the other hand, is a more difficult way to talk. Most of the time, it's best to work between two nodes and use ALE (Automatic Link Establishment) to find a frequency that works between two nodes. This is much better than set frequency, which is what Link-11 and Link-22 use. If you use ALE, you'll be able to connect better in tough situations.

TDL Market Trend and Growth Analysis

Based on solution, the TDL market is divided into two main divisions like, hardware and software. The software segment is projected to be the fastest growing segment. The growth of the segment is due to the growing adoption of advanced processing software from the defense forces. The software system is used to enhance the capabilities of hardware components by providing seamless connectivity among hardware systems. In January 2021, Defense Advanced Research Projects Agency (DARPA)[111] developed software and that bridges multiple disparate radio networks to enable communication between incompatible tactical radio data links. In 2021, the hardware segment retained a sizable market share. Sensors, antennae, weapon data link controllers, and processors are among the advanced hardware components in the TDL system. As a result, the expanding use of a tactical data link system as a result of rising international security concerns and political tensions among neighboring nations is likely to drive segment expansion. Growing demand for Link 22 will help to expand the size of the other category during the coming decade.[112]

Depending on the type of data link, the TDL market is divided into Link 16 and others. Link 16 will keep getting bigger over the next few years. The segment is growing because more and more units in the air, on the sea, and on the ground want options that use the link 16 network. Link 16 is a data link that allows tactical command, control, communications, computers, and intelligence (C4l) devices to share information. In January 2021, Viasat Inc., a global communications company, announced that it had increased production run rates to over 200 Non-Developmental Item (NDI) of Link 16 Next-Generation Tactical Data Links radios per month to meet current interest and pending orders from U.S. and international defence customers. So, the need for these high-tech devices will continue to grow over the next ten years. Link 1, 4, 6, 7, 10, 11, 14, 22, SADL, Inter/Intra, Flight Data Link (IFDL), Situation Awareness Data Link (SARL), JREAP, and SIMPLE are all types of data links in the other section. The group had the biggest share in 2021, and it is expected to keep growing at the fastest rate. This growth is because the U.S. and other NATO countries are buying more systems that use the Link 22 network. Link 22 can communicate BLOS, so the growing use of drones for BLOS operations is likely to increase the need for Link 22 in the future. Link 22 is also the newest NATO standard for how military groups can share tactical information with each other. The structure of the Link 22 network layer lets any type and amount of data be sent with automated routing and relaying.

Military R&D spending is increasing and that leads to the development of network enabled weapons (NEWs) and the collaboration of human and unmanned systems. Western air forces are confronted with two key trends like, the expansion of Integrated Air Defence Systems (ADS) and that leads to more complicated and difficult operational situations, and a fall in the number of western combat aircraft. In addition, the collaboration of manned aircraft and unmanned systems provides the augmented combat mass required in highly contested environments. UAVs, also known as Remote Carriers (RCs), work alongside next generation fighters (NGF) in a variety of missions such as target acquisition and reconnaissance, air to air combat, and airborne electronic attack. According to an updated fact sheet on government expenditures on defense research and development by the US and Other OECD Countries 2020[113] like, the U.S. had spent USD 55.4 billion on defense research and development activities in 2017.[114] However, the increasing use of NEWs is the latest trend in the market. NEWs can find, track, and engage a target faster than conventional weapons.[115] As a result, it helps avoid

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duplication of efforts, reducing the potential for fratricide, de-conflicting operations, and increasing the possibility of real-time target hitting.

Rising International security threats and disputes between neighboring nations are propelling market expansion. The global increase in terrorist activities has remained a major source of concern. This factor increased the defence budget in order to improve the nation's defence capabilities through the adoption of advanced military communication technologies and systems. In addition, the increasing cross-border activities around the world have emphasized the importance of enhancing the capabilities of military application systems. Emerging economies such as China and India are increasing their defense expenditure to modernize the conventional communication system. In addition, these countries are spending on the procurement of UAVs, unmanned underwater vehicles (UUVs),[116] and fighter jets. In April 2021, according to new data published by the Stockholm International Peace Research Institute (SIPRI), China and India's military expenditure reached an estimated USD 252 billion and USD 72.9 billion, respectively.[117]

The growing need to improve military personnel safety and security is pushing the development of automated fire control systems. As a result of the introduction of automated fire control systems, there is a greater demand for tactical communication software solutions to control weapon-based systems from a remote location, which drives TDL market growth. Thousands of civilians were killed in 2019 clashes between Saudi Arabia and Yemen. Conflicts between the militaries of Armenia and Azerbaijan, Israel and Palestine, and others caused instability and insecurity in 2020. Thus, increased cross-border concerns and terrorist activities in Middle Eastern countries boost TDL market expansion. The French Armament General Directorate (DGA) granted Airbus Helicopters a USD 11.3 billion contract in December 2021 for the development and procurement of the H160M under the Light Joint Helicopter program (HIL). The SafranEuroflir 410 electro-optical system will be installed on the H160M Guepard, as well as a self-protection package and satellite communication.[118]The growing demand for improved interoperability among armed forces and coalition partners is accelerating the production of advanced system solutions. The interoperability allows the system or arm forces to work together in a particular situation and improve communication security. Therefore, there is an increase in the adoption of tactical data link solutions from end-users due to the increasing need for secure communication.

NATO is an intergovernmental alliance between North American and 31 European countries.[119]NATO communicated with its coalition partners via military data link 16 networks. Link 16 is used to communicate with NATO members in order to command the companion and make decisions. Increasing procurement of TDL systems by defense forces to improve military communication capabilities is again anticipated to drive market expansion. Northrop Grumman signed a three-year contract with the Australian Defence Force Tactical Data Link Authority (ADFTA) in November 2019 to provide TDL systems and training for the ADF's joint data network development.[120]The ADFTA ensured TDL functionality for the Australian Defence Force (ADF) to achieve single, joint, and combined TDL interoperability. NATO has defined a precise standard to which all NATO members and other countries must adhere. However, the market's expansion is hampered by these stringent regulations. Furthermore, defence equipment must meet many military criteria in order to be purchased by defence forces. Aside from military standards, defence equipment must meet the size, weight, and power (SWaP) criteria of military aircraft.[121] The declining defense budget and diverting it to the healthcare sector due to the COVID-19 pandemic has temporarily hampered the growth of the market. For example, South Korea cuts USD 485.8 million from yearly defense budget in 2022 to handle post pandemic.[122] So, declining defense expenditure amid the pandemic and stringent military standards restricts the TDL market growth.

Forecast of TDL Future Market

The global TDL market size was valued at USD 6.64 billion in 2021. The TDL market is accepted to grow from USD 7.00 billion in 2022 to USD 12.00 billion by 2029, exhibiting a CAGR of 7.7% in the next decade.[123] The global COVID-19 pandemic has been unprecedented and staggering, with TDL experiencing lower-than -anticipated demand around the compared to pre pandemic levels. The global market exhibited a low growth of 3.9 % in 2020 as compared to 2019.[124]Different countries make up different parts of the global tactical data link market. Like: North America, Europe, Asia-Pacific, and the rest of the world. The size of the North America market in 2021 was USD 2.52 billion, and the U.S., which spends the most on defence, is likely to be the market leader. More money is also being spent on building advanced military security solutions, and there are a lot of hardware and software developers in the region, which will help the market grow in the coming years. As a member of NATO, the U.S. can use link 1, link 2, link 11, link 16, and link 22 to send and receive tactical info. Over the next few years, the market in Asia-Pacific is expected to grow at the fastest rate. The rise is due to the fact that China, India, South Korea, Japan, Taiwan, and other countries are spending more money on defence. Link-K is the name of the TDL network that South Korea has made.

The South Korean defence department chose Hanwha Systems in November 2020 to develop the main and auxiliary equipment of Link-K, boost its transmission speed, and interlock with international data lines; Europe had a considerable market share last year. Military modernization program of the United Kingdom, France, Russia, and other countries are credited with the increase. The existence of significant companies such as Thales Group, Saab AB, Leonardo S.p.A., and others drives market growth in Europe and the United States, which own the biggest TDL production company/organization. The rest of the world is predicted to increase somewhat during the next few years. The UAE government's growing contract with NATO to boost its military capabilities is expected to help market

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growth.[125] Again, the limited defense expenditure by several countries In the Middle East, Africa and Latin America, except for Saudi Arabia, the UAE, and Turkey is anticipated to restrict the market growth during next few years. However, key TDL companies around the globe are: Elbit Systems Ltd. (Israel);[126] Thales Group (France)[127]; Saab AB (Sweden)[128]; Leonardo S.p.A. (Italy)[129]; BAE System Ltd (UK)[130]; Curtiss-Wright Corporation Ltd (U.S.)[131]; General Dynamics Corporation (U.S.)[132], Honeywell International (U.S.)[133]; L3Harris Technologies Inc (U.S.); Northrop Grumman Corporation (U.S.)[134]; ViasatInc (U.S.)[135]; Raytheon Technologies Corporation (U.S.)[136]; etc.

Future Development and Use of TDL

Multifunction Advanced Data Link (MADL) is a fast switching narrow directional communications data link between stealth aircraft.[137] It began as a method to coordinate between F-35 and that is known as the Joint Strike Fighter. However, HQ Air Combat Command wants to expand the capability to coordinate future USAF strike forces of all AF stealth aircraft, including the B-2, F-22, and unmanned systems. MADL is expected to provide needed throughput, latency, frequency-hopping and anti-jamming capability with phased Array Antenna Assemblies (AAAs) [138] and that send and receive tightly directed radio signals.[139] MADL uses the Ku band. As we know that, K_u band is the portion of the electromagnetic spectrum in the microwave[140] range of frequencies from 12 to 18 GHz. K_u band is primarily used for satellite communications;[141] most notably the downlink used by direct broadcast satellites to broadcast satellite television,[142] and for specific applications. Such as: NASA's[143] Tracking Data Relay Satellite used for International Space Station (ISS)[144]communications and SpaceX Starlink satellites.[145] The Air Force and Navy were directed by the Office of the Undersecretary of Defence for Acquisition, Technology, and Logistics to integrate MADL among the F-22, F-35, and B-2, as well as the rest of the network. Critics argue that because Link 16 is the standard by which US and allied aircraft communicate, updates to Link-16 radios that provide the same capabilities as MADL while retaining interoperability should be promoted.[146] The MADL could be used beyond a four-ship flight.[147]

People are still utilizing Ethernet despite the fact that Link 16 is 35 years old. There are aspects of Link 16 or other types of TDL that are Ethernet-secured. The fixed formatted messages are a comprehensive library of information message standards. And the second component consists of the radio, the waveform travelling about the battlespace, and everything else that a digital radio does. Modern TDL designers are now pushing the J series message, which is the lexicon, across Ethernet or other modes of transmission and getting them out by satellite relay. The aim is to move information in a standard format, which is then visibly, graphically shown on the warrior's display in the cockpit, CIC, or on the ground. So, regardless of our original language or where we come from, the knowledge is all the same, and everyone works together as a team. An excellent analogy is when someone connects with a farmhouse in a very rural area by taking up his phone and dialing another phone number in a modern city that speaks some urban language. However, he cannot communicate with the farmer because they do not speak the same local language.

Today's typical soldier on the battlefield is a young adult between the ages of 18 and 21 who has grown up with these technologies and is entirely at ease with them. Interestingly, the information has such a limited shelf life, so who cares? The military must utilize the most readily available item. The soldier must be able to obtain pertinent information as soon as possible. The monitor is perhaps 4 inches by 3 inches, and it is a display. Today, that is precisely what a combatant need when he is being shot at. If we consider the future of the TDL community, we find that the tactical data link community, which was established roughly ten to twelve years ago, has an International Data Links Society. Participating industries, militaries, and governments represent approximately 40 countries. According to Marty McDonough, "TCG recently established the U.S. chapter of the Society, and there are now approximately 130 U.S. members." The Society was established by industry as a means of communication to organize "everything data links" in industry and make this information accessible to the militaries of the world in a coherent manner.

Equipping users with the latest technology has been, and will continue to be, crucial to the success of Surveillance, and Reconnaissance (ISR) and TDL operations.[148] As the operational environment becomes more RF complex, the way users work with others becomes more complex too. For instance, ISR is used by a number of agencies, from military to government and civil security organizations, who increasingly work together to share information either for inter-agency, or siloed operations.[149] Each user or team has its own independent data exchange requirement, which must remain encrypted and only accessible to those that need access to it. Therefore, compartmentalizing data allows each to access only the data required for their operation, while everything else remains encrypted and inaccessible for viewing. Intelligence analysis often requires the ability to share information securely, especially where such large volumes of data are transferred in real-time.[150] When it comes to TDLs, data throughput can become vulnerable to attacks as the demands from sensors grow. Highly secure, robust TDL technology can mitigate this and ensure data security using sophisticated embedded encryption algorithms. Operational users are also incorporating TDL systems into more multi-role platforms on land, in air or at sea.

Until recently, with a few exceptions, TDLs were primarily utilised in confined areas and for individual duties such as troop transportation, combat search and rescue, or ISR. However, 5th or 6th generation fighter aircrafts are being designed to be multi-rolled,

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which is causing platform integrators and OEMs to design solutions that must incorporate ISR mission systems (at the very least) and C5ISR (in a broad sense) installed across all platforms with the ability to carry on, or rapidly mount and dismount. This finally provides users with more options when deploying ISR or TDL assets. As a result, in the near future, the capacity to reconfigure platforms decreases the load on platform availability, and these same platforms can be successfully repurposed and deployed for the most critical tasks.[151]The conflict in Ukraine has led to a sense of unease across eastern and northern Europe and has put border security to the top of the security agenda. With cross border incursions and mass migration from Ukraine to boarding countries, keeping borders safe is of utmost importance.[152]Since 2022, this means that more ISR and TDL assets will need to be put at the border to keep an eye on things. So, for more effective security and surveillance control across borders and battle-space, it is important that TDL (in general) and ISR (in particular) are deployed in a precise and planned way.

In the future, TDLs will be used in business, and they will improve situational awareness by using the full potential of data flow in tactical and strategic settings. They will be used a lot in business and civil organizations. With the help of business-friendly TDLs of the future, users and customers will be able to take part in various data links from which their TDL system gets information about their desired destinations. Future TDLs will have interfaces, sensors, data link hardware and software, and users/customers will be able to accept, translate, and forward normalized data flow from hundreds of data links to users/customers in the formats they need. Future TDL may use user friendly operating software like Microsoft Windows,[153] Linux,[154] etc. A robust SQL-like[155] language enables users/customers interaction with individual datalink messages or with broad filtration.[156] Those commercial TDLs will facilitate to use text-based, no-code language processor, and enable users to modify forwarding rules, Interface Control Documents (ICDs) and other files via Vim or Notepad. This provides users the opportunity to adjust specifications or network topology for changing tactical situations, and enables inclusion of new datalinks for translation and forwarding within a few hours.[157]

Conclusion

The significance of remote sensors in modern warfare is becoming increasingly important. They transmit live, high-quality video, radar, and audio data in real time, making them essential for Intelligence, ISR. Supporting civil authorities and governments in a variety of operations is greatly aided by the increased speed with which intelligence can be disseminated and decisions can be made as a result of this. Tactical data links provide for the rapid and secure transfer of mission-critical situational data between assets like fixed and rotary wing aircraft and decision-makers in static or fixed command centres, allowing for accurate, real-time sensor intelligence. In order to make better, faster judgements and improve command and control skills in dynamic scenarios, data fusion brings together data from numerous sources in real time to create a more accurate and consistent representation of the operational picture. To deal with the massive amounts of data generated by operational sensors, TDL innovations are continually being made. For instance, customers may now send data further from their ISR capabilities to the point of application thanks to tiny, lightweight, low-power, and high-performance Data Links. Cost-effectively perform ISR missions in the air, sea, or land domain at extreme ranges up to 200 km when integrated with an unmanned system like a drone. Software Defined Radio (SDR) technology is useful for long-range, high-data-rate connections because it allows for multiple waveforms to coexist in the same transmission without disrupting the established, reliable connection. Teams may be able to switch the radio capabilities on the same platform from mesh to point to point LOS long range, depending on the notion of operations and the intended user case.

Today, there have been significant advancements in the technology that encodes and decodes video, audio, and IP data, allowing for the transfer of numerous high-quality movies to deliver more detailed video intelligence for more informed decision-making. However, these enhancements result in marginal gains that are significant. The expansion of technology platforms, from radars and sensors to networks and software applications, provides a challenge to effective, real-time information transmission. TDLs will be widely employed in corporate and civil organizations in the future to provide optimal situational awareness by capturing the full potential of data flow in tactical and strategic environments. Future business-friendly TDLs will enable users/customers to join in many data linkages from which their own TDL system will receive information about their desired destinations. Modern TDL, such as Link 22, will be used successfully in both LOS and BLOS in the future. As we all know, the twenty-first century is the century of digital communication, so TDLs have become essential components for battle-space and even some extend for business/commercial purposes for safe, secure, and appropriate data/information transfer while maintaining the highest level of integrity, which will undoubtedly aid in decision making.

Fortune-business-insights predicted that the TDL market will grow from USD 7 billion in 2022 to USD 12 billion in 2029, with a CAGR of 7.7%. When we looked at the world market share by platform, we found that around 42% of the ground platform, 33% of the air platform, and 25% of the sea platform used TDL. The market is divided into air, land, and sea platforms. The air section is expected to grow the most over the next ten years. This growth is because there is more desire. The rise of the segment will be driven by TDL radio for real-time communication between military personnel and the growing number of weapons and military vehicles bought by defence forces that can connect to networks. The Sea Segment is expected to grow a lot, and that will keep happening. This growth is caused by

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more money being spent on defence and more attention being paid to improving the naval sector because there are more wars going on. This helps the market grow. The marine section is likely to grow as more advanced frigates, destroyers, and other types of warships are made. Link 22 can be used for both LOS and BLOS communications. As the use of UGVs, UAVs, and UUVs for BLOS operations grows, the demand for Link 22 is likely to rise. Again, TDL will be used more in business and commerce in the future.
Even after Link 11's estimated lifespan of 2023, the same tactical radios can be used with Link 22. However, in order to send and receive Link 22 communications, a new Data Link Processor (DLP) and System Network Controller (SNC) will need to be implemented. The NILE Project Management Office uses the only version of the latter, but there are other versions of Link 22 DLP in use. Connecting tactical data systems in the air, on the surface, below the surface, and on the ground is what Link 22 is all about. As a combined capability, landlocked countries as well as maritime ones can benefit from Link 22. As a matter of fact, flaws in Link 11 were the inspiration for Link 22. Once again, Link 22 works with Link 16 and will eventually take the place of Link 11. Yet in the twenty-first century, all armed forces must be able to deter attacks in all domains, including cyberspace, the cyber-aerial domain, the cyber-sea domain, and the cyber-land domain. The United States Department of Defence and its allies have the support of well-known corporations (such as Lockheed Martin) and research institutions that are dedicated to improving their operational understanding and decision-making. Threats can be deterred in seconds rather than minutes by utilizing data from all possible sources on the All-Domain battle-space. In the future, JADO will integrate all forms of platforms, weaponry, sensors, navigation equipment, and JADC2 systems in a creative new way to give commanders a clearer view of the battle field and aid them in making quick, effective judgements. Therefore, in the event of a crisis or actual war, all commands across all domains will be able to make more informed decisions on the battlefield thanks to the future TDLs system.

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