Fault Tree Analysis for a Modern Communication System

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***Abstract*- Wireless communications became one of the most widespread means for transferring information. Speed and reliability in transferring the piece of information are considered one of the most important requirements in communication systems in general. Moreover, Quality and reliability in any system are considered the most important criterion of the efficiency of this system in doing the task it is designed to do and its ability for satisfactory performance for a certain period of time, Therefore, we need fault tree analysis in these systems in order to determine how to detect an error or defect when happening in communication system and what are the possibilities that make this error happens. This research deals with studying TETRA system components, studying the physical layer in theory and practice, as well as studying fault tree analysis in this system, and later benefit from this study in proposing improvements to the structure of the system, which led to improve gain in Link Budget. A simulation and test have been done using MATLAB, where simulation results have shown that the built fault tree is able to detect the system's work by 82.4%.**

Keywords: Fault Tree Analysis, TETRA, MATLAB.

I. Introduction

TETRA is an abbreviation of Terrestrial Trunked Radio, which means a trunked terrestrial communications system. It is an open standards digital radio communications system. It was adopted by the European Telecommunication Standard Institute (ETSI) to meet most of the requirements of wireless radio communications system.

TETRA serves Private Mobile Radio networks (PMR) and Public Access Mobile Radio networks (PAMR). Thus, it serves many different fields such as police, ambulance, firefighters, traffic, security men, armed forces, public services, transport services, private individual's networks, factories, mines, etc.

TETRA is characterize by speed calls, providing necessary needs for a group of users, ability of direct communication between devices. It provides optimal use of frequencies and operates with a high degree of safety. It is distinguish from other networks by its ability to cancel noise effect, which makes the voice clearly audible even in places known for high degree of noise such as airports and construction sites [1].

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II. System Components

Figure (1) shows TETRA components, which consists of:

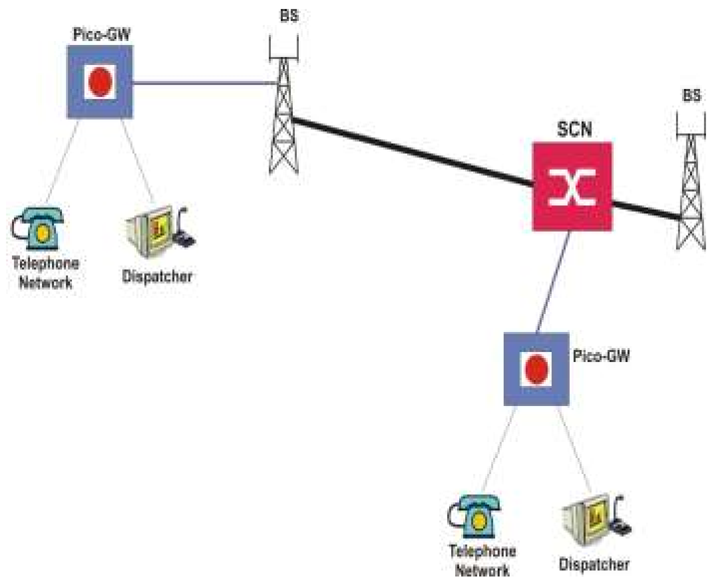


Figure 1. TETRA Components

A. Switching and Control Node (SCN)

This element is consider as the core network element for managing the network database and system communication interface. The communication interface is a tool to link the base station, command and control unit (dispatcher), and other switchboards in the network and the digital voice recorder in the network managing system (NMS).

The switchboard is also consider as the central nucleus of the network. It also has gateways port. There is a number of SCNs that form peer-to-peer network or form a network or star geographical physical structure and others [2].

B. Base Station (BS)

Base Station is responsible for geographical coverage with radio waves for an area, which is called the cell. It also provides a radio communication interface in the air for command and control unit (Dispatcher) and devices that are handled by persons and in mobile vehicles.

The Base Station is directly controlled by SCN, where (ISDN, PSN, PABX, Dispatcher) are connected to the Base Station by a local communication interface in the station. Each Base Station supports 8 frequency carriers. Each carrier contains four time channels. As for antennas, connections are suitable according to the demand of the network investor.

This special case could work individually and without connecting the switchboard. This special case is known as Fallback status and it occurs when the station loses its connection with the switchboard (This may be due to a malfunction in the switchboard or in the connection line between them). When the station has fallback status, it can provide a partial set of fallback status; it can provide a partial set of services provided by switchboard in normal situations [2].

C. Pico-GW

Gateway secures the interfacing between the network and other networks like external phone networks and analogue radio systems that exist in the present time and will exist in the future. Gateways depend on (HW/SW) standards with high flexibility in the possibility of update and connecting different protocols [2].

D. Command and Control Unit (Dispatcher)

Command and Control Unit is a fixed station connected to the SCN by EI adapter that is used by the Dispatcher operator which is identified as a TETRA user, where it can reach TETRA services by Graphic User Interface (GUI) such as basic telephone services (voice calls, SDS, messages, call priority, etc.) and advanced telephone services, which are unsuitable for radio users (ambience listening call, allowed call by the Dispatcher), as well as managing and controlling the subscribers [2].

E. Command and Control Room

Command and Control Room (C&CR) is a system of integral digital converting and assembling, which is employed in multi-*tasking distribution for voice calls and advanced integral* data.

All calls are coded and distributed within the control room with VoIP format, which gives the C&CR operator the following advantages:

- Using one or more voice channels among known channels
- To intersect (assemble) two or more identical channels with each other
- Establishing calls between the operator and PABX/PSTN terminals

- *Allows two or more operators to communicate with each other*
- *Records all current calls (with digital format) on radio channels and telephone lines.*

F. TETRA Voice Recorder

Recording Unit in TETRA (RU) is the element in the network that secures functions of recording voice calls within the network, and allowing recording calls for individuals and groups are arranged (granting or blocking them) in their files within Home Location Register (HLR).

Calls are directly recorded in the TETRA-coded format, and are stored into a database of the RU, where a set of playback stations allows operators to browse the stored calls and to listen to them.

Recording Unit (RU) consists of two racks: the link unit (WAS-P), which allows linking up to 6 SCNs, where each SCN sends its local calls to the Recording Unit (RU) in order to record them, as well as a single management server SRUS, which manages three different recording units (RUs).

III. Physical Layer

TETRA allocated a set of standard adapters to secure and achieve an open-vendors market as shown in figure (2).

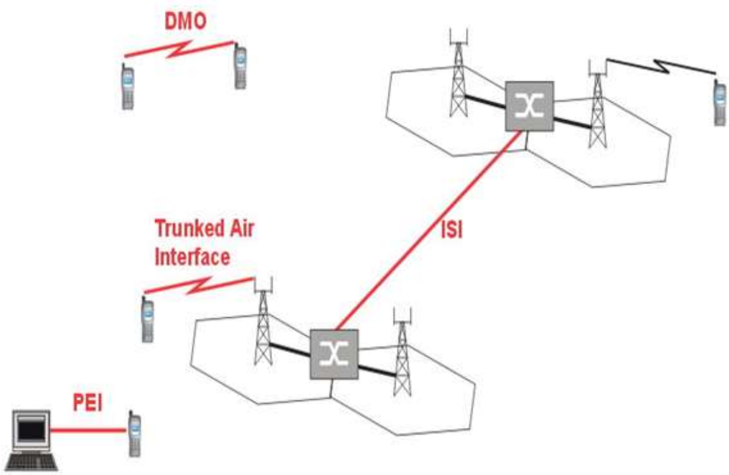


Figure 2. TETRA Standard Adapters

A. Trunked Air Interface (TAI)

It is the air interface defined by the European Telecommunications Standards Institute (ETSI) between terminals and Switching and Management Infrastructure (SwMI). It allows the air interface of two operation modes, where switching between them is done manually, they are:

- Direct Mode Operation (DMO): Direct Mode Operation does not use infrastructure of TETRA. Communication is done directly between two users. This operation is not usually done when there is not enough coverage from the system. To achieve this communication, both terminals should be within the coverage of the other terminal. Communication in this mode is a simplex communication. The terminal uses the same carrier in both sending and receiving operations. In some necessary cases, in order to establish direct communication between two terminals and each of them is not within the coverage of the other, benefit from signal repeater may be done. Repeater basically increases the coverage scope for each terminal. However, both terminals should be within the coverage scope of signal repeater. It is noteworthy that the repeater is a terminal that was programmed to operate as a repeater [3].
- Trunked Mode Operation (TMO): The terminal in the Trunked Mode Operation uses the TETRA Infrastructure, and the management of the terminal operation is fully done by the switchboard which is considered the heart of the network and responsible for its management. For the terminal to get use of the network infrastructure, it should do the recording at every operation for it. Recording is requested from the switchboard when the terminal changes its specified location area (LA). The specified location for each terminal is defined as a set of one or more network cells. The advantage of these cells is that the cell can move within them without the need to inform the network management of these movements [3].

B. Frequency Distribution

TETRA uses TDMA technique, where it provides 4 channels for users by using one frequency carrier as shown in figure (3). The width of frequency domain for each carrier is 25 KHz, which means an efficiency in using frequency domain, where the used frequency domain is 380-400 MHz. Hence, the frequency domain 380-390 MHz is used for the uplink and 390-400 MHz is used for the downlink. The frequency space for the duplexer is 10 MHz. Therefore, the frequency difference between sending and receiving frequency is 10 MHz (ETSI standard Recommendation).

The frequency plan analysis is based on the hexagonal reuse pattern. Since the system must support both TMO and DMO operation the derived allocated band for each mode is 4.5MHz for each uplink and downlink band and an additional 0.5 MHz to support 20 DMO channels (minimum requirement) for both links. Operating frequencies for DMO mode could be chosen from both frequency domains 380-385 MHz and 390-395 MHz.

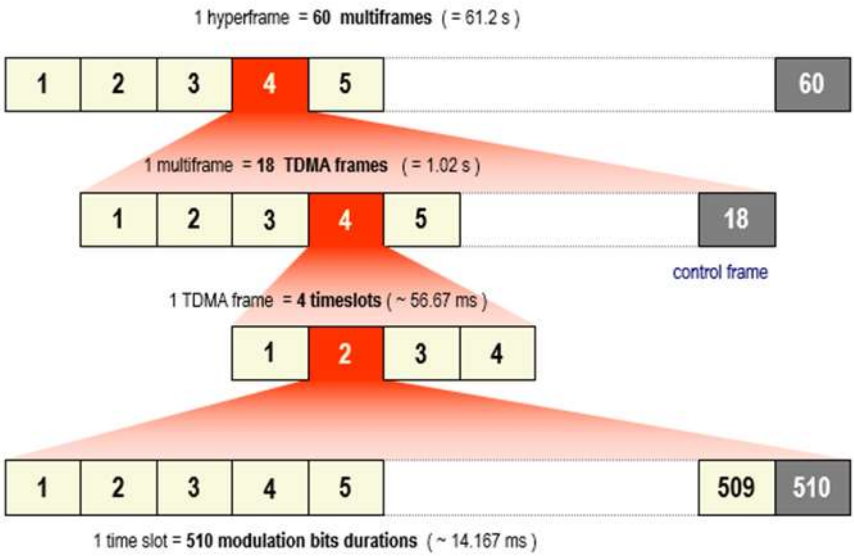
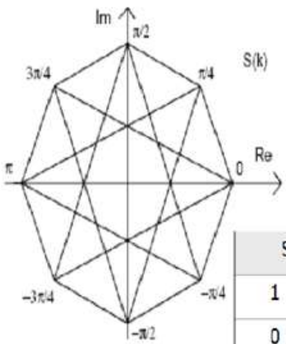


Figure 3. TDMA Frame Structure

C. Modulation

The modulation scheme used by the TETRA system is called π/4-Differential QPSK:

- the bit sequence is mapped onto a sequence of modulation symbols S(k)
- a modulation symbol is associated to a pair of modulating bits
- because of the differential encoding scheme, the generic symbol S(k) is obtained by applying a phase transition DΦ(k) to the previous symbol S(k-1)
- the phase transition DΦ(k) is a multiple of π/4



S(k) value		DΦ(K)
1	1	-3π/4
0	1	+3π/4
0	0	+π/4
1	0	-π/4

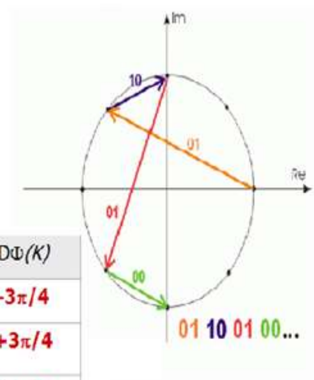


Figure 4. Modulation Technique π/4-DQPSK

IV. The Error In The System Under Study

A field study has been done under the supervision of the General authority of Syrian Wireless Communications System, which operates the system under study. The study included visits in different times to the distributing channels in Damascus city and it was located in Ibn al-Nafees Station. Problems that the system suffers from were also seen by engineers supervising its operating. They have been summarized as follows (Without referring to human errors resulted from the lack of practice):

- Number Unreachable: Sometimes there is a terminal registered in the network, but when you try to dial a call, a message appears on it that it is out of coverage areas.
- Dropped call: This problem occurs when the call is dropped before ending the conversation without dropping the call by any of the call parties.
- No Voice: In this case, the calling party is not able to hear the called party, whereas the latter can hear the calling party or both call parties could not hear each other.
- Called Busy: One of the terminals requests to establish a connection with another one, but this request is not done, and TETRA says that the second terminal is busy, while it is unoccupied.

These errors were checked practically in coordination with the General Authority, where a terminal was used and put under the circumstances under which the above-mentioned errors occur.

During making the previous tests, request was done to record all information related to the connection and it the state of connection is successful or unsuccessful. Table (1) gives the information recorded in the switchboard.

TABLE I
STRUCTURE OF INFORMATION RECORDED DURING TESTS

Characteristic Name	Values
Connection Duration	Decimal number estimated by seconds
Used Protocol	Protocol Name (text value)
Required Services	Service Name (text value)
Number of sent from mobile device bytes	Decimal Number
Number of sent from station bytes	Decimal Number
Connection Importance	Value (0) is important, otherwise the value is (1)
The number of times of failure sign into network	Decimal Number
Was signing in done	Value (0) means singing in was done, otherwise the value is (1)
Error Rate	Positive real number

First, a simulation for the physical connection channel of the system under study was done using Matlab to evaluate the system's performance. Then, information recorded during tests were used to analyze errors.

V. PRACTICAL APPLICATION

A. Simulation of physical channel of TETRA

Figure (5) gives a TETRA simulation model that has been carried out via Matlab.

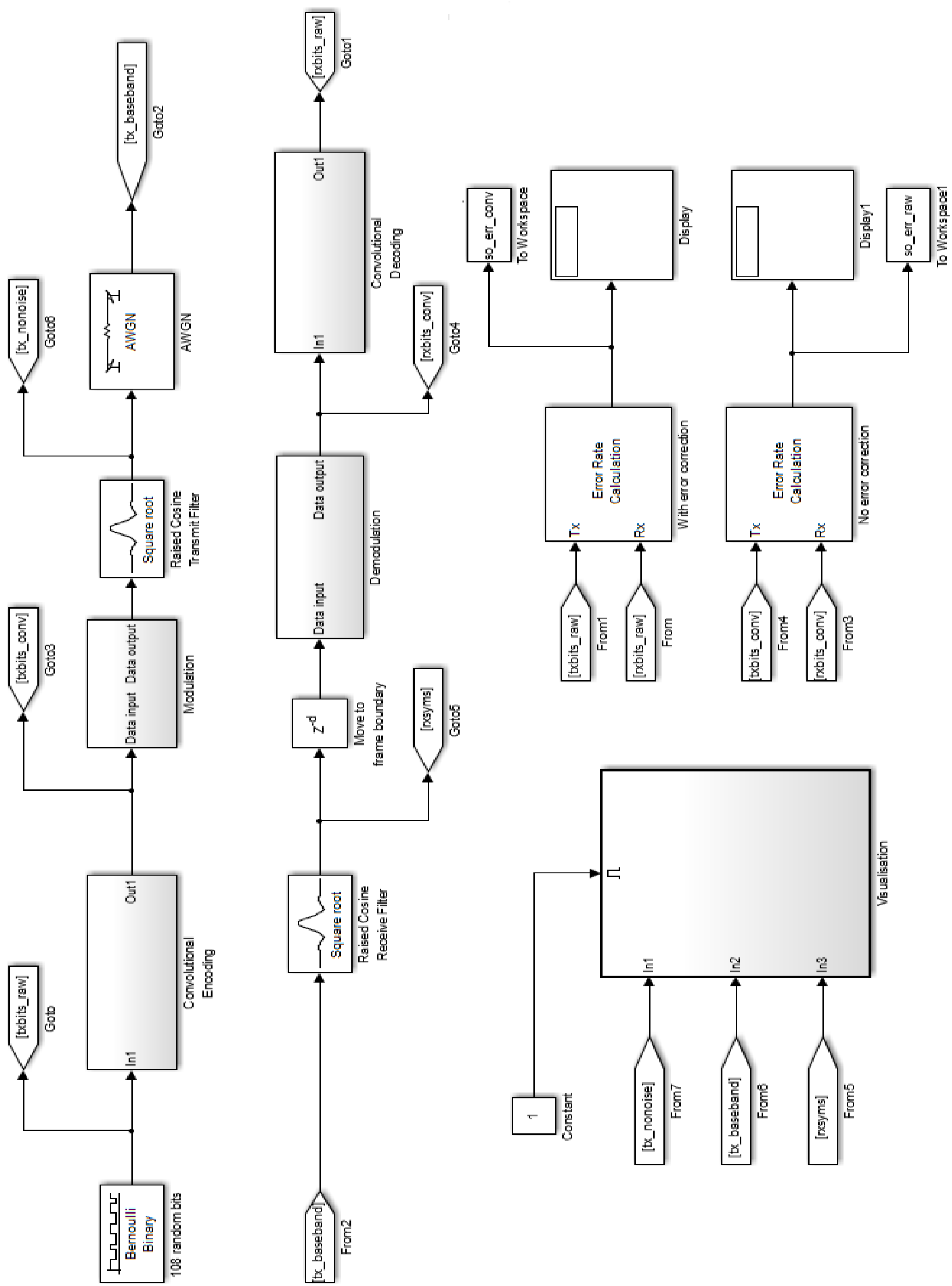


Figure 5. Simulation Model of Physical Layer

B. Explaining the simulation components

1. The Transmitter: constitutes of the following blocks respectively as shown in figure (5).
   - Error detecting and correcting Encoding and spreading: TETRA depends on convolutional encoder to detect and correct errors. Figure (6) gives the structure of the used encoder according to TETRA.

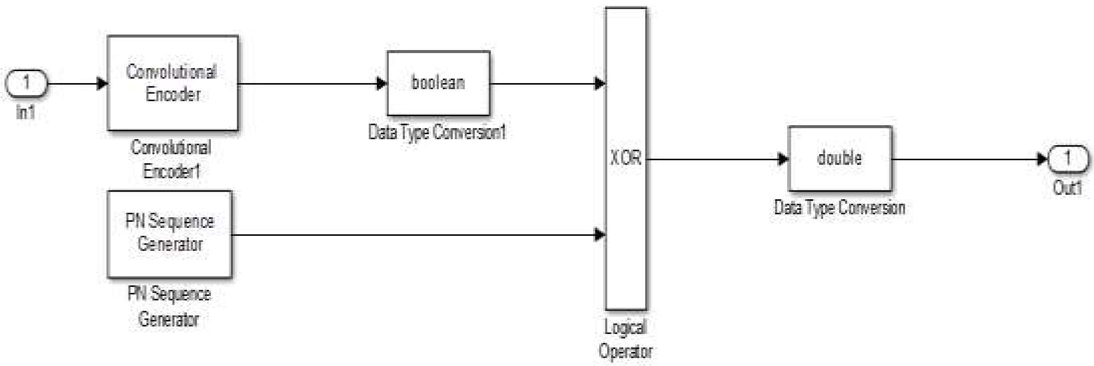


Figure 6. Error Detecting and Correcting Encoder

It also depend in spectrum disperse on dispersing using direct chains. The Convolutional Encoder 1 block carries out the encoding process, while the PN Sequence Generator block generates pseudo-random chain. Then the encoder output is multiplied by the chain output to carry out the dispersing process.

- Modulation: This block carries out the process of shaping the frame, and then it carries out the modulation. The process of the frame shaping includes the following:
  - First training sequence: It is a fixed sequence used to secure the synchronization between generators of pseudo-random sequences in transmitter and receiver. This sequence is 4 bits, which are: 0,0,1,1.
  - Adding 216 sequences of zeros.
  - Second training sequence.
  - Information bits: Which is 216-bit length.
  - End sequence is similar to finish sequence.

After that, DQPSK modulation is done, and then Guard Intervals are added with a length of 24 codes. Figure (7) gives components of modulation block.

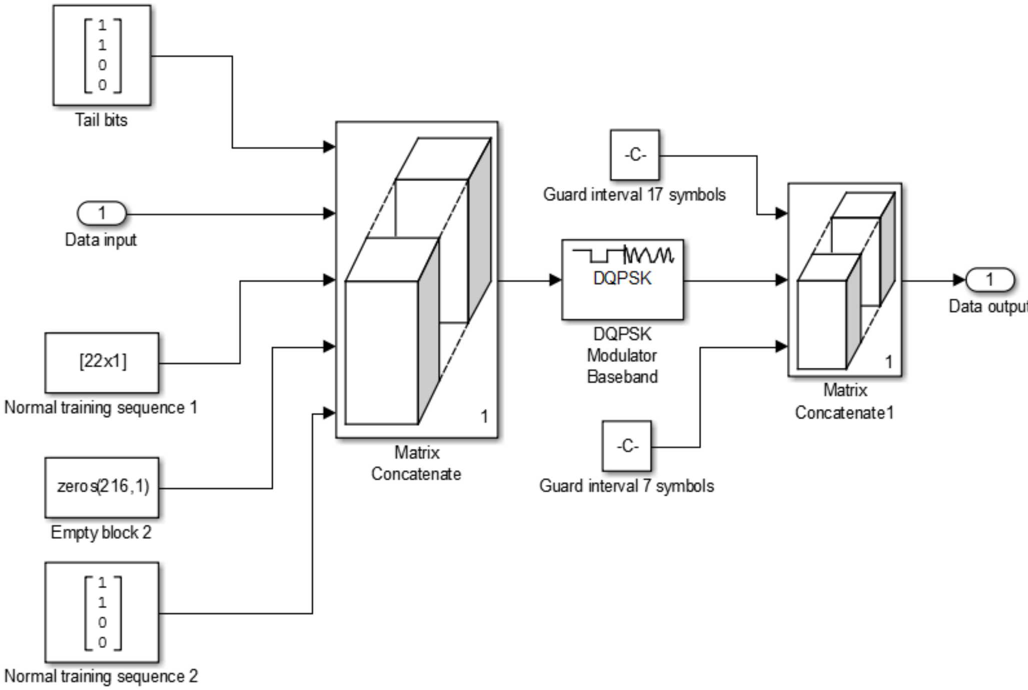


Figure 7. Shaping and Modulating Frame

- Pulse shaping: TETRA depends on pulse shaping to overcome the problems of the channel with memory, which results in Inter Symbol Interference (ISI). It depends on pulse shaper of raised cosine.

2. The Receiver: Receiving process is done oppositely to sending process as follows:
   - Pulse Shaping Decoding: Which is done using pulse shaper of raised cosine.
   - Modulation Decoding: In this block, the Guard Intervals that were added in the transmitter are deleted. Then the modulation is decoded using DQPSK modulation decoder. Finally, information are extracted from the frame resulted after modulation decoding. Figure (8) gives modulation decoding block diagram.

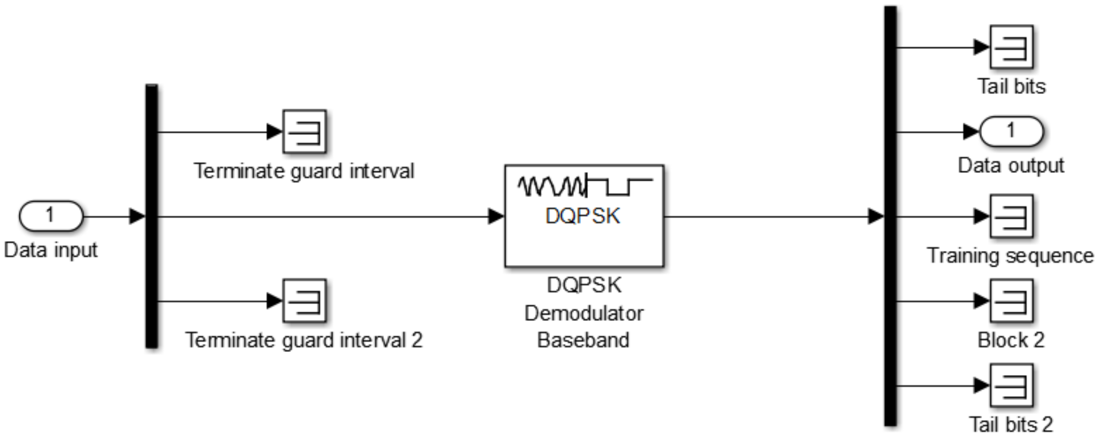


Figure 8. Modulation Decoder and Frame Decoding

- Decoding: In this block, dispersing process are being decoded by generating random sequence identical to that generated in the transmitter, and then multiply the extracted information frame to this sequence. Finally, decoding is done using Viterbi decoder. Figure (9) gives decoder diagram.

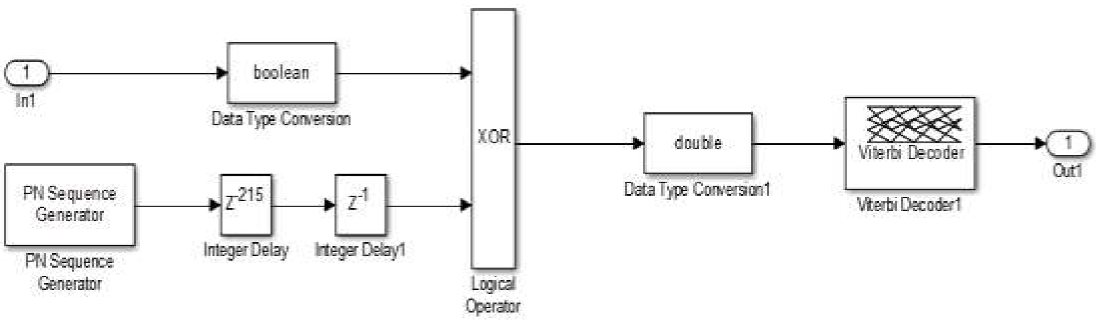


Figure 9. Error Detecting Decoder

VI. Results Of Simulation Of Physical Channel of Tetra

Simulation was done in the case of Additive Gaussian White Noise channel (AWGN) at signal to noise ratio (SNR) equal to 10 dB. Figure (10) gives Scatter Plot for the received signal, while figure (11) gives error rate.

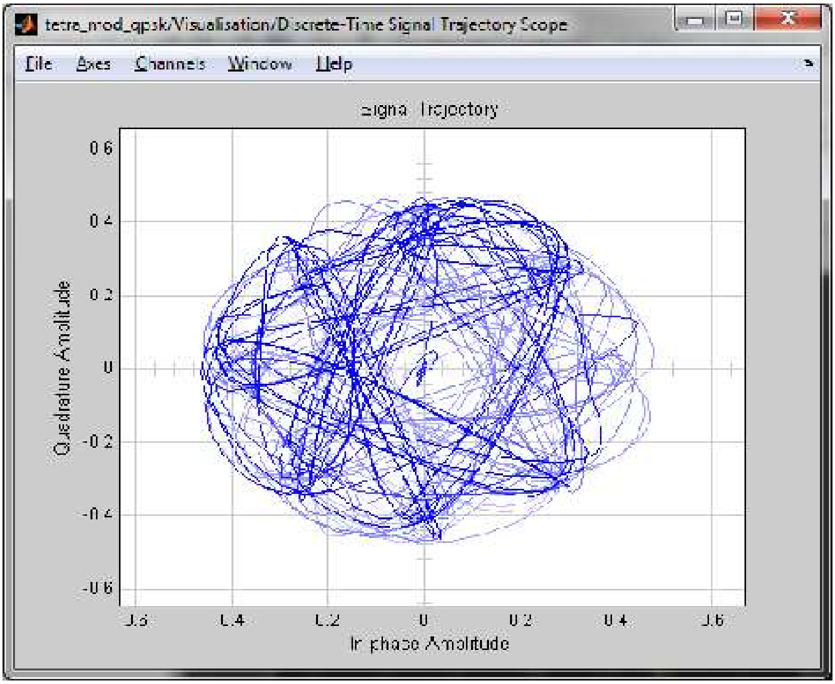


Figure 10. Scatter Plot

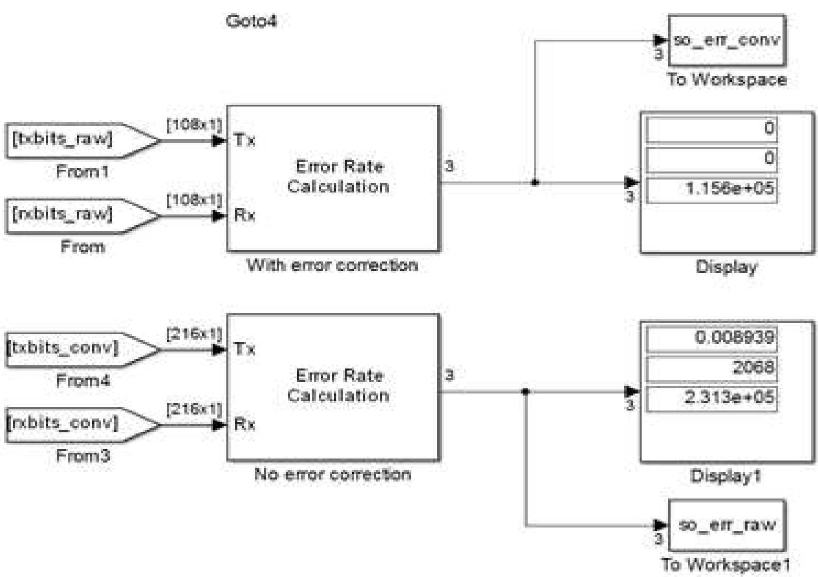


Figure 11. Error Rate

From figure (11), it is shown that the expected performance in case of signal to noise ratio (SNR) with using error detecting and correcting encoding that equals zero, while figure (10) shows that the distribution of received codes resulted from using DQPSK modulation, where this modulation is lesser resistant to noise. Yet, it secures an acceptable transfer rate to secure the system's services.

Figure (12) gives the curve of TETRA performance in case of additive Gaussian white noise channel, where it is shown that to achieve voice transfer that is achieved at an error rate that is lesser than or equal to 10-3, the system needs SNR that is more than or equal to dB 13. However, in reality, the channel is not an additive Gaussian white noise channel; therefore, the SNR should be much more than this value.

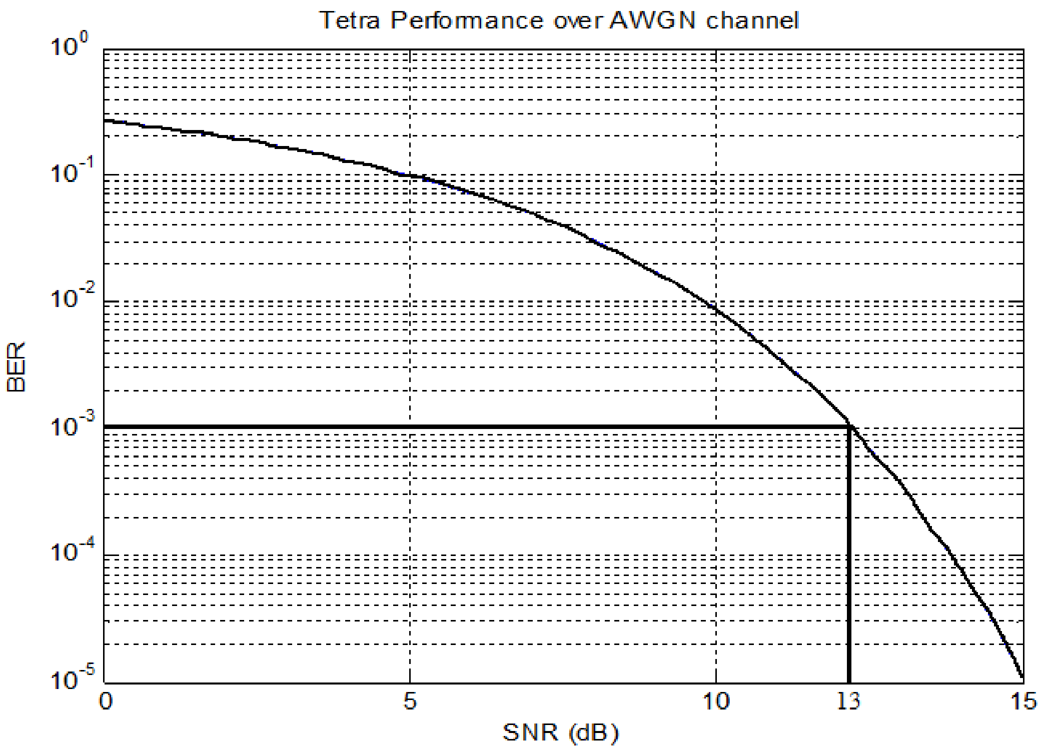


Figure 12. Curve of TETRA Performance in Case of Additive Gaussian White Noise Channel

A. Analyzing recorded data file

Data file will be used during the field tests to analyze the behavior of the system under study and to conclude when an error occurs.

From table (1), it is shown that the frame structure is variable between text values, decimal values and digital ones. Therefore, first a modulation for recorded values type should be done, where all of them are of one type. Then, choosing real numbers values is done in field [0,1]. We call this phase the Preprocessing phase. After that, analyzing is done using neural networks to extract Fault Tree Analysis (FTA), which demonstrates how errors occur in the system under study [4] [5] [6] [7]. At the end, this tree will be tested.

1. Preprocessing: The preprocessing aims at transforming all information into digital ones as follows:
    - Digitalizing text values: First, each text value is replaced by an increasing decimal number. Assuming that the file contains different text value n, then the values that it takes are {0, 1, 2… n-1}. After that, an estimation for the possibility that this value appears during the tests period is done after repeating it many times during the test and dividing it along the file.
    - Decimal values: Which are different information such as the call duration estimated by seconds and number of sent bites from the mobile device or from the station. Processing each of these information is done separately. For the call duration, which is usually small numbers (one-hour call corresponds 3600 seconds), a bigger value is found for the call duration during the test and division is done on it. For the sent bites number, it is a number constitutes of 32 bits. Consequently, it is either too small or too big to be transformed into a real value that uses the logarithmic function. The logarithmic function is a non-text function. Therefore, for small values, it does not change their values a lot. Yet, for big values, there is a big change. There has not been a division on the bigger value during the test period, as there could be cases in which the number of sent bites does not exceed some kilobytes, and cases in which they are close to gigabyte. When being divided, the small values become very close to zero.

2. Training: The recorded file contains about 20,000 frames vary between frames that express a successful connection without problems and other that express a failed connection for some reason (one of the errors explained previously). One thousand cases were taken that express a successful connection and other one thousand express a failed connection. We notify that in current time we are not concerned about determining the error type that led to failure. These values were included to the neural networks. In order to make the training process, then drawing the detected errors tree was done and it is given in figure (13), where:

X1: Bit Error Rate, X2: Frame Error Rate, X3: Packet Error Rate, X4: Duration, X5: Number of Transmitted Bytes, X8: Number of Received Bytes, X9: Received Power, X12: Number of Retries, X32: Number of Retransmit Requests (for services other than call).

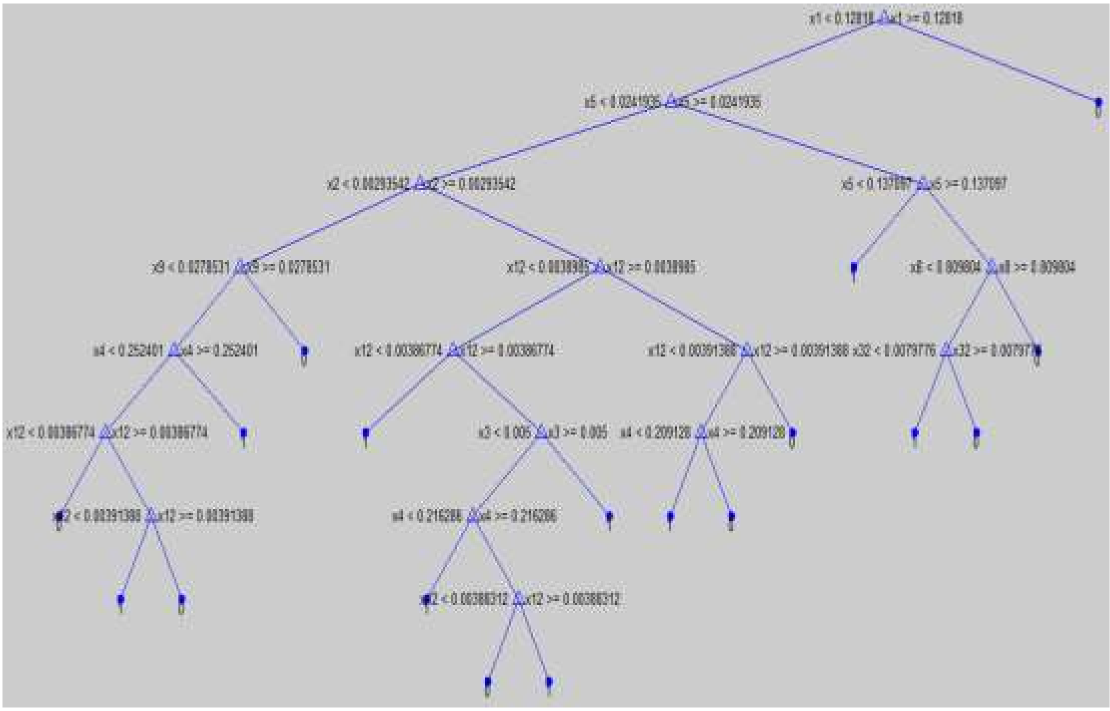


Figure 13. Fault Tree

B. Training Evaluation

The detected tree was tested during training process on the whole recorded data file (during tests, which is given in table (1)). The test result was the success of tree in detecting error occurrence at rate of 82.4% as shown in figure (14).

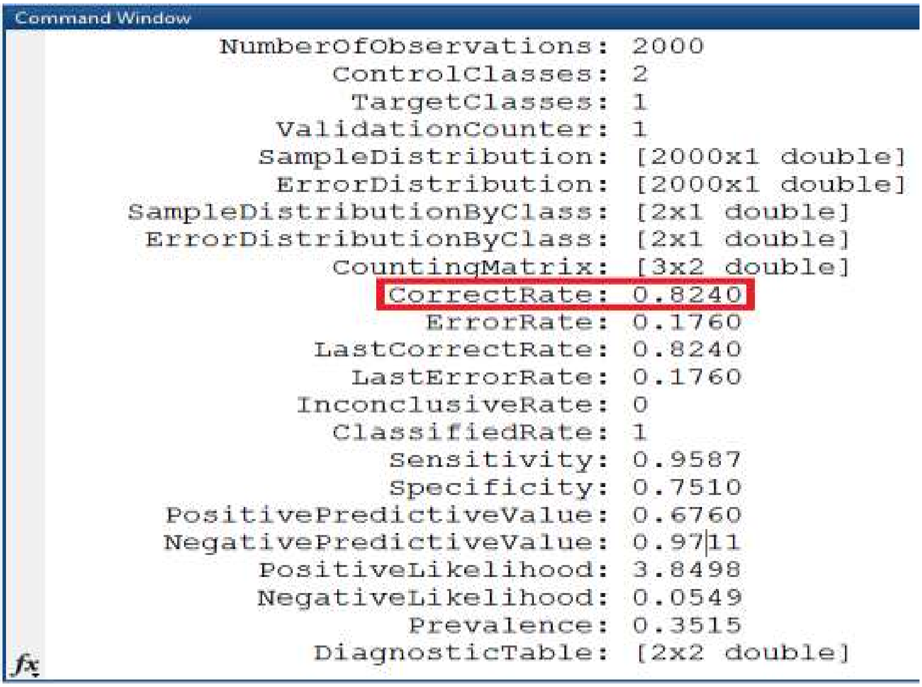


Figure 14. Performance of the built fault tree

From figure (10), it is shown that decoding of detecting and correcting error is suitable in case of high SNR values. But, in case that its values are low, it fails and error rate increases, which in turn directly leads –according to figure (12)– to an error in connection if the error rate exceeded X1=0.128, while the detected fault tree demonstrates that the error rate coefficient is the key factor in the connection's failure. If it is more than 0.128, the connection fails immediately. If the number of sent bits is less than 1000 bits and the number of received bits is more than 500 bits, then the connection fails. Otherwise, it would be successful.

ACKNOWLEDGMENT

This paper research provided a reference study for wireless digital communications system under study in the Syrian Arab Republic with regard to communications and services that it is supposed to provide for investors. It also tackled the problems resulted from investment, which was analyzed and in which fault tree was abstracted. It considered as well the simulation of the physical layer using Matlab.

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