ANALYSIS ON LINK-16 TACTICAL DIGITAL INFORMATION LINK (TADIL) SYSTEM NETWORKS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
ÇANKAYA UNIVERSITY

BY
KAAN KIR

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
ELECTRONIC AND COMMUNICATION ENGINEERING

DECEMBER 2010

Title of the Thesis: **Analysis on Link-16 Tactical Digital Information Link (TADIL) System Networks**

Submitted by **Kaan Kır**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University

Prof.Dr. Taner ALTUNOK

Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Assoc.Prof.Dr. Celal Zaim ÇİL

Head of Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Assoc.Prof.Dr. Celal Zaim ÇİL

Supervisor

Examination Date : 01.12.2010

Examining Committee Members:

Assoc.Prof. Dr. Celal Zaim ÇİL	(Çankaya Univ.)	
Asst.Prof. Dr. Asım Egemen YILMAZ	(Ankara Univ.)	
Dr. Cebrail TAŞKIN	(Türk Telekom)	

STATEMENT OF NON-PLAGIARISM PAGE

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name	:	Kaan KIR
Signature	:	
Date	:	01.12.2010

ABSTRACT

ANALYSIS ON LINK-16 TACTICAL DIGITAL INFORMATION LINK (TADIL) SYSTEM NETWORKS

KIR, Kaan
M.Sc Department of Electronics and Communication Engineering
Supervisor : Assoc.Prof.Dr. Celal Zaim ÇİL

December 2010, 30 pages

Link-16 Joint Tactical Information Distribution System (JTIDS) allows a tactical information exchange between air, ground and naval units near real time in the presence of adversary units. Link-16 employs the Time Division Multiple Access (TDMA) technique for data communication, and at the same time by using frequency hopping capability and encryption properties interconnects various units simultaneously in synchronized nets concurrently near real time in accordance with the mission requirements. In this study, a network design and management tool is developed that designs, programs and manages the Link-16 Network. This tool's objective is to effectively and reliably distribute the time slots among the tactical participants based on the mission requirements and scenario.

Keywords: Network Management Tool, Link-16, Joint Tactical Information Distribution System, Time Division Multiple Access

ÖZ

LİNK-16 TAKTİK DİJİTAL ENFORMASYON LİNKİ (TADIL) SİSTEM AĞLARI ÜZERİNDE ANALİZ

KIR, Kaan
Yükseklisans, Elektronik ve Haberleşme Mühendisliği Anabilim Dalı
Tez Yöneticisi : Doç.Dr.Celal Zaim ÇİL

Aralık 2010, 30 sayfa

Link-16 Taktik Enformasyon Dağıtım Sistemi hava, yer ve deniz unsurları arasında düşmanın da bulunduğu ortamda gerçek zamanlı taktik enformasyon değişimine olanak sağlar. Link-16, veri haberleşmesinde Zaman Bölmeli Çoklu Erişim prensibini kullanır, aynı zamanda frekans atlaması ve kriptolama özelliği sayesinde görev farklılıklarına göre çeşitli unsurları gerçek zamanlı olarak eşzamanlı ağlar içinde birbirine bağlar. Bu çalışmada Link-16 ağını tasarlayan, programlayan ve yöneten bir ağ yönetim aracı geliştirilmiştir. Bu ağ yönetim aracının amacı zaman dilimlerini görev ihtiyacına ve senaryoya göre taktik unsurlara etkin ve güvenilir bir şekilde dağıtmaktır.

Anahtar Kelimeler: Ağ Yönetim Aracı, Link-16, Taktik Enformasyon Dağıtım Sistemi, Zaman Bölmeli Çoklu Erişim

ACKNOWLEDGMENTS

I would like to extend my gratitude to my supervisor, Assoc.Prof.Dr. Celal Zaim ÇİL, for the support and guidance I received from him. Without his supervision, this work would not have been a reality.

I would also like to thank Asst.Prof.Dr. Asım Egemen YILMAZ and Dr. Cebrail TAŞKIN for agreeing to be on my thesis committee and reviewing my thesis.

Finally, and most importantly, I would like to thank "to my family", for all the support and encouragement I received during the course of my education. Thanks for pushing me to be the best, and giving me a shoulder to lean on when times were hard.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

Abbreviation of symbol	**Term**
AAR	After Action Review
ASW	Anti Submarine Warfare
AWACS	Airborne Warning and Control System
C2	Command and Control
EW	Electronic Warfare
FDL	Fighter Data Link
FDMA	Frequency Division Multiple Access
FJU	Forwarding JTIDS Unit
GIS	Geographical Information System
HUR	High Update Rate
IEJU	Initial Entry JTIDS Unit
IER	Information Exchange Requirement
IJMS	Interim JTIDS Message Specification
IPF	Interference Protection Feature
ISI	Interoperability Systems International
JNDA	Joint Network Design Aid
JTIDS	Joint Tactical Information Distribution System
JU	JTIDS Unit
LOS	Line Of Sight
MIDS-LVT	Multi-Functional Information Distribution System Low-Volume Terminal
MSEC	Message Security
MTPS	Multi-TDL Planning System
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
NECT	Net Entry Control Terminal

NPG	Network Participant Group
P2DP	Packed-2 Double Pulse
P2SP	Packed-2 Single Pulse
P4SP	Packed-4 Double Pulse
PATRIOT	Phased Array Tracking Radar Intercept Of Target
PPLI	Precise Participant Location and Identification
PU	Participating Unit
RF	Radio Frequency
RTT	Round Trip Time
RU	Reporting Unit
SAM	Surface to Air Missile
STANAG	Standardization Agreement
STD-DP	Standard Double Pulse
TADIL	Tactical Digital Information Link
TDL	Tactical Data Link
TDMA	Time Division Multiple Access
THAAD	Terminal High-Altitude Area Defense
TSDF	Time Slot Duty Factor
TSEC	Transmission Security
UHF	Ultra High Frequency

CHAPTER 1

INTRODUCTION

Link-16 is a tactical digital information system. It provides a network to the participants on the surface (land and sea) and in air to exchange tactical information in the presence of adversary. It uses RF frequencies in UHF band and needs a line of sight (LOS) connection between the network participants. Link-16 uses standard formatted message structure, called J-type messages, and both the message security (crypto) and anti-jamming measures are provided. It uses a time-division multiplexing access (TDMA) process for the participants to transmit and receive data. Frequency hopping technique is used to spread the spectrum (anti-jamming) and to establish multi nets in the same area between participants. This property of allocating frequency sequences to form nets can be considered as frequency division multiplexing access (FDMA) process as well. It uses a network participation group (NPG) structure to group the participants towards accomplishing certain tasks.

Link-16 is a NATO standard. Previously, in 1970s, it was named by Joint Tactical Information Distribution System (JTIDS), and introduced by the US Air Force and Navy. A Link-16 or JTIDS system is mainly composed of three subsystems: the terminal, the central processor unit of the platform (mission computer) and the antenna. The mission computer of the platform performs some of the Link-16 functions. The terminal sends internal messages to the mission computer and receives internal messages from the mission computer. Mission computer collects platform specific data required by the terminal either in a periodic fashion or instantly as required (such as the navigation data from the navigation system of the platform, fuel status, weapon data from the platform and the operator actions etc.) and sends them to the terminal. Terminal sends the information related to the positions of the other platforms (friend and adversary), navigation data from the Link-16 system, situation, air control and surveillance information, network time reference etc. to the mission computer.

In the previous applications, due to the level of technology available then, a JTIDS terminal used to occupy large space filling a cabinet and consume considerable amount of power. Due to this reason, only bigger platforms such as a ship, an AWACS aircraft or a land air defense system could accommodate a JTIDS terminal. As technology advanced, the terminals have shrinked to a size that can be accommodated by a fighter aircraft platform. These small terminals are called as the Multi-function Information Distribution System Low-Volume Terminal (MIDS-LVT), or the Fighter Data Link (FDL). With MIDS and FDL nowadays all participating platforms in a tactical scenario can be equipped with these terminals and Link-16 network operations are to be established.

Link-16 is a static link. The network structure is not flexible and the network design, once set-up, would not be changed easily during the operation. Due to this reason the network has to be designed, tested and verified properly prior to the operation. The test and verification of the network design could be accomplished in two ways: either the designed Link-16 network based on the specific requirements and scenario is tested with a previously verified and certified simulation based on lessons-learned, or the designed network is tested in a real exercise or a real operation. Of course, testing in an exercise or operation is very costly, and sometimes could not be tolerated. Simulations of Link-16 system, if they were available, on the other hand would provide the cost efficiency and flexibility. The Link-16 network, designed in accordance with the specific requirements and scenario, would be tested on a simulation and the problems and inconsistencies observed would be corrected before the real exercise or operation. Therefore a better network design with minimum number of problems and inconsistencies are obtained and used in the real exercise or operation by minimizing the need to be changed during the operation. During the operation all the activities, message exchanges and networking activities are closely monitored and necessary information are recorded. After the exercise or operation, an after action review (AAR) is performed and the areas where the corrections and improvements needed are determined and they are modified or corrected. Now the improved and verified network design is stored in a network library to be retrieved again for future uses. When a new network design is required, firstly among the previously designed and tested network designs a proper one is selected and modified in accordance with the new requirements. The designed network is distributed to the participants with an up task message before the exercise or operation.

The Link-16 network should be designed properly first. To properly design the network important arrangements must be made in accordance with the capacity and technical property of the Link-16 system, the types and properties and information exchange requirements (IER) of the participant platforms, and the geographic and topographic conditions of the territory where the exercise or operation will be executed. Based on these, the time slots, message package densities, the frequency allocations, multi-net planning and crypto assignments are calculated and organized and distributed among the participants. A tool is needed to perform these properly. The subject of this thesis is to design a Link-16 network design and management tool.

Link-16 network design tools are available on the market. Some of these are: Joint Network Design Aid (JNDA), TMO 2100, Multi-TDL Planning System (MTPS).

The Joint Network Design Aid from Northrop Grumman Mission Systems is an automated software program used by network designers to create Link 16 networks that satisfy the communication requirements for a variety of missions. THA JNDA supports the Network Design stage and, to a lesser extent, the Network Planning stage of the four stage Network Design and Management Process described in the

Joint Tactical Information Distribution System (JTIDS) / Tactical Digital Information Link (TADIL) J Concept of Operations. The network design contains the baseline data that defines the Time Division Multiple Access (TDMA) connectivity architecture for use by the battle force [1].

TMO 2100 from Thales Group is a Link-16 network design and planning tool using the platform Link-16 initialization and control as well as Link-16 online network management [2]. The tool has the main characters of:

- MIDS, JTIDS, Link 16 and IJMS
- NATO standards
- Multi-platform
- Multi-equipment.

MTPS is a joint development project of two companies: Network Centric Solutions (Tactical Data Link and Network Centric consulting, training, and course development) and ISI Hellas (Tactical Data Link system design and development). MTPS integrates the NAVSEA Capabilities and Limitations database architecture, making it interoperable with all the U.S. forces and any other service or nation that uses this system. This database greatly enhances and simplifies the multi-TDL planning process, especially when integrating multiple platforms, services, and nations [3].

Although such tools are available on the market, they may not meet the requirements of the national Link-16 network properties. As a defense related product, the tools may not be releasable to Turkish Armed Forces' use, or when released there may be some restrictions applied on their export versions and so on. With the developed tool, a network design can be made in accordance with our national Link-16 networking requirements. Our motivation in developing this tool is to provide our national users a tool that they can use without asking any permission from the manufacturer on how to utilize and apply. Since it is an indigenously developed tool, improvement and modification can be done in accordance with the specific requirements or requirements that may not arise now but may occur in future.

Link-16 tactical digital information distribution system is quite a complicated one that has been in use since 1970s in the US and also in NATO. Although introduced a long time ago, it has been upgraded, modified and improved through years so that it is still the mostly advanced tactical digital information system in use in the world. It seems that it will be on the service for many years from now. Link-16 system is quite complicated in the TDMA, frequency hopping and communication and transmission security features. It is prefered not going into details of the features of Link-16 system in this thesis as it is not possible to cover all, but rather leave it to the reader to consult on reference [4], which defines the system features well and in quite detail. Therefore, it is assumed that at least a basic knowledge on Link-16 system features has been acquired by the reader. However, when it is absolutely necessary details of Link-16 are given, as appropriate.

The network design and management tool is developed by using Visual Basic language and has human-machine interface pages for data entry. Data entry is done with developed user interfaces, and tables for network management are created and presented in Microsoft Office Excel. The tool generates scenarios and manages these scenarios using the properties of the Link-16 military communications network.

CHAPTER 2

THE NETWORK DESIGN AND MANAGEMENT TOOL

In the implementation of a Link-16 network in the exercise or actual combat conditions the network pre-design and verification are required. Network design process consists of the following stages:

- Analysis of the operational combat requirements
- Determination of the information exchange requirements (IER)
- Establishment of the network design
- Verification of the network design
- Distribution of the network design to users
- Analyzing and reviewing the operational results,
- Correcting or modifying the initial design as required.

2.1. Data Collection from the User

First of all, the user needs to know the objectives of the generated and prepared scenario. The user must specify this information to the tool.

There are 3 modes of communication in developed terminals to provide Link-16 communication. These are Mode1, Mode2 and Mode4. Mode3 is an invalid mode. In fact, Mode4 described above is called “Mode3” in the NATO standardization agreement (STANAG).

Mode1 is an operating mode, which can be applied with some constraints or full capacity on network capabilities and capacity. According to this mode frequency hopping for the platform is possible. The transmission packing structure is limited to Standard or Packed-2 Single Pulse. Time-slot usage is minimized to a system level of 40% capacity and a terminal level of 20% capacity. Time slot duty factor (TSDF) is designated as 40/20 [5].

In Mode2 all pulses are transmitted on a single frequency so there are no frequency-hopping. Time-slot usage is designated to a system level of 100% capacity and a terminal level of 50% capacity. TSDF is designated as 100/50.

Mode4 is a working state that is lacking the multinetting and management of constraints. There are no frequency-hopping and some communication security processing is eliminated.

With the interface of the network design and planning tool, firstly the user determines which communication mode will be used as shown in Figure 2.1. This communication mode choice is stored in the database. This is important because when allocating time slots to platforms if an overload occurs, the network should be redesigned.

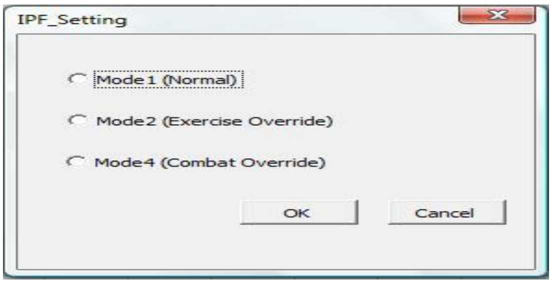


Figure 2.1 Communication Mode Choice

After determining the communication mode the user defines the platforms which will participate in the scenario. The user defines platform name, terminal type and number of items as shown in Figure 2.2. There are four types of terminal to be defined. These are: [5]

- MIDS LVT (MIDS Low Volume Terminal) - Terminals of very small platforms.
- FDL (Fighter Data Link) - Terminals of small platforms with poor capability.
- JTIDS Class 2 - Terminals of big platforms which have most of the load.
- JTIDS/Unknown – The other terminals.

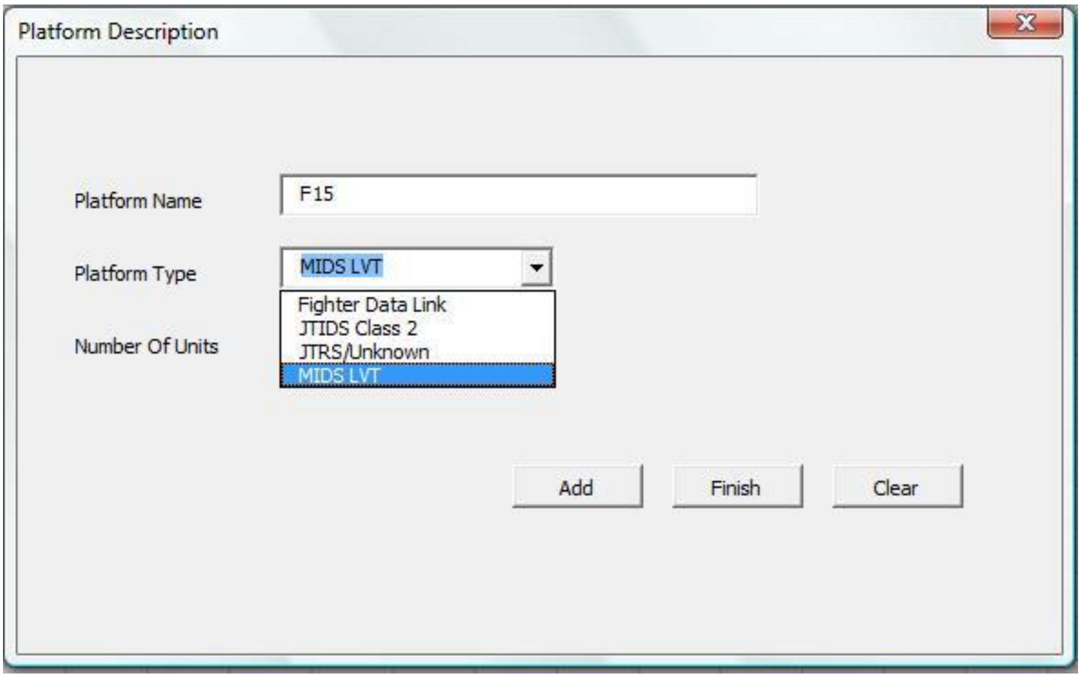


Figure 2.2 Platform Description

After the Platform Description, Network Participant Groups (NPGs) must be defined. NPGs support operational communications needs. They allow the network designer to separate the functions implemented in the J-series messages. Network capacity is first allocated to NPGs, and then to the users that participate in that NPG. Generally, networks are designed to support particular operational goals. The NPGs described here may or may not be included in a given network, depending on the objectives and functional requirements that the network was designed to meet.

NPG 1: Initial Entry

This NPG supports coarse synchronization and entry onto the network. The JU assigned as Net Time Reference periodically transmits net entry messages in this NPG to be used by other terminals in acquiring system time. Net entry messages are also transmitted by any JU defined to be an Initial Entry JU (IEJU), also called a Net Entry Control Terminal (NECT), and by all active relays. The Class-2 terminal transmits the TADIL-J Initial Entry message as the net entry message in the A-0-6 slots on Net 0, unless an alternate net entry slot is designated. This is the first time slot of every frame, and preempts any other assignment that might have been made during initialization. Because this NPG supports coarse synchronization and entry onto the network, it is required for all networks. Every JU participates in this NPG [4].

NPG 2: RTT A (Dedicated)

RTT messages are automatically exchanged between JTIDS terminals on this NPG to support fine synchronization. This NPG also supports network entry and facilitates relative navigation computations. The time slots in this group are dedicated for use by specifically identified JUs and the RTTs they exchange are addressed RTTs. When this NPG is not included in the network, the RTT messages preempt occasional time slots in NPG 5 or 6. During synchronization, Class-2 terminals transmit up to three RTT messages within 12 seconds. After fine synchronization is achieved, Class-2 terminals exchange RTT messages about once per minute [4].

NPG 3: RTT B (Contention)

This NPG performs the same function as NPG 2, but the time slots are shared by a group of JUs using an access method in which all units can transmit. It is usually configured as a stacked net, with the net numbers corresponding to values of the Time Quality parameter — 0 through 15 [4].

NPG 4: Network Management

This NPG permits the redistribution of network capacity through commands issued over the network. Navy units exercise a limited amount, if any, of net management. However, all JTIDS terminals are capable of receiving and processing network management messages [4].

NPG 5: PPLI and Status, Pool A

This NPG is used by nonC_2 units in conjunction with NPG 6. By using time slots assigned to both NPGs 5 and 6, fast-moving fighters are able to transmit their location with a High Update Rate (HUR). Ships do not need to update their position as often as aircraft. Terminal status messages containing information such as fuel and weapons status are also broadcast automatically by each terminal in these PPLI NPGs [4].

NPG 6: PPLI and Status, Pool B

This NPG is used by all JUs, C2 and nonC2 alike, for identification, synchronization, and relative navigation. In addition to identification and detailed positional information, the PPLIs include the voice and air control net numbers that each platform is using. All JUs can display any JU's PPLI. By default, when an RTT NPG has not been separately defined, the JTIDS terminals will exchange RTTs on this NPG as well [4].

NPG 7: Surveillance

Surveillance consists of searching for, detecting, identifying, and tracking objects. Air, surface, and subsurface tracks, land-point SAM sites, reference points, ASW points, acoustic bearings, and EW bearings and fixes are all exchanged on this NPG [4].

NPG 8: Weapons Coordination

NPG 8 provides a means for a command-designated unit to coordinate Battle Group weapons and order weapons engagements, and for all C2 JUs to report engagement status, controlling unit status, and tactical pairings [4].

NPG 9: Air Control

This NPG provides the means for C2 JUs to control nonC2 JUs. It is divided into two components each of which is configured as a stacked net: the uplink and the back link. Each net is assigned to a specific controller, either a ship or E-2C, and the fighter aircraft being controlled. The controlling unit provides mission assignments, vectors, and target reports to fighter aircraft on the time slots assigned to the uplink. On the NPG 9 back link, or downlink, fighters transmit radar targets, pilot responses to commands, and status to their controlling units. The back link time slots are distributed such that each controlled fighter has dedicated access to its assigned time slots. A maximum of 16 fighters can participate, with options available to permit either 4 or 8 fighters instead [4].

NPG 10: Electronic Warfare

This NPG supports the dissemination of electronic warfare orders and parametric data among EW-capable ships and E-2Cs. It is often multinetted with the NPG for fighter PPLIs, since the fighters do not participate in this C_2-to-C_2 exchange of EW data [4].

NPG 12: Voice Group A

This NPG provides a secure, digitized voice channel for use by all JUs. It is usually configured as a stacked net with 127 possible sub circuits. A net initialized with the 128th number, net number 127, is understood by the terminal to mean currently undefined. During operations, the terminal uses a number supplied by the operator. The operator can change this number at will. Thus, voice nets initialized with net number 127 feature a "dial-a-net" capability [4].

NPG 13: Voice Group B

This NPG provides a second voice channel with the same characteristics as NPG 12 [4].

NPG 14: Indirect PPLI

This NPG supports multilink operations by providing time slots in which a Forwarding JU (FJU) will transmit PPLIs containing position and identification information for Link-11 PUs and Link-11B RUs that are not participating directly on the JTIDS network, but whose data is being forwarded to Link-16 by the FJU [4].

NPG 19: Fighter-to-Fighter (Dedicated)

NonC2 units, such as fighters, exchange radar sensor target information and status on this NPG. It is usually configured as a stacked net, with each fighter group assigned dedicated time slots on one of the nets. A controller can access all the nets in the stack with the dial-a-net capability. The maximum fighter flight size is 8 fighters, but options are provided to allow either 2, 4, or 8 fighters per net [4].

NPG 20: Fighter-to-Fighter (Contention)

This NPG serves the same purpose as NPG 19, but the time slots are allocated for contention access [4].

NPG 21: Engagement Coordination

This NPG is used solely by the U.S. Army for inter-Army coordination of engagements by PATRIOT and THAAD units [4].

NPG 27: Joint PPLI

Identification and location information can be exchanged during Joint operations on this NPG [4].

NPG 28: Distributed Network Management

This NPG is not used at the present time [4].

NPG 29: Residual Message

This is a special NPG provided to ensure a transmission opportunity for messages that are not assigned to one of the other NPGs. Such a left-over, or residual, message could occur when the particular NPG with which the message is usually associated was not included in the network in use, or if the message is not normally assigned to a particular NPG [4].

NPG 30: IJMS Position & Status

The IJMS Position & Status messages, or P-messages, are transmitted in this NPG [4].

NPG 31: IJMS Messages

All IJMS messages except for position messages and voice are transmitted on this NPG. These are the IJMS T-messages [4].

Table 2.1 NPG definitions [4]

NPG	Function
1	Initial Entry
2	RTT A
3	RTT B
4	Network Management
5	PPLI and Status A
6	PPLI and Status B
7	Surveillance
8	Weapons Coordination
9	Air Control
10	Electronic Warfare
12	Voice Group A
13	Voice Group B
14	Indirect PPLI (Navy Only)
19	Fighter-to-Fighter Targeting (Dedicated)
20	Fighter-to-Fighter Targeting (Contention)
21	Engagement Coordination (Army Only)
27	PPLI (Joint Net Broadcast)
28	Distribution Network Management
29	Residual Message
30	IJMS Position & Status
31	IJMS Messages

In the Figure 2.3, the user defines NPGs, access methods, relay requirements, TSEC and MSEC variable numbers and packing limitations.

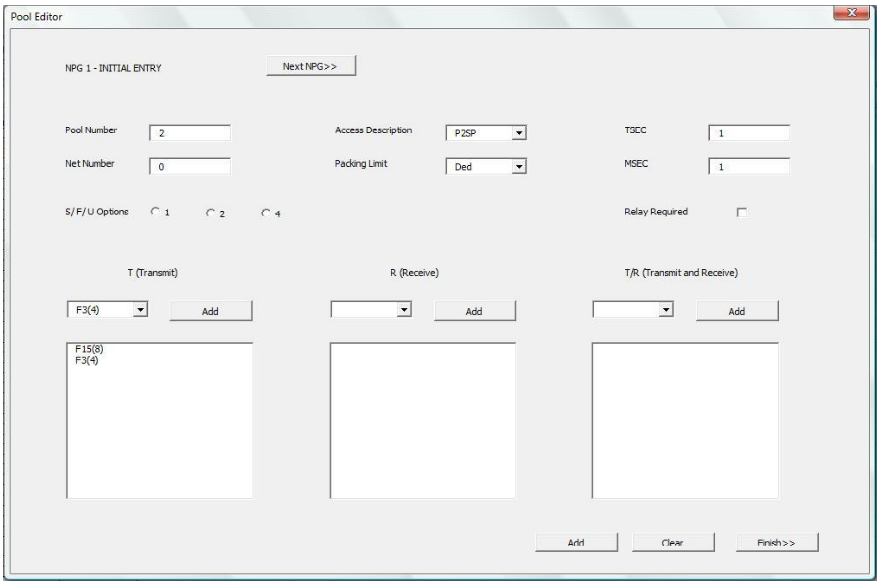


Figure 2.3 Pool Editor

There are two options for access method. These are dedicated access, which is defined for only one platform in the network and contention access, which is defined for all network, not only for one platform, but they can take time slots from the pool dedicated to the NPG if available. When two JUs ask for the same time slot from the pool collisions may occur. Although this type of addressing includes the risk of collision among the JUs, it provides an efficient use of the time slot resources and flexibility to some extent to the network.

Relay requirement appears when a platform fails to reach the other one due to the lack of line of sight (LOS) between them. Special instructions will be sent to relay platforms as to which time slots they should re-transfer. By doing so communication between the platforms which have no LOS connection, are provided.

In the Link-16 system there are two types of cryptos defined. These are TSEC and MSEC, which are defined by numbers. TSEC is defined as transmission security crypto variable. If the platforms have the same value of crypto variables then they can transfer data with each other. MSEC is defined as message security crypto variable. It is used for understanding the message content between platforms. If the platforms have the same value of TSECs but have different value of MSECs, they can transfer data to each other however they can not understand the meaning of the message [5].

2.2. Data Processing

In this section, information process will be explained as previously entered by the user. The user firstly had entered the information of IPF setting. This information will be stored in the database in the tool and network overload detection will be done using the following formula. If a network overload appears, the tool re-allocates the time slots to the tactical units.

$$TSDF = \frac{72x + 258y + 444z \ \text{ x } 100}{1536 \text{ x } 258} \tag{2.1}$$

x = Total number of RTT-A time slots

y = Total number of STD-DP and P2SP time slots

z = Total number of P2DP and P4SP time slots

The information (2.1) will be stored in “TSDF Calculation Table” section of the tool shown in the Figure 2.4.

Platform	Unit TSDF	Relay TSDF	Total Unit TSDF w/o	Voice TSDF	Total Unit TSDF w/Voice
E3(1)	13,74%	7,03%	20,77%	22,92%	43,96%
E3(2)	13,74%	7,03%	20,77%	22,92%	43,96%
CRCI(1)	3,52%	0.00%	3,52%	8,33%	11,58%
CRCI(2)	3,52%	0.00%	3,52%	8,33%	11,58%
CRCI(3)	3,52%	0.00%	3,52%	8,33%	11,58%
F16(1.1)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.2)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.3)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.4)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.5)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.6)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.7)	1,76%	0.00%	1,76%	0.00%	1,76%
F16(1.8)	1,76%	0.00%	1,76%	0.00%	1,76%
F15E(1.1.1)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(1.1.2)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(1.1.3)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(1.1.4)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(4.1.1)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(4.1.2)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(4.1.3)	2,02%	0.00%	2,02%	0.00%	2,02%
F15E(4.1.4)	2,02%	0.00%	2,02%	0.00%	2,02%
F3(1.1.1)	1,24%	0.00%	1,24%	0.00%	1,24%
F3(1.1.2)	1,24%	0.00%	1,24%	0.00%	1,24%
F3(1.1.3)	1,24%	0.00%	1,24%	0.00%	1,24%
F3(1.1.4)	1,24%	0.00%	1,24%	0.00%	1,24%
JPC(1)	3,06%	0.00%	3,06%	14,58%	17,64%
PAT_ICC(1)	2,02%	0.00%	2,02%	0.00%	2,02%
PAT_ICC(2)	2,02%	0.00%	2,02%	0.00%	2,02%
F16(2.1)	5,54%	0.00%	5,54%	0.00%	5,54%
F16(2.2)	5,54%	0.00%	5,54%	0.00%	5,54%

Connectivity Matrix / Allocation Table / SET A / SET B / SET C / TSDF Calculation Table

Figure 2.4 TSDF Calculation Table

In the next step, user should enter the platform data using the Platform Description Interface and NPG data using the Pool Editor Interface. This information is stored in corresponding page of the tool. Then, Connectivity Matrix and Allocation Table are created using this information.

In Figure 2.5 it is given as an example of created Connectivity Matrix including platform and NPG informations.

	A	E F	I	J	K	L	M	N	O
1		Slot Group	1	2	3	4	5	6	7
2			RTT-A	RTT-A	NMGT	NMGT	PPLI_A	PPLI_B	PPLI_B
3		NPGs	2	2	4	TY	5	6	TY
4		Net Number	0	0	0	0	0	0	0
5		TSEC Variable	1	1	1	1	1	1	1
6		MSEC Variable	1	1	1	1	1	1	1
7		Access Mode	D	D	D		D	D	
8		Overlaying Group							
9		Packing Limiting	RTT	RTT	P2SP		P2SP	P2SP	
10		Per Unit Slot/Frame	2	2			4	1	
11		Total Slots/Frame	16	40	4	4	80	20	20
12									
13									
14									
15		Participant ID							
16	1	E3(1)	R	T/R	R	Y		R	Y
17	2	E3(2)	R	T/R	R	Y		R	Y
18	3	CRC(1)							
19	4	CRC(2)							
20	5	CRC(3)							
21	6	F16(1.1)	R	T/R	R	R	T/R	T/R	R
22	7	F16(1.2)	R	T/R	R	R	T/R	T/R	R
23	8	F16(1.3)	R	T/R	R	R	T/R	T/R	R
24	9	F16(1.4)	R	T/R	R	R	T/R	T/R	R
25	10	F16(1.5)	R	T/R	R	R	T/R	T/R	R
26	11	F16(1.6)	R	T/R	R	R	T/R	T/R	R
27	12	F16(1.7)	R	T/R	R	R	T/R	T/R	R
28	13	F16(1.8)	R	T/R	R	R	T/R	T/R	R

Figure 2.5 Connectivity Matrix

An Allocation Table is also created, which is shown in Figure 2.6 using information of platform properties and NPG data with the working algorithm in the background of the Microsoft Office Excel program. The Allocation Table is important because Time Slot Map will be created and reported to the user by utilizing the information in this table.

This algorithm decides to allocate the time slots to the platforms using the entered data from the user. For example, the allocation of time slots are repeated frequently in the network and time slots of platforms, which have different net numbers go to SET C, when allocations of time slots are repeated rarely in the network and when the platforms are in the default net then the time slots are allocated from SET B; stacked nets will have the same time slot allocation and etc. [5].

SB/Agg	NPG	Net	Set	Idx	RRN
1.1	2	0	B	18	10
2.1	2	0	B	26	10
2.2	2	0	B	29	10
2.3	2	0	B	81	8
2.4	2	0	B	77	8
3.1	4	0	B	1	8
4.1	4/TY	0	B	9	8
5.1	5	0	A	3	12
5.2	5	0	B	6	10
6.1	6	0	B	4	10
6.2	6	0	B	17	8
7.1	6/TY	0	B	12	10
7.2	6/TY	0	B	25	8
8.1	6	0	B	49	8
9.1	6	0	B	65	8
10.1	6/TY	0	B	73	8
11.1	7	0	C	7	12
11.2	7	0	B	8	11
12.1	7	0	A	14	11
12.2	7	0	B	2	10
13.1	7/TY	0	B	0	11
13.2	7/TY	0	B	10	10
14.1	8	0	B	20	10
14.2	8	0	B	30	9
15.1	8/TY	0	B	28	10
15.2	8/TY	0	B	33	9
16.1	8	0	B	22	10
17.1	9	127	C	5	11
18.1	9	127	C	13	11
19.1	9	127	C	1	12
19.2	9	127	C	3	12
20.1	10	0	B	14	10
21.1	12	127	A	3	13
22.1	13	127	A	0	13
22.2	13	127	A	2	12
22.3	13	127	A	6	11
23.1	19	1	A	1	13
24.1	20	1	A	0	12
25.1	29	0	B	62	9
25.2	29	0	B	113	8
26.1	30	1	B	41	9
27.1	30/TY	1	B	45	9
28.1	30	1	B	5	10
28.2	30	1	B	57	9
29.1	31	1	B	3	13
29.2	31	1	B	21	10
30.1	31	1	C	0	14
31.1	12	1	A	3	13
32.1	5	0	B	89	8
33.1	6	0	B	13	8
34.1	19	1	A	2	12
35.1	5	10	C	0	13
35.2	5	10	C	2	11

Connectivity Matrix | Allocation Table | SET /

Figure 2.6 Allocation Table

Examples of time slot maps that are created by the developed tool are shown in Figures 2.7, 2.8 and 2.9 for the scenarios given. These maps have been reduced by 20%.

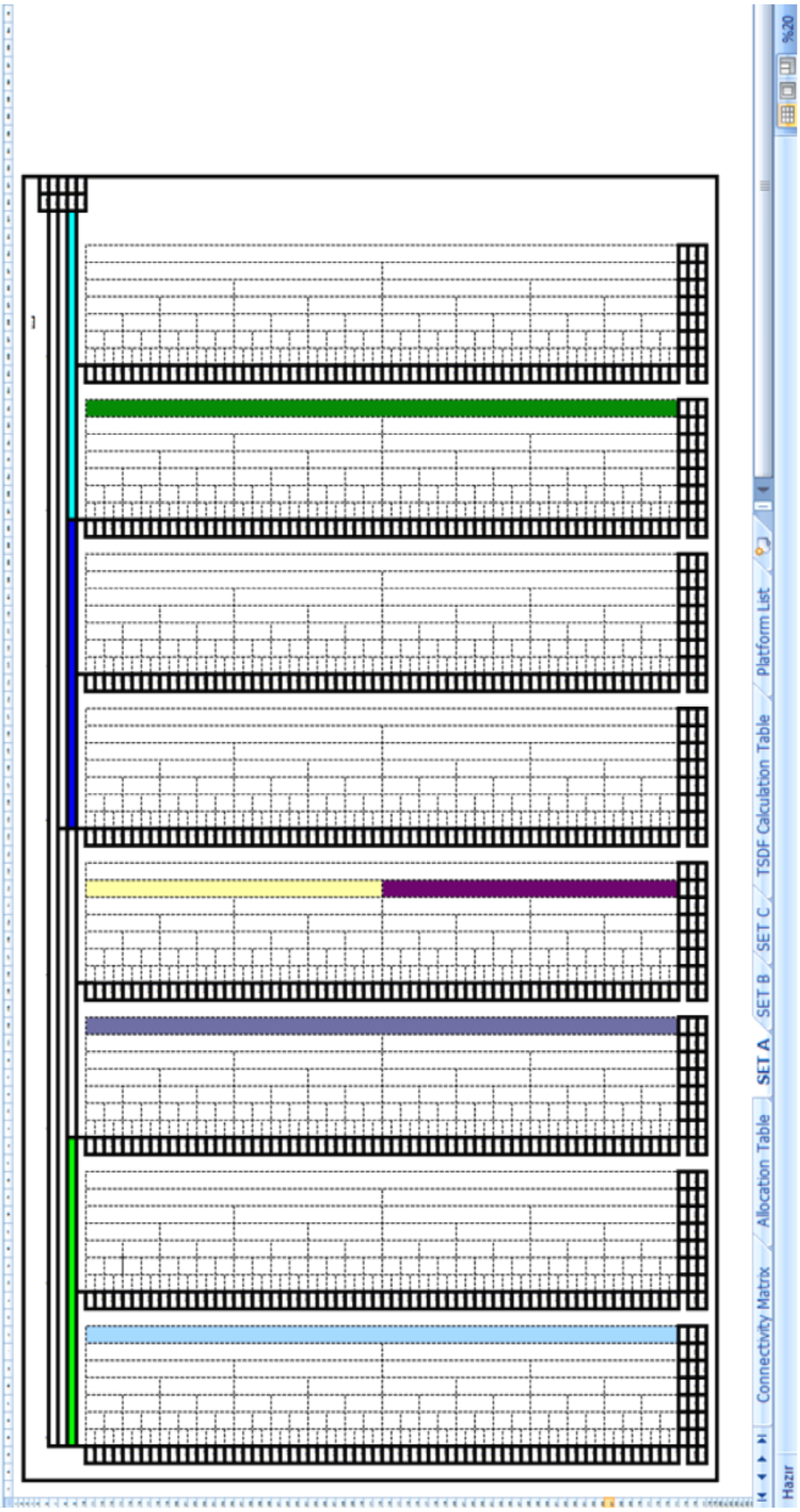


Figure 2.7 Time Slot Map (SET A)

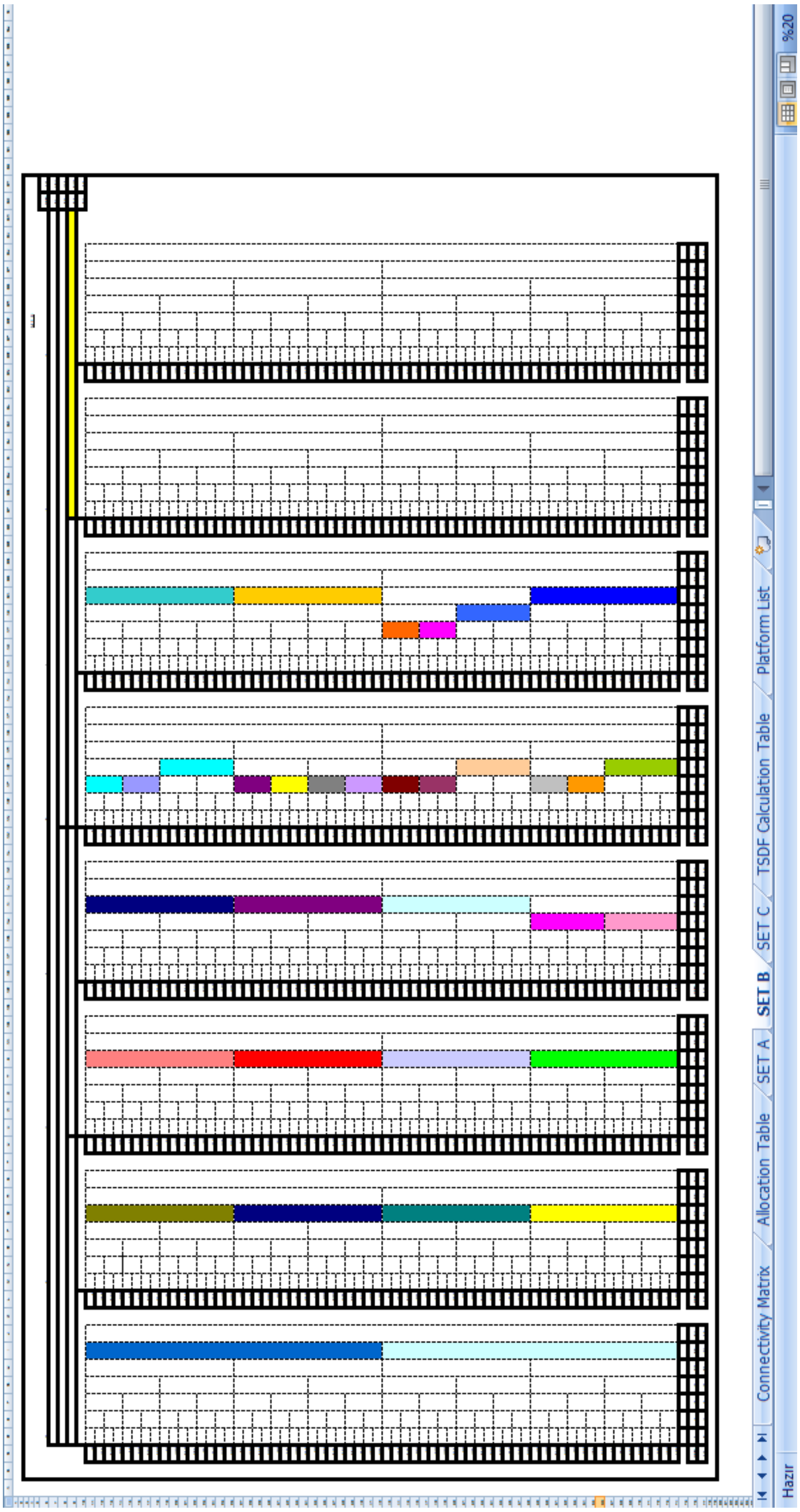


Figure 2.8 Time Slot Map (SET B)

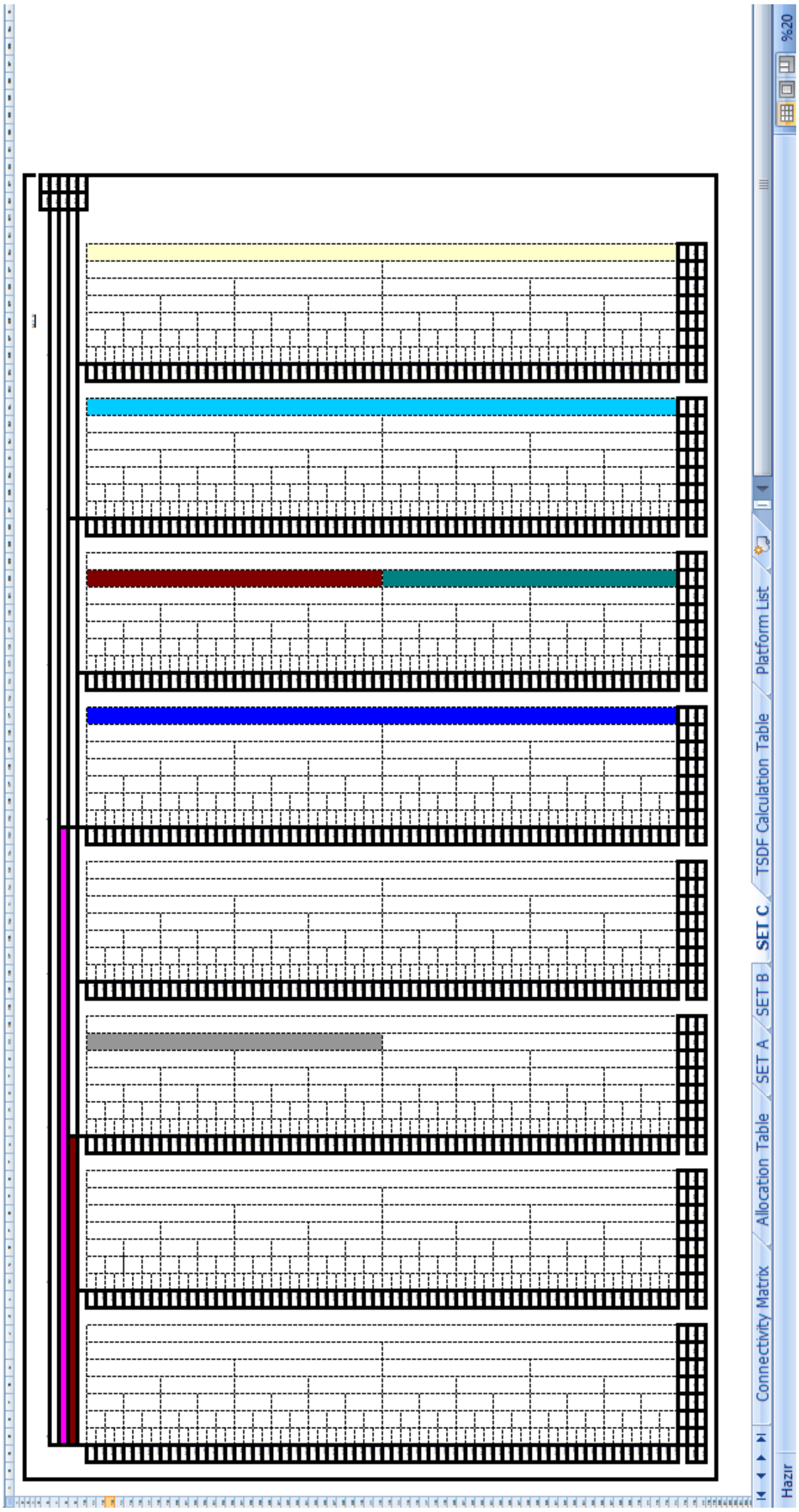


Figure 2.9 Time Slot Map (SET C)

CHAPTER 3

A SCENARIO EXAMPLE

Firstly, user defines the mode of communication.

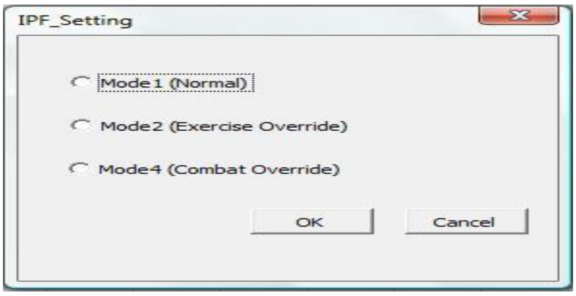


Figure 3.1 Mode of Communication (scenario)

User defines the platform names, terminal types, and number of items.

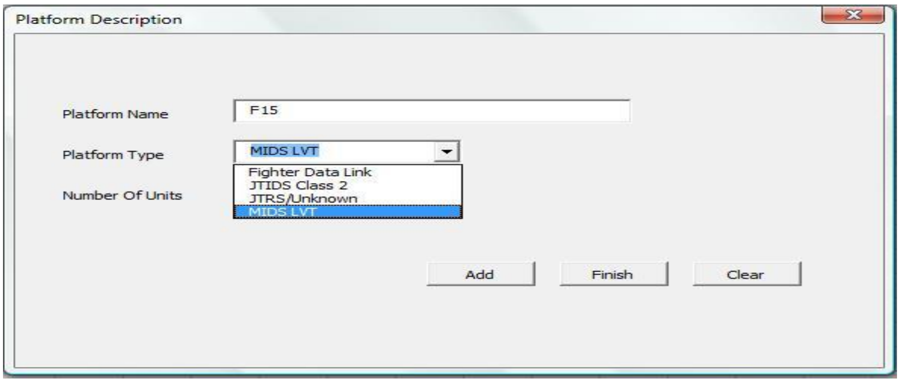


Figure 3.2 Platform Description (scenario)

The participant list in first scenario:

- E-3 (2 items)
- F-16 (32 items)
- F-4 (1 item)
- ERIEYE (1 item)
- SHIP (1 item)
- PAT ICC (2 items)
- TYPHOON (1 item)
- F-5 (2 items)
- F-3 (1 item)
- F-15E (1 item)
- TANKER (1 item)
- CRC-I (4 items).

Platform list is generated in the tool accordingly.

Participant Name	Participant Type	Number of Units
E3	JTIDS Class 2	2
F16	MIDS LVT	32
F4	MIDS LVT	1
ERIEYE	MIDS LVT	1
SHIP	JTRS/Unknown	1
PAT ICC	JTRS/Unknown	2
TYPHOON	MIDS LVT	1
F5	MIDS LVT	2
F3	MIDS LVT	1
F15E	MIDS LVT	1
TANKER	JTRS/Unknown	1
CRC-I	JTRS/Unknown	4

Figure 3.3 Platform List (scenario)

The user defines NPGs, access methods, relay requirements, TSEC and MSEC variable numbers and packing limitations in the pool editor:

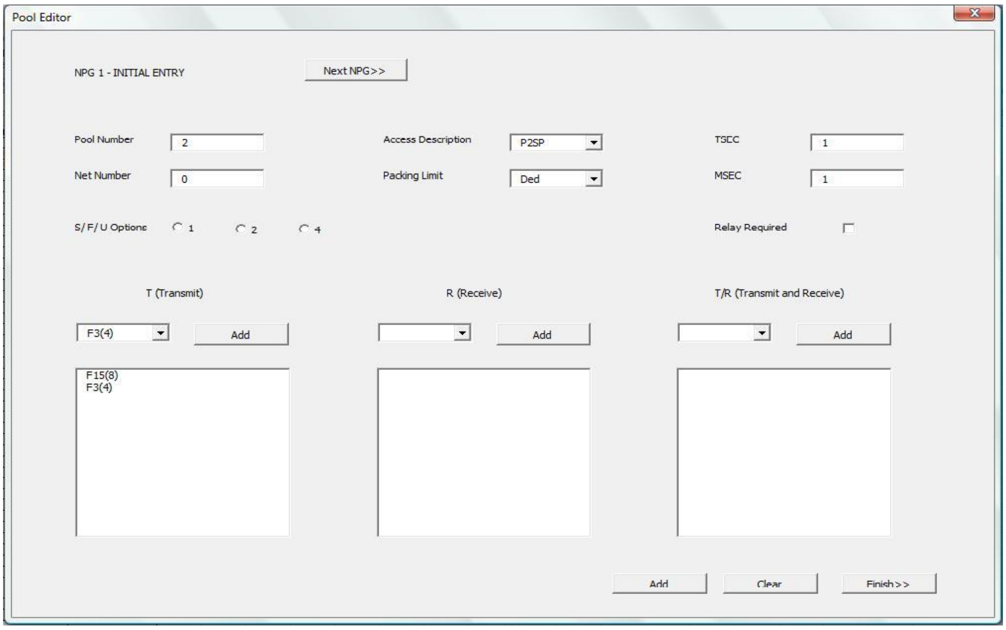


Figure 3.4 Pool Editor (scenario)

Connectivity Matrix generated in the tool:

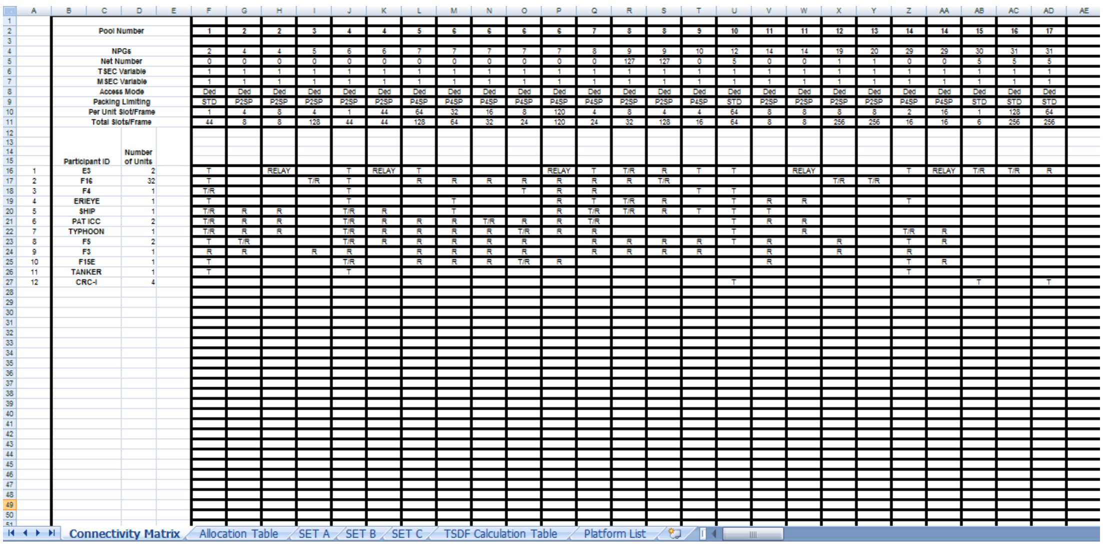
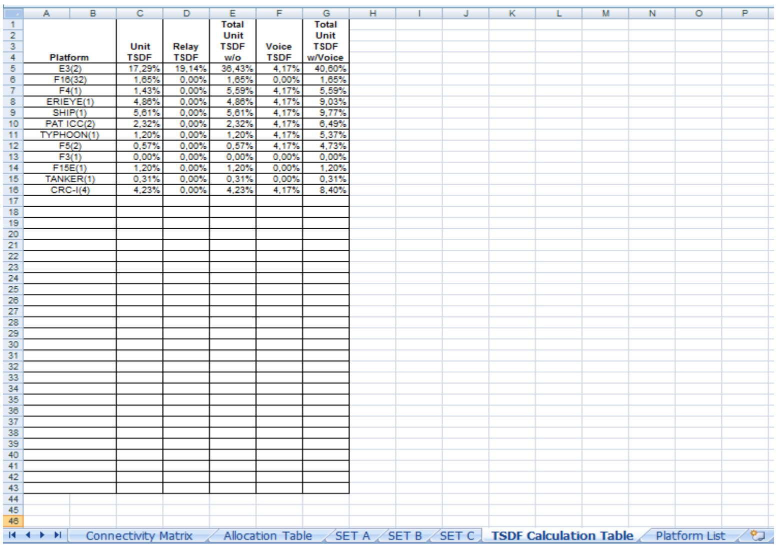


Figure 3.5 Connectivity Matrix (scenario)

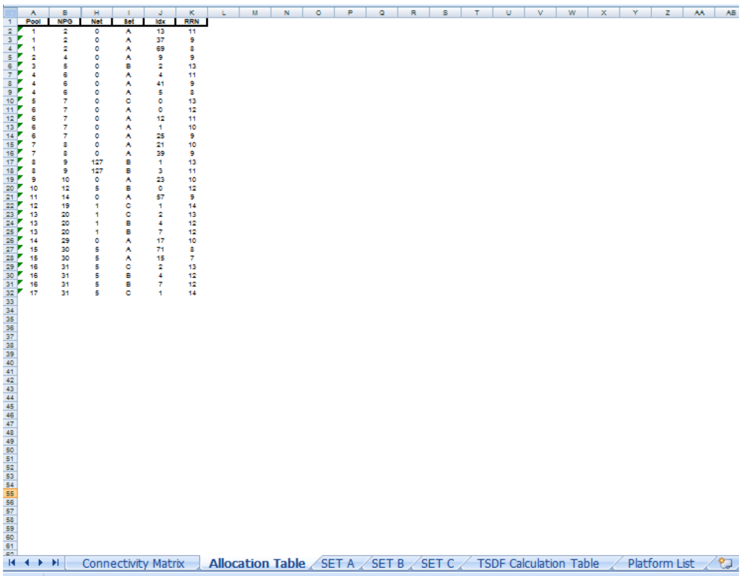
Time Slot Duty Factor (TSDF) calculated in the tool. The information is stored in "TSDF Calculation Table" section of the tool. If an overload occurs the tool re-allocates the time slots to the tactical units:



Platform	Unit TSDF	Relay TSDF	Total Unit TSDF w/o	Voice TSDF	Total Unit TSDF w/Voice
E3(2)	17,29%	19,14%	36,43%	4,17%	40,60%
F16(32)	1,65%	0,00%	1,65%	0,00%	1,65%
F4(1)	1,43%	0,00%	5,59%	4,17%	5,59%
ERIEYE(1)	4,86%	0,00%	4,86%	4,17%	9,03%
SHIP(1)	5,61%	0,00%	5,61%	4,17%	9,77%
PAT ICC(2)	2,32%	0,00%	2,32%	4,17%	6,49%
TYPHOON(1)	1,20%	0,00%	1,20%	4,17%	5,37%
F5(2)	0,57%	0,00%	0,57%	4,17%	4,73%
F3(1)	0,00%	0,00%	0,00%	0,00%	0,00%
F15E(1)	1,20%	0,00%	1,20%	0,00%	1,20%
TANKER(1)	0,31%	0,00%	0,31%	0,00%	0,31%
CRC-I(4)	4,23%	0,00%	4,23%	4,17%	8,40%

Figure 3.6 TSDF Calculation Table (scenario)

After all, the Allocation Table is generated by the tool:



Pool	NPG	Net	Set	Idx	RRN
1	2	0	A	13	11
1	2	0	A	37	9
1	2	0	A	69	8
2	4	0	A	9	9
3	5	0	B	2	13
4	6	0	A	4	11
4	6	0	A	41	9
4	6	0	A	5	8
5	7	0	C	0	13
6	7	0	A	0	12
6	7	0	A	12	11
6	7	0	A	1	10
6	7	0	A	25	9
7	8	0	A	21	10
7	8	0	A	39	9
8	9	127	B	1	13
8	9	127	B	3	11
9	10	0	A	23	10
10	12	5	B	0	12
11	14	0	A	57	9
12	19	1	C	1	14
13	20	1	C	2	13
13	20	1	B	4	12
13	20	1	B	7	12
14	29	0	A	17	10
15	30	5	A	71	8
15	30	5	A	15	7
16	31	5	C	2	13
16	31	5	B	4	12
16	31	5	B	7	12
17	31	5	C	1	14

Figure 3.7 Allocation Table (scenario)

Lastly, the Time Slot Maps are successfully created, and network design is distributed to the user.

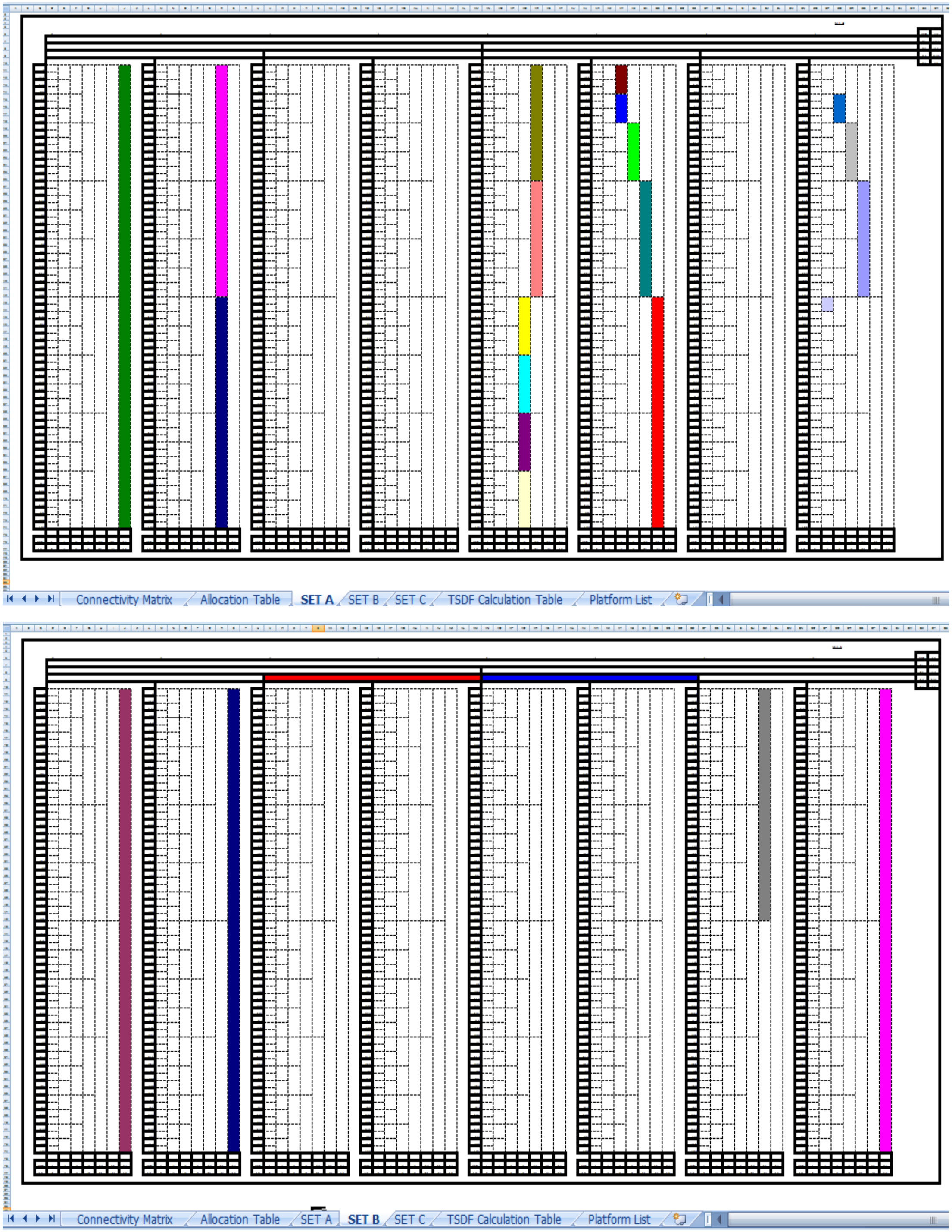


Figure 3.8 Time Slot Maps – SET A, SET B (scenario)

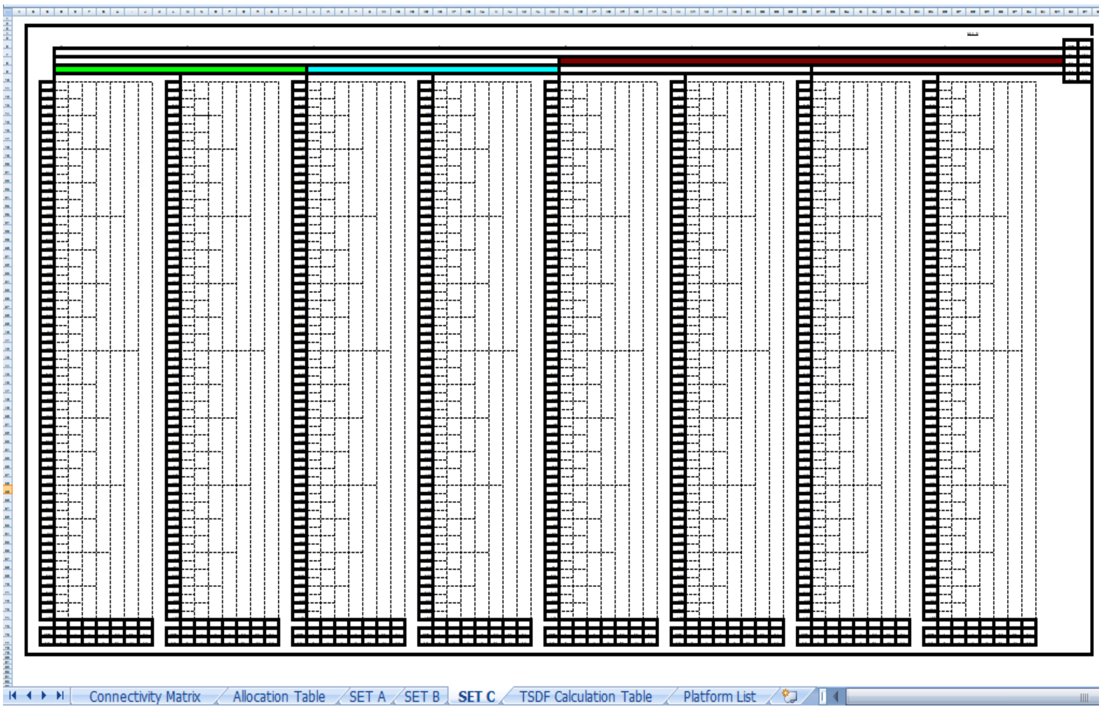


Figure 3.9 Time Slot Maps – SET C (scenario)

CHAPTER 4

CONCLUSION

In this thesis, a Link-16 Network and Management Tool was developed and also some of the Link-16 properties are presented. In the tool, data entry is performed with developed algorithms using Microsoft Visual Basic language.

Link-16 is mostly a static network. Network designated before mission and information exchange is done during the mission according to this design. There is no flexibility to solve problems that could occur during the mission. Hence, for completing the mission perfectly therefore, the network design must be done correctly before the mission.

The Link-16 Network and Management Tool design process begins with collecting the data from user. Firstly, communication mode choice is done by the user. This communication mode choice is stored in the database. If an overload occurs in allocating time slots to platforms, the network should be redesigned. After determining the communication mode, platform names, terminal types and number of platforms defining are done. With the pool editor interface NPGs, access methods, relay requirements, TSEC and MSEC variable numbers and packing limitations of platforms are done. Then, Connectivity Matrix and Allocation Table are created using these informations. Time Slot Map created and reported to user using information in the Allocation Table. These operations handled step by step in an example of scenario and reported to the user as Microsoft Office Excel tables.

The tool is tested with many scenarios. One of them is given in Chapter 4 as an example. It has been shown that the network design is made properly and the time slot distribution is made successfully by the tool.

In the market, various types of network design tools can be found. But these tools may not meet the requirements of national network properties. The network design tool developed can enable national network design for the tactical units. Disadvantage of this tool from other current tools is that the relay requirement must be defined by the user because the tool lacks a visual interface that can calculate the LOS according to platforms geographical position. For removing this disadvantage and integrating the network design tool with a Geographical Information System (GIS), the ArcGIS software package is tried to utilize, however the application was failed. Due to the lack of time the problems couldn’t solve. This could be performed as a future work.

The network design tool which is developed in this thesis contains the Link-16 information and properties. The tool is developed by using the Visual Basic language and has human-machine interfaces. The tool creates outputs using Microsoft Office Excel program. With this tool, the tactical units participation in an exercise or operation using the Link-16 system for tactical information exchange can complete their mission perfectly in a prespecified scenario and meet the requirements of the network design. The tool is flexible to change the algorithm according to network requirements.

In the future, as stated, the tool can be improved by adding an interface that one can enter geographical information with a compatible GIS software package. So, the tool can also calculate the LOS data and determine the relay requirements automatically with a coverage analysis.

REFERENCES

[1] http://www.janes.com/articles/Janes-C4I-Systems/Joint-Network-Design-Aid-United-States.html

[2] http://www.thales.co.uk/Portfolio/Defence/LandJoint_Products_Data_Link_L16_Network/?pid=1153

[3] http://www.network-centric.com/mtps.php?LHS=12

[4] *Understanding Link-16: A Guidebook for New Users* Third Rev. , Northrop Grumman Corporation, San Diego, ABD, September 2001

[5] KAAN KIR, CELAL ZAİM ÇİL (2010), *Link-16 Ulusal Ağ Tasarım ve Yönetim Aracı*, HAVA HARP OKULU - I. Aviyonik ve Sistem Entegrasyon Sempozyumu (ASES 2010)