DESIGN OF MOBILE DVB-T SINGLE FREQUENCY NETWORK(SFN) TO COVER İSTANBUL-ANKARA HIGHWAY

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

BY

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

SEPTEMBER 2009

Title of the Thesis: Design of Mobile DVB-T Single Frequency Network(SFN) To Cover İstanbul-Ankara Highway.

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ABSTRACT

DESIGN OF MOBILE DVB-T SINGLE FREQUENCY NETWORK(SFN) TO COVER İSTANBUL-ANKARA HIGHWAY

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September 2009, 91 pages

In this thesis, it is aimed to implement a DVB-T Single Frequency Network (SFN) for mobile reception which will cover the populated area of İstanbul, the İstanbul-to-Ankara-Highway, E-5 Road and the populated area of Ankara which is surrounded by the Ankara-Ring Highway. In this thesis, it will be designed DVB-T SFN Networks for mobile reception in two different DVB-T modes which are 2k and 8k modes. According to results of the SFN networks, the more suitable one for mobile reception will be obtained. A simulation software with a name of RTVplan is used to show the results and obtain the optimum design.

Keywords: Doppler Frequency, Mobile reception, Single Frequency Network.

ÖZ

İSTANBUL-ANKARA OTOYOLUNU KAPSAMAK İÇİN
MOBİL ALIŞA UYGUN
DVB-T TEK FREKANS AĞI TASARIMI

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Yüksek Lisans, Elektronik ve Haberleşme Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Yahya K. Baykal

Eylül 2009, 91 sayfa

Bu tez çalışmasında, İstanbul yerleşim alanını, İstanbul-Ankara Otoyolunu, E-5 Karayolunu ve Ankara-Çevreyolu ile çevrelenmiş Ankara yerleşim alanını kapsayacak, mobil alışa uygun bir DVB-T Tek Frekans Ağı tasarlanması amaçlanmaktadır. DVB-T Standardının iki farklı modu olan, 2k ve 8k modları için ayrı ayrı Tek Frekans Ağı tasarımları yapılacak ve tasarım sonuçları kıyaslanacaktır. Çalışma sonuçlarını göstermek ve en uygun tasarımı elde etmek için, RTVplan isimli bir simulasyon programı kullanılmıştır.

Anahtar Kelimeler: Doppler Frekansı, Mobil Alış, Tek Frekans Ağı.

ACKNOWLEDGEMENT

The author wishes to express his deepest gratitude to his supervisor Prof. Dr. Yahya K. BAYKAL for his guidance, advice, criticism, encouragements and insight throughout the research.

The author thanks to the Administration of the Radio and Television Supreme Council of Turkey for the written permission of usage of RTVplan Software.

The author would also like to thank to the Administration of Bilkent University-Communications and Spectrum Management Research Center for the permission of usage of RTVplan Software and their technical assistance.

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LIST OF ABBREVIATIONS

BER	Bit Error Ratio
BPN	EBU Technical Document
C/N	Carrier to Noise Ratio
CCIR 601	ITU-R Recommendation BT.601
CNR	Carrier to Noise Ratio
COFDM	Coded Orthogonal Frequency Division Multiplex
DVB-T	Digital Video Broadcasting - Terrestrial
EBU	European Broadcasting Union
ERP	Effective Radiated Power
ETSI	European Telecommunications Standards Institute
F	Noise Figure
FCC	Federal Communications Commission
FFT	Fast Fourier Transform
FM	Frequency Modulation
GIS	Geographical Information System
GPS	Global Positioning System
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union, Radiocommunication Sector
MFN	Multi Frequency Network

MPEG	Moving Picture Experts Group
OFDM	Orthogonal Frequency Division Multiplex
PER	Packet Error Ratio
PR	Protection Ratio
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RF	Radio Frequency
RMD	Reflection and Multiple Diffraction
SDTV	Standard Definition Television
SFN	Single Frequency Network
T-DAB	Terrestrial - Digital Audio Broadcasting
UHF	Ultra High Frequency
VHF	Very High Frequency
VHS	Video Home System

CHAPTER 1

INTRODUCTION

In this thesis, it is aimed to design a DVB-T Single Frequency Network (SFN) for mobile reception which will cover the populated area of İstanbul, the İstanbul-to-Ankara Highway, E-5 Road and the populated area of Ankara which is surrounded by the Ankara-Ring Highway. İstanbul is the biggest city of the Turkey with a population of greater than 12 millions and Ankara is the capital city and the second crowded city of the Turkey with a population of greater than 4 millions. İstanbul-to-Ankara Highway and E-5 Road are the roads between Ankara and İstanbul with a distance of greater than 450 kilometers. At the same time, these roads have heavy transportation traffic.

In this thesis, the most important thing is that DVB-T receiver is mobile, not fixed. Because of this reason, the speed of the receiver is an important parameter. And also the dimensions of the TV sets inside the vehicles are probably in the sizes of the conventional TV sets, not hand-held.

By the implementation of this thesis, someone inside a vehicle can watch same TV program without changing its channel during his/her vacation throughout the İstanbul city, İstanbul-to-Ankara Highway, E-5 Road, Ankara city and Ankara-Ring Highway.

In this study, a procedure which is followed to specify the required parameters and the criteria should be taken into consideration to design a DVB-T SFN network for mobile reception was developed. By using the results of this thesis, someone can decide which network option is convenient to cover only inside a city or through a road etc. for DVB-T mobile reception. And also the borders of the SFN under consideration could be expanded to the other adjacent roads and the cities. Moreover this thesis can be applied to the railway between Ankara and İstanbul. At this situation, there will be a need to the geographical coordinates of the railway and the maximum speed of the trains.

In this thesis study, it is used International Telecommunication Union, ITU Recommendation, Rec.ITU-R BT.1368-6[1] and European Broadcasting Union, EBU Technical Reports, BPN-047[2] and BPN-005[3] about the Planning of Terrestrial Digital Television and Mobile DVB-T to obtain the required technical parameters for planning of mobile DVB-T SFN network. And also, some of the coordinates of the transmitter sites is selected from the Turkey's Terrestrial Digital Television Frequency Plan[4] and Turkish Radio and Television Association (TRT)'s TV and FM Radio transmitter sites.

During the studies, a simulation software with a name of RTVplan[5] which was produced by Bilkent University-Communications and Spectrum Management Research Center was used to show the results and obtain the optimum design.

Also there is a M.Sc. Thesis[6,7] about the Terrestrial Digital Audio Broadcasting (T-DAB) Single Frequency Network between İstanbul-Ankara Highway which compares the T-DAB SFN networks according to their cost and coverage efficiencies.

In this section, it will be given also some information about the Terrestrial-Digital Video Broadcasting, DVB-T and the RTVplan[5] simulation software.

1.1 Terrestrial-Digital Video Broadcasting, DVB-T

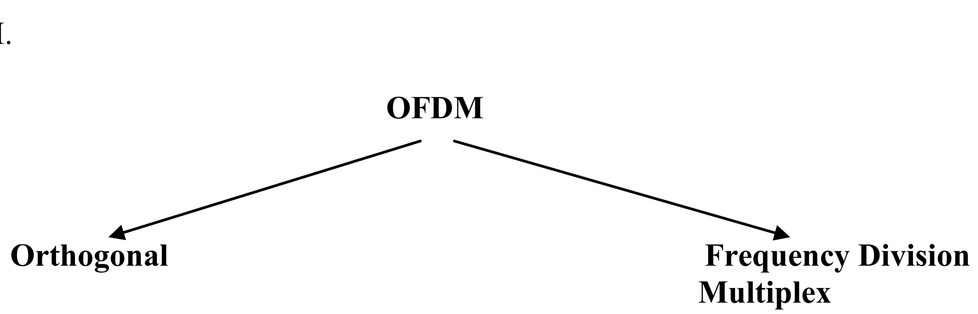
In 1995, the standard for terrestrial transmission of digital TV programs was defined in ETSI 300 744 by the DVB-T Project. A DVB-T channel can have a bandwidth of 8, 7 or 6 MHz. There are two types of different operating modes in DVB-T. They are 2k mode and 8k mode where 2k stands for a 2048 sub-carriers and 8k stands for a 8192 sub-carriers.

In DVB-T, a symbol length of about 250 μs used for 2k mode and 1 ms used for 8k mode. According to the requirements, 2k or 8k modes can be selected. While 2k mode has a greater spacing between sub-carriers of about 4 kHz and a symbol period is much shorter, 8k mode has a sub-carriers spacing of about 1 kHz.

In the single frequency network planning, the 8k mode will be generally selected due to the greater transmitter spacing possible. On the other hand, the 2k mode is better in mobile reception due to the greater sub-carrier spacing. The DVB-T standard allows a flexible control of the tranmission parameters. Besides the symbol length which is dependent on the use of 2k or 8k mode, the guard interval can be selected as of 1/4, 1/8, 1/16 and 1/32 of the symbol length. It is also possible to select the type of modulation as of QPSK, 16-QAM and 64-QAM. For the error protection, the DVB-T transmission can be adopted according to the requirements for robustness or net data rates by adjusting the code rate to 1/2, 2/3, 3/4, 5/6 and 7/8.[8]

1.1.1 Coded Orthogonal Frequency Division Multiplex, COFDM

The Orthogonal Frequency Division Multiplex, OFDM is a multi-carrier modulation method with up to thousands of sub-carriers, none of them interfere with each other because they are orthogonal to each other. The information data to be transmitted is distributed over to the many sub-carriers. They are firstly added for the appropriate error protection and resulting in Coded Orthogonal Frequency Division Multiplex, COFDM. Each of these sub-carriers is modulated with the QPSK, 16-QAM or 64-QAM.



OFDM is a composite of orthogonal (sub-carriers at right angles to each other) and Frequency Division Multiplex (division of the information data into many sub-carriers in the frequency domain).[8]

1.1.2 Digital Video Compression Standards

Standardization of compressed digital video formats facilitates the manipulation and storage of full motion video as a form of computer data and its transmission over computer networks or terrestrial broadcasting channels. Application areas of digital video compression standards include all digital TV applications, videoconferencing, videophone, digital movies, video games, education, etc.[9]

Digital SDTV (Standard Definition Television) video signals have a data rate of 270 Mbits/s. This data rate is too much for broadcasting. Therefore, this amount of data must be reduced before transmission. The data rate of 270 Mbits/s must be compressed to a value of 2…6 Mbits/s. This is possible by using of a variety of redundancy reduction mechanisms. [8]

1.1.2.1 MPEG-2

Firstly, MPEG-1 was created as the standard for moving picture coding together with sound. The purpose of the MPEG-1 was to obtain a picture quality close to the quality of VHS at CD data rate less than 1.5 Mbits/s. MPEG-1 was provided only for applications on storage media (CD, hard disk) and not for broadcasting.[8]

The quality of MPEG-1 compressed video at 1.2 Mbits/s has been found unacceptible for most applications. CCIR 601 video can be compressed with an excellent quality at 4-6 Mbits/s. The MPEG-2 was intended as a compatible extension of MPEG-1 to serve a wide range of applications at various bit rates (2-20 Mbits/s) and resolutions.[9]

MPEG-2 video coding methods were developed further for higher resolution and better quality. Transmission of data was also considered in addition to the storage of data. MPEG-2 can accommodate a multiplexed data stream over 20 programs.[8]

1.1.2.2 MPEG-4

MPEG-4 is a standard for multimedia applications with interactivity. This standard includes not only video and audio signals but also applications which have a number of different objects. Its structure is object oriented similar to the programming language C++.

MPEG-4 can cope with synthetic visual and audiovisual objects such as synthetic sound. MPEG-4 can be transmitted as a program stream in IP packets. Therefore, MPEG-4 applications can be used in the Internet, interactive multimedia applications on the PC and in the broadcasting field.[8]

1.2 RTVplan Software

During the preparation of this thesis, a simulation software with a name of RTVplan was used to show the results and to obtain the optimum design. In this thesis study, two modules of the RTVplan software were used. These modules are the Basic Module and the Broadcasting Module.[5]

1.2.1 Basic Module of RTVplan

This module is a general-purpose software for Windows® 98/ NT/ 2000/ XP Operating Systems. Basic Module has a set of engineering analysis tools for wireless communication networks operating in a frequency range from 10 kHz to 40 GHz. By using this module, point-to-area, point-to-point and odd azimuth analyses can be done. The module can obtain the population inside the predicted coverage area. This module also can find the inter-modulation frequency products. Basic Module includes a set of propagation models, full mapping capabilities and full access to terrain elevation, demographic and other databases.[5]

Technical functions of the Basic Module are:

- Propagation Prediction

- Database registration, query and reporting
- Utility Functions

Basic Module includes a set of propagation prediction models appropriate for the systems from 10 kHz to 40 GHz. The available Propagation Models in the module are ITU-R P.370, ITU-R P.529, ITU-R P.1146, Free-space (ITU-R P.525), GRWAVE, FCC, ITU-R P.1546, Okumura-Hata, Custom Model.

In this module, Reflection and Multiple Diffraction corrections, RMD can be added to ITU, FCC and Free-space models. These RMD methods are Epstein-Peterson, Deygout, Vogler and Bullington.[5]

In this thesis study, ITU-R P.1546 propagation prediction model and Epstein-Peterson Reflection and Multiple Diffraction correction, RMD method were selected.

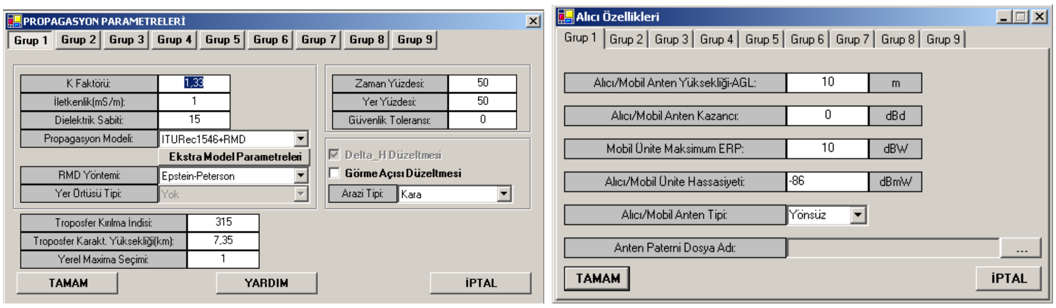


Figure-1.2.1.1: Program interfaces to enter required propagation parameters and to define receiver specifications[5]

In the Basic Module, the supported area/coverage study types are Line of Sight (LOS), Path Loss, Field strength, Received power, Received voltage, Best server and Talk back region.

Basic Module allows to define and study with a lot of transmitters in a single project. It provides a set of antenna patterns for transmitter and receiver antennas. User can also define and use his/her own antenna pattern.

The Basic Module has the following utility functions which can be used while doing spectrum engineering studies:

- Plotting of horizontal and vertical antenna patterns,
- Calculation of distance, bearing angle, effective antenna height, and delta-H value,
- Coordinate conversion
- Sattelite look angle
- Calculation of sattelite link budget
- Healt safety distance
- Plotting of ITU-R P.1546 propagation curves

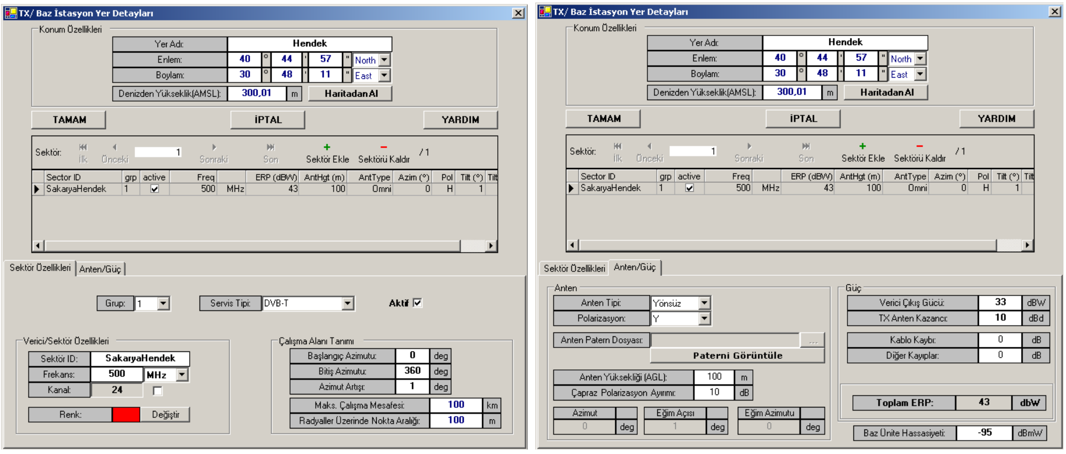


Figure-1.2.1.2: Program interfaces to enter the required technical parameters of a transmitter and to define the study conditions.[5]

It is also possible to display the study results and spatial data simultaneously on a layered GIS architecture. These study results can be exported to common image formats and displayed as color-coded plots on a map. Also, contour plots can be created on a selected layer. GIS facility included in the module allows to access the information such as geographical coordinates, terrain elevation, 1st and 2nd best servers.[5]

1.2.2 Broadcasting Module of RTVplan

Broadcasting Module is an advanced tool which is specifically designed for analog and digital broadcasting services.

Technical functions of Broadcasting Module are:

- Terrestrial Digital Audio/Video Broadcasting analysis
- Terrestrial Analog Audio/Video Broadcasting analysis
- Interference analysis between various broadcasting services

Broadcasting module uses the Basic Module to define transmitter parameters and to find the coverage areas. In the interference analysis, time percentage propagation prediction results for one percent and fifty percent are used.

The interference analysis studies can be performed for continuous or tropospheric interference. The minimum required field strength and protection ratio values can be defined by user.[5]

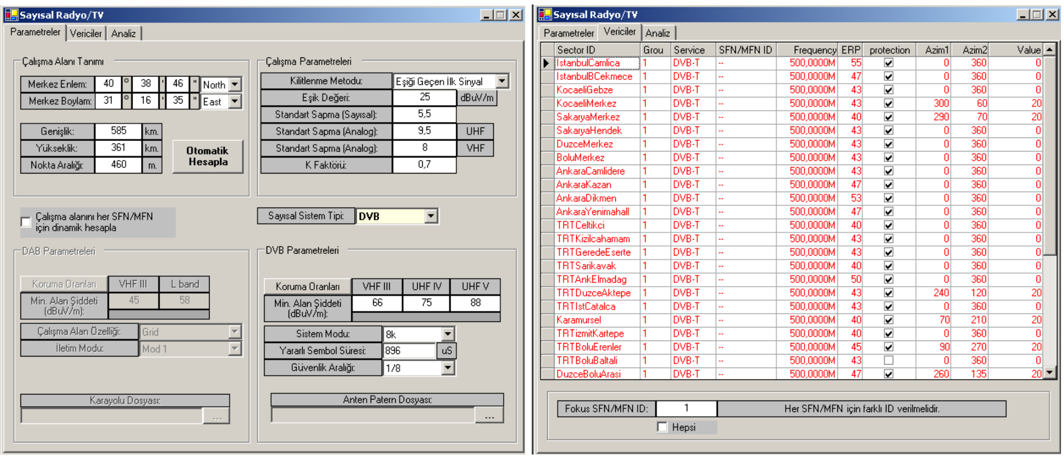


Figure-1.2.2.1: Program interfaces to enter the required technical parameters of an SFN and to select the transmitters which are included in the SFN.[5]

In the analysis of analog broadcasting services, ITU Recommendations, Rec.ITU-R BS.412, Rec.ITU-R BT.417 and Rec.ITU-R BT.655 are used.

In the Broadcasting Module, T-DAB (Terrestrial-Digital Audio Broadcasting) analysis in VHF and L-bands and DVB-T (Digital Video Broadcasting-Terrestrial) analysis in UHF band can also be done. DVB-T studies can be performed in any rectangular area which is defined by the user.

T-DAB studies can also be done in any rectangular area or throughout a route with the coordinates which are defined by the user. T-DAB and DVB-T services can be analyzed either as a Single Frequency Network (SFN) or a Multi Frequency Network (MFN). Before making analysis in T-DAB and DVB-T services, coverage area studies for transmitters are performed by using Basic Module.

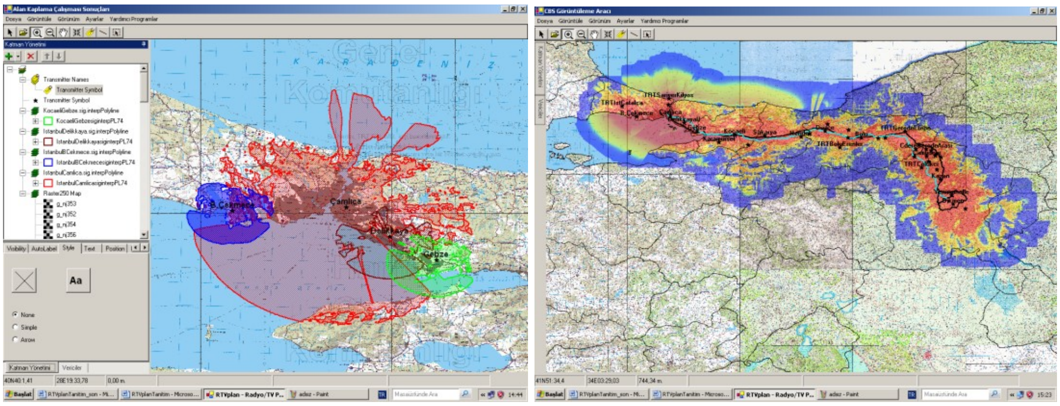


Figure-1.2.2.2: Program interfaces show the contours of the useful signal levels (Left) and coverage probability levels for an SFN study in DVB-T analysis.[5]

By using T-DAB and DVB-T analyses, the interference-free coverage areas of the Networks under consideration can be obtained. Broadcasting Module can also calculate the total useful signal level, total interfering signal level, network gain, protection ratio and coverage probability. EBU Recommendations are used to do the coverage probability calculations.

It is also possible to see the study results graphically. The contours of various levels can be displayed on a map background. Multiple images or contours can be displayed on a map, simultaneously. Also, the population inside any contour can be obtained.[5]

CHAPTER 2

SINGLE FREQUENCY NETWORKS (SFNs)

Single Frequency Networks have many advantages according to the conventional single-transmitter networks. SFN networks have more efficient spectrum usage, better coverage, less interference, less power usage, and higher reliability.

In the conventional single-transmitter terrestrial-broadcasting networks, it is possible to increase the coverage area only by increasing the transmitter output power, increasing antenna height and/or increasing or changing antenna gain of the transmitters. If it is not possible to do these changes to increase the coverage area, another transmitter/transmitters will be added by using different TV channels for broadcasting of the same TV program. In the case of SFN network, it is easy to extend the coverage area by adding the lower-power transmitters inside the desired coverage area.[10]

2.1 Description of Single Frequency Network

In general, there are two types of terrestrial digital broadcasting networks. These are Multi Frequency Networks (MFNs) and Single Frequency Networks (SFNs).

- Multi Frequency Networks (MFN) allow the same or different programs to be transmitted by individual transmitters using different frequencies.

- Single Frequency Networks (SFNs) use multiple transmitters operating on the same frequency and carrying the same programs to satisfy the required coverage.

In an SFN, the receiving locations within the coverage area will be covered by more than one transmitter. This satisfies a level of redundancy to the received signal and improves the service availability. Especially for portable and mobile reception, the field strength of a received signal from a single transmitter shows statistical variations because of the presence of obstacles on the propagation path.This field strength variations can be reduced by the presence of several transmitters, located at different sites as seen from the receiver. When one transmitter signal is shadowed, the other transmitter signals can be receivable.

In an SFN, all transmitters of a network use the same frequency. They have a common coverage area and cannot be operated independently. As seen in the Figure-2.1.1, all the tarnsmitters of the SFN are operating on the same channel.

When operating in an SFN, the signals of each tranmitter should be:

- synchronous in time,
- nominally coherent in frequency,
- have identical multiplex content.

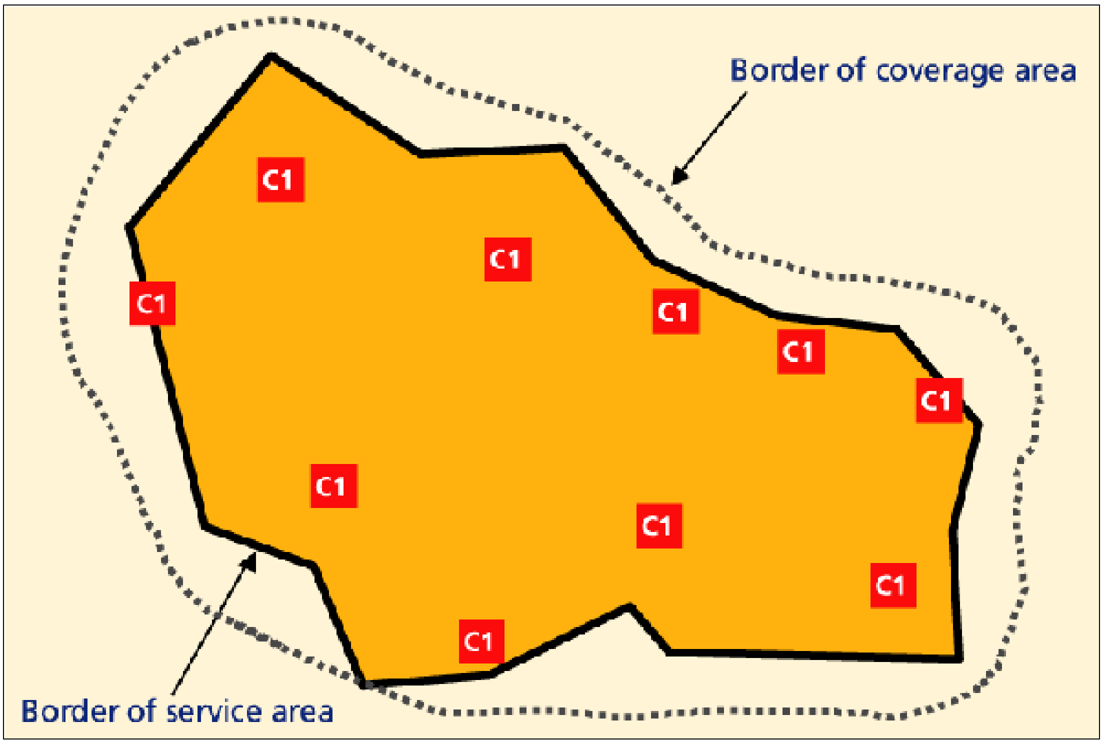


Figure-2.1.1: Single Frequency Network (SFN)[12]

The SFN allows a more homogeneous field strength distribution than the MFN, which is important especially for portable and mobile reception. In the case of mobile reception, the SFN does not require a frequency hand over in the receiver when moving within the whole coverage area. At the same time, compared with a conventional MFN, an SFN network allows significant improvements in spectrum utilization.[12]

2.2 Impact of DVB-T Parameters on SFN Performance

2.2.1 Constellation

The DVB-T specification allows for three different phase/amplitude constellations, QPSK, 16-QAM and 64-QAM. The choice of constellation determines the number of bits that are carried at a time on each sub-carrier; 2 bits for QPSK, 4 bits for 16-QAM and 6 bits for 64-QAM can be carried.

When QPSK constellation provides a low data capacity and a very rugged service, the 64-QAM constellation provides a high data capacity but does not provide rugged service.[12]

2.2.2 Code Rate

Different code rates can be used according to the required bit rate or ruggedness of service. When the code rate of 1/2 has the highest redundancy and the lowest data throughput, the code rate of 7/8 has the lowest redundancy and the highest data throughput.[12]

2.2.3 2k and 8k Transmission Modes

DVB-T Standard defines two types of transmission modes (2k and 8k) each using different numbers of sub-carriers (2048 and 8192 respectively) to constitute the OFDM signal. This means that they have different symbol times, T_u=224µs for 2k mode and T_u=896µs for 8k mode. The 8k system provides a higher degree of protection against inter-symbol interference caused by multipath propagation. In the 2k system, due to the considerably shorter usable symbol time of 224µs, signal delays can exceed easily the guard interval durations. Therefore, the 2k systems are not suitable for large area SFNs.[12]

2.2.4 Guard Intervals

In an SFN, each transmitter is required to radiate the same OFDM symbol at the same time. This is for the fact that echoes generated by the co-channel transmitters will be confined in the guard interval period. The DVB-T specification offers a selection of system guard intervals of 1/32, 1/16, 1/8 and 1/4 times of the useful symbol duration.

In a 2k system, the guard interval values correspond to 7µs, 14µs, 28µs and 56µs for guard intervals of 1/32, 1/16, 1/8 and 1/4 respectively. These values also can be translated into distances as 2.1km, 4.2km, 8.4km and 16.8km respectively.

In a 8k system, the guard interval values correspond to 28µs, 56µs, 112µs and 224µs for guard intervals of 1/32, 1/16, 1/8 and 1/4 respectively. These values also can be translated into distances as 8.4 km, 16.8 km, 33.6 km and 67.2 km respectively.[12]

2.3 Spectrum Efficiency

In a single frequency network, large areas can be covered with a common multiplex at a common radio frequency channel. However, in the case of MFN, similar networks offerring other program multiplexes in adjacent areas will require additional radio frequency channels. Therefore the frequency efficiency of an SFN is very high with compared to MFNs. Gaps in the coverage area of an SFN can easily be filled by adding a new transmitter without the need for additional frequencies.[12]

2.4 Power Efficiency

The single frequency network is also a power efficient network. In conventionally planned networks, a common way to achieve service continuity at a high percentage of locations is to increase the transmitter power significantly. However with omni-directional reception in SFNs, where the wanted signal consists of several signal components from different transmitters, the fades in the field strength of one transmitter may be filled by another transmitter. As a consequence, SFNs can use lower powered transmitters. This power efficiency of an SFN is important in the fringe of a coverage area and is often called as network gain.[12]

2.5 Network Gain

In an SNF coverage area, many receiving locations can be covered by more than one transmitter, this provides a level of redundancy and improves the service availability, especially in the case of portable reception. In portable reception, the field strength values from a single transmitter shows statistical variations due to the presence of obstacles on the propagation path. This field strength variations can be reduced by the presence of several transmitters, located at different sites as seen from the receiver. When one transmitter signal is shadowed, the other transmitter signals can be receivable. This is known as network gain. As a result of network gain, SFNs can be operated at lower power transmitters and the field strength distribution over coverage area is more homogeneous as compared to MFNs.[12]

CHAPTER 3

TECHNICAL BASES FOR MOBILE DVB-T PLANNING

3.1 General Aspects of Mobile Reception

3.1.1 Definition of Mobile Reception

Mobile reception is defined as the reception of a DVB-T signal while in motion, where the motion includes the speeds from a walking man to a car driven on a highway. Also reception in high-speed trains, buses and etc. can be considered as a mobile reception. Mobile reception uses one or more outdoor omni-directional antennas situated at no less than 1.5 meters above ground level.[2]

3.1.2 Definition of Mobile Channel

A mobile channel is corresponding to a Rayleigh channel but on the move. In this channel, there are several statistically independent incoming signals affected by Doppler shift/spread and they have different delay times, none of them dominates and together with thermal noise. Because of the multipath propagation, there will be rapid and severe variations in the received signal. But, the main degradation to the received signal is caused by the movement of bus or train carrying the DVB-T receiver. The movement of bus or train carrying the DVB-T receiver corresponds to a Doppler frequency.[2,3]

3.1.3 Coverage Definition of Mobile DVB-T Reception

Digital television service coverages are characterised by a very rapid transition from near perfect reception to no reception at all. Because of this reason, it is much more critical to define which areas are going to be covered. In order to guarantee coverage, it may be necessary either to increase the transmitter powers or to increase the number of transmitters. Thus, the coverage definition of "good" has been defined as the situation where 95% of the locations within a small area (like 100m*100m) are covered. And the coverage definition of "acceptable" has been defined as the situation where 70% of the locations within a small area are to be covered.[3]

In the case of mobile reception, 99% of the locations inside a specified coverage area should be covered.[1]

3.1.4 Factors Influencing Mobile DVB -T Reception

When planning a network for mobile reception, there is a trade-off between data-throughput, robustness and speed of the receiver. In a mobile channel, the code rate and error coding should be robust enough to cope with the degradation. The maximum Doppler frequency is directly proportional with the inter-carrier spacing and inversely proportional with the operating frequency.[2]

3.2 System Characteristics of Mobile Reception

The mobile reception corresponds to a difficult environment which has a large influence on the DVB-T receiver behaviour and the Quality of Service delivered to the users.

Some DVB-T system parameters have a direct effect on mobile reception capabilities which are:

- **FFT size**: has a direct impact on the achievable maximum speed of the receiver. The 8k DVB-T mode has more closely spaced carriers than the 2k mode. Because of this reason, 2k system can cope with four times higher Doppler shift frequencies. Also, the Doppler frequency is inversely proportional to the transmission frequency used, i.e. the influence of Doppler shift is less at lower frequencies. Therefore, VHF Band frequencies are more suitable than UHF Band frequencies for mobile reception from a Doppler point of view.
- **Constellation type**: the more complex the modulation constellation is, the more difficult the receiver to demodulate the DVB-T signal. This means that, QPSK and 16-QAM constellations will give a better mobile reception

performance than the 64-QAM for the same code-rate. However for the same data throughput, a higher order modulation with a robust coding provides a better mobile performance than a lower order modulation with a weak code-rate.

- **Code-rate**: the error correcting code used must be robust enough to cope with the degradation provided in a time varying channel. This means that the code rates of 1/2 and 2/3 are preferable for mobile reception.
- **Guard interval**: in a mobile environment, where the receivers have to cope with fast variations of the transmission channel characteristics, the use of guard interval constitutes a disadvantage. The channel estimation in the receiver, neeeded for tracking the fast channel variations in the mobile channel, becomes more difficult when a guard interval is introduced into the signal. Therefore, a short guard interval is an advantage in this situation. Also, a short guard interval will provide more data capacity. The disadvantage of a short guard interval is that the use of SFN becomes more difficult. Therefore, code rates higher than 2/3 give high penalty in terms of required C/N and Doppler degradation in the difficult mobile reception environment. For this reason, a subset of all available DVB-T modes is given in Table-3.2.1 for the code rates of 1/2 and 2/3.[2]

		Bit rate (Mbit/s)			
Modulation	**Code Rate**	**GI = 1/4**	**GI = 1/8**	**GI = 1/16**	**GI = 1/32**
QPSK	**1/2**	4.98	5.53	5.85	6.03
QPSK	**2/3**	6.64	7.37	7.81	8.04
16-QAM	**1/2**	9.95	11.06	11.71	12.06
16-QAM	**2/3**	13.27	14.75	15.61	16.09
64-QAM	**1/2**	14.93	16.59	17.56	18.10
64-QAM	**2/3**	19.91	22.12	23.42	24.13

Table-3.2.1: A subset of DVB-T modes, selected for mobile reception with their bit rates.[2]

3.3. Signal Levels and Coverage Targets

3.3.1 Minimum Required C/N Values for Planning Mobile DVB-T Diversity Reception

A number of graphs have been produced to estimate the minimum required C/N values with respect to Doppler frequencies for mobile reception for the diversity case. These graphs are given in Appendix-A.1 for the typical urban channel. The graphs include the C/N degradations due to the increasing Doppler frequency. The graphs are also given for the 8k mode and for a PER level of 10^{-4}. To find the required C/N values for the 2k mode, the Doppler frequency should be multiplied by 4.

The shortest Guard Interval of 1/32 is the least critical case in terms of Doppler effect. The given C/N values in the graphs in Appendix-A.1 are given for a guard interval of 1/32. Use of longer guard intervals will not affect the required C/N values. But the maximum Doppler frequencies will be about 85%.

According to the selected planning parameters, the corresponding Doppler frequency is calculated. By using the Eqn.(4.1), the corresponding Doppler frequency is calculated for the maximum speed of the receiver and the operating frequency of the SFN network. After finding the Doppler frequency, the minimum required C/N values are found by using the graphs which are given in Appendix-A.1 for the planning parameters like transmission mode (2k or 8k), modulation technique (QPSK, 16-QAM, 64-QAM), code rate (1/2, 2/3, 3/4, 5/6 or 7/8) and diversity or non-diversity reception.[2]

3.3.2 Minimum Required Field Strength Values for Mobile DVB-T Reception

To find the required minimum field strength values, it is necessary to know the minimum required C/N values. As stated in the Section 3.3.1, the minimum C/N values can be obtained from the graphs in Appendix-A.1 for the selected planning parameters. After finding the minimum required C/N value, this value is substituted to the formula which is given in Appendix-A3. By doing the necessary calculations, the minimum required field strength value can be found. These calculations for Band VHF-III, UHF-IV and V are given in the Section 4.1 for the selected planning parameters.[2]

3.3.3 Protection Ratios for DVB-T Digital Terrestrial Television Signal Interfered by a DVB-T Signal

In the following Tables-3.3.3.1 and 3.3.3.2, co-channel and adjacent channel protection ratios (dB) for a DVB-T signal interfered by a DVB-T signal are given. The protection values are given for a Rayleigh channel which is used for mobile reception.

Modulation	Code Rate	Protection Ratios for Rayleigh channel (dB)
QPSK	1/2	8
QPSK	2/3	11
16-QAM	1/2	13
16-QAM	2/3	16
16-QAM	3/4	18
64-QAM	1/2	19
64-QAM	2/3	23
64-QAM	3/4	25

Table-3.3.3.1: Co-channel protection ratios for a DVB-T signal interfered by a DVB-T signal.[1]

Channel	N-1	N+1
Protection Ratio(dB)	-30	-30

Table-3.3.3.2: Protection ratios(dB) for a DVB-T signal interfered by a DVB-T signal in the lower(N-1) and upper(N+1) adjacent channels.[1]

The given protection ratios in Tables-3.3.3.1 and 3.3.3.2 are given in dB and valid for both continuous and tropospheric interference. The wanted and unwanted DVB-T signals have the same channel bandwidth.[1]

CHAPTER 4

DESIGN OF MOBILE DVB-T SINGLE FREQUENCY NETWORK(SFN) TO COVER İSTANBUL-ANKARA HIGHWAY

In this thesis, it is aimed to implement a DVB-T Single Frequency Network (SFN) for mobile reception which will cover the populated area of İstanbul, the İstanbul-to-Ankara-Highway and the populated area of Ankara which is surrounded by the Ankara-Ring Highway.

During the preparation of the Turkey's Terrestrial Digital Television Frequency Plan[4] in 1998, 1,172 locations was measured by GPS over Ankara-İstanbul Highway and Ankara-Ring Highway to determine the coordinates of that roads.[Appendix-B]

In this thesis, it will be designed DVB-T SFN Networks for mobile reception in two different DVB-T modes which are 2k and 8k modes. According to results of the SFN networks, the one which is more suitable for mobile reception, will be obtained.

To design an SFN network, it is necessary to find the required minimum field strength values for the selected DVB-T modes. To do this, there is a need to define the receiving conditions. Firstly it must be given the answers to the following questions;

1- Which type of reception will be preferred, diversity or non-diversity reception?

2 - What is the maximum speed of the mobile DVB-T receiver?

3 - What is the operating frequency of the network?

4 - Which DVB-T mode will be used, 2k or 8k mode?

5 - Which coverage probability will be used, 90%, 95% or 99%?

In this thesis;

- Diversity reception,
- 120 km/h, for the maximum speed of the receiver,
- 500 MHz, for the operating frequency of SFN network,
- Coverage probability of 99%,

will be taken and then the network designs will be done for both 2k and 8k modes separately. It will be shown also the coverages for mobile reception with selected plan parameters of Turkey’s Terrestrial Digital Television Frequency Plan[4]. This plan was prepared for fixed antenna reception and to cover populated areas of Turkey.

In this thesis, it will be firstly used the current transmitter sites of that plan to see the coverage area for the mobile reception in İstanbul, along the İstanbul-to-Ankara Highway and in Ankara. After that, the SFN networks will be designed for 2k and 8k transmission modes to cover completely populated areas of İstanbul and Ankara and the roads of the İstanbul-to-Ankara Highway, E-5 Road and Ankara-Ring Highway.

4.1 Calculation of Minimum Field Strength and Minimum Median Equivalent Field Strength Values

To calculate the required minimum field strength values, it is necessary to know the minimum required C/N values. A number of graphs have been produced to estimate the minimum required C/N values with a degradation of increasing Doppler frequency. These graphs are given for the 8k transmission mode. For the 2k mode, the Doppler frequency should be multiplied by 4 to find the required C/N values.[2]

In this thesis, the maximum speed of the receiver which is situated inside a car driven on a motorway is chosen as **120 km/h**. The shortest Guard Interval of 1/32 is the least critical case in terms of Doppler effect. Use of longer guard intervals will not affect the required C/N values. But the maximum Doppler frequencies will be about 85%. In this thesis, the Guard Interval will be taken as **1/8** because of its convenience to the SFN networks.[2]

4.1.1 Calculation of Minimum Field Strength and Minimum Median Equivalent Field Strength Values for UHF Band IV

Calculation of the minimum field strength and minimum median equivalent field strength values for mobile reception, UHF Band IV (500 MHz) and 99% coverage probability, it is necessary to find the Doppler frequency firstly.

The Doppler frequency, f_d is calculated using the following formula;

f_d = [velocity / (speed of light)] * frequency [2]……………….…………(4.1)

Substituting the values in Eqn.(4.1);

f_d = [(120 km/h) / (3*10^8m/s)] * 500 MHz

f_d = 55.55 Hz

To compensate the decrease due to the using of Guard Interval of 1/8 instead of 1/32.

f_{dmax}* 0.85 = 55.55 Hz ⇨ f_{dmax}= 65.36 Hz

If it is found the minimum required C/N value from Figure-A.1.1[2] corresponding to a Doppler frequency of approximately 65 Hz for a planning criteria of Diversity reception, 8k mode, 64 QAM, and 2/3 code rate.

Minimum required C/N = 32 dB

To calculate the minimum field strength and minimum median equivalent field strength values;

Receiver noise input power, P_n;

P_n = F + 10 * $\log_{10}$(k * T_0 * B) [1] ……………………….……………(4.2)

P_n = 7 dB + 10 * $\log_{10}$(1.38*10^{-23} J/K * 290 K * 7.61*10^6Hz)[Appendix-A3]

P_n = –128.163 dBW

Minimum Receiver Input Power, P_{smin};

P_{smin} = C/N + P_n [1] ……………………………………………….....(4.3)

P_{smin} = 32 dB + (–128.163 dBW)

P_{smin} = –96.16 dBW

Effective antenna aperture (dBm^2), A_a;

$A_a = G_D + 10 \log_{10} (1.64\lambda^2/4 \pi)$ [3] ……………………………………………(4.4)

λ = speed of light(m/s) / frequency(Hz) ……………………………………...(4.5)

$\lambda = (3*10^8 m/s) / (500*10^6 Hz) = 0.6$ m

Antenna gain, G_D for Band IV is 0 dB.[2]

$A_a = 0 dB + 10 \log_{10} (1.64*(0.6m)^2/(4*3.14))$

$A_a = -13.278$ dBm^2

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

$\varphi_{min} = P_{s\,min} - A_a$ [1,3] ………………………………………………(4.6)

$\varphi_{min} = -96.16$ dBW – (–13.278 dBm^2)

$\varphi_{min} = -82.88$ dBW/m^2

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

$E_{min} = \varphi_{min} + 120 + 10 \log (120 \pi)$ [1,3] ………………………………(4.7)

$E_{min} = \varphi_{min} + 145.8 = -82.88$ dBW/m^2 + 145.8

E_{min} = 62.92 dBμV/m ≈ 63 dB(μV/m)

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

$\varphi_{med} = \varphi_{min} + P_{mmn} + C_l + L_h$ [3] ……………………………………..(4.8)

where C_l, location correction factor;

$C_l = \mu * \sigma$ [3] ……………………………………………………………(4.9)

μ is the distribution factor, 0.52 for 70%, 1.28 for 90%, 1.64 for 95% and 2.33 for 99% coverage probability.[1]

σ is the standard deviation, 5.5 dB for outdoor reception.[3]

C_l = 2.33 * 5.5 dB =12.815 dB ≈ 13 dB

φ_{med} = –82.88 dBW/m^2 + 0 dB + 13 dB + 12 dB[2]

φ_{med} = –57.88 dBW/m^2 ≈ –57.9 dBW/m^2

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

E_{med} = φ_{med} + 145.8[3] …………………...……………………………...(4.10)

E_{med} = –57.88 dBW/m^2 + 145.8 = 87.92 dBμV/m

E_{med} ≈ 88 dBμV/m for mobile reception, Band IV (500 MHz), 99% coverage probability.

4.1.2 Calculation of Minimum Field Strength and Minimum Median Equivalent Field Strength Values for VHF Band III

As done before, it must be firstly found the Doppler frequency for mobile reception, VHF Band-III (200 MHz) and 99% coverage probability.

The Doppler frequency, f_d for VHF Band-III, 200 MHz;

Substituting the values in Eqn.(4.1),

f_d = [(120 km/h) / (3*10^{8}m/sn)] * 200 MHz

f_d = 22.22 Hz

To compensate the decrease due to the using of Guard Interval of 1/8 instead of 1/32.

f_{dmax}* 0.85 = 22.22 Hz ⇨ f_{dmax}= 26.14 Hz ≈ 26 Hz

If it is found the minimum required C/N value from Figure-A.1.1 corresponding to a Doppler frequency of approximately 26 Hz for a planning criteria of Diversity reception, 8k mode, 64 QAM, and 2/3 code rate.

Minimum required C/N = 22.5 dB

Minimum Receiver Input Power, P_{smin};

Substituting the values in Eqn.(4.3),

P_{smin} = 22.5 dB + (–128.163 dBW)

P_{smin} = –105.663 dBW

Effective antenna aperture (dBm^2), A_a;

Substituting the values in Eqn.(4.5) for the wavelength;

$\lambda = (3*10^8 m/sn) / 200*10^6 Hz) = 1.5$ m

Antenna gain, G_D for Band III is –2.2 dB.[2]

Substituting the values in Eqn.(4.4) ;

$A_a = -2.2 \text{ dB} + 10 \log_{10} (1.64*(1.5m)^2/(4*3.14))$

$A_a = -7.52 \text{ dBm}^2$

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

Substituting the values in Eqn.(4.6);

$\varphi_{min} = -105.663 \text{ dBW} - (-7.52 \text{ dBm}^2)$

$\varphi_{min} = -98.143 \text{ dBW/m}^2$

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

Substituting the values in Eqn.(4.7);

$E_{min} = –98.143\ dBW/m^2 + 145.8$

$E_{min} = 47.66\ dB\mu V/m$

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

Substituting the values in Eqn.(4.8);

Allowance for man-made noise (dB), P_{mmn} is 1 dB and height loss, L_h is 10 dB for Band III.

$\varphi_{med} = –98.143\ dBW/m^2 + 1\ dB + 13\ dB + 10\ dB$ [2]

$\varphi_{med} = –74.143\ dBW/m^2$

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

Substituting φ_{med} in Eqn.(4.10);

$E_{med} = –74.143\ dBW/m^2 + 145.8 = 71.657\ dB\mu V/m$

$E_{med} \approx 72\ dB\mu V/m$ for mobile reception, VHF Band III(200 MHz), 99% coverage probability.

4.1.3 Calculation of Minimum Field Strength and Minimum Median Equivalent Field Strength Values for UHF Band V

The Doppler frequency, f_d for UHF Band V, 800 MHz;

Substituting the values in Eqn.(4.1);

$f_d = [(120\ km/h) / (3*10^8 m/s)] * 800\ MHz$

$f_d = 88.88\ Hz$

To compensate the decrease due to the using of Guard Interval of 1/8 instead of 1/32.

f_{dmax}* 0.85 = 88.88 Hz ⇨ f_{dmax}= 104.6 Hz ≈ 105 Hz

If it is found the minimum required C/N value from Figure-A.1.1 corresponding to a Doppler frequency of approximately 105 Hz for a planning criteria of Diversity reception, 8k mode, 64 QAM, and 2/3 code rate, it is not found any available C/N value for that Doppler frequency. It can be found a value for minimum required C/N value from Figure-A.1.3 corresponding to a Doppler frequency of approximately 105 Hz for a planning criteria of Diversity reception, 8k mode, 16 QAM, and 2/3 code rate.

Minimum required C/N = 28 dB

Minimum Receiver Input Power, P_{smin};

Substituting the values in Eqn.(4.3);

P_{smin} = 28 dB + (–128.163 dBW)

P_{smin} = –100.163 dBW

Effective antenna aperture (dBm^2), A_a;

Substituting the values in Eqn.(4.5) for wavelength;

$\lambda = (3*10^8 \text{ m/s}) / (800*10^6 \text{ Hz}) = 0.375 \text{ m}$

Substituting the values in Eqn.(4.4) ;

$A_a = 0 \text{ dB} + 10 \log_{10} (1.64*(0.375\text{m})^2/(4*3.14))$

$A_a = -17.36 \text{ dBm}^2$

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

Substituting the values in Eqn.(4.6);

$$\varphi_{min} = -100.163 \text{ dBW} - (-17.36 \text{ dBm}^2)$$

$$\varphi_{min} = -82.80 \text{ dBW/m}^2$$

Substituting the values in Eqn.(4.7);

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

$$E_{min} = -82.80 \text{ dBW/m}^2 + 145.8$$

$$E_{min} = 63 \text{ dB}\mu\text{V/m}$$

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

Substituting the values in Eqn.(4.8);

$$\varphi_{med} = -82.80 \text{ dBW/m}^2 + 0 \text{ dB} + 13 \text{ dB} + 12 \text{ dB [2]}$$

$$\varphi_{med} = -57.8 \text{ dBW/m}^2$$

Substituting φ_{med} in Eqn.(4.10);

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

$$E_{med} = -57.8 \text{ dBW/m}^2 + 145.8 = 88 \text{ dB}\mu\text{V/m}$$

E_{med} = 88 dBμV/m for mobile reception, UHF Band V(800 MHz), 99% coverage probability.

4.2 Coverage for Mobile Reception by Using the Plan Transmitter Sites with Selected Parameters of the Plan

The Turkey's Terrestrial Digital Television Frequency Plan[4] was prepared for fixed antenna reception and to cover the populated areas of Turkey. This plan was prepared for 8k transmission mode, 1/8 Guard Interval, 2/3 Code Rate and 64 QAM. In this plan, there are sixteen transmitter sites in İstanbul, near the İstanbul-to-Ankara Highway and in Ankara. In this section, it will be used the current transmitter sites of that plan to see the coverage area for the mobile reception in İstanbul, along the İstanbul-to-Ankara Highway and in Ankara.

The transmitter sites and their planning parameters are given in Table-4.2.1 for İstanbul, near the İstanbul-to-Ankara Highway and Ankara.

Transmitter Site Name	Longitude (East)	Latitude (North)	Altitude (m)	Channel No	ERP (dBW)	Antenna Height	Antenna Tilt	Polari zation	Vertical Gain
İstanbul-B.Çekmece	28:37:27	41:00:47	200	24	**20**	100 m	1°	H	7 dB
İstanbul-Çamlıca	29:04:08	41:01:40	256	24	**45**	150 m	3°	H	10 dB
İstanbul-Delikkaya	29:14:26	40:54:45	300	24	**30**	100 m	3°	H	10 dB
Kocaeli-Gebze	29:25:22	40:49:22	250	24	**20**	100 m	1°	H	7 dB
Kocaeli-Merkez	29:55:38	40:46:36	200	24	**30**	100 m	1°	H	10 dB
Sakarya-Merkez	30:19:25	40:45:38	300	24	**30**	100 m	1°	H	10 dB
Sakarya-Hendek	30:48:11	40:44:57	300	24	**20**	100 m	1°	H	7 dB
Düzce-Cumaova	30:56:44	40:50:50	200	24	**25**	100 m	1°	H	7 dB
Düzce-Merkez	31:07:30	40:49:19	200	24	**20**	100 m	1°	H	7 dB
Bolu-Merkez	31:36:29	40:44:02	800	24	**35**	100 m	1°	H	10 dB
Bolu-Yeniçağa	32:01:56	40:46:19	971	24	**20**	100 m	1°	H	7 dB
Bolu-Gerede	32:11:55	40:48:07	1355	24	**25**	100 m	1°	H	7 dB
Bolu-Dörtdivan	32:03:30	40:43:08	1200	24	**20**	100 m	1°	H	7 dB
Ankara-Çamlıdere	32:28:28	40:29:28	1284	24	**25**	100 m	1°	H	7 dB
Ankara-Kazan	32:39:29	40:11:07	900	24	**20**	100 m	1°	H	7 dB
Ankara-Dikmen	32:49:42	39:51:43	1224	24	**40**	100 m	3°	H	10 dB

Table-4.2.1: The transmitter sites and their planning parameters are given for İstanbul, near the İstanbul-to-Ankara Highway and Ankara.[4]

In this thesis, the mobile reception conditions were specified as Diversity reception, 120 km/h for the maximum speed of the receiver, 500 MHz for the operating frequency of SFN network and coverage probability of 99%.

For the selected parameters of that plan[4] with 8k transmission mode, 1/8 Guard Interval, 2/3 Code Rate and 64 QAM modulation type, the minimum required field strength was calculated in the Section 4.1.

$E_{med} \approx 88$ dBμV/m

Figure-4.2.1: SFN coverage for mobile reception with the current plan[4] Transmitters and using their planning parameters.

As seen from the Figure-4.2.1, the coverage areas of the plan transmitters are very small and they are not sufficient to cover the desired coverage area for mobile reception. It is understood that the powers of the transmitters are not adequate to satisfy the required minimum field strength values for the desired coverage areas for the selected parameters of the plan.[4] It is also seen that, it is necessary to change the parameters of the existent transmitters and to add additional transmitter sites in proper places to obtain the sufficient signal levels in the desired coverage areas.

4.3 SFN Planning for Mobile Reception with 2k Transmission Mode

In this section, it will be designed a DVB-T SFN Network for mobile reception in 2k transmission mode. The network will be for Diversity reception, 120 km/h for the maximum speed of the receiver, 500 MHz for the operating frequency of SFN network and a coverage probability of 99%. The goal is to design a network to cover completely populated areas of İstanbul and Ankara and the roads of the İstanbul-to-Ankara Highway and Ankara-Ring Highway.

4.3.1 Case-1: SFN Planning for Diversity Reception, 2k Transmission Mode, 16 QAM Modulation Type, 2/3 Code Rate

In the Case-1 situation, it will be designed the SFN network for 2k transmission mode, 1/4 Guard Interval, 2/3 Code Rate and 16 QAM modulation type. For these selected planning parameters, the minimum required field strength will be calculated here.

Calculation of the minimum field strength and minimum median equivalent field strength values for mobile reception, there is a need firstly to find the minimum required C/N values from the graphs given in Appendix-A.1.

The Doppler frequency, f_d = 55.55 Hz for 500 MHz, the operating frequency of SFN network.

To compensate the decrease due to the using of Guard Interval of 1/4 instead of 1/32.[2]

$$f_{dmax} * 0.85 = 55.55 \text{ Hz} \Rightarrow f_{dmax} = 65.36 \text{ Hz}$$

These graphs which are given in Appendix-A.1 are for the 8k transmission mode. For the 2k mode, the Doppler frequency should be multiplied by 4 to find the required C/N values.[2]

Because of this reason, it will be used f_{dmax} as;

$$f_{dmax} = 65.36/4 = 16.34 \text{ Hz}$$

If it is found the minimum required C/N value from Figure-A.1.3[2] corresponding to a Doppler frequency of approximately 16 Hz for a planning criteria of Diversity reception, 2k mode, 16 QAM, and 2/3 code rate.

Minimum required C/N = 16.5 dB

To calculate the minimum field strength and minimum median equivalent field strength values;

Receiver noise input power, P_n as calculated in Section 4.1.

$$P_n = -128.163 \text{ dBW}$$

Substituting P_n and C/N value in Eqn.(4.3);

Minimum Receiver Input Power, P_{smin};

$$P_{smin} = 16.5 \text{ dB} + (-128.163 \text{ dBW})$$

$$P_{smin} = -111.663 \text{ dBW}$$

Effective antenna aperture (dBm^2), A_a as calculated in Section 3.1

$$A_a = -13.278 \text{ dBm}^2$$

Substituting $P_{s\,min}$ and A_a values in Eqn.(4.6);

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

$\varphi_{min} = -111.663$ dBW – (–13.278 dBm^2)

$\varphi_{min} = -98.385$ dBW/m^2

Substituting the values in Eqn.(4.7);

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

$E_{min} = -98.385$ dBW/m^2 + 145.8

$E_{min} = 47.415$ dBμV/m ≈ 48 dBμV/m

Substituting the values in Eqn.(4.8);

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

$\varphi_{med} = -98.385$ dBW/m^2 + 0 dB + 13 dB + 12 dB [2]

$\varphi_{med} = -73.385$ dBW/m^2 ≈ –73.4 dBW/m^2

Substituting φ_{med} in Eqn.(4.10);

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

$E_{med} = -73.385$ dBW/m^2 + 145.8 = 72.415 dBμV/m

E_{med} ≈ 73 dBμV/m for mobile reception, Band IV (500 MHz), 99% coverage probability.

The transmitters and their planning parameters are given in the following Table-4.3.1.1 for the SFN network with Diversity reception, 2k mode, 16 QAM, and 2/3 code rate.

Transmitter Site Name	Longitude (East)	Latitude (North)	Altitude (m)	Ch. No	ERP (dBW)	Antenna Height	Protec. Sector	Protec. Ratio(dB)	Anten. Tilt	Polarization	Vertical Gain
RTÜK-İstanbul-Çamlıca	29:04:08	41:01:40	256	24	**50**	150 m	0-0	0	3°	H	10 dB
RTÜK-Kocaeli-Merkez	29:55:38	40:46:36	200	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Sakarya	30:19:25	40:45:38	300	24	**33**	100 m	270-00	20	1°	H	10 dB
RTÜK-Sakarya-Hendek	30:48:11	40:44:57	300	24	**33**	100 m	0-0	0	1°	H	10 dB
Duzce-Cumaova	30:56:44	40:50:50	200	24	33	100 m	0-0	0	1°	H	10 dB
RTÜK-Düzce	31:07:30	40:49:19	200	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-BoluMer.	31:36:29	40:44:02	800	24	**33**	100 m	0-0	0	1°	H	10 dB
Bolu-Yeniçağa	32:01:56	40:46:19	971	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ankara-Kazan	32:39:29	40:11:07	900	24	**33**	100 m	120-200	20	1°	H	10 dB
Bolu-Dortdivan	31:07:30	40:49:19	200	24	**33**	100 m	120-200	20	1°	H	10 dB
RTÜK-Ankara-Yenimahalle	32:48:23	39:58:35	1000	24	**43**	100 m	300-60	20	3°	H	10 dB
RTÜK-Ankara-Dikmen	32:49:42	39:51:43	1222	24	**45**	100 m	0-0	0	3°	H	10 dB
TRT-KHamam-Çeltikci	32:24:16	40:20:33	1232	24	**33**	100 m	120-360	20	1°	H	10 dB
TRT-K.Hamam	32:39:40	40:28:45	1007	24	**33**	100 m	120-360	20	1°	H	10 dB
TRT-Cankurtaran	32:17:58	40:34:31	1600	24	**33**	100 m	120-360	20	1°	H	10 dB
TRT-Çamlıdere-Sarıkavak	32:18:45	40:29:07	1397	24	**33**	100 m	150-300	20	1°	H	10 dB
TRT-Sakarya-Hendek	30:53:54	40:49:22	492	24	**33**	100 m	0-0	0	1°	H	10 dB
TRT-BoluBaltalı	31:49:51	40:43:47	1043	24	**33**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası	32:27:50	40:35:02	1844	24	**33**	100 m	300-150	20	1°	H	10 dB
Bolu-Yeniçağ-Arası	31:55:15	40:43:55	1400	24	**33**	100 m	90-270	20	1°	H	10 dB
TRT-Bolu Dağı-Emniyet	31:25:39	40:44:03	900	24	**33**	100 m	150-300	20	1°	H	10 dB
Çamlıdere-K.Hamam-Arası	32:31:57	40:33:53	1700	24	**33**	100 m	300-150	20	1°	H	10 dB
Çamlıdere-Gerede-Arası-II	32:22:25	40:38:31	1563	24	**33**	100 m	120-300	20	1°	H	10 dB
Çamlıdere-KHamamArasıI	32:35:17	40:29:47	1600	24	**33**	100 m	330-180	20	1°	H	10 dB
Sakarya-Hendek-II	30:54:41	40:47:01	728	24	**33**	100 m	60-270	20	1°	H	10 dB
Çamlıdere-Cankurtaran	32:19:45	40:35:10	1800	24	**33**	100 m	0-0	0	1°	H	10 dB
Kızılcahamam-Çeltikci-II	32:29:51	40:25:24	1561	24	**33**	100 m	330-210	20	1°	H	10 dB
KazanCeltikci2k	32:32:10	40:16:09	1200	24	**33**	100 m	0-150	20	1°	H	10 dB
KazanKhamam2	32:43:44	40:26:36	1460	24	**33**	100 m	270-90	20	1°	H	10 dB
Kazan-Khamam2k_1	32:39:31	40:20:06	1205	24	**33**	100 m	0-150	20	1°	H	10 dB
Sarıkavak-Celtikci2k	32:25:51	40:27:29	1300	24	**33**	100 m	330-160	20	1°	H	10 dB

Table-4.3.1.1: The transmitters and their planning parameters for Case-1 situation.

SFN coverage for mobile reception with the Case-1 transmitters is shown in the Figure-4.3.1.1:

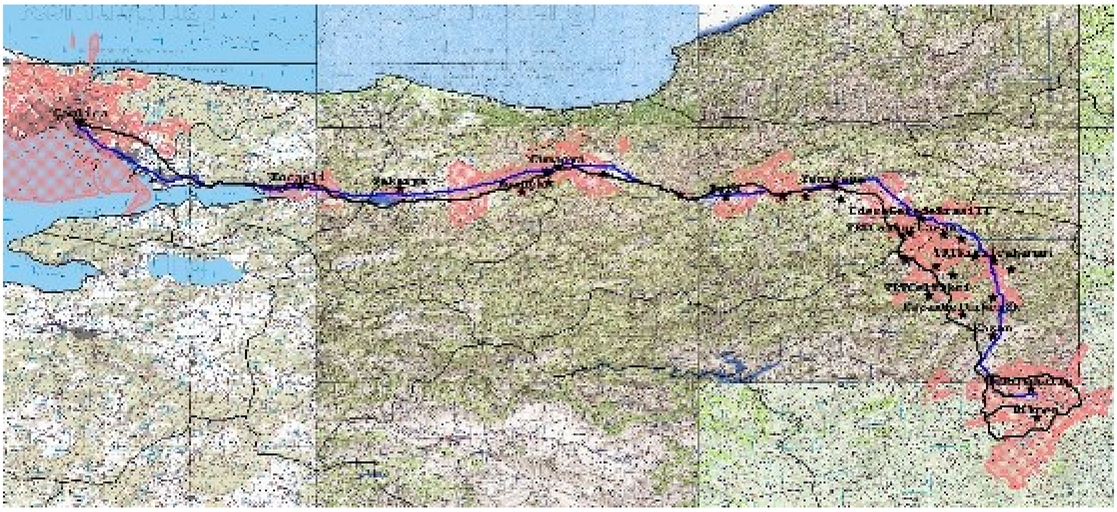


Figure-4.3.1.1: SFN coverage for mobile reception with the Case-1 transmitters and their planning parameters for Diversity reception, 2k mode, 16 QAM, and 2/3.

As seen from the Figure-4.3.1.1, the coverage areas of the specified transmitters are not sufficient to cover the desired coverage area for mobile reception. It is very difficult to form a large SFN in the case of 2k mode. In this situation, the distances between transmitters must be very small less than 16.8 km.

In this case, it is specified 31 transmitter sites with their planning parameters. 12 tranmitter coordinates are selected from Turkey's Terrestrial Digital Television Frequency Plan[4], 11 tranmitter coordinates are selected from TRT's TV and FM Radio transmitter sites and 8 transmitter coordinates are determined additionally by using the RTVplan software. RTVplan software can give the geographical coordinate of the maximum point of a selected rectangular area on the map.

4.3.2 Case-2: SFN Planning for Diversity Reception, 2k Transmission Mode, 64 QAM Modulation Type, 2/3 Code Rate

In the Case-2, it will be designed an SFN network for 2k transmission mode, 1/8 Guard Interval, 2/3 Code Rate and 64 QAM modulation type. For these selected planning parameters, the minimum required field strength will be calculated.

Calculation of the minimum field strength and minimum median equivalent field strength values for mobile reception, it is necessary firstly to find the minimum required C/N values from the graphs given in Appendix-A1.

The Doppler frequency, f_d = 55.55 Hz for 500 MHz, the operating frequency of SFN network.

To compensate the decrease due to the using of Guard Interval of 1/8 instead of 1/32.

$$f_{dmax} * 0.85 = 55.55 \text{ Hz} \quad \Rightarrow \quad f_{dmax} = 65.36 \text{ Hz}$$

These graphs which are given in Appendix-A.1 are for the 8k transmission mode. For the 2k mode, the Doppler frequency should be multiplied by 4 to find the required C/N values.[2]

Because of this reason, it will be used f_{dmax} as;

$$f_{dmax} = 65.36/4 = 16.34 \text{ Hz}$$

If it is found the minimum required C/N value from Figure.A.1.1[2] corresponding to a Doppler frequency of approximately 16 Hz for a planning criteria of Diversity reception, 2k mode, 64 QAM, and 2/3 code rate.

Minimum required C/N = 22.2 dB

To calculate the minimum field strength and minimum median equivalent field strength values;

Receiver noise input power, P_n as calculated in Section 3.1.

$P_n = –128.163$ dBW

Substituting P_n and C/N value in Eqn.(4.3);

Minimum Receiver Input Power, P_{smin};

$P_{smin} = 22.2$ dB + (–128.163 dBW)

$P_{smin} = –105.96$ dBW

Effective antenna aperture (dBm^2), A_a as calculated in Section 4.1

$A_a = –13.278$ dBm^2

Substituting $P_{s\,min}$ and A_a values in Eqn.(4.6);

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

$\varphi_{min} = –105.963$ dBW – (–13.278 dBm^2)

$\varphi_{min} = –92.685$ dBW/m^2

Substituting the values in Eqn.(4.7);

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

$E_{min} = –92.685$ dBW/m^2 + 145.8

E_{min} = 53.115 dBμV/m ≈ 53 dBμV/m

Substituting the values in Eqn.(4.8);

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

φ_{med} = –92.685 dBW/m^2 + 0 dB + 13 dB + 12 dB [2]

φ_{med} = –67.685 dBW/m^2 ≈ –67.7 dBW/m^2

Substituting φ_{med} in Eqn.(4.10);

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

E_{med} = –67.685 dBW/m^2 + 145.8 = 78.115 dBμV/m

E_{med} ≈ 78 dBμV/m for mobile reception, Band IV (500 MHz), 99% coverage probability.

The transmitters and their planning parameters are given in Table-4.3.2.1 for the SFN network with Diversity reception, 2k mode, 64 QAM, and 2/3 code rate.

Transmitter Site Name	Longitude (East)	Latitude (North)	Altitude (m)	Ch. No	ERP (dBW)	Antenna Height	Protec. Sector	Protec. Ratio(dB)	Anten. Tilt	Polarization	Vertical Gain
RTÜK-İstanbul-Çamlıca	29:04:08	41:01:40	256	24	**50**	150 m	0-0	0	3°	H	10 dB
RTÜK-Kocaeli	29:55:38	40:46:36	200	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜK-Sakarya	30:19:25	40:45:38	300	24	**37**	100 m	270-00	20	1°	H	10 dB
RTÜK-Sakarya-Hendek	30:48:11	40:44:57	300	24	**37**	100 m	0-0	0	1°	H	10 dB
Duzce-Cumaova	30:56:44	40:50:50	200	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜK-Düzce	31:07:30	40:49:19	200	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜK-Bolu	31:36:29	40:44:02	800	24	**37**	100 m	0-0	0	1°	H	10 dB
Bolu Yeniçağa	32:01:56	40:46:19	971	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜKAnkKazan	32:39:29	40:11:07	900	24	**37**	100 m	120-200	20	1°	H	10 dB
Bolu-Dortdivan	31:07:30	40:49:19	200	24	**37**	100 m	120-200	20	1°	H	10 dB
RTÜK-Ankara-Yenimahalle	32:48:23	39:58:35	1000	24	**43**	100 m	300-60	20	3°	H	10 dB
RTÜK-Ankara-Dikmen	32:49:42	39:51:43	1222	24	**45**	100 m	0-0	0	3°	H	10 dB
TRT-KHamam-Çeltikci	32:24:16	40:20:33	1232	24	**37**	100 m	120-360	20	1°	H	10 dB
TRT-K.Hamam	32:39:40	40:28:45	1007	24	**37**	100 m	120-360	20	1°	H	10 dB
TRT-Cankurtaran	32:17:58	40:34:31	1600	24	**37**	100 m	120-360	20	1°	H	10 dB
TRT-Çamlıdere-Sarıkavak	32:18:45	40:29:07	1397	24	**37**	100 m	150-300	20	1°	H	10 dB
TRT-Sakarya-Hendek	30:53:54	40:49:22	492	24	**37**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu-Baltalı	31:49:51	40:43:47	1043	24	**37**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası	32:27:50	40:35:02	1844	24	**37**	100 m	300-150	20	1°	H	10 dB
Bolu-Yeniçağ-Arası	31:55:15	40:43:55	1400	24	**37**	100 m	90-270	20	1°	H	10 dB
TRT-Bolu Dağı-Emniyet	31:25:39	40:44:03	900	24	**37**	100 m	150-300	20	1°	H	10 dB
Çamlıdere-K.Hamam-Arası	32:31:57	40:33:53	1700	24	**37**	100 m	300-150	20	1°	H	10 dB
Çamlıdere-Gerede-Arası-II	32:22:25	40:38:31	1563	24	**37**	100 m	120-300	20	1°	H	10 dB
Çamlıdere-KHamamArasıI	32:35:17	40:29:47	1600	24	**37**	100 m	330-180	20	1°	H	10 dB
Sakarya-Hendek-II	30:54:41	40:47:01	728	24	**37**	100 m	60-270	20	1°	H	10 dB
Çamlıdere-Cankurtaran	32:19:45	40:35:10	1800	24	**37**	100 m	0-0	0	1°	H	10 dB
Kızılcahamam-Çeltikci-II	32:29:51	40:25:24	1561	24	**37**	100 m	330-210	20	1°	H	10 dB
Kazan-Celtikci2k	32:32:10	40:16:09	1200	24	**37**	100 m	0-150	20	1°	H	10 dB
Kazan-Khamam2k	32:43:44	40:26:36	1460	24	**37**	100 m	270-90	20	1°	H	10 dB
Kazan-Khamam2k_1	32:39:31	40:20:06	1205	24	**37**	100 m	0-150	20	1°	H	10 dB
Sarıkavak-Celtikci2k	32:25:51	40:27:29	1300	24	**37**	100 m	330-160	20	1°	H	10 dB

Table-4.3.2.1: The transmitters and their planning parameters for Case-2 situation.

SFN coverage for mobile reception with the Case-2 transmitters is shown in the Figure-4.3.2.1:

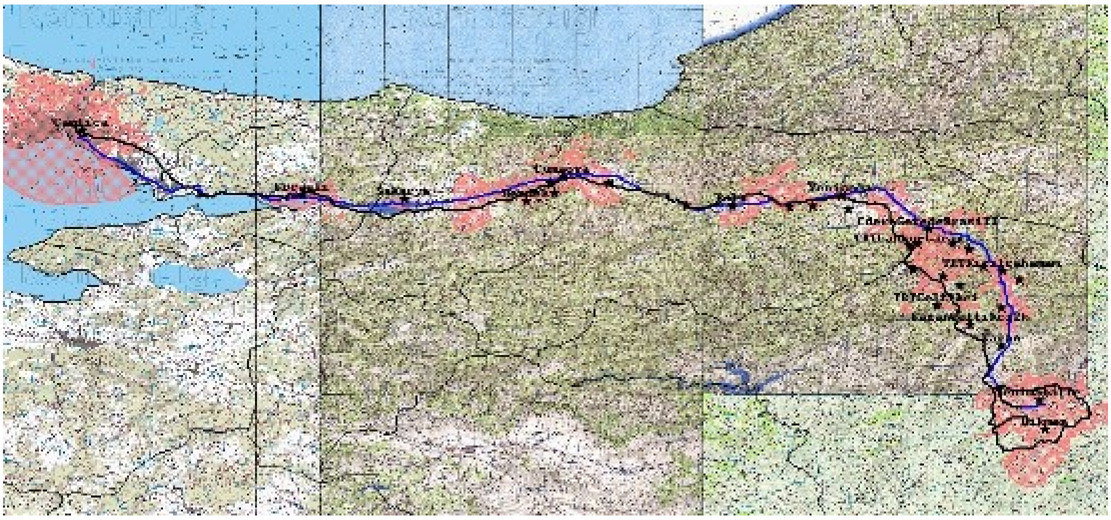


Figure-4.3.2.1: SFN coverage for mobile reception with the Case-2 transmitters and their planning parameters for Diversity reception, 2k mode, 64 QAM, and 2/3.

As seen from the Figure-4.3.2.1, the coverage areas of the specified transmitters are not sufficient to cover the desired coverage area for mobile reception. At this case also, it is very difficult to form a large SFN to cover the desired coverage area.

In this case, it is used 31 transmitter sites with their planning parameters. 12 tranmitter coordinates are selected from Turkey's Terrestrial Digital Television Frequency Plan[4], 11 tranmitter coordinates are selected from TRT's TV and FM Radio transmitter sites and 8 transmitter coordinates are determined additionally by using the RTVplan software.

4.4 SFN Planning for Mobile Reception with 8k Transmission Mode

In this section, the DVB-T SFN Networks will be designed for mobile reception in 8k transmission mode. They will be also designed for Diversity reception, 120 km/h for the maximum speed of the receiver, 500 MHz for the operating frequency of SFN network and a coverage probability of 99%. The goal is to design a network to cover completely populated areas of İstanbul and Ankara and the roads of the İstanbul-to-Ankara Highway, E-5 Road and Ankara-Ring Highway.

4.4.1 Case-3: SFN Planning for Diversity Reception, 8k Transmission Mode, 16 QAM Modulation Type, 2/3 Code Rate

In the Case-3 situation, an SFN network will be designed for 8k transmission mode, 1/8 Guard Interval, 2/3 Code Rate and 16 QAM modulation type. For these selected planning parameters, the minimum required field strength will be calculated here.

Calculation of the minimum field strength and minimum median equivalent field strength values for mobile reception, it is necessary firstly to find the minimum required C/N values from the graphs given in Appendix-A.1.

The Doppler frequency, f_d = 55.55 Hz for 500 MHz, the operating frequency of SFN network.

To compensate the decrease due to the using of Guard Interval of 1/8 instead of 1/32.

f_{dmax}* 0.85 = 55.55 Hz ⇨ f_{dmax}= 65.36 Hz

If it is found the minimum required C/N value from Figure-A.1.3[2] corresponding to a Doppler frequency of approximately 65 Hz for a planning criteria of Diversity reception, 8k mode, 16 QAM, and 2/3 code rate.

Minimum required C/N = 18.5 dB

To calculate the minimum field strength and minimum median equivalent field strength values;

Receiver noise input power, P_n as calculated in Section 4.1.

P_n = –128.163 dBW

Substituting P_n and C/N value in Eqn.(4.3);

Minimum Receiver Input Power, P_{smin};

P_{smin} = 18.5 dB + (–128.163 dBW)

P_{smin} = –109.663 dBW

Effective antenna aperture (dBm^2), A_a as calculated in Section 4.1

A_a = –13.278 dBm^2

Substituting $P_{s\,min}$ and A_a values in Eqn.(4.6);

Minimum power flux density at receiving place (dBW/m^2), φ_{min};

φ_{min} = –109.663 dBW – (–13.278 dBm^2)

φ_{min} = –96.385 dBW/m^2

Substituting the values in Eqn.(4.7);

Equivalent minimum field strength at receiving place (dBμV/m), E_{min};

$E_{min} = -96.385$ dBW/m^2 + 145.8

$E_{min} = 49.415$ dBμV/m

Substituting the values in Eqn.(4.8);

Minimum median power flux density, planning value (dBW/m^2), φ_{med};

$\varphi_{med} = -96.385$ dBW/m^2 + 0 dB + 13 dB + 12 dB [2]

$\varphi_{med} = -71.385$ dBW/m^2 ≈ –71.4 dBW/m^2

Substituting φ_{med} in Eqn.(3.10);

Minimum median equivalent field strength, planning value (dBμV/m), E_{med};

$E_{med} = -71.385$ dBW/m^2 + 145.8 = 74.415 dBμV/m

$E_{med} \approx 75$ dBμV/m for mobile reception, Band IV (500 MHz), 99% coverage probability.

The transmitters and their planning parameters are given in Table-4.4.1.1 for the SFN network with Diversity reception, 8k mode, 16 QAM, and 2/3 code rate.

Transmitter Site Name	Longitude (East)	Latitude (North)	Altitude (m)	Ch. No	ERP (dBW)	Antenna Height	Protec. Sector	Protec. Ratio(dB)	Anten. Tilt	Polari-zation	Vertical Gain
RTÜK-İstanbul-B.Çekmece	28:37:27	41:00:47	200	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜK-İstanbul-Çamlıca	29:04:08	41:01:40	256	24	**45**	150 m	0-0	0	3°	H	10 dB
RTÜK-Kocaeli-Gebze	29:25:22	40:49:22	250	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Kocaeli	29:55:38	40:46:36	200	24	**33**	100 m	300-60	20	1°	H	10 dB
RTÜK-Sakarya	30:19:25	40:45:38	300	24	**30**	100 m	290-70	20	1°	H	10 dB
RTÜK-Sakarya-Hendek	30:48:11	40:44:57	300	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Düzce	31:07:30	40:49:19	200	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Bolu	31:36:29	40:44:02	800	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ankara-Çamlıdere	32:28:28	40:29:28	1286	24	**33**	100 m	0-0	0	1°	H	10 dB
RTÜKAnkKazan	32:39:29	40:11:07	900	24	**37**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ankara-Yenimahalle	32:48:23	39:58:35	1000	24	**37**	100 m	0-0	0	3°	H	10 dB
RTÜKAnk.Dikmen	32:49:42	39:51:43	1222	24	**43**	100 m	0-0	0	3°	H	10 dB
TRT-K.ahamam-Çeltikci	32:24:16	40:20:33	1232	24	**30**	100 m	0-0	0	1°	H	10 dB
TRT-Gerede-Esertepe	32:11:18	40:48:54	1655	24	**33**	100 m	0-0	0	1°	H	10 dB
TRT-Çamlıdere-Sarıkavak	32:18:45	40:29:07	1397	24	**30**	100 m	0-0	0	1°	H	10 dB
TRT-Ank.Elmadağ	32:59:20	39:48:12	1850	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu-Erenler Doruğu	31:19:20	40:36:18	1700	24	**35**	100 m	90-270	20	3°	H	10 dB
TRT-Düzce-Aktepe	31:09:34	40:54:51	287	24	**33**	100 m	240-120	20	1°	H	10 dB
TRT-İst.-Çatalca	28:25:45	41:08:50	301	24	**33**	100 m	0-0	0	1°	H	10 dB
İst.-Karamürsel	29:43:05	40:40:16	800	24	**30**	100 m	70-210	20	1°	H	10 dB
TRT-İzmit-Kartepe	30:06:02	40:38:36	1652	24	**30**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu-Baltalı	31:49:51	40:43:47	1043	24	**33**	100 m	0-0	0	1°	H	10 dB
Düzce-Bolu-Arası	31:26:04	40:50:17	1330	24	**37**	100 m	260-135	20	1°	H	10 dB
ÇeltikciKazan-Arası	32:36:39	40:18:42	1688	24	**33**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası	32:27:50	40:35:02	1844	24	**30**	100 m	0-0	0	1°	H	10 dB
TRTSarıyerKilyos	29:02:54	41:15:11	26	24	**30**	100 m	0-0	0	1°	H	10 dB
Bolu-Yeniçağ-Arası	31:55:15	40:43:55	1400	24	**33**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu Dağı-Emniyet	31:25:39	40:44:03	900	24	**30**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-K.Hamam-Arası	32:31:57	40:33:53	1700	24	**33**	100 m	0-0	0	1°	H	10 dB
TRT-Sarıyer-II	29:02:42	41:10:04	100	24	**30**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası-II	32:22:25	40:38:31	1563	24	**30**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-KHamamArasıII	32:35:17	40:29:47	1600	24	**33**	100 m	0-0	0	1°	H	10 dB
İst.DelikkayaII	29:15:18	40:55:50	528	24	**37**	100 m	0-0	0	1°	H	10 dB
SakaryaHendekII	30:54:41	40:47:01	728	24	**33**	100 m	90-240	20	1°	H	10 dB
Çamlıdere-Cankurtaran	32:19:45	40:35:10	1800	24	**33**	100 m	0-0	0	1°	H	10 dB
KHamamÇeltikciII	32:29:51	40:25:24	1561	24	**30**	100 m	0-0	0	1°	H	10 dB

Table-4.4.1.1: The transmitters and their planning parameters for Case-3 situation.

SFN coverage for mobile reception with the Case-3 transmitters is shown in the Figures-4.4.1.1-Part-A and Part-B:

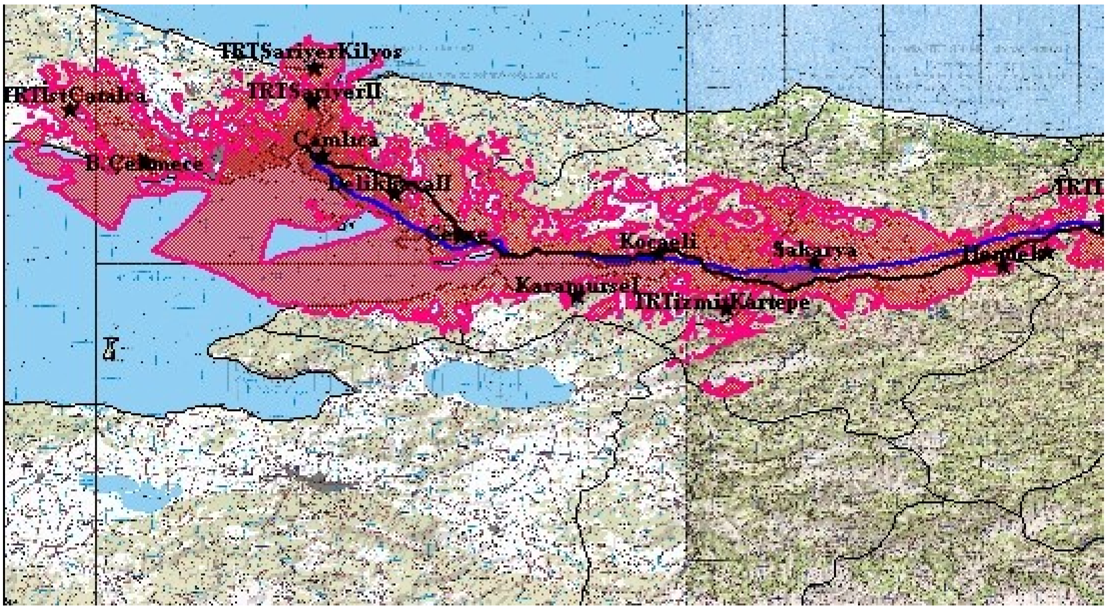


Figure-4.4.1.1-Part-A: SFN coverage for mobile reception with the Case-3 transmitters and their planning parameters for Diversity reception, 8k mode, 16 QAM, and 2/3.

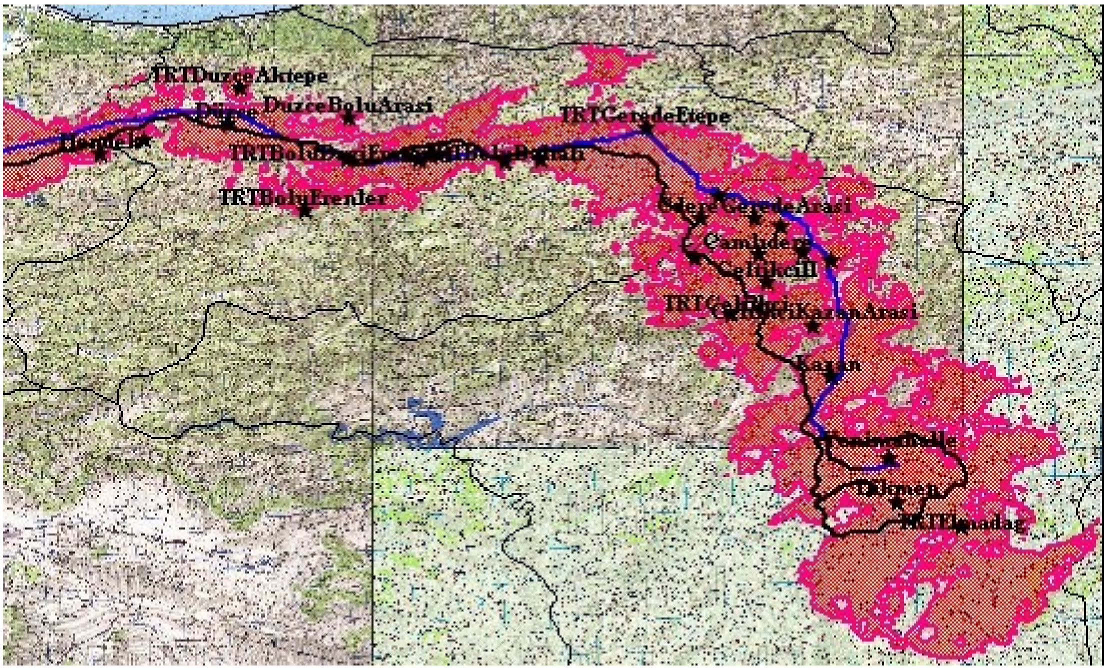


Figure-4.4.1.1-Part-B: SFN coverage for mobile reception with the Case-3 transmitters and their planning parameters for Diversity reception, 8k mode, 16 QAM, and 2/3.

As seen from the Figures-4.4.1.1-PartA and Part-B, the coverage areas of the specified transmitters are sufficient to cover the desired coverage area for mobile reception. The specified transmitter parameters are adequate to satisfy the required minimum field strength values for the desired coverage. It is also seen that, some small areas which are not covered, these areas have at least a 90% coverage probability.

In the Case-3 SFN network, it is specified 36 transmitter sites with their planning parameters. 12 tranmitter coordinates are selected from Turkey's Terrestrial Digital Television Frequency Plan[4], 12 tranmitter coordinates are selected from TRT's TV and FM Radio transmitter sites and 12 transmitter coordinates are additionally determined by using the RTVplan software.

4.4.2 Case-4: SFN Planning for Diversity Reception, 8k Transmission Mode, 64 QAM Modulation Type, 2/3 Code rate

In the Case-4, it will be designed an SFN network for 8k transmission mode, 1/8 Guard Interval, 2/3 Code Rate and 64 QAM modulation type. For these selected planning parameters, the minimum required field strength was calculated in the Section 4.1 as $E_{med} \approx 88$ dBμV/m for UHF Band IV.

The transmitters and their planning parameters are given in Table-4.4.2.1 for the SFN network with Diversity reception, 8k mode, 64 QAM, and 2/3 code rate.

Transmitter Site Name	Longitude (East)	Latitude (North)	Altitude (m)	Ch. No	ERP (dBW)	Antenna Height	Protec. Sector	Protec. Ratio(dB)	Anten. Tilt	Polari-zation	Vertical Gain
RTÜK-İstanbul-B.Çekmece	28:37:27	41:00:47	200	24	**43**	100 m	0-0	0	1°	H	10 dB
RTÜK-İstanbul-Çamlıca	29:04:08	41:01:40	256	24	**50**	150 m	0-0	0	3°	H	10 dB
RTÜK-Kocaeli-Gebze	29:25:22	40:49:22	250	24	**43**	100 m	0-0	0	1°	H	10 dB
RTÜK-Kocaeli	29:55:38	40:46:36	200	24	**40**	100 m	300-60	20	1°	H	10 dB
RTÜK-Sakarya	30:19:25	40:45:38	300	24	**37**	100 m	290-70	20	1°	H	10 dB
RTÜKSakaryaHendek	30:48:11	40:44:57	300	24	**40**	100 m	0-0	0	1°	H	10 dB
RTÜK-Düzce	31:07:30	40:49:19	200	24	**43**	100 m	0-0	0	1°	H	10 dB
RTÜK-Bolu	31:36:29	40:44:02	800	24	**43**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ankara-Çamlıdere	32:28:28	40:29:28	1286	24	**40**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ank-Kazan	32:39:29	40:11:07	900	24	**43**	100 m	0-0	0	1°	H	10 dB
RTÜK-Ankara-Yenimahalle	32:48:23	39:58:35	1000	24	**43**	100 m	0-0	0	3°	H	10 dB
RTÜK-AnkDikmen	32:49:42	39:51:43	1222	24	**50**	100 m	0-0	0	3°	H	10 dB
TRTKHamamÇeltikci	32:24:16	40:20:33	1232	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-K.Hamam	32:39:40	40:28:45	1008	24	**40**	100 m	0-0	0	1°	H	10 dB
TRTGeredeEsertepe	32:11:18	40:48:54	1655	24	**43**	100 m	0-0	0	1°	H	10 dB
TRT-Çamlıdere-Sarıkavak	32:18:45	40:29:07	1397	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-Ank-Elmadağ	32:59:20	39:48:12	1850	24	**45**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu-Erenler Doruğu	31:19:20	40:36:18	1700	24	**43**	100 m	90-270	20	3°	H	10 dB
TRT-Düzce-Aktepe	31:09:34	40:54:51	287	24	**40**	100 m	240-120	20	1°	H	10 dB
TRT-İst.-Çatalca	28:25:45	41:08:50	301	24	**43**	100 m	0-0	0	1°	H	10 dB
İst.Karamürsel	29:43:05	40:40:16	800	24	**43**	100 m	70-210	20	1°	H	10 dB
TRT-İzmit-Kartepe	30:06:02	40:38:36	1652	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu-Baltalı	31:49:51	40:43:47	1043	24	**40**	100 m	0-0	0	1°	H	10 dB
Düzce-Bolu-Arası	31:26:04	40:50:17	1330	24	**43**	100 m	260-135	20	1°	H	10 dB
ÇeltikciKazanArası	32:36:39	40:18:42	1688	24	**43**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası	32:27:50	40:35:02	1844	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-SarıyerKilyos	29:02:54	41:15:11	26	24	**43**	100 m	0-0	0	1°	H	10 dB
Bolu-Yeniçağ-Arası	31:55:15	40:43:55	1400	24	**40**	100 m	0-0	0	1°	H	10 dB
TRT-Bolu Dağı-Emniyet	31:25:39	40:44:03	900	24	**40**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-K.Hamam-Arası	32:31:57	40:33:53	1700	24	**43**	100 m	0-0	0	1°	H	10 dB
TRT-Sarıyer-II	29:02:42	41:10:04	100	24	**43**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-Gerede-Arası-II	32:22:25	40:38:31	1563	24	**43**	100 m	0-0	0	1°	H	10 dB
Çamlıdere-KHamamArasıII	32:35:17	40:29:47	1600	24	**43**	100 m	0-0	0	1°	H	10 dB
İst.DelikkayaII	29:15:18	40:55:50	528	24	**45**	100 m	0-0	0	1°	H	10 dB
SakaryaHendekII	30:54:41	40:47:01	728	24	**43**	100 m	90-240	20	1°	H	10 dB
Çamlıdere-Cankurtaran	32:19:45	40:35:10	1800	24	**43**	100 m	0-0	0	1°	H	10 dB
KHamamÇeltikciII	32:29:51	40:25:24	1561	24	**43**	100 m	0-0	0	1°	H	10 dB
İstanbul-Avcılar	28:42:15	40:59:54	106	24	**37**	100 m	0-0	0	1°	H	10 dB

Table-4.4.2.1: The transmitters and their planning parameters for Case-4 situation.

SFN coverage for mobile reception with the Case-4 transmitters is shown in the Figures-4.4.2.1-Part-A and Part-B:

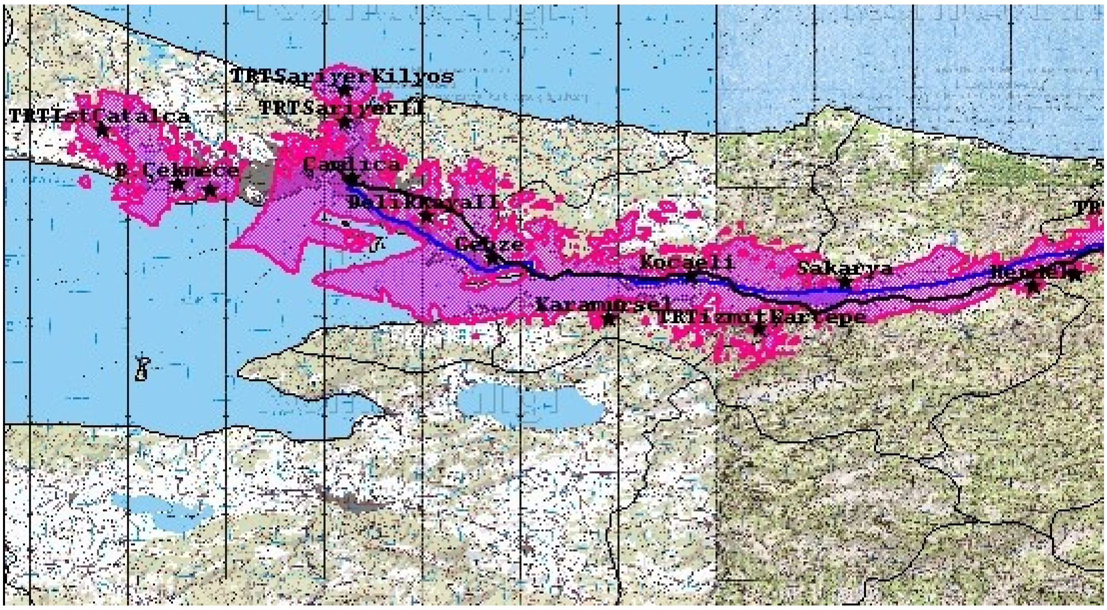


Figure-4.4.2.1-Part-A:SFN coverage for mobile reception with the Case-4 transmitters and their planning parameters for Diversity reception, 8k mode, 64 QAM, and 2/3.

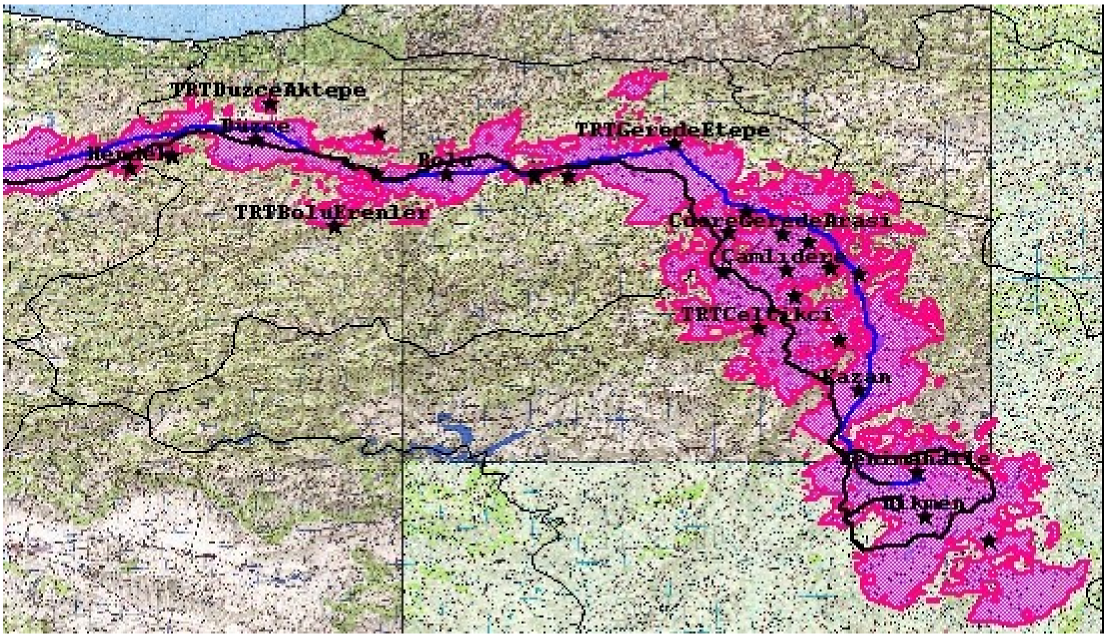


Figure-4.4.2.1-Part-B: SFN coverage for mobile reception with the Case-4 transmitters and their planning parameters for Diversity reception, 8k mode, 64 QAM, and 2/3.

As seen from the Figures-4.4.2.1-Part-A and Part-B, the coverage areas of the specified transmitters are sufficient to cover the desired coverage area for mobile reception. The coverage area is sufficient but narrower than that of the Case-3 SFN network in spite of increasing the number of transmitters and increasing the powers of transmitters. The defined transmitter parameters are adequate to satisfy the required minimum field strength values for the desired coverage area. It is also seen that, some small areas which are not covered, these areas have at least a 90% coverage probability.

In the Case-4 SFN network, it is specified 38 transmitter sites with their planning parameters. 13 tranmitter coordinates are selected from Turkey’s Terrestrial Digital

Television Frequency Plan[4], 13 tranmitter coordinates are selected from TRT's TV and FM Radio transmitter sites and 12 transmitter coordinates are additionally specified by using the RTVplan software.

4.5 Comparison of SFN Networks Planned with 2k and 8k Transmission Modes

In this thesis, all of the network designs were prepared for the following conditions;

- Diversity reception,
- 120 km/h, for the maximum speed of the receiver,
- 500 MHz, for the operating frequency of SFN network,
- Coverage probability of 99%.

And also in this thesis, the coordinates of the transmitter sites were especially selected from the Turkey's Terrestrial Digital Television Frequency Plan[4] and Turkish Radio and Television Association (TRT)'s TV and FM Radio transmitter sites. It has been selected these sites because the most of them have the required infrastructure already to install a transmitter on that stations, like antenna tower, building, electricity and road etc.

In the Case-1 situation, it is tried to design an SFN network for 2k mode, 1/4 Guard Interval, 2/3 Code Rate and 16 QAM modulation type. For these selected planning parameters, the minimum required field strength was calculated as;

$E_{med} \approx 73$ dBμV/m.

At the same time, there will be a data throughput of 13.27 Mbits/s for an 8 MHz TV channel. This means that 2-3 SDTV programs can be transmitted through an 8 MHz TV channel throughout the SFN network.

In the Case-1 SFN network, 31 transmitters were used. 12 of them have the same coordinates with the Turkey's Terrestrial Digital Television Frequency Plan[4]. 11 of them have the same coordinates with TRT's TV and FM Radio transmitter sites. And the coordinates of the other 8 transmitter sites were determined additionally.

As seen from the Figure-4.3.1.1 which shows the SFN coverage, 2k mode is not suitable for large SFNs.

In the Case-2 situation, it is tried to design an SFN network for 2k mode, 1/4 Guard Interval, 2/3 Code Rate and 64 QAM modulation type. For these selected planning parameters, the minimum required field strength was calculated as;

$$E_{med} \approx 78 \text{ dB}\mu\text{V/m}.$$

At the same time, there will be a data throughput of 19.91 Mbits/s for an 8 MHz TV channel. This means that 4-5 SDTV programs can be transmitted through an 8 MHz TV channel throughout the SFN network.

In the Case-2 SFN network, 31 transmitters were used. 12 of them have the same coordinates with the Turkey's Terrestrial Digital Television Frequency Plan[4]. 11 of them have the same coordinates with TRT's TV and FM Radio transmitter sites. And the coordinates of the other 8 transmitter sites were determined additionally.

As seen from the Figure-4.3.2.1 which shows the SFN coverage, 2k mode is not suitable for large SFNs.

In the Case-3 situation, it is designed an SFN network for 8k mode, 1/8 Guard Interval, 2/3 Code Rate and 16 QAM modulation type. For these selected planning parameters, the minimum required field strength was calculated as;

$E_{med} \approx 75$ dBμV/m.

At the same time, there will be a data throughput of 14.75 Mbits/s for an 8 MHz TV channel. This means that 2-3 SDTV programs can be transmitted through an 8 MHz TV channel throughout the SFN network.

In the Case-3 SFN network, 36 transmitters were used. 12 of them have the same coordinates with the Turkey's Terrestrial Digital Television Frequency Plan[4]. 12 of them have the same coordinates with TRT's TV and FM Radio transmitter sites. And the coordinates of the other 12 transmitter sites were determined additionally. The planned powers of the transmitters are as follows;

Number of Transmitters	Power of Transmitters
1	45 dBW
1	43 dBW
1	40 dBW
5	37 dBW
1	35 dBW
16	33 dBW
11	30 dBW

Table-4.5.1: The number of used transmitters and their powers for Case-3.

The Figure-4.5.1 shows the SFN network gain throughout coverage area of the SFN. If the guard interval were selected as 1/4 in this case then there would be a data throughput of 13.27 Mbits/s. On the other hand less transmitters would be needed to cover the SFN coverage area. There is a trade-off here between the number of used transmitters and the data throughput of the SFN. In the Figure-4.5.1, a network gain between 0 and 1dB is shown by a “White Colored Area”, 1dB and 3dB is shown by a “Yellow Colored Area”, a network gain between 3dB and 6dB is shown by a “Green Colored Area”, a network gain between 6dB and 10dB is shown by a “Blue Colored Area”, a network gain between 10dB and 15dB is shown by a “Red Colored Area” and a network gain between 15dB and 20dB is shown by a “Purple Colored Area”.

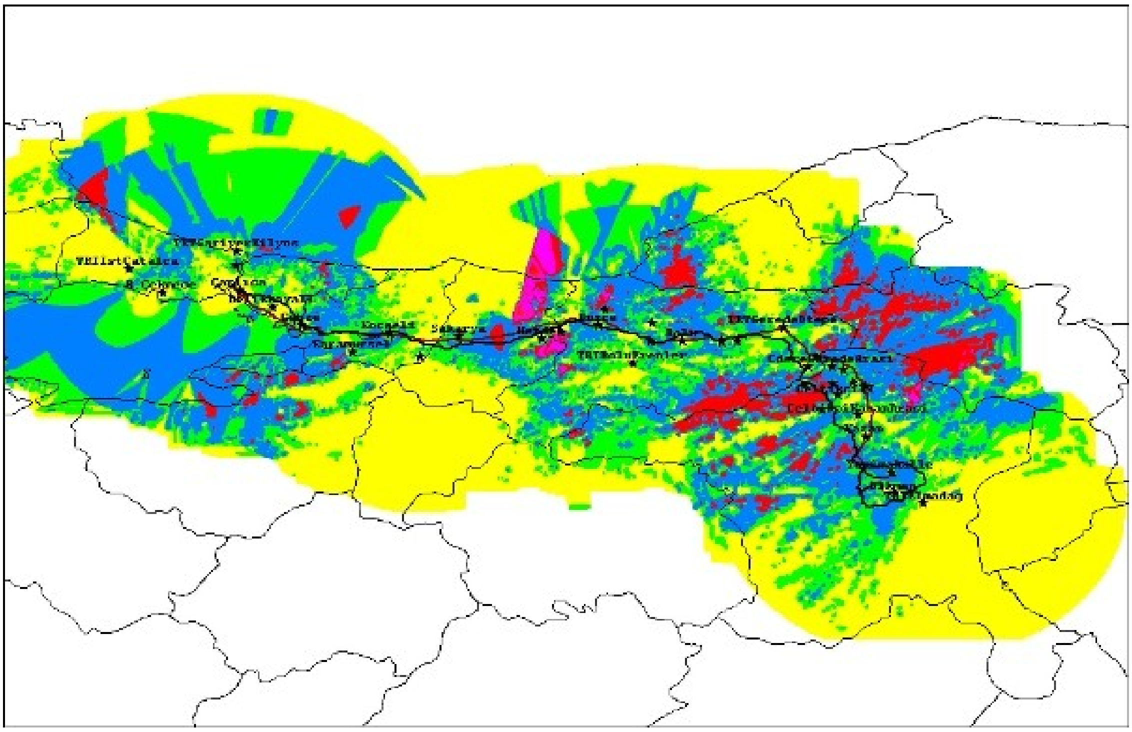


Figure-4.5.1: SFN network gain for the Case-3 SFN network

In the Case-4, it is designed an SFN network for 8k mode, 1/8 Guard Interval, 2/3 Code Rate and 64 QAM modulation type. For these planning parameters, the minimum required field strength was calculated as;

$E_{med} \approx 88$ dBµV/m.

At the same time, there will be a data throughput of 22.12 Mbits/s for an 8 MHz TV channel. This means that 4-5 SDTV programs can be transmitted through an 8 MHz TV channel throughout the SFN network.

In the Case-4 SFN network, 38 transmitters were used. 12 of them have the same coordinates with the Turkey's Terrestrial Digital Television Frequency Plan[4]. 13 of them have the same coordinates with TRT's TV and FM Radio transmitter sites. And the coordinates of the other 13 transmitter sites were determined additionally. The planned powers of the transmitters for Case-4 are shown in Table-4.5.2;

Number of Transmitters	Power of Transmitters
2	50 dBW
2	45 dBW
20	43 dBW
12	40 dBW
2	37 dBW

Table-4.5.2: The number of used transmitters and their powers for Case-4.

As seen from Table-4.5.2, there is a large amount of increase in the powers of the used transmitters with respect to the Case-3 SFN network where the planning parameters are 8k mode, 1/8 Guard Interval, 2/3 Code Rate and 16 QAM modulation type and which corresponds to a data throughput of 14.75 Mbits/s for an 8 MHz TV channel.

The Figure-4.5.2 shows also the SFN network gain throughout the coverage area of the SFN. In the Figure-4.5.2, a network gain between 0 and 1dB is shown by a "White Colored Area", 1dB and 3dB is shown by a "Yellow Colored Area", a network gain between 3dB and 6dB is shown by a "Green Colored Area", a network gain between 6dB and 10dB is shown by a "Blue Colored Area", a network gain between 10dB and 15dB is shown by a "Red Colored Area" and a network gain between 15dB and 20dB is shown by a "Purple Colored Area".

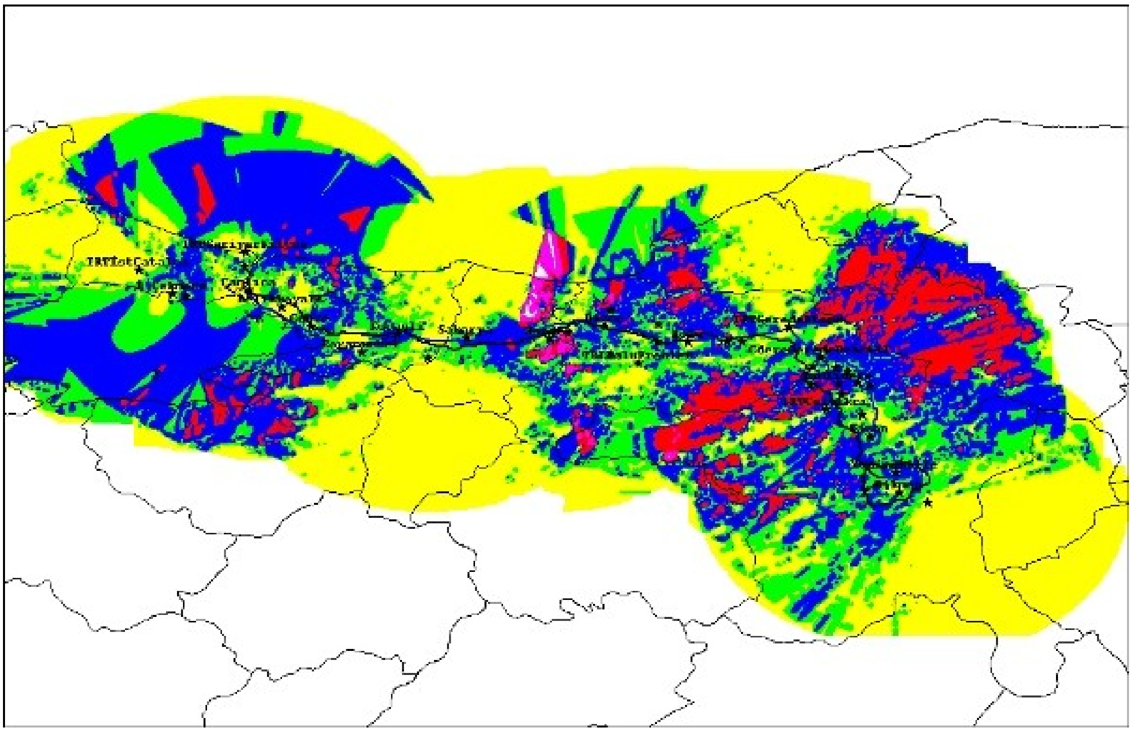


Figure-4.5.2: SFN network gain for the Case-4 SFN network

CHAPTER 5

CONCLUSION

In this thesis, it is designed a DVB-T Single Frequency Network (SFN) for mobile reception which will cover the populated area of İstanbul, the İstanbul-to-Ankara-Highway, E-5 Road and the populated area of Ankara which is surrounded by the Ankara-Ring Highway. Firstly it is investigated the case of the transmitter sites and their planning parameters of the Turkey's Terrestrial Digital Television Frequency Plan.[4] It is observed that it is not sufficient to cover the populated area of İstanbul, the İstanbul-to-Ankara Highway and the populated area of Ankara which is surrounded by the Ankara-Ring Highway, for mobile reception. In this thesis it was designed DVB-T SFN Networks for mobile reception in two different DVB-T modes which are 2k and 8k modes. It is seen that 8k mode is more suitable for large SFNs but it is difficult to design a network with higher data throughputs and higher operating frequencies. It is more convenient to design a network for lower data throughputs and lower frequencies. Therefore, the Case-3 Network is more feasible from the standpoint of data throughputs of the SFN network and the coverage of the SFN area with the transmitters of optimum powers. On the other hand 2k transmission mode is more convenient for higher speeds of the receiver. But it is not feasible for large SFNs and more transmitters are needed.

In this study also, a procedure was developed to specify the required parameters and the criteria should be taken into consideration to design a DVB-T SFN network for mobile reception. This procedure can be followed to design a DVB-T SFN network to cover inside a city, a road or both of them for mobile reception. By using the results of this thesis, someone can decide which network option is convenient to cover only inside a city or through a road etc. for DVB-T mobile reception. And also the borders of the SFN under consideration could be expanded to the other adjacent roads and the cities. Moreover this project can be applied to the railway between Ankara and İstanbul.

REFERENCES

1. **INTERNATIONAL TELECOMMUNICATION UNION, Rec. ITU-R BT.1368-6**[2006], *Planning Criteria For Digital Terrestrial Television Services In The VHF/UHF Bands*.

2. **EUROPEAN BROADCASTING UNION, EBU**[2002], *BPN-047, Planning Criteria For Mobile DVB-T.*

3. **EUROPEAN BROADCASTING UNION, EBU**[2001], *BPN-005-Third Issue, Terrestrial Digital Television Planning And Implementation Considerations.*

4. **RADYO ve TELEVİZYON ÜST KURULU, RTÜK**[2001], *Türkiye Karasal Sayısal Televizyon Frekans Planı.*

5. **BİLKENT UNIVERSITY-COMMUNICATIONS AND SPECTRUM MANA-GEMENT RESEARCH CENTER(İSYAM)**[2006], RTV*plan*, *Analog ve Sayısal Radyo-Televizyon Servisleri için Analiz ve Planlama Yazılımı, Sürüm 1.0, Kullanıcı Kılavuzu.*

6. **YÜCEL,T.**[1996], *Design of the İstanbul-Ankara T-DAB Single Frequency Network,* M.Sc. Thesis, Dept.of Electrical and Electronics Eng., Boğaziçi University, Turkey.

7. **TANYER,S.G., YÜCEL,T.**, **ŞEKER,S.**[1997], *Topography Based Design of The T-DAB SFN For a Mountainous Area,* IEEE Transactions On Broadcasting, Vol.43, No.3, 309-314.

8. **FISCHER, W.**[2004], *Digital Television, A Practical Guide for Engineers,* Springer, München, Germany.

9. **TEKALP, A.M.**[1995], *Digital Video Processing,* Prentice Hall, Upper Saddle River, NJ.

10. **MATTSSON,A.**[2005], *Single Frequency Networks in DTV,* IEEE Transactions On Broadcasting, Vol.51, No.4, 413.

11. **EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE, ETSI** [2004], EN 300 744 V1.5.1 (2004-11), *Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for digital terrestrial television.*

12. **EUROPEAN BROADCASTING UNION, EBU**[2005], *BPN-066, Guide on SFN Frequency Planning and Network Implementation with regard to T-DAB and DVB-T.*

APPENDIX A

A.1 Minimum Required C/N Values as Function of Doppler Frequency

To calculate the required minimum field strength values, it is necessary to know the minimum required C/N values. A number of graphs have been produced to estimate the minimum required C/N values with a degradation of increasing Doppler frequency.[2]

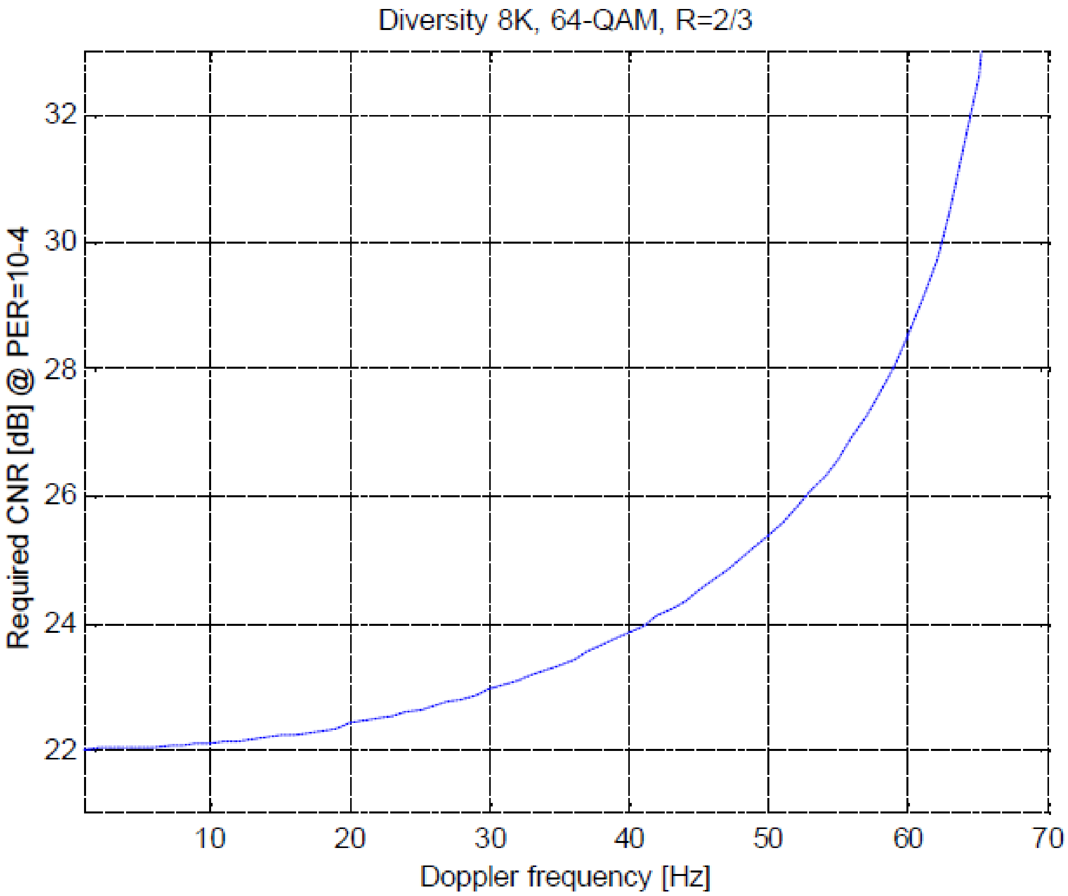


Figure-A.1.1: Required C/N versus Doppler frequency for Diversity reception, 8k mode, 64 QAM and R=2/3.[2]

These graphs are given for the 8k transmission mode. For the 2k mode, the Doppler frequency should be multiplied by 4 to find the required C/N values. In this thesis, the graphs are used for diversity reception and a QoS level, PER 10-4.[2]

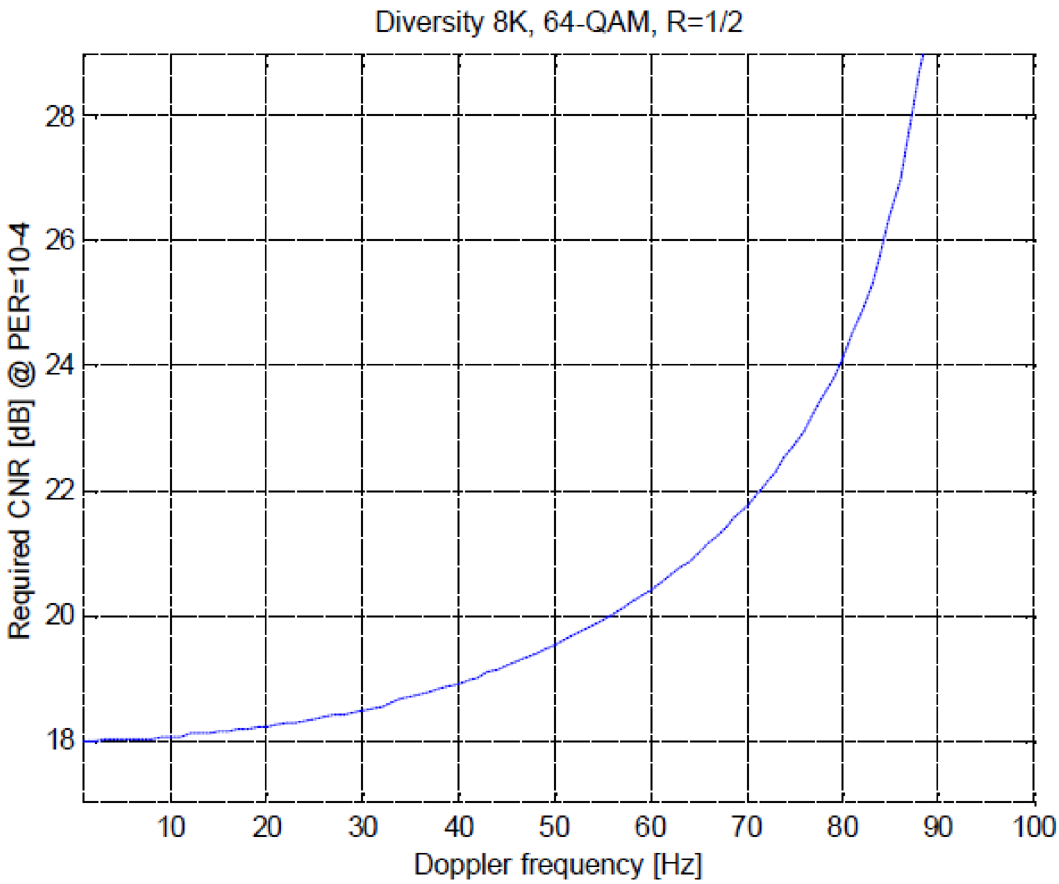


Figure-A.1.2: Required C/N versus Doppler frequency for Diversity reception, 8k mode, 64 QAM and R=1/2.[2]

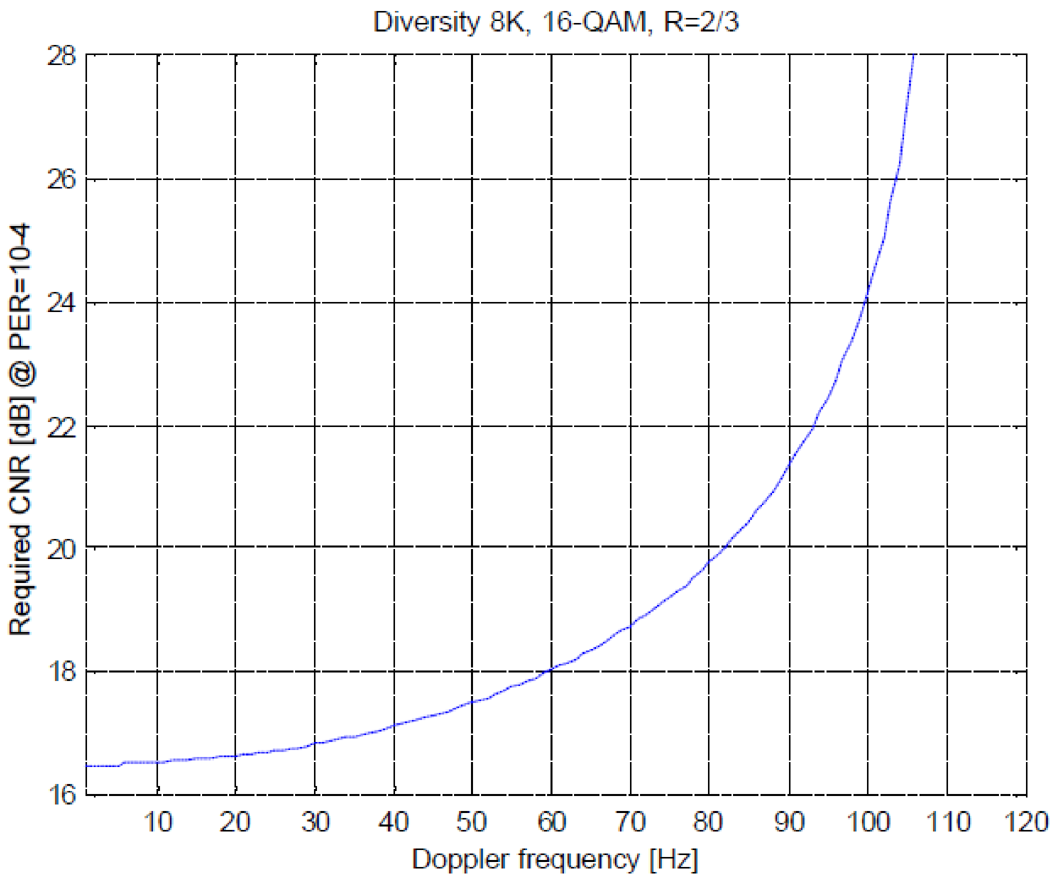


Figure-A.1.3: Required C/N versus Doppler frequency for Diversity reception, 8k mode, 16 QAM and R=2/3.[2]

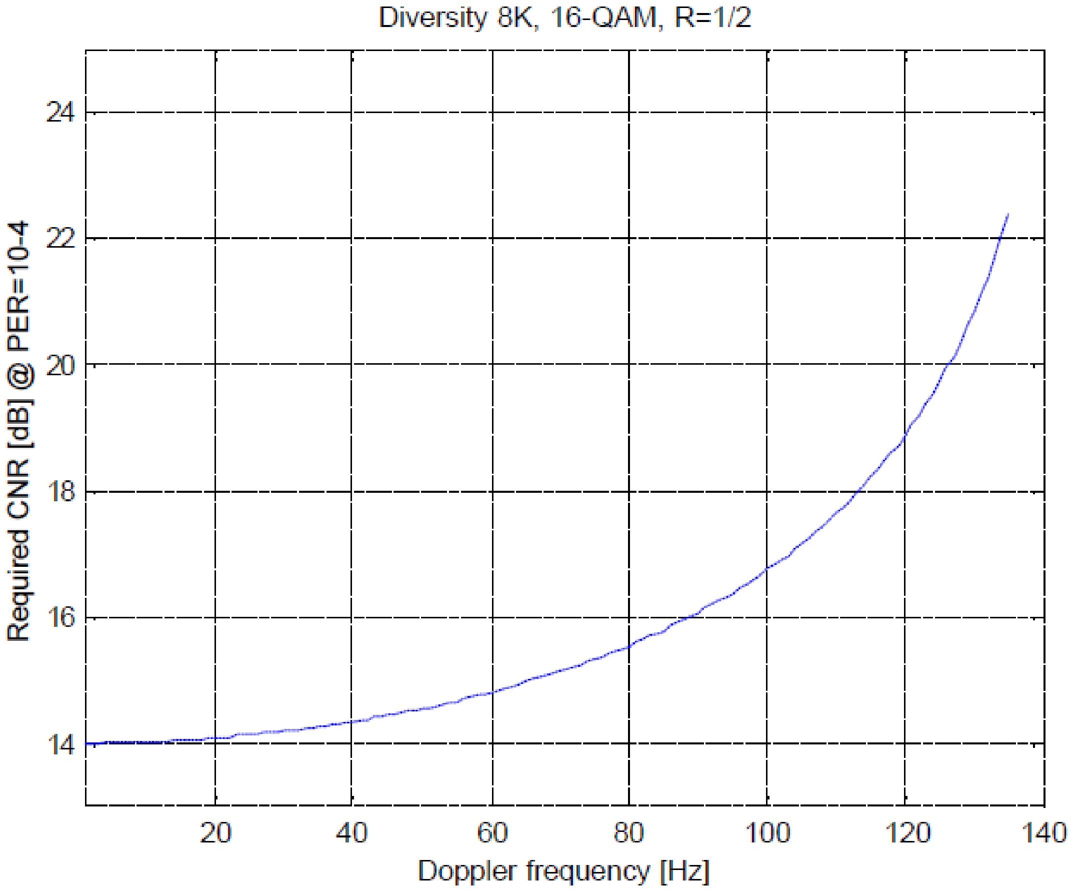


Figure-A.1.4: Required C/N versus Doppler frequency for Diversity reception, 8k mode, 16 QAM and R=1/2.[2]

A.2 Minimum Required Field Strength Values for Mobile DVB-T Reception

In order to find the minimum required field strength values, it is necessary to take the minimum C/N values with any increase required to take into account Doppler degradation from the graphs in Appendix A.1.[2]

Minimum required field strength values for Band IV is given in Table-A.2.1.

Receiving condition: Mobile, Band IV.

Frequency	f [MHz]	500				
C/N required by system	**[dB]**	**8**	**14**	**20**	**26**	**32**
Min. receiver signal input power	$P_{s\ min}$ [dBW]	-120.2	-114.2	-108.2	-102.2	-96.2
Min. equivalent receiver input voltage, 75Ω	$U_{s\ min}$ [dBmV]	19	25	31	37	43
Antenna gain relative to half wave dipole	G_D [dB]	0				
Effective antenna aperture	A_a [dBm^2]	-13,3				
Min power flux density at receiving place	φ_{min} [dBW/m^2]	-106.9	-100.9	-94.9	-88.9	-82.9
Min equivalent field strength at receiving place	E_{min}[dBµV/m]	39	45	51	57	63
Allowance for man made noise	P_{mmn} [dB]	0				
Height loss	L_h [dB]	12				

Location probability: 90%

Location correction factor	C_l [dB]	7				
Minimum median power flux density at 10m a.g.l. 50% of time and 50% of locations	φ_{med}[dBW/m^2]	-87.9	-81.9	-75.9	-69.9	-63.9
Minimum median equivalent field strength at 10m a.g.l. 50% of time and 50% of locations	E_{med}[dBµV/m]	58	64	70	76	82

Location probability: 95%

Location correction factor	C_l [dB]	9				
Minimum median power flux density at 10m a.g.l. 50% of time and 50% of locations	φ_{med}[dBW/m^2]	-85.9	-79.9	-73.9	-67.9	-61.9
Minimum median equivalent field strength at 10m a.g.l. 50% of time and 50% of locations	E_{med}[dBµV/m]	60	66	72	78	84

Location probability: 99%

Location correction factor	C_l [dB]	13				
Minimum median power flux density at 10m a.g.l. 50% of time and 50% of locations	φ_{med}[dBW/m^2]	-81.9	-75.9	-69.9	-63.9	-59.9
Minimum median equivalent field strength at 10m a.g.l. 50% of time and 50% of locations	E_{med}[dBµV/m]	64	70	76	82	88

Table-A.2.1: Minimum median power flux density and equivalent minimum median field strength in Band IV for 90%, 95% and 99% location probability, mobile reception.[2]

A.3 Calculation of Minimum Field Strength and Minimum Median Equivalent Field Strength for Mobile DVB-T Reception

The minimum field strength and minimum median equivalent field strength values calculated using the following equations[2]:

$$P_n = F + 10 \log (k\, T_0\, B)$$

$$P_{s\,min} = C/N + P_n$$

$$A_a = G + 10 \log (1.64\lambda^2/4\,\pi)$$

$$\varphi_{min} = P_{s\,min} - A_a$$

$$E_{min} = \varphi_{min} + 120 + 10 \log (120\,\pi)$$

$$= \varphi_{min} + 145.8$$

$$E_{med} = E_{min} + P_{mmn} + C_l + L_h$$ for portable outdoor and mobile reception

where:

- P_n : receiver noise input power (dBW)
- F : receiver noise figure (dB)
- k : Boltzmann's constant ($k = 1.38 \times 10^{-23}$ (J/K))
- T_0 : absolute temperature ($T_0 = 290$ (K))
- B : receiver noise bandwidth ($B = 7.61 \times 10^6$ (Hz))
- $P_{s\,min}$: minimum receiver input power (dBW)
- C/N : RF S/N at the receiver input required by the system (dB)
- A_a : effective antenna aperture (dBm^2)
- G : antenna gain related to half dipole (dBd)
- λ : wavelength of the signal (m)
- φ_{min} : minimum pfd at receiving place (dBW/m^2)
- E_{min} : equivalent minimum field strength at receiving place (dBμV/m)
- E_{med} : min. median equivalent field strength, planning value (dBμV/m)
- P_{mmn} : allowance for man-made noise (dB)
- L_h : height loss (reception point at 1.5 m above ground level) (dB)
- C_l : location correction factor (dB)
- σ : standard deviation macro-scale ($\sigma = 5.5$ (dB))

μ : distribution factor being 0.52 for 70%, 1.28 for 90%, 1.64 for 95% and 2.33 for 99%.[2]

A.4 The Net Bit Rates for All Combinations of Coding Rates and Modulation Types.

			Required C/N for BER=2 10^{-4} after Viterbi (quasi error-free after Reed-Solomon)			Net bitrate (Mbit/s)			
System	Modulation	Code Rate	Gaussian channel	Ricean channel (F_1)	Rayleigh channel (P_1)	D/T_U =1/4	D/T_U =1/8	D/T_U =1/16	D/T_U =1/32
A1	QPSK	1/2	3.1	3.6	5.4	4.98	5.53	5.85	6.03
A2	QPSK	2/3	4.9	5.7	8.4	6.64	7.37	7.81	8.04
A3	QPSK	3/4	5.9	6.8	10.7	7.46	8.29	8.78	9.05
A5	QPSK	5/6	6.9	8.0	13.1	8.29	9.22	9.76	10.05
A7	QPSK	7/8	7.7	8.7	16.3	8.71	9.68	10.25	10.56
B1	16-QAM	1/2	8.8	9.6	11.2	9.95	11.06	11.71	12.06
B2	16-QAM	2/3	11.1	11.6	14.2	13.27	14.75	15.61	16.09
B3	16-QAM	3/4	12.5	13.0	16.7	14.93	16.59	17.56	18.10
B5	16-QAM	5/6	13.5	14.4	19.3	16.59	18.43	19.52	20.11
B7	16-QAM	7/8	13.9	15.0	22.8	17.42	19.35	20.49	21.11
C1	64-QAM	1/2	14.4	14.7	16.0	14.93	16.59	17.56	18.10
C2	64-QAM	2/3	16.5	17.1	19.3	19.91	22.12	23.42	24.13
C3	64-QAM	3/4	18.0	18.6	21.7	22.39	24.88	26.35	27.14
C5	64-QAM	5/6	19.3	20.0	25.3	24.88	27.65	29.27	30.16
C7	64-QAM	7/8	20.1	21.0	27.9	26.13	29.03	30.74	31.67

Table-A.4.1: The net bit rates after the Reed-Solomon decoder for non-hierarchical transmission (8 MHz) to achieve a BER = $2*10^{-4}$ after the Viterbi decoder for all combinations of coding rates and modulation types.[3]

APPENDIX B

During the preparation of the Turkey's Terrestrial Digital Television Frequency Plan[4] in 1998, 1172 locations was measured by GPS over Ankara-İstanbul Highway and Ankara-Ring-Highway to determine the coordinates of these Highways

B.1 The Geographical Coordinates of the İstanbul-Ankara Highway Between Ankara and Kaynaşlı with 500 Locations

" HIGHWAY ", " ANKARA_TO_KAYNASLI ", 500

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.740450	039.945100		032.287433	040.586833
032.732700	039.945217		032.287250	040.589933
032.721533	039.945350		032.288450	040.593850
032.715283	039.945417		032.288100	040.597283
032.706867	039.947433		032.285867	040.599650
032.699217	039.952133		032.281683	040.601517
032.687183	039.959600		032.278300	040.603633
032.680133	039.962967		032.275333	040.607333
032.671150	039.967083		032.271983	040.611033
032.662933	039.971100		032.267867	040.613500
032.659217	039.976317		032.260367	040.613300
032.656433	039.984300		032.256017	040.612283
032.655000	039.988650		032.251583	040.613333
032.654467	039.991900		032.247500	040.616983
032.655250	039.998967		032.243650	040.620017
032.655667	040.004017		032.240417	040.622100
032.655117	040.010233		032.238267	040.625367
032.654300	040.014150		032.238567	040.628833
032.652783	040.018650		032.238050	040.632517
032.650850	040.022550		032.235683	040.635817
032.648800	040.024533		032.232983	040.638150
032.647333	040.025633		032.231233	040.641383
032.643333	040.024700		032.231667	040.645317
032.641367	040.022133		032.233917	040.648200
032.634233	040.019817		032.237400	040.651650
032.628767	040.018750		032.237700	040.655400
032.625567	040.019383		032.238000	040.659767

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.622033	040.021633		032.240067	040.663250
032.617667	040.024683		032.239883	040.668283
032.611533	040.028517		032.236283	040.672217
032.608033	040.030700		032.226633	040.677383
032.604217	040.033217		032.222800	040.680400
032.600117	040.036217		032.221650	040.683983
032.596767	040.038900		032.223033	040.689733
032.594250	040.041067		032.222983	040.693550
032.592067	040.043133		032.222250	040.699133
032.590300	040.045367		032.222467	040.703217
032.589400	040.046917		032.223083	040.708133
032.588200	040.050417		032.222183	040.713200
032.587917	040.053717		032.220417	040.716567
032.588283	040.056650		032.218050	040.719367
032.589183	040.059283		032.214483	040.722133
032.590700	040.061950		032.210150	040.724333
032.593250	040.064767		032.206417	040.726500
032.595683	040.066867		032.201333	040.731950
032.597617	040.068933		032.196867	040.735667
032.599650	040.072133		032.191800	040.738133
032.601533	040.075517		032.186950	040.739367
032.604100	040.079850		032.184000	040.739717
032.606417	040.083700		032.175767	040.740283
032.609050	040.087833		032.169250	040.740650
032.611350	040.091417		032.161617	040.740567
032.613117	040.094667		032.154833	040.740133
032.614233	040.098767		032.147017	040.739650
032.614317	040.101700		032.142267	040.739550
032.614033	040.103467		032.137383	040.739933
032.611333	040.108883		032.132983	040.740750
032.608317	040.112650		032.125917	040.742450
032.605933	040.115633		032.117783	040.744333
032.603467	040.120233		032.111883	040.745500
032.602133	040.124867		032.105483	040.746233
032.601067	040.129717		032.097700	040.746767
032.600250	040.133700		032.092650	040.747217
032.599400	040.137933		032.088600	040.748000
032.598700	040.141767		032.082917	040.750067
032.598200	040.145683		032.075333	040.753100
032.597967	040.148433		032.068617	040.755767
032.597817	040.151350		032.065100	040.757550
032.597683	040.154067		032.062467	040.760083
032.596917	040.157567		032.058883	040.763167
032.595950	040.159633		032.053533	040.764900
032.594750	040.161467		032.047833	040.764900
032.592767	040.163650		032.042683	040.764717
032.590467	040.165717		032.036767	040.765100

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.589383	040.166983		032.032550	040.765667
032.588700	040.168183		032.025267	040.765850
032.588167	040.171050		032.012100	040.764117
032.588967	040.173900		032.004550	040.763150
032.590500	040.176183		031.999683	040.762617
032.591250	040.178017		031.993450	040.762200
032.590950	040.180817		031.985917	040.761900
032.589683	040.183317		031.980650	040.761483
032.589283	040.185400		031.976417	040.760350
032.589850	040.187383		031.968400	040.756550
032.591367	040.189367		031.962817	040.754100
032.592483	040.191100		031.957367	040.753283
032.593017	040.193233		031.950350	040.753533
032.592800	040.195267		031.946233	040.753017
032.592050	040.197033		031.939533	040.751533
032.590400	040.199017		031.934800	040.751100
032.588433	040.200400		031.930200	040.751850
032.585817	040.201483		031.923517	040.753683
032.582667	040.202083		031.919033	040.754717
032.579550	040.202567		031.914200	040.754617
032.574467	040.204300		031.907917	040.752967
032.571383	040.206183		031.901517	040.751233
032.568817	040.208517		031.894633	040.749050
032.567133	040.210517		031.888267	040.748367
032.564700	040.213183		031.877950	040.746133
032.562117	040.215383		031.871500	040.744600
032.559367	040.217267		031.864883	040.743467
032.556533	040.218250		031.855633	040.742600
032.553467	040.218417		031.849600	040.742067
032.548983	040.219217		031.845133	040.741433
032.546267	040.221300		031.840400	040.740483
032.544983	040.222967		031.835900	040.739550
032.541417	040.225483		031.831300	040.739300
032.538517	040.226100		031.824050	040.739383
032.533917	040.226917		031.820250	040.738183
032.526600	040.229650		031.814317	040.735867
032.522133	040.231400		031.809317	040.734333
032.518783	040.233000		031.804667	040.734500
032.514617	040.235800		031.797450	040.737183
032.510800	040.238067		031.792767	040.738950
032.507217	040.239533		031.788067	040.740383
032.502650	040.241100		031.784117	040.742267
032.499600	040.242467		031.781483	040.745517
032.494983	040.245400		031.779150	040.748717
032.491233	040.247983		031.776633	040.751300
032.487850	040.250050		031.773950	040.754183
032.485233	040.251483		031.771433	040.757683

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.482633	040.252983		031.767783	040.759933
032.480033	040.254950		031.761817	040.761700
032.478100	040.257233		031.756933	040.763650
032.477100	040.259100		031.752200	040.766200
032.476400	040.261700		031.748933	040.767367
032.476483	040.264483		031.740483	040.768967
032.477167	040.266717		031.735933	040.769917
032.479450	040.270050		031.732917	040.771267
032.482717	040.272917		031.729350	040.773617
032.484550	040.274950		031.724567	040.776867
032.485433	040.276750		031.721483	040.778817
032.485600	040.279117		031.718517	040.779950
032.484833	040.281217		031.714483	040.780567
032.482967	040.283417		031.710367	040.780250
032.481600	040.285133		031.705233	040.778667
032.480267	040.287217		031.699950	040.777767
032.477700	040.289117		031.694333	040.777300
032.474983	040.290467		031.689650	040.776850
032.472733	040.292800		031.684833	040.775367
032.472200	040.294767		031.676900	040.772650
032.472483	040.296367		031.671417	040.771500
032.473850	040.298417		031.663700	040.771517
032.477083	040.300433		031.659317	040.771117
032.479700	040.302633		031.655967	040.769900
032.481000	040.305417		031.652000	040.769100
032.481033	040.308267		031.645667	040.769000
032.481283	040.311050		031.640233	040.767033
032.482683	040.313300		031.634150	040.766567
032.485250	040.315383		031.630017	040.766750
032.488383	040.317800		031.625533	040.765800
032.489750	040.319900		031.617283	040.764683
032.491300	040.324183		031.609200	040.763633
032.492850	040.328683		031.603450	040.762650
032.494333	040.332833		031.598267	040.761017
032.494767	040.335900		031.592933	040.761367
032.494217	040.339067		031.588367	040.761533
032.492717	040.342100		031.583233	040.758883
032.491117	040.344100		031.573950	040.756233
032.488667	040.346250		031.567800	040.753967
032.484850	040.348333		031.564067	040.751567
032.481633	040.349333		031.561100	040.747483
032.477667	040.349833		031.560050	040.742533
032.474017	040.350483		031.560067	040.742533
032.471033	040.352483		031.556600	040.739650
032.469850	040.354583		031.550150	040.739283
032.469617	040.356483		031.544700	040.740667
032.468733	040.358933		031.537300	040.738967

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.467067	040.360633		031.532367	040.734883
032.465233	040.362633		031.527533	040.732967
032.464417	040.364450		031.521233	040.732217
032.464417	040.367033		031.513917	040.729817
032.465800	040.369483		031.508850	040.726500
032.468683	040.371933		031.505633	040.725083
032.470800	040.374517		031.497400	040.722600
032.470867	040.377150		031.491967	040.721100
032.468983	040.379500		031.487067	040.720650
032.465717	040.380733		031.479983	040.721433
032.460800	040.380800		031.476783	040.721900
032.457050	040.381817		031.475567	040.723233
032.454183	040.382767		031.478067	040.722433
032.450917	040.382767		031.478517	040.720350
032.447650	040.382800		031.476033	040.718433
032.445383	040.383633		031.472683	040.718683
032.443367	040.386633		031.470083	040.719450
032.444100	040.389150		031.467250	040.719100
032.445100	040.392700		031.458050	040.720050
032.443600	040.395400		031.448650	040.721167
032.440583	040.397600		031.442667	040.722683
032.438683	040.400600		031.438733	040.724950
032.438983	040.407150		031.434517	040.729033
032.438417	040.411117		031.430500	040.733117
032.435933	040.416133		031.427050	040.736417
032.433467	040.420517		031.424500	040.739050
032.429983	040.426650		031.420867	040.742683
032.426800	040.429900		031.417150	040.746183
032.420217	040.433400		031.413450	040.748233
032.415617	040.435850		031.410317	040.749067
032.410200	040.438733		031.408617	040.749633
032.405100	040.440883		031.404983	040.749000
032.402050	040.441650		031.403017	040.748483
032.397867	040.442117		031.400167	040.750700
032.392717	040.442167		031.398183	040.752183
032.389133	040.443067		031.394700	040.752983
032.385800	040.445183		031.392367	040.753800
032.383417	040.448267		031.390467	040.754483
032.380233	040.453167		031.390467	040.754483
032.378217	040.455417		031.388367	040.753217
032.372817	040.459500		031.386683	040.752050
032.367267	040.463500		031.384650	040.751750
032.362350	040.467100		031.383650	040.750983
032.358017	040.470633		031.383317	040.749233
032.353183	040.475300		031.383250	040.747733
032.347417	040.479800		031.381700	040.746800
032.343317	040.484050		031.380183	040.746967

" Longitude "	" Latitude "		" Longitude "	" Latitude "
032.337817	040.486383		031.376633	040.747933
032.330333	040.487150		031.375133	040.749150
032.326117	040.488450		031.374200	040.751317
032.323150	040.490900		031.373283	040.753400
032.320417	040.492800		031.371550	040.754733
032.314367	040.493817		031.369817	040.756533
032.305700	040.492833		031.366317	040.756950
032.299433	040.494467		031.365350	040.755100
032.295667	040.497700		031.363650	040.753733
032.292900	040.499367		031.361467	040.755500
032.288650	040.500933		031.359750	040.757333
032.285567	040.503283		031.356950	040.758133
032.284533	040.507833		031.353383	040.758983
032.285933	040.514133		031.350800	040.759950
032.287283	040.518600		031.348967	040.761817
032.286967	040.525883		031.348883	040.765167
032.287150	040.529250		031.353900	040.765183
032.289017	040.532350		031.357000	040.766500
032.290767	040.535367		031.356733	040.769633
032.295400	040.539017		031.354650	040.771300
032.297400	040.541917		031.348883	040.771633
032.299000	040.545567		031.338400	040.772033
032.301400	040.548650		031.330483	040.772350
032.304017	040.551650		031.325633	040.772617
032.304833	040.555133		031.318767	040.773417
032.305250	040.557833		031.310500	040.775067
032.307883	040.560817		031.303450	040.776333
032.310450	040.563533		031.294450	040.777900
032.310467	040.567500		031.290183	040.778633
032.307800	040.570300		031.287533	040.779000
032.303783	040.572717		031.282667	040.780233
032.300833	040.576033		031.278050	040.781833
032.298267	040.578100		031.278033	040.781833
032.294300	040.579800		031.277517	040.782567
032.290633	040.581933		031.277517	040.784533

Table-B.1.1 The Geographical Coordinates of the İstanbul-Ankara Highway Between Ankara and Kaynaşlı with 500 Locations

B.2 The Geographical Coordinates of the İstanbul-Ankara Highway Between Kaynaşlı and İstanbul with 478 Locations

" HIGHWAY ", " KAYNASLI_TO_ISTANBUL ", 478

" Longitude "	" Latitude "		" Longitude "	" Latitude "
031.277133	040.784650		030.234167	040.692833
031.275600	040.787033		030.228333	040.695333
031.274317	040.788183		030.223517	040.698233
031.273367	040.787933		030.221133	040.699783
031.273083	040.787183		030.218267	040.701283
031.272383	040.786167		030.215033	040.702500
031.270983	040.785800		030.212133	040.703233
031.268500	040.785567		030.207667	040.703850
031.264983	040.785800		030.203150	040.704100
031.261917	040.786583		030.199750	040.704250
031.257350	040.787983		030.194650	040.704483
031.253783	040.789067		030.190083	040.704750
031.251367	040.789767		030.187300	040.704983
031.248850	040.790283		030.181550	040.705600
031.245500	040.790467		030.174600	040.706400
031.242900	040.790533		030.168250	040.707117
031.237050	040.790683		030.163433	040.707633
031.234033	040.790767		030.158467	040.708167
031.230033	040.790917		030.151450	040.708950
031.224400	040.791100		030.139950	040.710167
031.219450	040.791267		030.135367	040.710500
031.213633	040.791667		030.129117	040.710933
031.210617	040.792067		030.122817	040.711917
031.206317	040.792850		030.118050	040.713517
031.202183	040.793850		030.113100	040.716400
031.198133	040.795083		030.110067	040.719167
031.193867	040.796583		030.105500	040.722400
031.187967	040.798633		030.100333	040.723967
031.182133	040.800650		030.094583	040.724950
031.177567	040.802217		030.087183	040.725717
031.174217	040.803250		030.081067	040.726267
031.170883	040.803933		030.078000	040.726617
031.166883	040.804333		030.070200	040.727917
031.162283	040.804717		030.063717	040.729483
031.157150	040.805383		030.059483	040.730850
031.153150	040.806333		030.054950	040.732850
031.146350	040.808833		030.052583	040.734283
031.142600	040.810267		030.048033	040.737900
031.138233	040.811283		030.045583	040.740150
031.130833	040.811417		030.043367	040.743117

" Longitude "	" Latitude "		" Longitude "	" Latitude "
031.123417	040.811267		030.041217	040.747617
031.119850	040.811650		030.039250	040.752850
031.113283	040.812400		030.035517	040.759383
031.106700	040.813133		030.031833	040.762550
031.102883	040.813550		030.024067	040.765600
031.096167	040.814283		030.018450	040.767067
031.092167	040.814717		030.009417	040.769200
031.082133	040.816483		030.005450	040.770033
031.079383	040.817350		029.999533	040.770633
031.074250	040.819200		029.977083	040.781583
031.066850	040.821900		029.956783	040.785533
031.060650	040.824167		029.955433	040.785850
031.054667	040.826383		029.951017	040.786150
031.049100	040.828467		029.945267	040.784717
031.044733	040.830150		029.940300	040.782617
031.042067	040.831350		029.934233	040.783300
031.036950	040.834100		029.929467	040.783200
031.032483	040.836717		029.923950	040.780200
031.027083	040.839850		029.920733	040.778483
031.026783	040.840033		029.914517	040.776567
031.018750	040.844050		029.905067	040.775150
031.011333	040.845400		029.901483	040.774933
031.007400	040.845317		029.899750	040.775200
031.003483	040.844667		029.880917	040.778700
031.000233	040.843683		029.874967	040.776117
030.995617	040.841867		029.870250	040.772383
030.988783	040.839717		029.867867	040.769533
030.979850	040.841283		029.864450	040.766767
030.972967	040.841617		029.860767	040.765700
030.943300	040.836367		029.856183	040.766033
030.942600	040.835983		029.850217	040.768167
030.939800	040.834217		029.844450	040.768433
030.936650	040.832400		029.840300	040.768633
030.929700	040.829467		029.833933	040.769317
030.924250	040.827033		029.827783	040.768983
030.920683	040.824800		029.823133	040.768017
030.916900	040.821550		029.815667	040.767317
030.914900	040.819700		029.807983	040.767850
030.911700	040.817267		029.801133	040.769267
030.907783	040.814983		029.796333	040.770083
030.901633	040.812400		029.790717	040.770517
030.894350	040.810183		029.785717	040.770533
030.888850	040.808967		029.780200	040.770617
030.884433	040.808283		029.775683	040.771217
030.880050	040.807850		029.770617	040.772333
030.873467	040.807600		029.762567	040.774117
030.869483	040.807683		029.756333	040.775500

" Longitude "	" Latitude "		" Longitude "	" Latitude "
030.866033	040.807783		029.750650	040.776783
030.860300	040.807117		029.745450	040.777933
030.855733	040.805767		029.741433	040.778383
030.852333	040.804117		029.737300	040.778183
030.849200	040.801883		029.732783	040.777433
030.847117	040.799833		029.729383	040.777017
030.844117	040.796783		029.724783	040.777167
030.841200	040.794450		029.719150	040.778333
030.836900	040.791817		029.715550	040.778967
030.833217	040.790050		029.709450	040.779000
030.830050	040.788883		029.704350	040.778883
030.826217	040.787783		029.699167	040.779367
030.821417	040.786883		029.696417	040.779667
030.816500	040.786250		029.691133	040.779850
030.813100	040.785550		029.687083	040.779567
030.809350	040.784483		029.681483	040.778800
030.805467	040.782950		029.677383	040.778567
030.802683	040.781700		029.672783	040.779067
030.800617	040.780933		029.666983	040.779733
030.796683	040.780033		029.660300	040.779033
030.794183	040.779667		029.656917	040.778533
030.791233	040.778933		029.652683	040.778800
030.789267	040.778150		029.646283	040.778367
030.787300	040.777050		029.639617	040.777417
030.785800	040.775883		029.636083	040.777067
030.784250	040.774300		029.634017	040.777217
030.783217	040.773217		029.628550	040.780867
030.780367	040.771267		029.626900	040.782533
030.777383	040.770367		029.622567	040.785950
030.774467	040.770233		029.619550	040.787800
030.770950	040.770333		029.616400	040.788400
030.765783	040.769417		029.611833	040.787267
030.761933	040.767500		029.608167	040.784083
030.759567	040.765550		029.606100	040.782150
030.756283	040.762967		029.603833	040.780933
030.753067	040.760917		029.601100	040.779817
030.749983	040.759283		029.595950	040.777867
030.746567	040.757817		029.590950	040.775367
030.743967	040.756867		029.586383	040.773517
030.740017	040.755767		029.584117	040.772633
030.736183	040.755000		029.580383	040.770550
030.731467	040.754433		029.575900	040.768900
030.721933	040.753950		029.567400	040.770000
030.712850	040.753450		029.564250	040.771117
030.705283	040.753067		029.557433	040.773350
030.697767	040.752300		029.550250	040.774267
030.691933	040.751217		029.541150	040.776733

" Longitude "	" Latitude "		" Longitude "	" Latitude "
030.685717	040.749550		029.536767	040.776000
030.681150	040.747950		029.531100	040.776083
030.677767	040.746567		029.527400	040.778817
030.673883	040.745100		029.525583	040.782983
030.669617	040.743833		029.522583	040.785767
030.665117	040.742867		029.517733	040.789783
030.662100	040.742417		029.515433	040.793267
030.657083	040.741650		029.513700	040.796050
030.653517	040.740750		029.508517	040.799400
030.650383	040.739683		029.504517	040.800600
030.646500	040.737950		029.500683	040.802083
030.643567	040.736250		029.494267	040.805300
030.641567	040.734867		029.462183	040.810333
030.638950	040.732667		029.456567	040.812717
030.636283	040.730533		029.453900	040.814267
030.632083	040.727967		029.451033	040.816283
030.628283	040.726250		029.448500	040.818250
030.625450	040.725250		029.444733	040.821383
030.622000	040.724333		029.441467	040.824167
030.615250	040.723050		029.438517	040.826667
030.608700	040.721933		029.435800	040.828683
030.601683	040.720833		029.429700	040.832083
030.595667	040.720000		029.425833	040.833667
030.589633	040.719267		029.423567	040.834633
030.584167	040.718633		029.418883	040.837250
030.578267	040.718050		029.415567	040.840350
030.575317	040.717767		029.413483	040.844300
030.570267	040.717333		029.412833	040.846983
030.562950	040.716767		029.411517	040.850783
030.556083	040.716317		029.409733	040.853833
030.550933	040.715967		029.405933	040.858483
030.546567	040.715650		029.403400	040.861100
030.542050	040.715217		029.401267	040.863600
030.538267	040.714717		029.398683	040.867133
030.534533	040.714133		029.394900	040.871783
030.528217	040.713117		029.389933	040.875583
030.524533	040.712617		029.387717	040.876817
030.520167	040.712167		029.384717	040.878550
030.515383	040.711983		029.382067	040.880300
030.510000	040.712100		029.378500	040.883150
030.505583	040.712417		029.373683	040.888283
030.502000	040.712817		029.370967	040.892533
030.498350	040.713383		029.368417	040.898383
030.491583	040.714867		029.366800	040.901233
030.486150	040.716333		029.364533	040.904167
030.482633	040.717300		029.360567	040.907883
030.480000	040.718000		029.347967	040.928200

" Longitude "	" Latitude "		" Longitude "	" Latitude "
030.477833	040.718550		029.347067	040.929067
030.474283	040.719317		029.342833	040.931783
030.470817	040.719917		029.334800	040.934800
030.464550	040.720567		029.328950	040.937967
030.459767	040.720750		029.321617	040.941450
030.455083	040.720667		029.312817	040.945833
030.450283	040.720300		029.309467	040.948217
030.442517	040.719433		029.304133	040.951183
030.438667	040.719017		029.296150	040.954200
030.434467	040.718650		029.292733	040.955900
030.430783	040.718483		029.279683	040.961717
030.425083	040.718417		029.276467	040.963583
030.417117	040.718450		029.267417	040.969800
030.410533	040.718467		029.261900	040.971250
030.406500	040.718367		029.255550	040.972200
030.403183	040.718050		029.189667	040.989900
030.399367	040.717283		029.177250	040.990867
030.396783	040.716483		029.173817	040.991800
030.393067	040.714883		029.172583	040.992150
030.387633	040.712067		029.169717	040.992833
030.383417	040.710050		029.166450	040.993683
030.379317	040.708600		029.161517	040.994400
030.374933	040.707767		029.157033	040.994483
030.370050	040.707500		029.153617	040.994500
030.367067	040.707683		029.147533	040.995050
030.359433	040.708983		029.143783	040.995783
030.354083	040.710133		029.138817	040.996700
030.347183	040.711517		029.135850	040.997017
030.340433	040.712300		029.133183	040.997017
030.334683	040.712733		029.129750	040.996717
030.329517	040.712650		029.123767	040.996000
030.323350	040.711033		029.119500	040.995817
030.320517	040.709067		029.112867	040.997050
030.317933	040.706683		029.108000	040.999650
030.314233	040.704717		029.102767	041.003733
030.311433	040.703417		029.097150	041.007550
030.309067	040.701750		029.090917	041.009550
030.305567	040.699600		029.084483	041.009300
030.302167	040.698433		029.078300	041.007100
030.297467	040.697650		029.074800	041.006067
030.293333	040.697650		029.070850	041.005733
030.290667	040.697317		029.065767	041.006867
030.287417	040.695583		029.063100	041.008917
030.285283	040.693167		029.061833	041.010850
030.281683	040.690367		029.058983	041.013600
030.278350	040.688667		029.054017	041.017050
030.274117	040.687200		029.051300	041.019033

" Longitude "	" Latitude "		" Longitude "	" Latitude "
030.270433	040.686150		029.048933	041.021267
030.267367	040.685100		029.046733	041.024650
030.263733	040.683450		029.045667	041.029067
030.260583	040.682150		029.045200	041.032933
030.257083	040.681500		029.043700	041.036317
030.253617	040.681683		029.041950	041.038783
030.250150	040.682550		029.040250	041.040150
030.245867	040.684433		029.036717	041.043467
030.242767	040.686550		029.034067	041.045967
030.240000	040.688967		029.030433	041.049433
030.237933	040.690617		029.025983	041.053500

Table-B.2.1 The Geographical Coordinates of The İstanbul-Ankara Highway Between Kaynaşlı And İstanbul With 478 Locations

B.3 The Geographical Coordinates of Ankara-Ring Highway with 194 Locations

" HIGHWAY " , " ANKARA_RING " ,194

" Longitude "	" Latitude "		" Longitude "	" Latitude "
31.5170312841227	40.7501157046377		31.2525947429987	40.7818167727125
31.5552655724503	40.7506870062121		31.2212216736004	40.7874871771761
31.5984911517396	40.758406104451		31.1967282451645	40.7974530280147
31.6204283010769	40.7598765815483		31.1709816849118	40.8050273998273
31.6480099632638	40.7608748073195		31.1533913031351	40.8111851129847
31.6787250224644	40.7628237914381		31.1351660939158	40.818291978243
31.7025521168524	40.7609439909567		31.1069189783126	40.8206020055838
31.7232391135907	40.7619169155084		31.0905782952941	40.8258001011647
31.7433048007412	40.7585952900272		31.0704820871154	40.8286009837636
31.7633668153356	40.7571770271616		31.0711096495871	40.8286028903546
31.7859369894836	40.752895795475		31.0692218714534	40.8290632519159
31.8059984969824	40.7424125399746		31.0472578825533	40.8266782187701
31.8310668894748	40.7319254786603		31.014002027223	40.8219009165739
31.8511200555874	40.7328755354962		30.9876551228487	40.8152120930149
31.8768165452813	40.7371565593101		30.9456327285189	40.8065951083934
31.9075284003443	40.7399980908544		30.8885806433769	40.7926968536045
31.9351083207848	40.7423578539955		30.8428270702519	40.7826064721101
31.9595603032935	40.7466216630404		30.8002147874934	40.7744120676364

" Longitude "	" Latitude "		" Longitude "	" Latitude "
31.9871507476878	40.7513525437921		30.759506918648	40.7633467261843
32.0210053568081	40.7532058912197		30.730676936176	40.7613596880609
32.0598717370075	40.7536089300016		30.730045205501	40.7623112748306
32.0924739546653	40.7549671747501		30.7318978584743	40.7608320614588
32.1206936745517	40.7572810724037		30.7087025957447	40.7517756935535
32.143893206421	40.7581720551732		30.6786196365456	40.7422360080842
32.1420170864802	40.759130703457		30.6523060852161	40.7317371222569
32.143893206421	40.7581720551732		30.6103489545224	40.7135917124906
32.1441351014949	40.7583976617133		30.5802971856728	40.7040263722633
32.160435692644	40.757457870129		30.5301953770236	40.7006202957783
32.1742309647013	40.754130613893		30.4963721408603	40.7005613871729
32.1867720922738	40.7498476100752		30.471930422615	40.704326392494
32.1961799810142	40.7427015636105		30.4499972805048	40.7066618382219
32.2062155778561	40.7307878157382		30.4330800838463	40.7075752935776
32.2131152177662	40.7183955252284		30.4136523875843	40.709433190935
32.2187607728597	40.7031421655916		30.3910912878723	40.7112790850884
32.2338012462486	40.6702514383325		30.3779308515289	40.7121949146541
32.2488269415056	40.6545205960889		30.3666469903272	40.7135916271677
32.2663470667684	40.6325899909923		30.3660229933039	40.7131130297305
32.280730431672	40.6154248124649		30.4674527900573	40.7054681451018
32.2844744107673	40.5977848380615		30.4404956838839	40.6998100631995
32.2900888938247	40.5749000169428		30.4123018800971	40.6974851351523
32.3100712230997	40.5491477215828		30.3759654130656	40.6942135538131
32.3337870850319	40.5238659052056		30.3483841030295	40.684244492049
32.3624728975162	40.4938069775612		30.3114265516185	40.6780931338915
32.3774227823839	40.4747218477983		30.2863779129703	40.6762107038944
32.3892527824443	40.4599292046626		30.2569489470017	40.6752790472032
32.4048104585965	40.4403629457037		30.2112450201922	40.6824488147092
32.4160247391968	40.4336729051101		30.1692891961343	40.6881709322844
32.4154043958365	40.4351040223752		30.1385994494795	40.6938829911346
32.4154043958365	40.4351040223752		30.1291957267495	40.704843260713
32.4154043958365	40.4351040223752		30.117286368604	40.7124642519816
32.416384734412	40.4335219641065		30.0953393195406	40.7277040044578
32.4245194449871	40.4197051330462		30.080277269138	40.7424693492364
32.4332697617812	40.4087487423514		30.0614534616231	40.7538916863005
32.4413958583626	40.396360885292		30.0438771200041	40.7653124729431
32.4513918108954	40.3820669558498		30.0168983723067	40.7729034491705
32.458266010197	40.3687233551281		29.98614795451	40.7814350507741
32.4651391519811	40.353949070611		29.9604184844572	40.7866313989851
32.4726382863773	40.3334537361308		29.9378281378423	40.7899219606702
32.477017672969	40.3143863385906		29.9121131146575	40.7898637449311
32.4795267974065	40.2953176894496		29.8832664456761	40.7888381990629
32.4926185513234	40.272440039528		29.8638351832799	40.7864019992499
32.5106793592836	40.2486088248931		29.8443930901857	40.7863460468895
32.5305932555441	40.2252516729431		29.831235330386	40.783922770688
32.546141229428	40.2004608933986		29.8312277163511	40.7853528779067
32.5629226401432	40.1818656286164		29.8312251782184	40.7858295802328

" Longitude "	" Latitude "		" Longitude "	" Latitude "
32.565402331486	40.1613643863955		29.8299177759432	40.7847003856938
32.568499636008	40.135141698649		29.8073458616737	40.7861817975331
32.569734431732	40.115593991557		29.769102751784	40.7905489989254
32.5777996969678	40.101288850641		29.7070357049002	40.8020877223546
32.5852446643373	40.0931813425808		29.6405560333655	40.8140730535468
32.5777999352805	40.1017656192784		29.6091876328233	40.8174286101452
32.5790401124206	40.0989046341932		29.562756884132	40.8250678144148
32.5859269950347	40.0929967383056		29.5138063343178	40.8307805873352
32.5921376362759	40.0825090660607		29.4560526082671	40.841709031514
32.6008288548418	40.0705910067498		29.3976315626984	40.8611883125683
32.6039332817361	40.0572416691877		29.3699546369302	40.8792616304814
32.6138598515436	40.0443691185079		29.3409938071206	40.9011394613137
32.6219226309332	40.0353100482273		29.3070041190139	40.918232157864
32.6306025455335	40.0229128825379		29.2874751898608	40.9301057327893
32.6330820052813	40.0195750433432		29.3169579266539	40.9154971693298
32.6312229186793	40.0238663350689		29.3037833327312	40.9288576547973
32.6312229186793	40.0238663350689		29.2899741452194	40.9417404173042
31.5165665160372	40.7504376873826		29.2742694896243	40.951285892988
31.5027764228803	40.750448247743		29.2604471948944	40.9613048999615
31.4908663001037	40.7499793279454		29.2491348716409	40.9694143535606
31.4758242273508	40.7518942733225		29.2252402476266	40.9770496976906
31.4563923161328	40.7519018194903		29.2076307555839	40.986586480847
31.4319461748016	40.7547669509891		29.1793211477556	40.9946892795247
31.4074974455508	40.7600104712942		29.1554111795158	40.9994499529282
31.3874357789966	40.7609597572243		29.1245752890595	41.0051548709375
31.3667446608206	40.7642888264605		29.1038019317612	41.0113368503154
31.3441639080508	40.7733334885946		29.0805005392682	41.0213260721559
31.3316186736212	40.7766614082813		29.068523639684	41.0308471083898
31.3228368957593	40.7785610983593		29.056545315713	41.0394135011244
31.3059014303683	40.7809289659555		29.0401666336013	41.0436825039747
31.2908536088642	40.7794828025293		29.0401632264108	41.0451125679473
31.2707876232187	40.7789816647246		29.0401632264108	41.0451125679473

Table-B.3.1 The Geographical Coordinates of Ankara-Ring Highway with 194 Locations