ANALYSIS OF RADIO WAVE PROPAGATION FOR A SPECIFIC METRO STATION

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ANALYSIS OF RADIO WAVE PROPAGATION FOR A SPECIFIC METRO STATION

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ABSTRACT

ANALYSIS OF RADIO WAVE PROPAGATION FOR A SPECIFIC METRO STATION

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In this thesis, radio propagation areas at Umitkoy and Inonu Neighborhood metro stations were analyzed at different distances and surfaces. At the same time, path losses in the radio propagation area were investigated. Studies have been carried out on the modeling of wireless coverage area in subway stations that vary in different distances and conditions. The theoretical calculations with empirical formulas were also controlled by measurements on the existing subway station in the field. As a result of the losses observed depending on the ambient conditions, the material used and the installation points, a method has been developed to enable optimization before the installation. The path loss was calculated using the codes written in the MATLAB program and the graphics were drawn according to the modeling type. The theoretical results and analyzes were compared with the field measurements and the error rate was obtained. In accordance with the observed and calculated results, necessary arrangements were made for the optimization studies and the ideal design for the radio coverage area was avoided, preventing the problems of non-reception and unnecessary material usage.

Keywords: Radio Wave, Radio Coverage Area, Path Loss, Modelling

ÖZ

ÖZEL METRO İSTASYONU İÇİN RADYO DALGA YAYILIMININ ANALİZİ

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Bu tezde Ümitköy ve İnönü Mahallesi metro istasyonlarında telsiz yayılma alanlarının farklı mesafe ve yüzeylerdeki analizi yapılmıştır. Aynı zamanda telsiz kapsama alanında meydana gelen yol kayıpları incelenmiştir. Farklı mesafelerde ve koşullarda değişkenlik gösteren metro istasyonlarındaki telsiz kapsama alanının modellenmesi üzerine çalışmalar yapılmıştır. Ampirik formüllerle teorik olarak yapılan hesaplamalar, sahada mevcut metro istasyonu üzerinde yapılan ölçümlerle de kontrol edilmiştir. Ortam koşullarına, kullanılan malzemeye ve kurulum noktalarına bağlı olarak gözlemlenen kayıplar neticesinde optimizasyonun kurulum öncesinde yapılabilmesini sağlayabilecek metot geliştirilmiştir. Yol kaybı modelleme çeşitlerine göre Matlab programında yazılan kodlarla hesaplanmış ve grafikleri çizdirilmiştir. Elde edilen teorik sonuç ve analizler sahada yapılan ölçümlerle karşılaştırılarak hata oranı çıkarılmıştır. Gözlemlenen ve hesaplanan sonuçlar doğrultusunda optimizasyon çalışmaları için gerekli düzenlemeler yapılmış olup telsiz kapsama alanı için ideal tasarım yapılarak, telsiz çekmeme sorunlarının ve gereksiz malzeme kullanımlarının önüne geçilmiştir.

Anahtar Kelimeler: Radyo Dalgası, Telsiz Kapsama Alanı, Yol Kaybı, Modelleme.

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LIST OF ABBREVIATIONS

RSSI	Received Signal Strength Indication
PL	Path Loss
TETRA	Terrestrial Trunk Radio
NMS	Network Management System
ETSI	European Telecommunications Standards Institute
VHF	Very High Frequency
D	Directivity (dimensionless)
D0	Maximum directivity (dimensionless)
U	Radiation intensity (W/unit solid angle)
Umax	Maximum radiation intensity (W/unit solid angle)
U0	Radiation intensity of isotropic source (W/unit solid angle)
Prad	Total radiated power (W)
GPS	Global Positioning Satellite
LOS	Line of Sight
PLF	Polarization Loss Factor
BS	Base Station
MS	Mobile Station
Gt	Gain of transmitter antenna
Gr	Gain of the receiving antenna
Λ	Transmission wavelength (m)
D	Distance between transmitter and receiver (m)
VPLE	The Variable Path Loss Exponent

CHAPTER 1

1. INTRODUCTION

1.1. Overview

Metro is one of the most dangerous closed areas where thousands of people pass by every day. In the event of accidents and terrorist attacks, the possibility of human catastrophe is extremely high, and it is very difficult to communicate in a technical situation.

In this context, the necessary infrastructure for today's metro stations and the station design are carried out in accordance with the specifications issued by the Ministry of Transport. It is necessary to provide communication systems which perform the following functions in order to provide communication between Metro control center, stations, workshop, storage area, vehicles and operation maintenance personnel of Metro stations [17].

- Two-way communication between the drivers and the control center with the operating channel,
- Internal communication between the control cabinets of vehicles in a series,
- Information can be announced manually to the passengers in the control center by the driver or by automatic selection of the control center (priority).
- Two-way in-store traffic communication between the vehicle drivers and the control center with the storage channel,
- Two-way communication with the maintenance channel between the control center and mobile maintenance vehicles,
- Two-way communication with the maintenance channel between the control center and maintenance / operating personnel,
- Two-way communication between maintenance / operating personnel and the

maintenance channel.

Although these conditions are basically provided for radio communication in subway stations, problems such as incorrect antenna positions and unnecessary material usage have been identified in the installations. In this context, rather than improving the designs with post-installation corrections, it would be an important solution for these problems to be tested by modeling before installation.

Propagation models are classified under two headings as open area and closed area. As the pilot application for the metro stations was chosen as Umitkoy subway and the problem was experienced in the most closed area stations, closed area modeling was emphasized.

1.2. Ministry of Transport Subway Stations Specification

The points mentioned in the relevant specification are as follows [18]:

1.2.1. Communication System Specification

Communication systems shall be provided in order to provide communication between Metro control center, stations, workshop, storage area, vehicles and operation maintenance personnel:

- Communication with radio system,
- Communication with telephone system,
- Communication with the announcement system.

Communication with radio system

A radio system must be provided that performs the following functions:

- Two-way communication between the drivers and the control center with the operating channel,
- Internal communication between the control cabinets of vehicles in a series,
- Information from the control center to passengers in vehicles can be made

manually by the driver or automatically (with priority) by direct selection of the control center).

- Two-way in-store traffic communication between the drivers and the control center with the storage channel,
- Two-way communication with the maintenance channel between the control center and mobile maintenance vehicles,
- Two-way communication with the maintenance channel between the control center and maintenance / operating personnel,
- Two-way communication between maintenance / operation personnel and the maintenance channel.

1.2.2. Radio System Specification

The radio system will provide 98% clean coverage overall route, providing communication at the underground, underground, tunnels, stations, technical spaces along the metro route. In the tunnels, leaking cable type of radio antenna shall be used. The system will ensure uninterrupted communication even in an emergency.

In order to ensure the frequency efficiency of the radio system to be provided in an open standard structure, TETRA (Terrestrial Trunk Radio) defined by the European Telecommunications Standards Institute (ETSI) shall be in the digital radio standard.

Necessary in-tunnel, in-station radio coverage systems and the number and location of base stations that will feed them and provide coverage on open lines will be determined by coverage simulation and traffic analysis.

The systems and equipment to be installed shall comply with the regulations of the Information and Communication Technologies Authority.

The radio system will provide uninterrupted communication of fire, safety, medical emergency services in the system as well as the system communication needs in metro lines and stations.

Cable systems to be used for radio coverage in tunnel and station works will be selected so that they can be integrated into GSM telephone networks.

1.2.3. System Components

1.2.3.1. Switcher

TETRA will be the core part of the network architecture.

1.2.3.2. Base station

TETRA, base station equipment is a network element that provides air interface between the radios (handheld radio, vehicle station, stationary station, etc.) located within the geographical area covered by the base station and other equipment within the entire TETRA network.

1.2.3.3. Network Management System (NMS)

NMS is a configuration and monitoring tool / software that allows the management of the TETRA system.

1.2.3.4. Dispatch Unit (Operator Console)

Operator Consoles shall be PC-based and shall have the necessary loudspeaker, microphone and headset to make the calls. Software-based operator consoles will be easily configurable and easily redesigned for possible expansion and changes.

1.2.3.5. Recorder

The central voice recorder shall record all voice communications over the radio system. The devices will store digital recordings of at least 1 month and will be interrogated on a date basis to listen to later.

1.2.3.6. Mobile Vehicle Radio Terminal

The vehicle shall be fixed assembled in driver cabins and mobile maintenance vehicles. Its main function will support multi-channel circuit data, IP packet data applications for file transfer, messaging, database update, as well as voice communication. It will have a high-quality loudspeaker with a rated power output of 15 watts, especially suitable for use in noisy environments. The device will work in accordance with the in-car announcement system.

1.2.3.7. Mobile (Hand) Radio Terminal

These are portable terminals used by the operation and maintenance personnel. It shall have a maximum power output of 4 watts.

CHAPTER 2

2. RADIO COMMUNICATION

2.1. What Is Antenna?

The antennas are designed to collect electromagnetic waves emitted in the cavity to allow transmission in the transmission channel (receiver) or to transmit electromagnetic waves into the cavity (transmitter). Antennas can transmit data to miles away by the waves they emit. The transmit and receive characteristics of an antenna are the same. This is called reciprocity. In the communication between satellites, the same antenna is used for both transmitting and receiving [16].

Electrical signals are carried between points in one of two ways: via transmission line or through empty space using antennas at the terminals. A transmission line confines the electrical signals and the energy of the associated electromagnetic waves to the region near, or inside, the transmission line. This is also the situation for conventional circuits where no energy appears distant from the circuit. Transmission lines often use a balanced system of conductors or a metallic enclosure to confine the energy to either entirely internal to the transmission line or very nearby. An antenna has the opposite purpose—to encourage electrical signals to reach large distances from the antenna: to radiate. For example, a good transmitting antenna will produce power densities that are detectable at great distances from the source. The IEEE defines an antenna as “that part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves.” [Sec. H.2: “IEEE Standard Definitions of Terms for Antenna”] A transmission line requires a guiding structure (typically at least one conductor), whereas an antenna requires no guiding structure. Examples of RF (radio frequency) transmission lines are coaxial cables, parallel-wire lines, and hollow pipe waveguides (see Fig. 6-31). It is appropriate to view an antenna as a transducer that converts a guided (or bound) wave on a transmission line to a free-space electromagnetic wave (for the transmitting case) or vice versa (for the receiving case). [2]

2.2. Types of Antenna

Antenna types are described below [16]:

2.2.1. Isotropic Antennas

Isotropic antennas are a theoretical point source that emits equal power electromagnetic waves in all directions in space or space and is used as a reference in understanding antenna gains. The spherical radiation of the isotropic antenna is as follows.

2.2.2. Omnidirectional Antennas

Weak or more or less directional antenna types intended to receive or propagate in all directions. These antenna types are used for relative, arbitrary or location unknown waves.

2.2.2.1. Monopole Antennas

It consists of a straight metal bar at a quarter wavelength (λ / 4), which is generally placed perpendicularly on a conducting plate called the earth plate and without electrical contact with the conducting plate. It is also known as a quarter-wave antenna or a morkoni antenna (produced by Guglielmo Marconi in 1895).

When the length of the antenna rod of the monopoly antenna is equal to λ / 4 and resonates at the integer multiples of λ / 4, they emit or receive maximum waves. In resonance, the impedance of the antenna consists of the resistor only (36.8Ω). It also does not include virtual numbers. The impedance of the monopoly antenna is capacitive when the length of the antenna rod is reduced to less than λ / 4 and inductive when it is increased above λ / 4. Monopoly antennas are separated according to the above structures. They are produced as stick or pole antenna, whip antenna as helical antenna and even more variants.

2.2.2.2. Half Wave Dipole Antennas

Another name is the Hertz antenna. It is a resonance antenna with two monopoly antenna elements and a length of λ / 2. Resonance impedance is 73 Ω.

2.2.2.3. Folded Dipole Antennas

Half-wave is obtained by folding the ends of the dipole antennas. It is a resonance antenna with a length λ / 2. The resonance impedance is four times the half-wave dipole impedance and is approximately 300 Ω. The bandwidth is greater than the width of the dipole.

2.2.3. Directional Antennas

Another name is Beam antennas. Directional antennas are antennas that can emit very strong radiation and emit very strong signals. The gains of such antennas are numerous where directed. Where it is not directed, it is very low. This prevents unwanted noises or transmissions. Let us now examine the diversity of these directional antennas.

2.2.3.1. Yagi-Uda Antennas

Also referred to as the oil antenna. VHF (Very High Frequency: 30-30 MHz) and UHF (Ultra high frequency: 300-3000 MHz) bands are widely used to receive television broadcasts. The Yagi antenna consists of three types of antenna elements made of metal bars or wires:

a. A half-wave dipole or folded dipole,
b. A reflector,
c. They consist of one or more directing elements.

The antenna elements are generally mounted at a spacing of 0.1 λ and mounted on a carrier rod.

2.2.3.2. Dish Antennas

The most common parabolic reflector antennas are used in space research, terrestrial broadcasting and many other fields. A parabola is a geometric arrangement of points equidistant from a fixed "F" point with a constant "d" line taken in a plane. This fixed point is called focus and directrix.

The parabolic reflective surface is the surface obtained by rotating a parabola about its axis; this is called paraboloid. The cross section of the paraboloid perpendicular to the x axis is circular. This is called antenna clarity.

Parabolic reflector antenna feeding methods:

a) Axial or front feed
b) Off-axis or offset feed
c) Cassegrain feed
d) Gregorian feed

2.2.3.3. Log-Periodic Antennas

Log-periodic antennas consist of a plurality of dipoles arranged on an axis at intervals which are the logarithmic function of the frequency. The successive antenna elements (dipoles) are fed with a phase difference of 180°. These antennas are narrow beam and wide band antennas and are used in VHF and UHF bands.

2.2.3.4. Rhombic Antennas

A rhombus-shaped wire made of directional, broadband antenna. HF (High Frequency) is used in the short-wave band. The antenna has a terminating resistor in the receive-send direction.

2.3. Antennas in Communication Systems

It is important to have an appreciation for the role played by antennas in their primary application area of communication links. The basic communication link model is shown in Fig. 1. In Sec. 2.4, we introduced methods for calculating the power output from a receiving antenna using maximum effective aperture. In this section, we model the complete link, including the distance of separation between the source and receiver, along with several loss mechanisms encountered in a typical link. We begin by revisiting the important parameters of antenna directivity and gain and establishing some fundamental relationships [19].

2.3.1. Antenna Parameters

Directivity

In a particular direction, the ratio of radiation intensity to antenna radiation intensity is taken as the average in each direction. The directivity is directly proportional to the maximum effective aperture, and the formula combining the two can be obtained in a variety of ways.

- The average radiation intensity: The total power radiated by the antenna divided by 4π.
- More simple terms, the directivity of a non-isotropic source is equal to the ratio of radiation intensity to an isotropic source in a given direction.

Ideally, the directivity of the dipole can be written as follows [3]:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}} \tag{2.1}$$

If no direction is specified, the direction of the maximum radiation intensity is indicated as follows:

$$D_{\max} = D_0 = \frac{U|_{\max}}{U_0} = \frac{U_{\max}}{U_0} = \frac{4\pi U_{\max}}{P_{\text{rad}}} \tag{2.2}$$

D = Directivity (dimensionless)

D0 = Maximum directivity (dimensionless)

U = Radiation intensity (W/unit solid angle)

Umax = Maximum radiation intensity (W/unit solid angle)

U0 = Radiation intensity of isotropic source (W/unit solid angle)

Prad = Total radiated power (W)

For an isotropic source, from (2-1) or (2-2), it is clear that directionality is unity, since U, Umax and U0 are equal.

For antennas having orthogonal polarization components, a given polarization for the partial orientation of an antenna and in the given orientation are defined as "a portion of the radiation intensity corresponding to a given polarization divided by the average total radiation intensity in each direction". This definition for partial directivity, then in a given direction, "the total directivity, is the sum of the partial directivities of any two orthogonal polarizations." For a spherical coordinate system, the total maximum directivity D0 for the orthogonal θ and φ components of an antenna, as follows:

$$D0 = D\theta + D\varphi \quad \textbf{(2.3)}$$

while the partial directivities Dθ and Dφ are expressed as

$$D_\theta = \frac{4\pi U_\theta}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi} \quad \textbf{(2.4)}$$

$$D_\phi = \frac{4\pi U_\phi}{(P_{\text{rad}})_\theta + (P_{\text{rad}})_\phi} \quad \textbf{(2.5)}$$

where

Uθ = radiation intensity in a given direction contained in θ field component

Uφ = radiation intensity in a given direction contained in φ field component

(Prad)θ = radiated power in all directions contained in θ field component

(Prad)φ = radiated power in all directions contained in φ field component

2.3.2. Antennas in Wireless Communication Systems

Wireless communication, or simply Wi-Fi, is a broad term that includes any electronic means of communication that do not use cables connecting terminals. Radio communications refers to systems employing radios and is part of wireless communications, although the terms are often used interchangeably. In general, the term wireless includes systems that do not use radio technology, such as infrared or ultrasonic techniques. Originally the term wireless was popular in its infancy, over a hundred years ago, followed by the term radio that lasted through most of the 20th century only to see wireless return to popularity at the end of the century. The term radio is also used to mean a device such as an electronic receiver or transceiver.

Major application areas for wireless are communication of voice, video, and data; position location; identification; paging; control; and medical. So-called location-based services expanded rapidly with the deployment of satellite constellations that provide signals for inexpensive mobile terminals to self-determine their location at no recurring cost. GPS (Global Positioning Satellite) is an example. Such services provide low-cost determination of position, but the position is only known at the terminal. A return link must be added to communicate the terminal's position to another location. Common ways to do this are to use a cellular or satellite link. Many innovative wireless applications continue to emerge in great numbers. One interesting example application in the medical profession is wireless capsule endoscopy that uses a swallowable pill with a camera for imaging the intestinal tract and telemetering the data to a body-worn receiving array [20].

2.4. Friis Transmission Equation

The Friis equation is the ratio of the power at the receiver antenna output to the power at the transmit antenna input in telecommunication [21].

Friis Transmission Formula

Assuming the transmitting antenna is isotropic, the communication connection at distance R is shown:

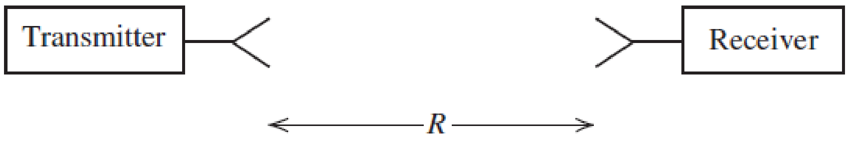

Figure 1: A Communication Link [19]

Suppose that the Pt Watts total power is transmitted to the transmitting antenna, that the transmitting antenna is versatile, lossless, and that the receiving antenna is in the remote area of the transmitting antenna. Then, the power density (in Watts per square meter) of the planar wave occurring on the receiving antenna is at the distance R from the transmitting antenna:

$$p = \frac{P_T}{4\pi R^2} \tag{2.6}$$

If there is an antenna gain in the direction of the receiving antenna given by the transmitting antenna, the above power density equation is:

$$p = \frac{P_T}{4\pi R^2} G_T \tag{2.7}$$

The term gain affects the directionality and loss of a real antenna. Assuming that the receiving antenna has an effective aperture given by the antenna theory, the power it receives (Pr):

$$P_R = \frac{P_T}{4\pi R^2} G_T A_{ER} \tag{2.8}$$

The effective aperture for any antenna can be expressed as:

$$A_e = \frac{\lambda^2}{4\pi} G \tag{2.9}$$

Aer that the receiver antenna and the receiver antenna's effective aperture for maximum response is assumed to be sharp and polarized. To clearly show both antenna gains, the received power (Pr) obtained when Aer's formula is written can be written as follows:

$$P_R = \frac{P_T G_T G_R \lambda^2}{(4\pi R)^2} \tag{2.10}$$

This formula gives the available power in terms of transmitted power, antenna gain and wavelength. This formula is the most popular form of the Friis transmission formula and forms the basis for communication analysis. There are several established assumptions. The most important assumption of these is a clear line-of-sight (LOS) path (free space conditions) without secondary wave paths caused by reflections from objects. It assumes that each of the antennas is directed towards each other to realize the maximum gain, that the transmitting and receiving antennas are matched to the impedance according to the connected transmission lines, having identical and aligned polarizations. A real communication link rarely meets all of these assumptions, but it is a simple matter to correct the loss caused by impedance mismatch, polarization mismatch, or antenna mismatch. Accurate inclusion of non–free space propagation conditions is more involved.

Another useful form of the Friis Transmission Equation is given in the following formula. Since the wavelength and frequency f are related to the velocity c, the Friis Transmission Formula in terms of frequency is as follows:

$$P_R = \frac{P_T G_T G_R c^2}{(4\pi R f)^2} \tag{2.11}$$

Equation [2] shows that more power is lost at higher frequencies. This is a fundamental result of the Friis Conduction Equation, and for antennas with certain gains, energy transfer will be highest at low frequencies. The difference between received power and transmitted power is known as path loss. The Friis Transmission Equation says that the path loss for higher frequencies is higher.

Finally, if the antennas do not match the polarization, the power given above can be multiplied by the Polarization Loss Factor (PLF) to accurately account for this mismatch. The above equation [2] can be modified to produce a generalized Friis Transmission Formula containing polarization mismatch:

$$P_R = (PLF) \frac{P_T G_T G_R c^2}{(4\pi R f)^2} \tag{2.12}$$

CHAPTER 3

3. RADIO PROPAGATION MODEL

3.1. What is Coverage area?

The coverage area is an area in which the emitted signal is covered. A cellular network is a radio network scattered in cell-called areas, each provided by at least one fixed-location transceiver known as a cell site or base station. These combined cells provide radio coverage over a wide geographical area. Many portable receivers, such as radio networks and mobile phones, communicate with each other [9, 10].

Cell coverage is environment dependent and varies by environment. Environments Urban, Urban and Rural. Reflection, diffraction and scattering are the three main mechanisms that lead to a reduction in cell coverage [1].

Reflection: The electromagnetic wave occurs when the signal strikes a smooth surface with large dimensions compared to the wavelength.

Diffraction: Occurs when electromagnetic wavelengths hit a surface that is larger than the signal wavelength, new secondary waves are generated.

Scattering: Occurs when a radio wave hits a rough surface whose dimensions are less than or equal to the signal wavelength.

3.2. What is Path Loss?

Path loss (PL) or path attenuation is a reduction in the progression of space at the power density (attenuation) of an electromagnetic wave. Path loss is the main component in the analysis and design of the connection budget of a telecommunications system [22].

This term is commonly used in wireless communication and signal propagation. Path loss may be caused by many effects such as loss of free space, refraction, diffraction, reflection, loss of aperture-medium coupling, and absorption. Path loss is also affected by terrain contours, the environment (urban or rural, vegetation and vegetation), the propagation environment (dry or humid air), the distance between the transmitter and receiver, and the height and position of the antennas [15].

3.3. Types of Radio Propagation Models

HATA Model

The formulation of HT is limited to certain ranges of input parameters and can only be applied in semi-flat terrain. Mathematical expression and applicability ranges are as follows [15]:

- **Carrier Frequency:** 150 MHz ≤ fc ≤ 1500 MHz
- **Base Station (BS) Antenna Height:** 30 m ≤ hb ≤ 200 m
- **Mobile Station (MS) Antenna Height:** 1 m ≤ hm ≤ 10 m
- **Transmission Distance:** 1 km ≤ d ≤ 20 km

A + B log10 (d) for urban areas

Lp (dB) =A + B log10 (d) – C for suburban area **(3.1)**

A + B log10 (d) – D for open area

Where:

A = 69.55 +26.161log10 (fc) – 13.82 log10 (hb) – a (hm) **(3.2)**

B = 44.9 – 6.55 log10 (hb) **(3.3)**

C = 5.4 + 2 [log10 (fc / 28)]2 **(3.4)**

D = 40.94 + 4.78 [log10 (fc)]2 – 18.33 log10 (fc) **(3.5)**

Where, a (hm) =

[1.1log10 (fc) –0.7] hm – [1.56log10 (fc) –0.8] for medium or small cities

8.29[log10 (1.54 hm)]2 – 1.1 for large city and fc ≤ 200 MHz

3.2 [log10 (11.75hm)]2 – 4.97 for large city and fc ≥ 400 MHz, **(3.6)**

Since fc = 450 MHz, the formulation in 3.6 was applied for the metro station within the scope of this thesis.

COST 231-HATA Model

Most future PCS systems are expected to operate in the 1800-2000 MHz frequency band. It has been shown that path loss at these frequencies may be more dramatic than in the 900 MHz range. Some studies have shown that path loss at 1845 MHz is about 10 dB greater than that experienced at 955 MHz and all other parameters are kept constant. The COST231-Fault model extends the Fault model for use in the 1500-2000 MHz frequency range, which is known to underestimate path loss. The model is represented by the following parameters [15]:

- **Carrier Frequency (fc):** 1500-2000 MHz
- **BS Antenna Height (hb):** 30-200 m
- **MS Antenna Height (hm):** 1-10 m
- **Transmission Distance (d):** 1-20 km

$$Lp\ (dB) = A + B \log10\ (d) + C \qquad \textbf{(3.7)}$$

Where;

$$A = 46.3 + 33.9 \log10\ (fc) - 13.28 \log10\ (hb) - a\ (hm) \qquad \textbf{(3.8)}$$

$$B = 44.9 - 6.55 \log 10\ (hb) \qquad \textbf{(3.9)}$$

C= 0 for medium city and suburban areas **(3.10)**

3 for metropolitan areas

Free Space Model

Free space path loss is as follows [23]:

$$L = \frac{P\ transmitted}{P\ received} \qquad \textbf{(3.11)}$$

Gt: Gain of transmitter antenna

Gr: Gain of the receiving antenna

λ: Transmission wavelength (m)

d: Distance between transmitter and receiver (m)

On the dB scale equals:

$$L = 20 \log 4\pi + 20 \log d - 10 \log Gt - 10 \log Gr - 20 \log \lambda \qquad \textbf{(3.12)}$$

The free space propagation assumes that there are no other scattering or reflective objects between the transmitter and the receiver. Power flux density at distance d for free space spreading conditions,

$$\frac{E^2}{120\pi} = \frac{P_t G_t}{4\pi d^2} = (W/m^2) \qquad \textbf{(3.13)}$$

The PtGt product is called EIRP, the equivalent isotropically emitted power. It emits power radiation at a fixed angle relative to the isotropic antenna.

A path loss in Free Space defines how much signal strength is lost during transmit from transmitter to receiver. The Free Space Model varies in frequency and distance. Calculated using the following equation. (one).

$$L = 32.45 + 20\log(d) + 20\log(f) \qquad \textbf{(3.14)}$$

f is the frequency in (MHz) and the distance in d (Km).

Variable Path Loss

The Variable Path Loss Exponent model considers the n exponent factor and the Constant Loss. Propagation parameters can be set per band of frequencies. Variable Path Loss Exponent model is also called the One-Slope model.

The equation used in this model is as follows [26]:

$$20 \log (4\pi/c) + 10\, n \log (d) + 20 \log (f) – Lc \qquad \textbf{(3.15)}$$

- It consists of n slopes and is applied as follows:

$$10n\log10\ (\text{distance}) \qquad \textbf{(3.16)}$$

- Lc represents the constant of the model and is typically a negative value.

3.4. Propagation Models Path Loss Results and Graphics With MATLAB

In MATLAB, where the carrier frequency value used in the subway station is 450 MHz and the line length are 2 km, the results were obtained according to these values. The path loss values, and graph are as follows:

Free Space Model

Distance (km)	**Path Loss (dB)**
0	-Inf
0.01	45.5143
0.1	65.5143
0.2	71.5349
0.3	75.0567
0.4	77.5555
0.5	79.4937
0.6	81.0773
0.7	82.4162
0.8	83.5761
0.9	84.5991
1.0	85.5143
1.1	86.3421
1.2	87.0979
1.3	87.7931
1.4	88.4368
1.5	89.0361
1.6	89.5966
1.7	90.1232
1.8	90.6197
1.9	91.0893
2	91.5349

Table 1: Calculation of path loss according to distance with MATLAB to Free Space Model

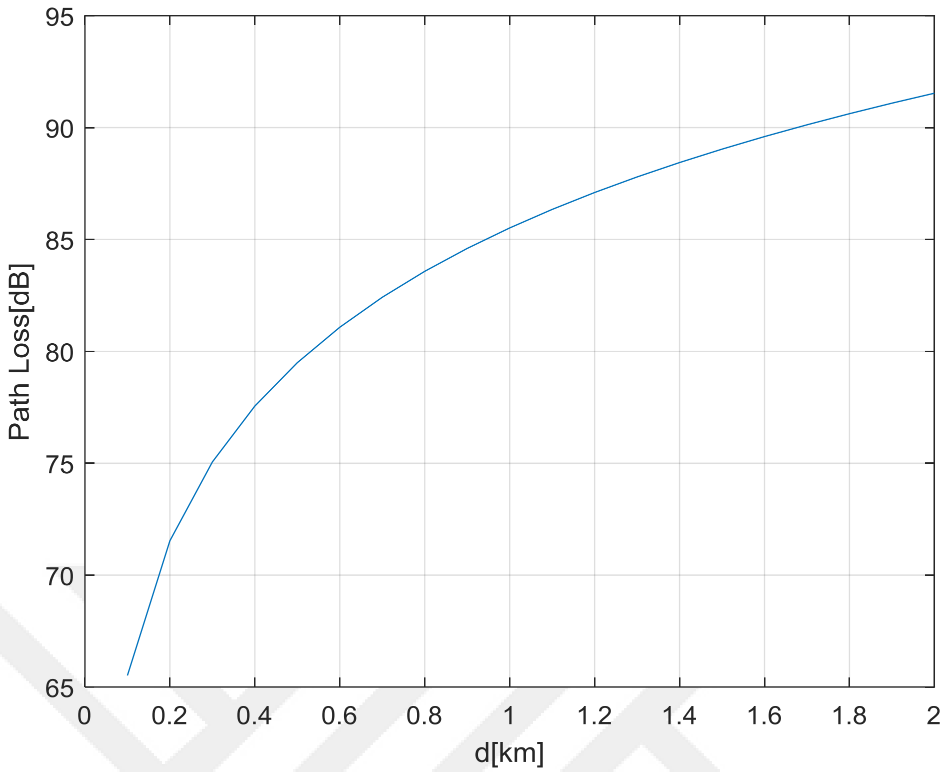

Figure 2: Graph of Free Space Model Calculation Results with MATLAB

HATA Model

Distance (km)	Path Loss (dB)
0	-Inf
0.01	57.7124
0.1	92.9372
0.2	103.5410
0.3	109.7437
0.4	114.1447
0.5	117.5583
0.6	120.3475
0.7	122.7057
0.8	124.7484
0.9	126.5503
1.0	128.1621
1.1	129.6201
1.2	130.9512
1.3	132.1757
1.4	133.3094
1.5	134.3649
1.6	135.3522
1.7	136.2796
1.8	137.1540
1.9	137.9811
2	138.7658

Table 2: Calculation of path loss according to distance with MATLAB to HATA Model

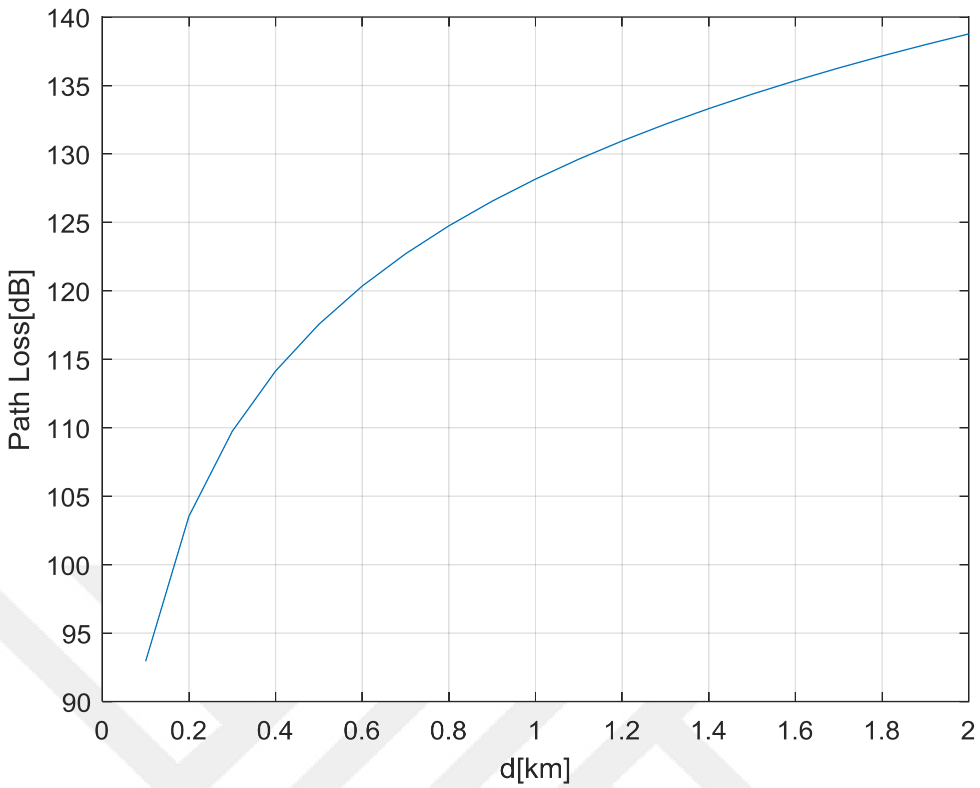

Figure 3: Graph of HATA model calculation results with MATLAB

COST 231-HATA Model

Distance (km)	Path Loss (dB)
0	-Inf
0.01	50.4841
0.1	85.7089
0.2	96.3127
0.3	102.5155
0.4	106.9164
0.5	110.3301
0.6	113.1192
0.7	115.4774
0.8	117.5202
0.9	119.3220
1.0	120.9338
1.1	122.3918
1.2	123.7229
1.3	124.9474
1.4	126.0811
1.5	127.1366
1.6	128.1239
1.7	129.0513
1.8	129.9257
1.9	130.7529
2	131.5375

Table 3: Calculation of path loss of COST 231-HATA model with MATLAB by distance

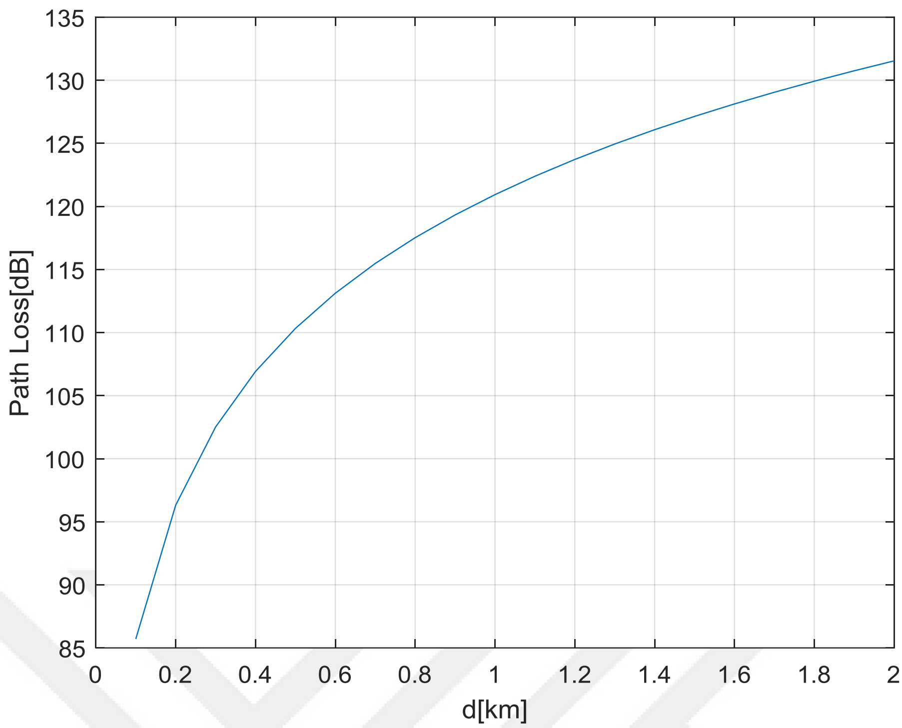

Figure 4: Graph of COST231-HATA model calculation results with MATLAB

Comparing Propagation Models

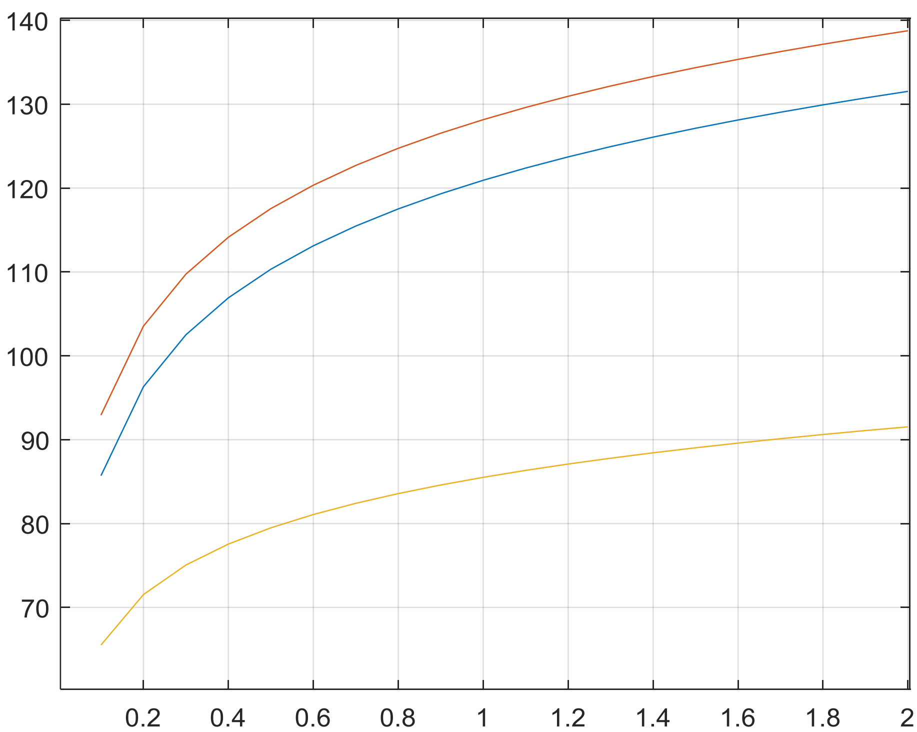

Figure 5: Graph of all propagation model's calculation results with MATLAB

Application Studies

Within the scope of this thesis, a field study was conducted for a room before the subway station. For this purpose, the details of these models were compared by using 3 models defined in the program within the scope of iBwave.

1- Cost 231
2- Fastray
3- Variable path loss propagation

COST-231 Office

COST 231 is the most advanced experimental model. All walls in the vertical plane between the transmitter and receiver are taken into account and separate material properties are considered for each wall.

Since the estimates for the COST 231 model are often somewhat pessimistic, an extension is added to the model. With increasing number of perforated walls, attenuation of the walls decreases. With this expansion, the COST 231 model achieves good results with minimal computational effort [24].

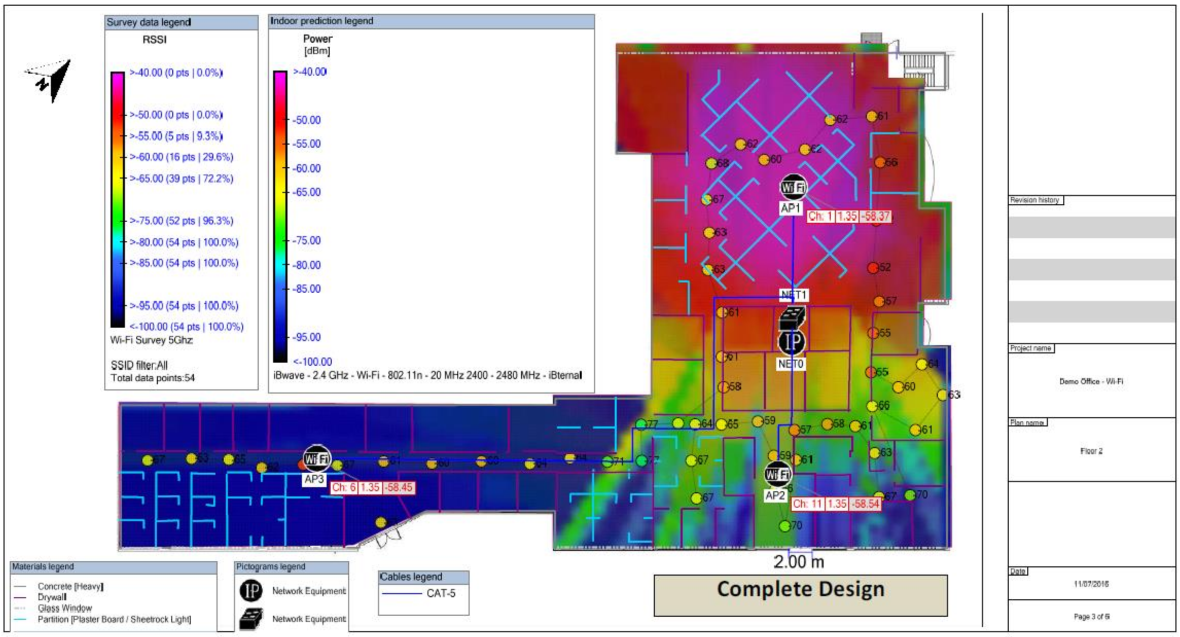

Figure 6: Cost 231 Path Loss Propagation Model

FASTRAY

This propagation model is a deterministic (path search) model. Depending on the signal source type (spot source or spreading cable), it uses a modified beam tracking algorithm to calculate the received signal strength at each pixel in the layout. The Fast Track Monitoring model has a very short calculation time compared to standard beam tracking [25].

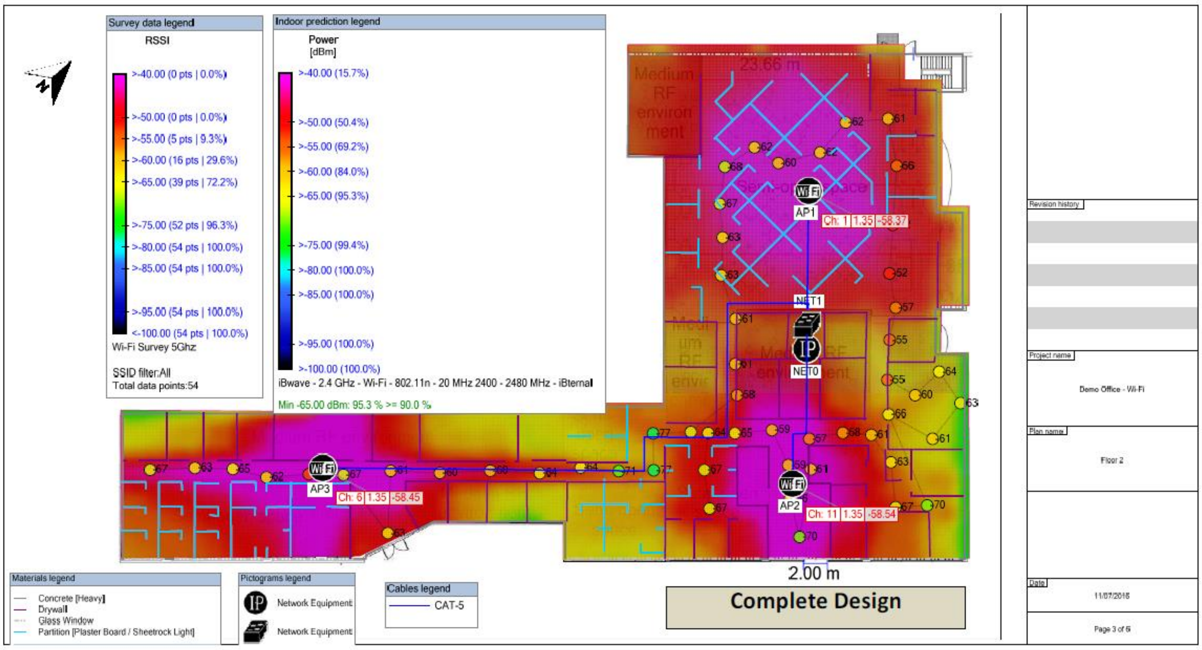

Figure 7: Fastray Path Loss Propagation Model

Variable Pathloss

The Variable Path Loss Axis model closely predicts the effect of signal loss and propagation on various characteristics of indoor environments. Using site-specific media types, path loss is estimated for a given site where antenna contours and signal strength estimates are accurately measured when considering considerations of the level of interference defined in the allocated environments. The VPLA algorithm also takes into account material loss when calculating interference between floors in which small cells are placed in a multi-level floor facility [26].

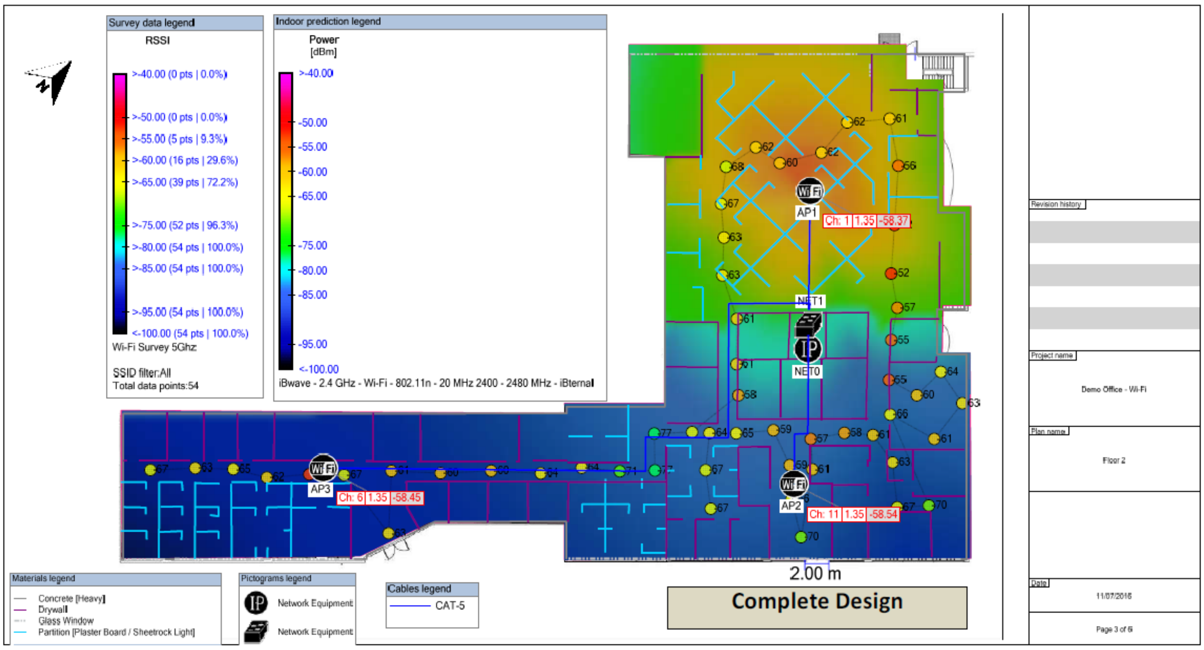

Figure 8: Variable Path Loss Propagation Model

CHAPTER 4

4. SYSTEM ARCHITECTURE

4.1. General Definition of M2 Metro Station

The construction and construction work of Kizilay-Cayyolu Metro Line, which started construction on 27.09.2002, consist of three phases and consist of a total of 16,590 meters of line and 11 stations. The first stage of this line is designed as Sogutozu (AŞTİ)- Umitkoy, the second stage is Sogutozu-Necatibey and the third stage is Kizilay-Cayyolu 2. It was opened on 13 March 2014. The M2 metro line is as shown Figure 10. [8].

Ankara Metro Stations and Stops

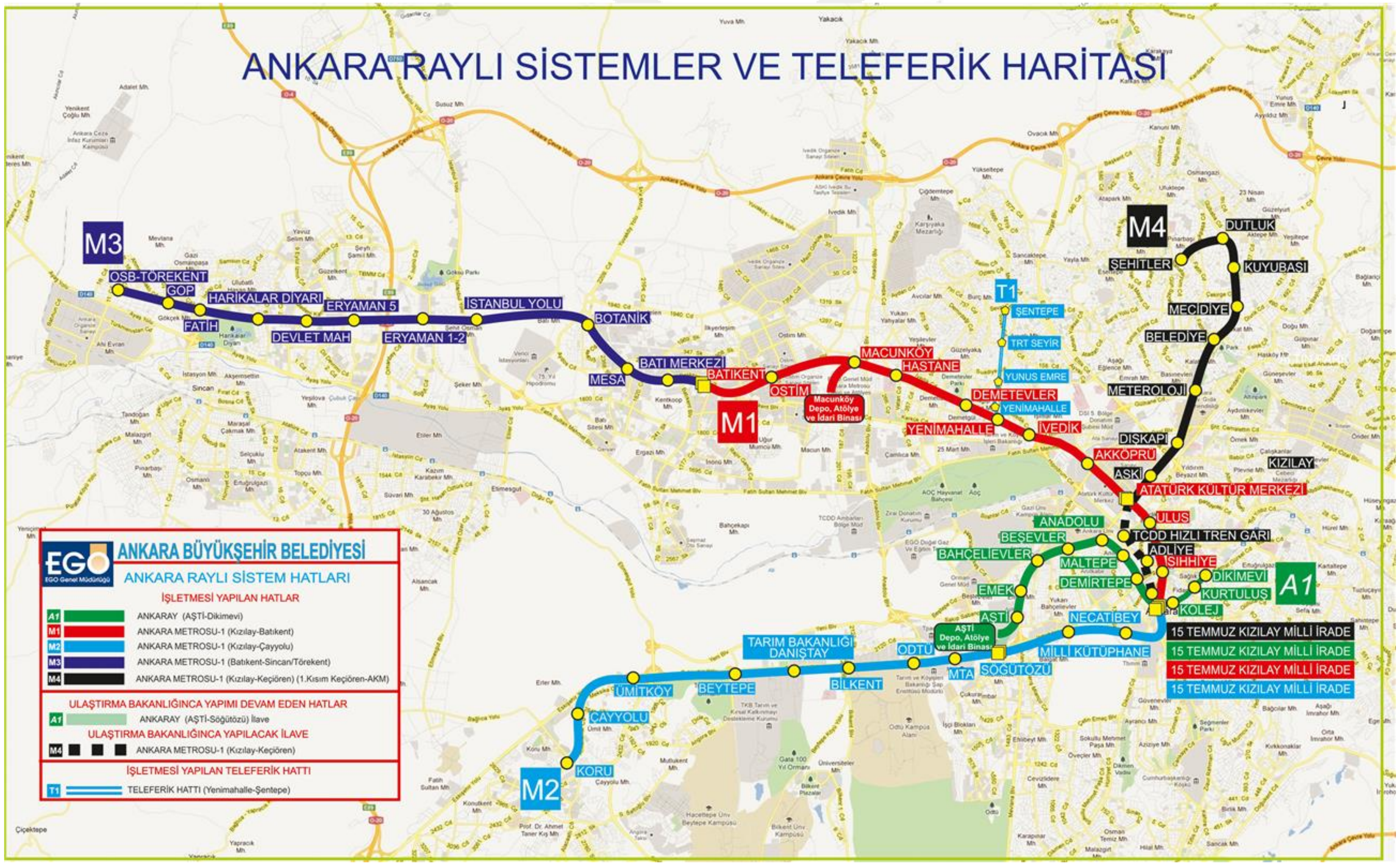

Figure 9: Ankara Metro Stations and Stops [14]

M2 Metro Station and Stops

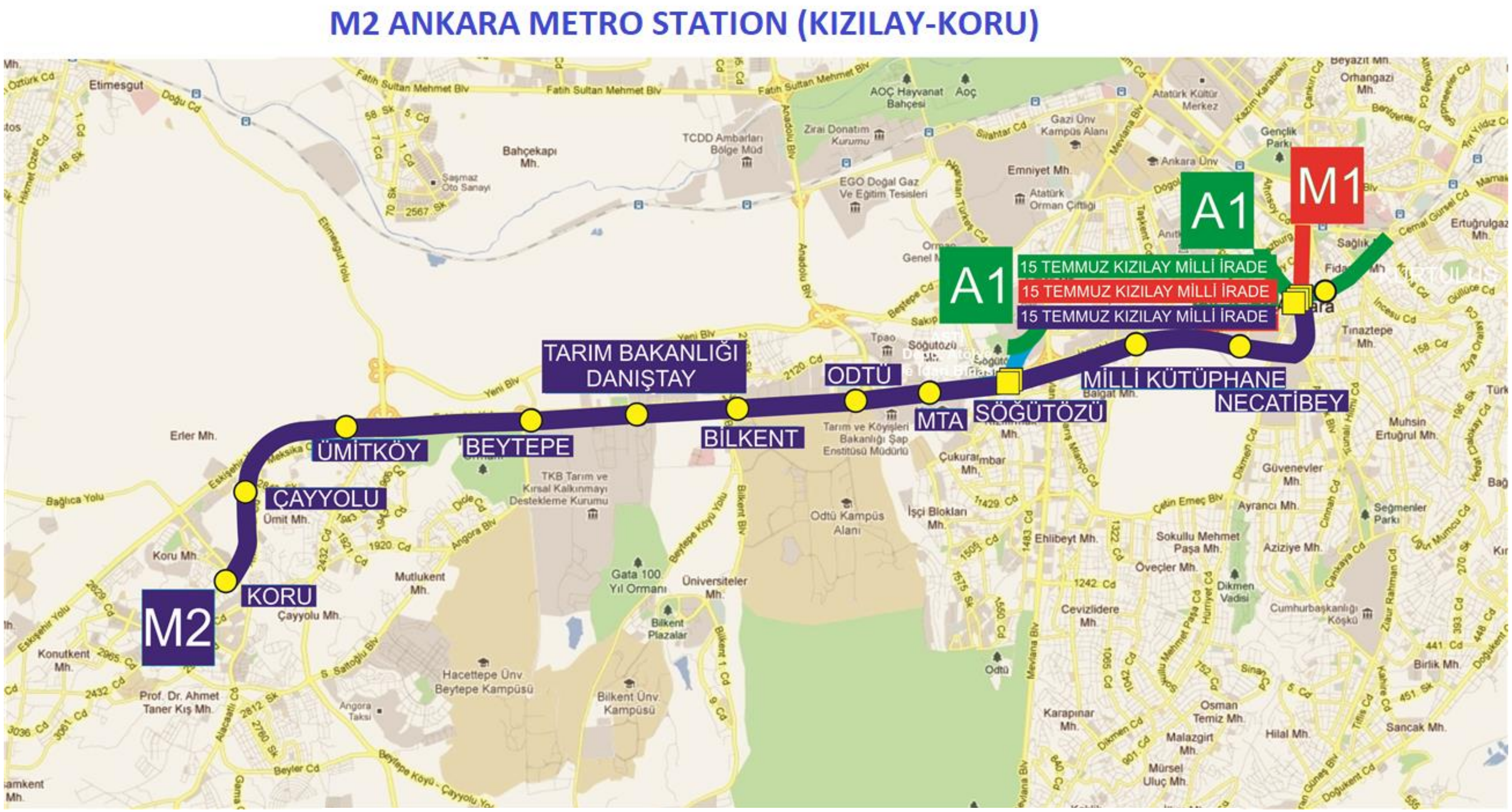

Figure 10: M2 Ankara Metro Stations and Stops [11]

4.2. Umitkoy Metro Station Architectural Sketch

Umitkoy Metro Station Ticket Hall Floor

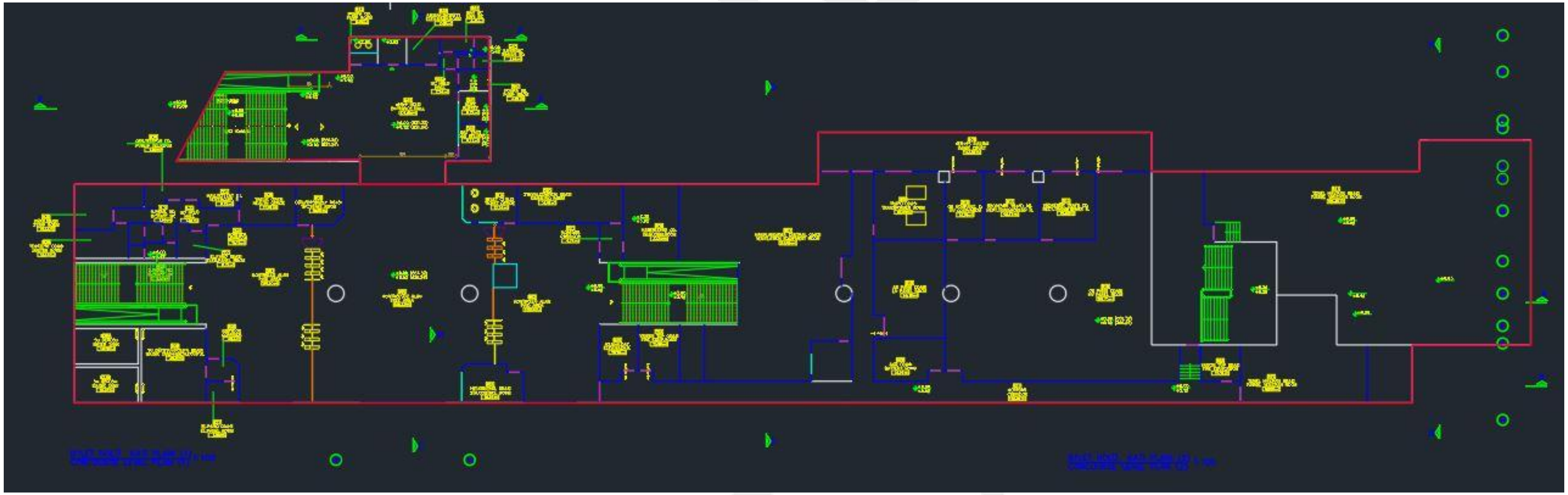

Figure 11: Architectural sketch of Umitkoy metro station ticket hall

Umitkoy Metro Station Platform Floor

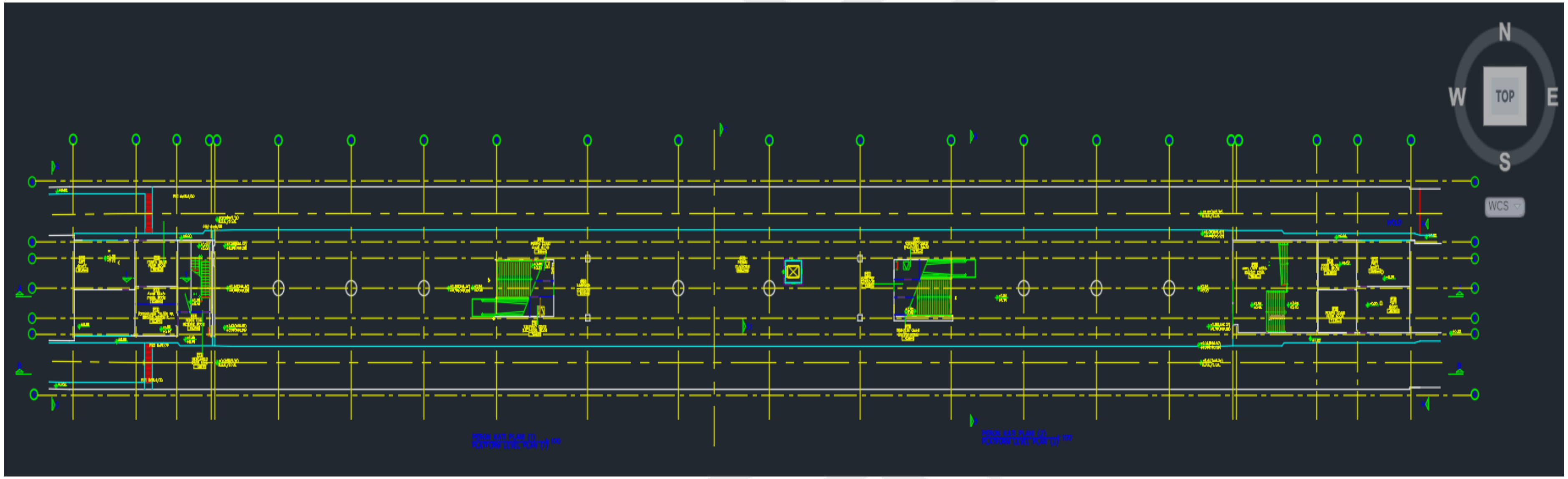

Figure 12: Architectural sketch of Umitkoy metro station platform floor

Communication System Architectural Sketch

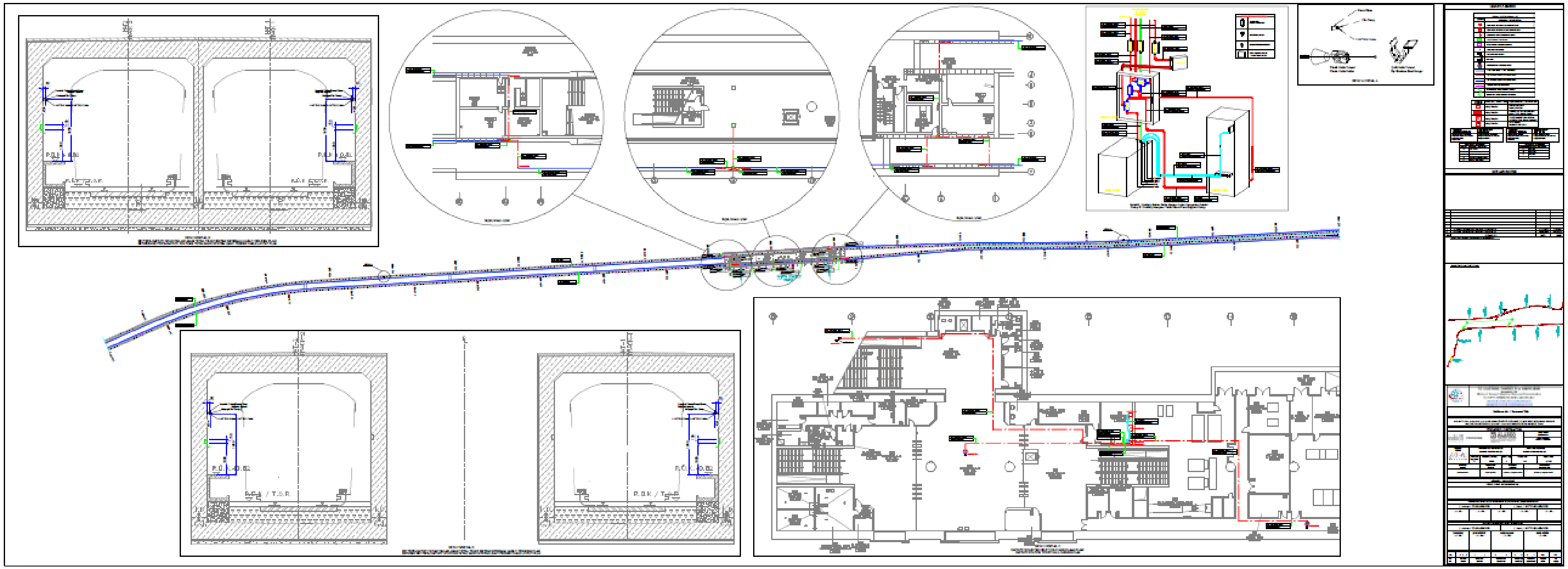

Figure 13: Between Beytepe-Umitkoy Stations Tetra Radio System Leaky Feeder Cable Layout Plan

Cabling Plan

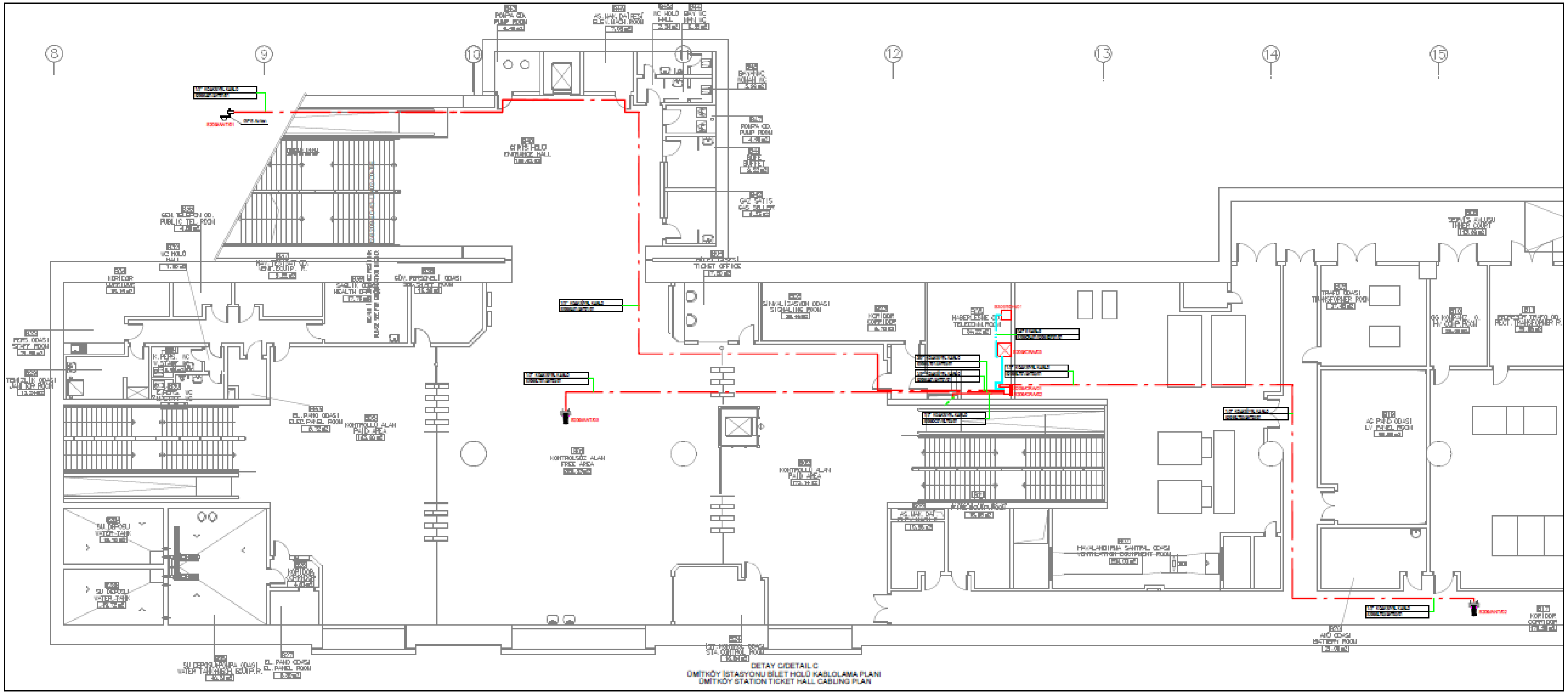

Figure 14: Umitkoy Station Ticket Hall Cabling Plan

4.3. Umitkoy Metro Station 3D Models

Umitkoy Metro Station Ticket Hall Floor

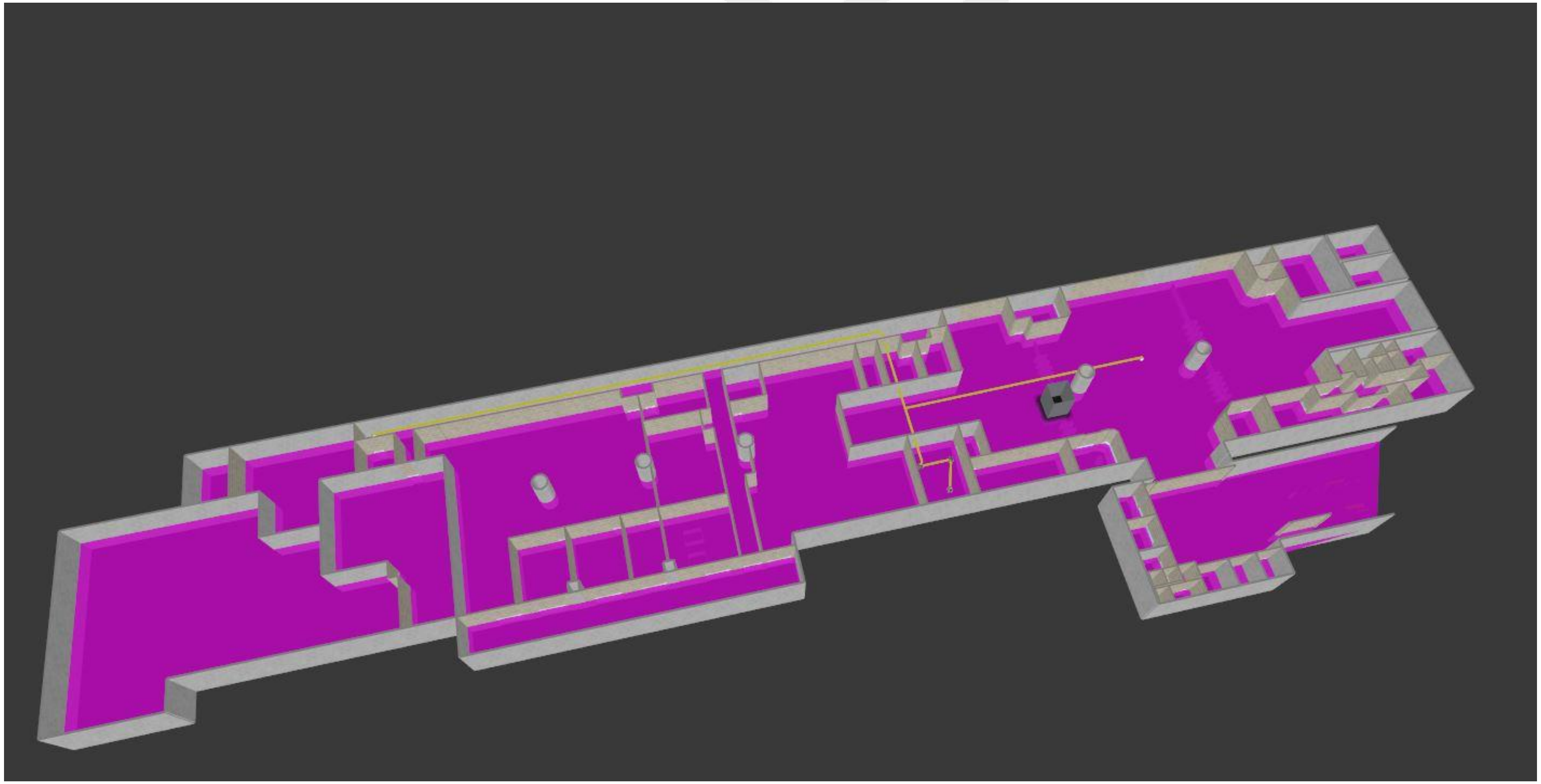

Figure 15: Umitkoy metro station ticket hall floor 3D model

General View of Two Floors

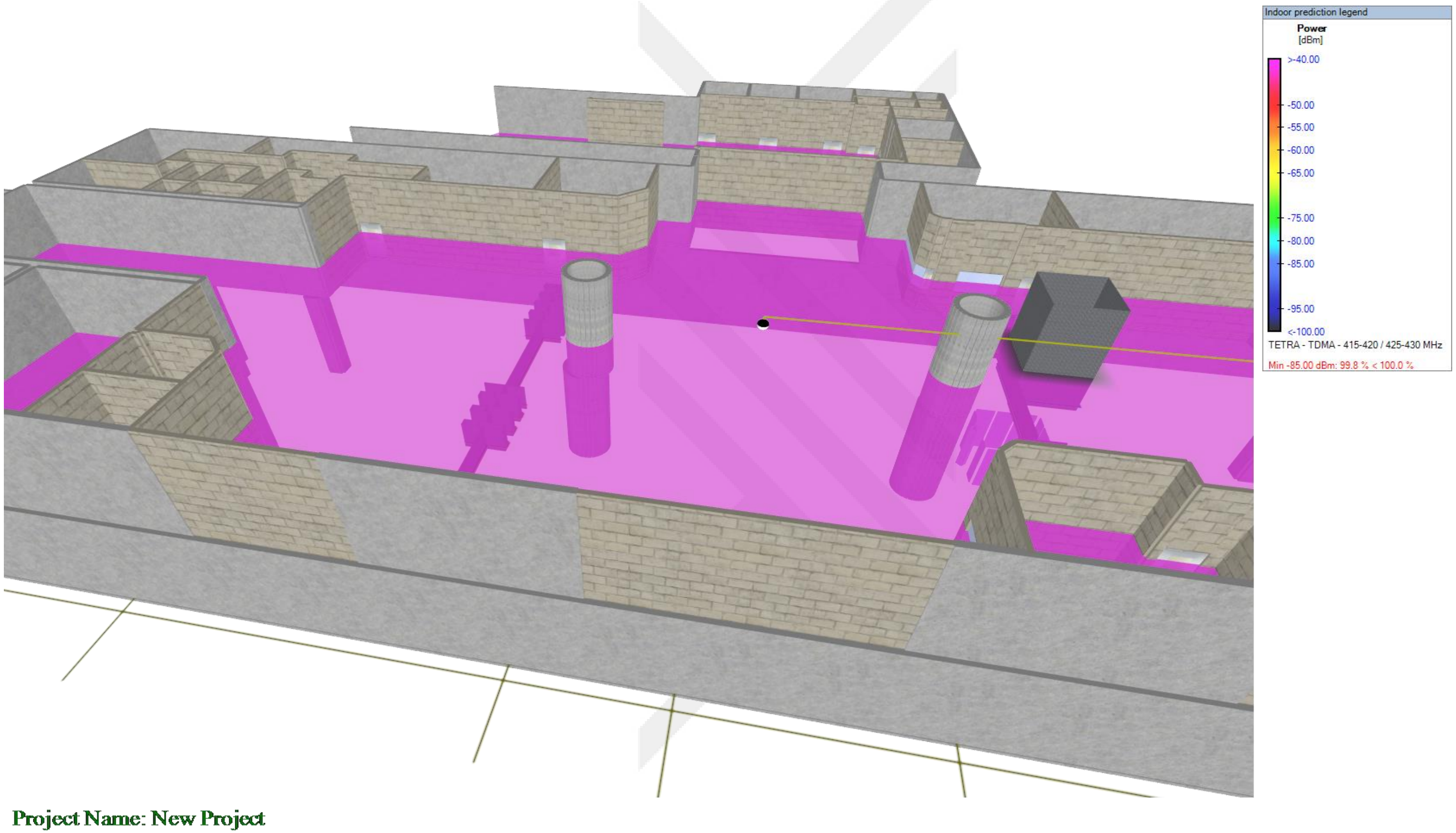

Figure 16: Umitkoy metro station general view of two floors 3D model

4.4. Umitkoy Metro Station Path Loss Propagation Models with iBwave

Communication Design

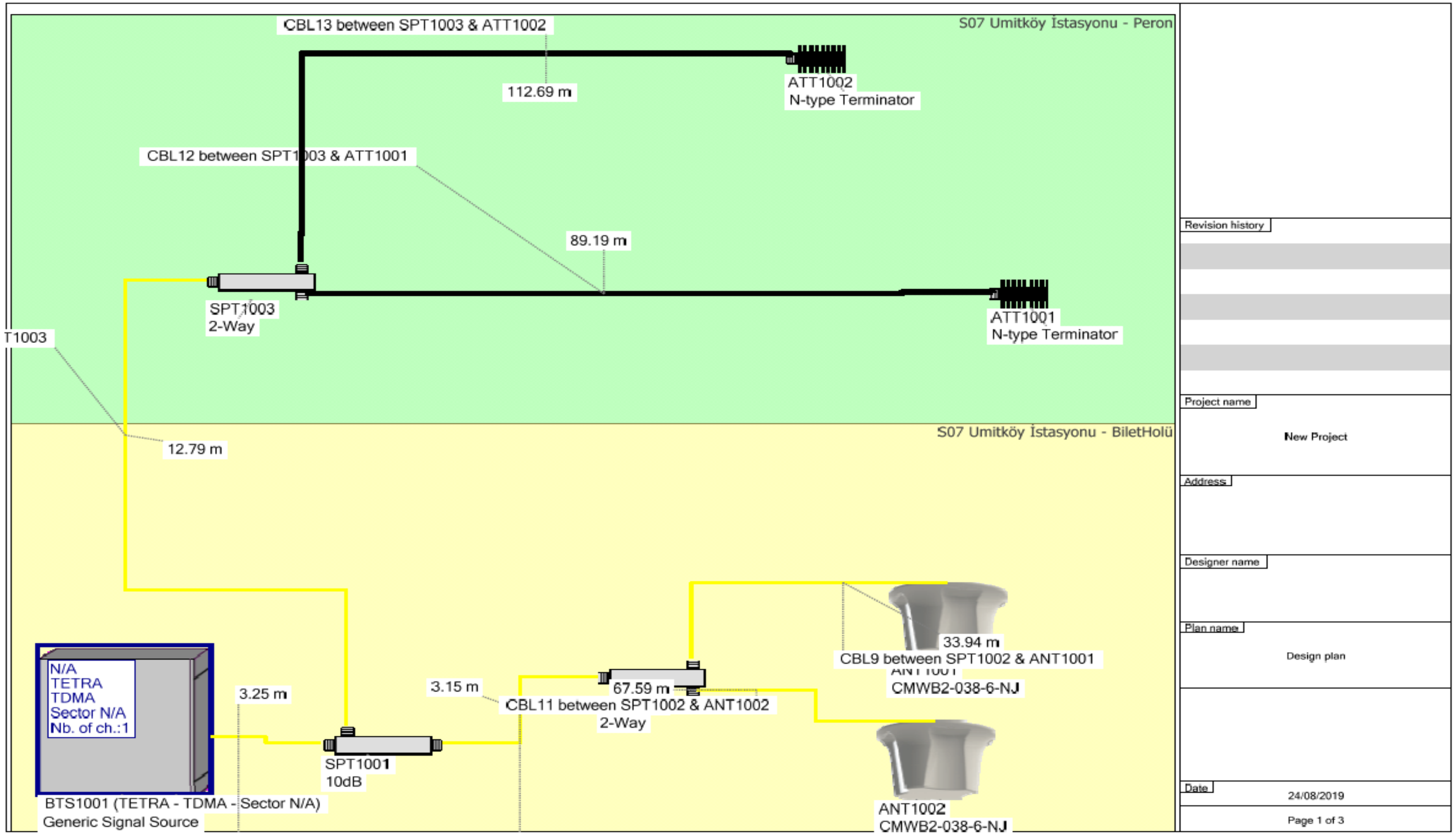

Figure 17: Umitkoy metro station communication design with iBwave

Equipment List for Communication System in Subway Station

Equipment List Report

Project name:	Ümitköy Metro Station	**Design company:**	Yüksel Proje Uluslararası A.Ş.
Project creation date:	24/08/2019	**Designer:**	

Type	Manufacturer	Model	Description	Inventory#	Qty
Antenna	Panorama	CMWB2-038-6-NJ	Inbuilding Wideband Ceiling Antenna - Tetra 380-430 / GSM850 / CDMA800 / GSM900 / GSM1800 / PCS1900 / 3G UMTS / 2.4 GHz WLAN / LTE / WiMAX - N Socket	N/A	2
Attenuator	Generic	N-type Terminator	200Watt High Power Termination Unit - N Female Connector - 70-2700 MHz	N/A	2
Cable	Generic	Coaxial-1/2"	50 ohms - 1/2" coaxial cable - foam dielectric	N/A	120.73 m
Cable	EUPEN Cable	RMC 114-T-HLFR	Radiating Mode Cable 1-1/4"	N/A	201.88 m
Connector	Generic	N-Male	Generic N-Male Coaxial Connector	N/A	10
Connector	EUPEN Cable	NM50R114MPA	Connector N Type, Male - O-Ring for LSC/RMC 114 (1"1/4) radiating cables	N/A	4
Splitter	Generic	10dB	10 dB Directional Coupler	N/A	1
Splitter	Generic	2-Way	2-Way Splitter / Combiner - 0-6000 MHz	N/A	2
Created on 09/09/2019					Page 1 / 1

Table 4: Umitkoy metro station communication design with iBwave

Antenna Pattern

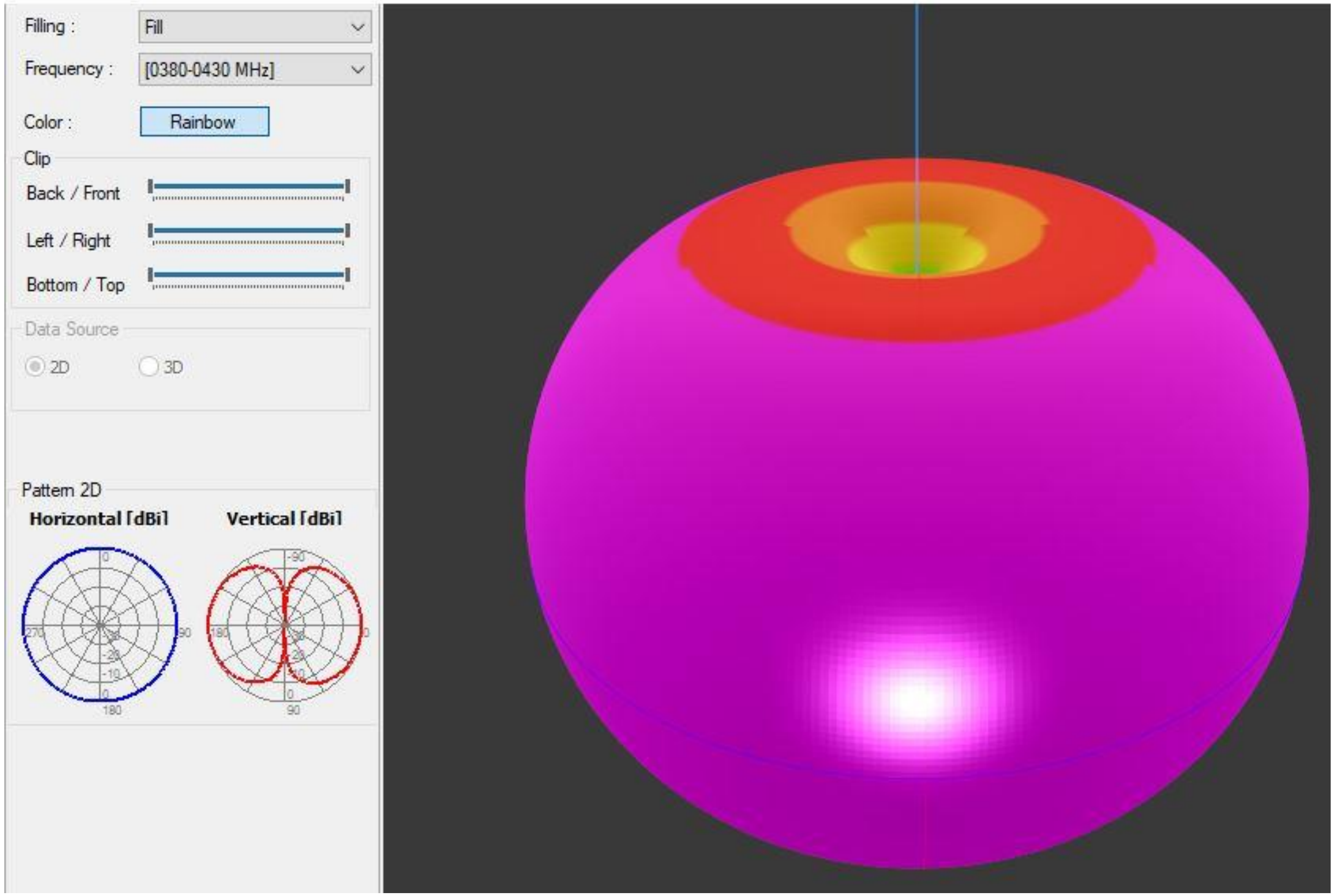

Figure 18: Panorama Antenna Pattern

Fast Ray Tracing Path Loss

Umitkoy Metro Station Ticket Hall Floor

Figure 19: Umitkoy Station Ticket Hall Floor’s Fast Ray Tracing Path Loss Propagation Model

Umitkoy Metro Station Platform Floor

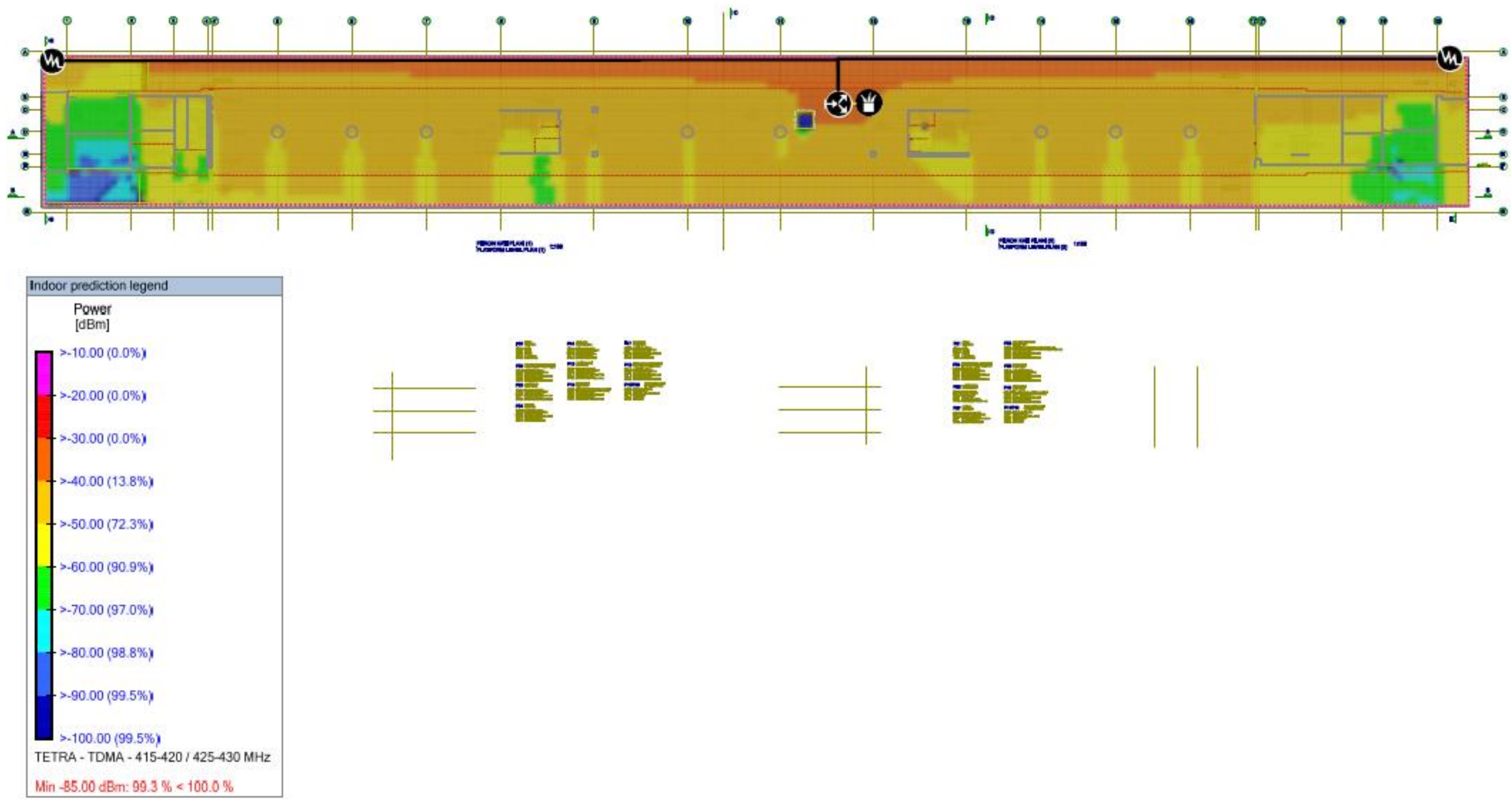

Figure 20: Umitkoy Station Platform Floor’s Fast Ray Tracing Path Loss Propagation Model

Empirical (COST 231) Path Loss

Umitkoy Metro Station Ticket Hall Floor

Figure 21: Umitkoy Station Ticket Hall Floor’s Empirical (COST 231) Path Loss Propagation Model

Umitkoy Metro Station Platform Floor

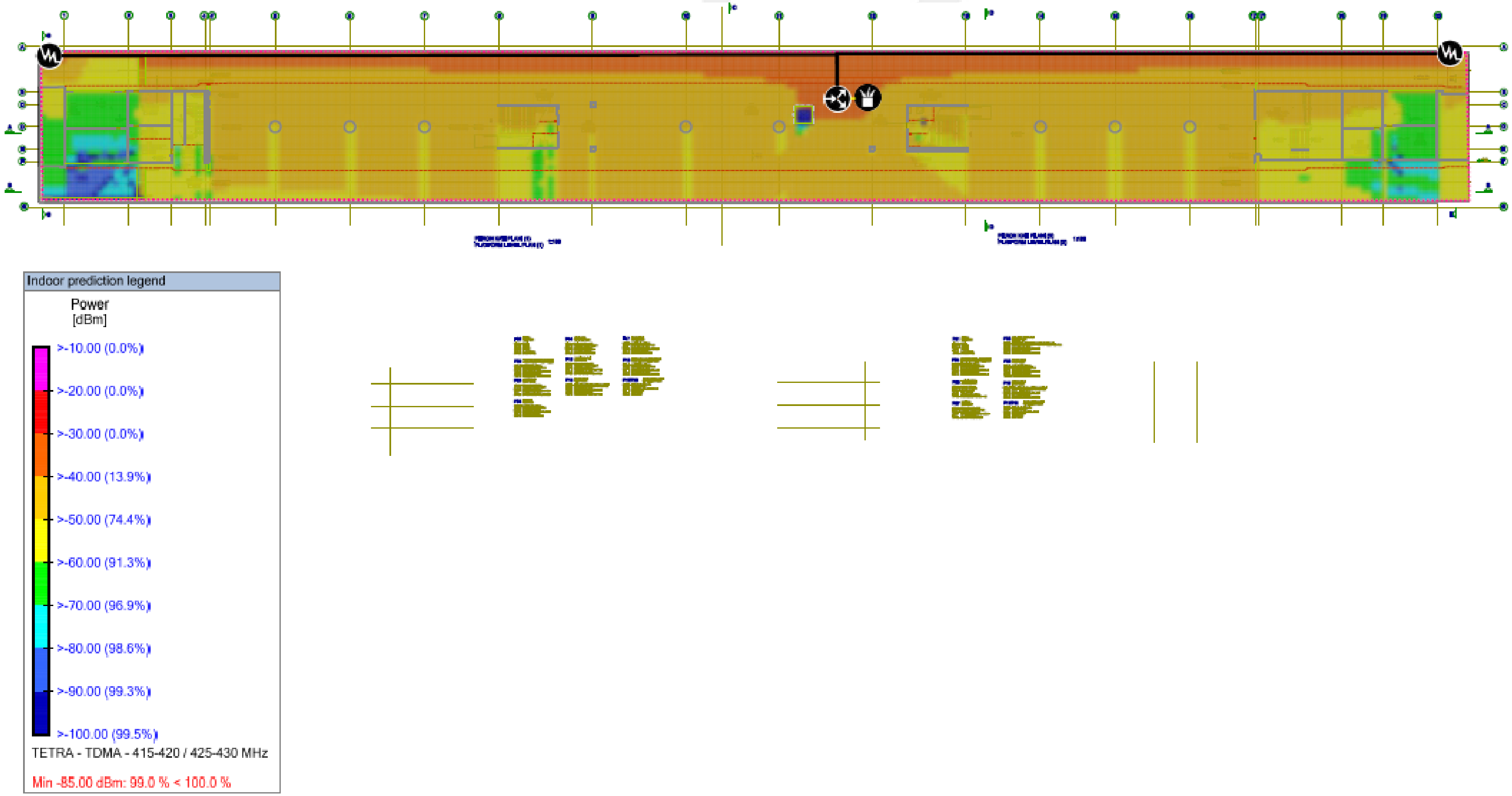

Figure 22: Umitkoy Station Platform Floor’s Empirical (COST 231) Path Loss Propagation Model

Variable Path Loss

Umitkoy Metro Station Ticket Hall Floor

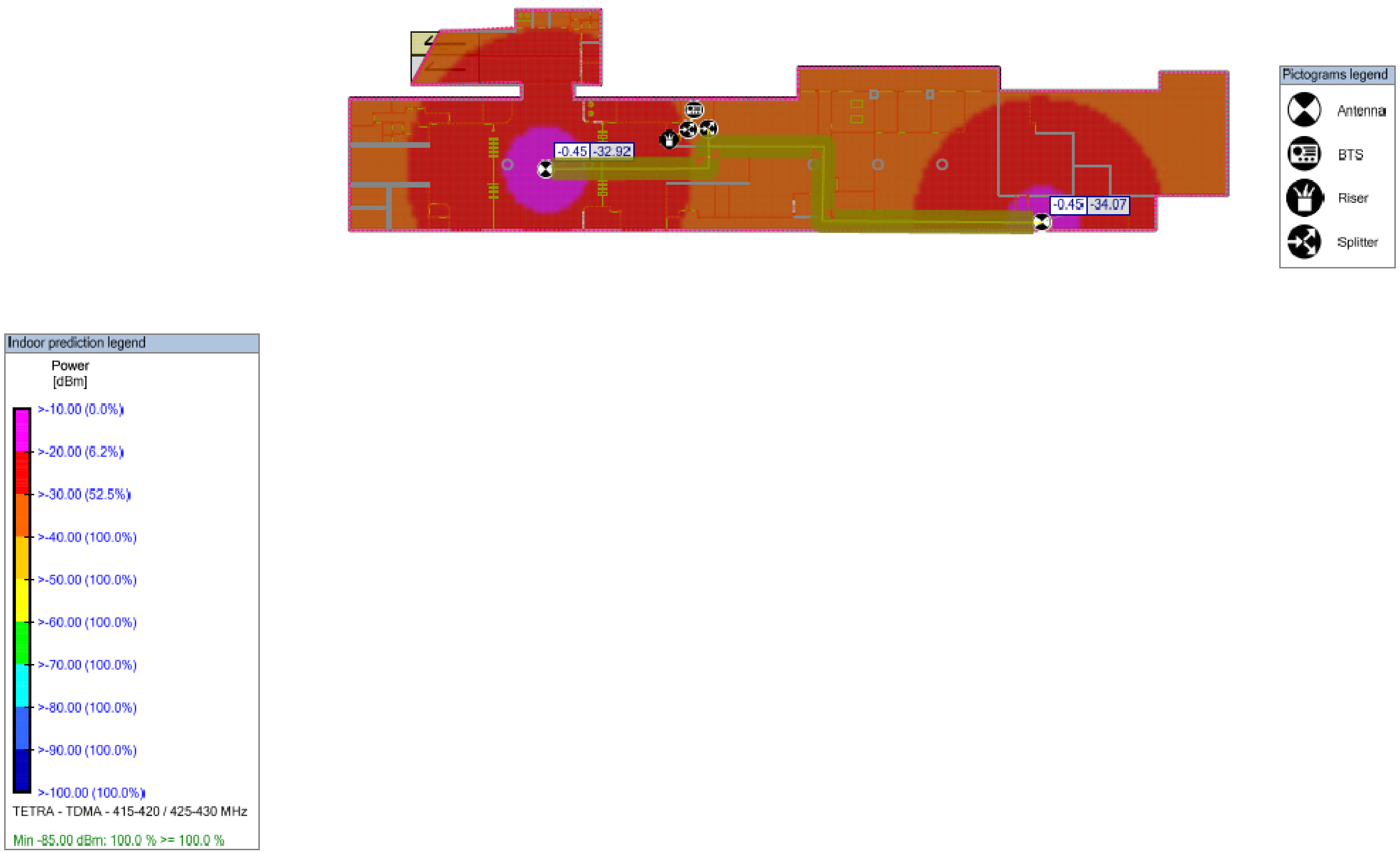

Figure 23: Umitkoy Station Ticket Hall Floor's Variable Path Loss Propagation Model

Umitkoy Metro Station Platform Floor

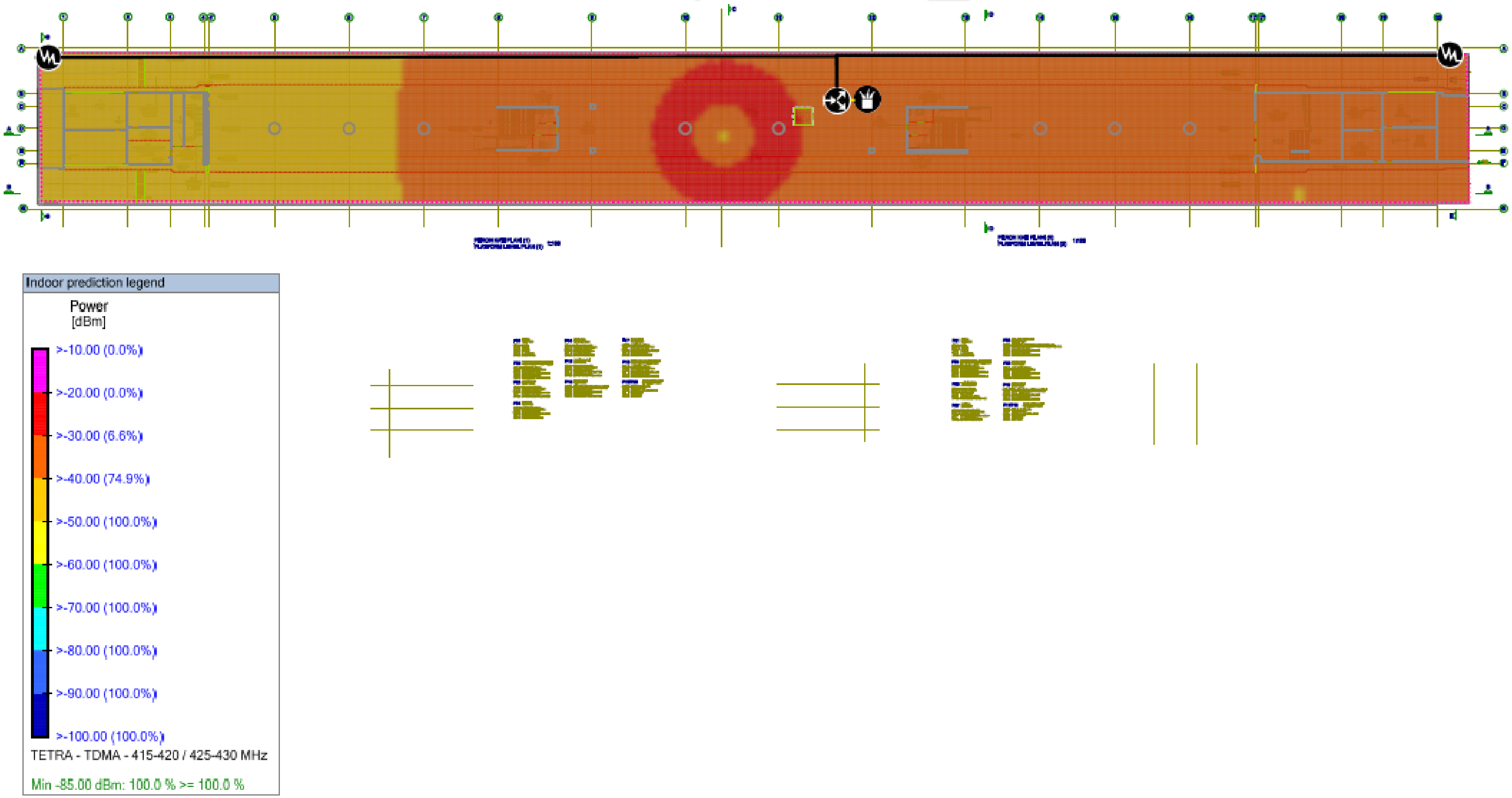

Figure 24: Umitkoy Station Platform Floor's Variable Path Loss Propagation Model

Comparison of Measurement Results of Propagation Models

Umitkoy Metro Station Ticket Hall Floor

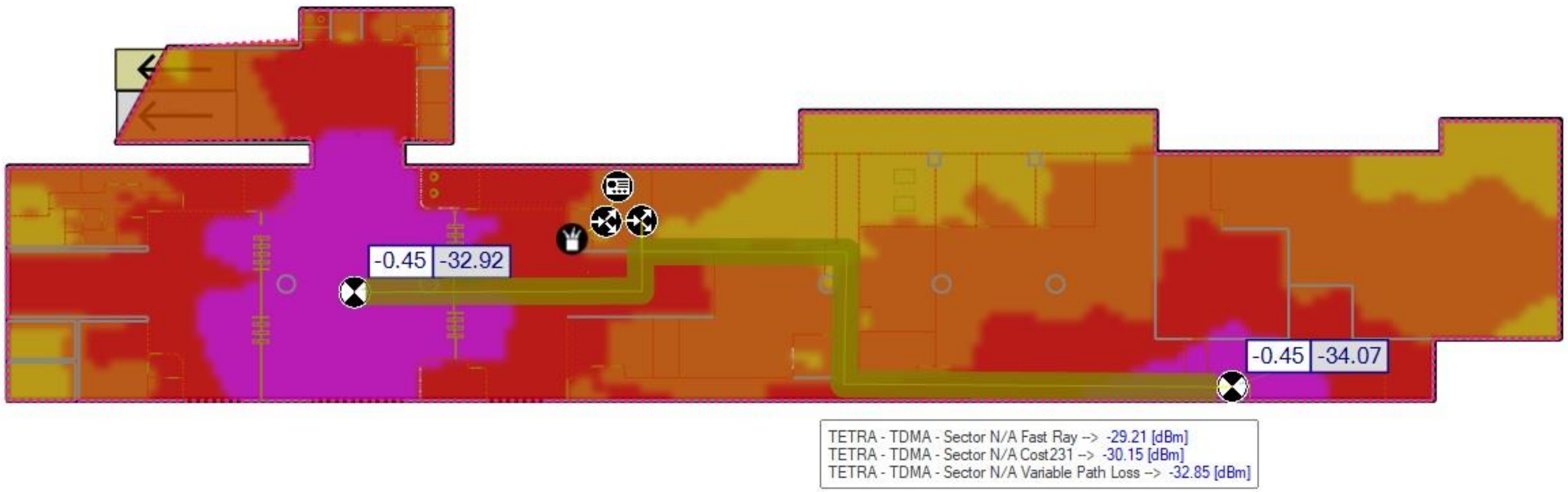

Figure 25: Measurement results from the same point for three propagation models

Umitkoy Metro Station Platform Floor

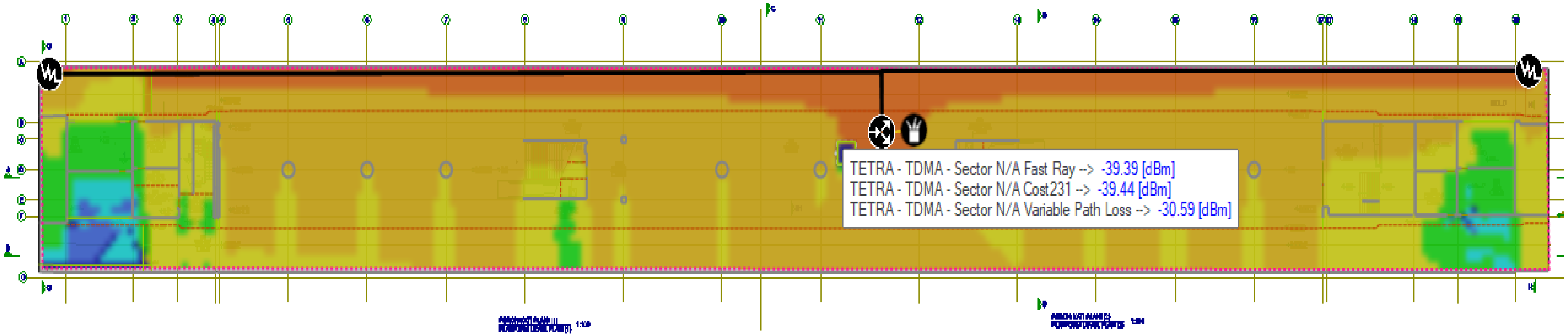

Figure 26: Measurement results from the same point for three propagation models

4.5. Measurement Results of Ümitköy Metro Station with Spectrum Analyzer and Radio

M2 Ümitköy Metro Station			
Point	**Radio Measurements**	**Spectrum Analyzer Measurements**	**Location**
1	-20	-23	Just below the antenna
2	-40	-42	Önü
3	-33	-38	Emergency exit door
4	-55	-58 to -63	Trafoların yanı
5	-40	-52	Column in front of stair
6	-38	-46 to -52	Front of elevator
7	-40	-58 -62	Leaky side
8	-39	-42 -43	10 11 ters
8	-52	-54 -60	Train passing by

Table 5: Umitkoy metro station measurement results with spectrum analyzer

4.6. Measurement Equipments' Details

Figure 27: Motorola MTP 3250 TETRA

Motorola MTP 3250 TETRA

- **Frequency Range** : 380-430 MHz
- **Rx Static Sensitivity** : -114dBm (min); -116dBm (typical)
- **Rx Dynamic Sensitivity:** -105 dBm (min); -107 dBm (typical)

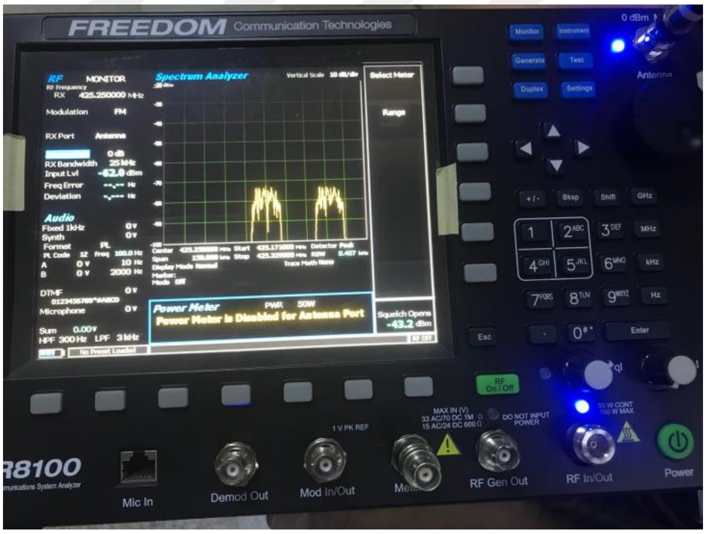

Figure 28: Freedom Communication Technologies R8100

Freedom Communication Technologies R8100

- **Frequency Range:** 1MHz-1GHz (250kHz to 1GHz typical); Optional to 3GHz
- **Frequency Resolution:** 1Hz
- **Span Accuracy:** 5%
- **Update Rate:** ~10 times per second (depending on span)

CHAPTER 5

5. IMPROVEMENT WORKS

5.1. General Definition of Sefakoy – Basaksehir Metro Station

Sefakoy - Basaksehir Rail System Line is approximately 17 km long. The route line extends from Kucukcekmece (Sefakoy) in the south of Istanbul to Basaksehir in the north. Light rail system parameters and design criteria were taken as basis in terms of system integrity and design.

Sefakoy - Basaksehir Rail System Line constitutes an important part of the rail system network planned for Istanbul within the framework of the rail system vision of Istanbul Metropolitan Municipality. The route of the said line intersects with the other rail system lines planned for Istanbul at 5 points.

While working on the route of Sefakoy - Basaksehir Rail System, a method was followed in line with the design philosophy, where the travel shots were the most, the station depths and expropriation needs were minimized, thus the construction costs were reduced, and the integration with the possible rail system and other transportation types was followed. The route prepared within this framework has been designed by utilizing the suggestions and opinions of the project parties and local governments. [11].

5.1.1. Sefakoy - Basaksehir Railway System Line

The length of the Sefakoy - Basaksehir Rail System Line is approximately 17 km. It has 11 stations as shown in Table 7. The route line is shown in Figure 29.

Line Length	Number of Stations	Platform Length	Array Configuration	Used Slope (Max.)	Min. Horizontal Curve Radius	Min. Vertical Curve Radius	Min. Vertical Curve Length
17 km	11	50 m	2'li Dizi	% 5.0	350 m	3000 m	100.00 m

Table 6: Route system characteristics

Station Number	Station Name	Station Km	Distance Between Stations (m)	Station Slope	Depth (m)	Station Type	Platform Structure
1	Sefakoy	0 + 125	0	%0.00	21.00	Open Close	Middle Platform
2	Courthouse	1 + 510	1385	%0.00	25.30	Open Close	Middle Platform
3	Inonu Neighborhood	3 + 120	1610	%0.00	25.15	Open Close	Middle Platform
4	Halkali Central	4 + 546	1426	%0.00	48.00	Deep Tunnel	Middle Platform
5	Toki	5 + 928	1382	%0.00	28.20	Open Close	Middle Platform
6	Arenapark	7 + 193	1265	%0.00	25.60	Open Close	Middle Middle Platform
7	Ziya Gökalp	9 + 343	2150	%0.00	24.80	Open Close	Middle Platform
8	Sites	10 + 997	1654	%0.00	31.20	Open Close	Middle Platform
9	Ertugrul Gazi	12 + 584	1587	%0.00	23.40	Open Close	Middle Platform
10	Başakpazarı	14 + 320	1848	%0.00	25.20	Open Close	Middle Platform
11-1	New Bus Station (Option-1)	16 + 271	1839	%0.00	16.50	Open Close	Middle Platform
11-2	New Bus Station (Option-2)	16 + 585	2153	%0.00	24.00	Open Close	Middle Platform

Table 7: Sefakoy - Basaksehir Rail System Line station names and features [11]

Sefakoy - Basaksehir Railway System Line

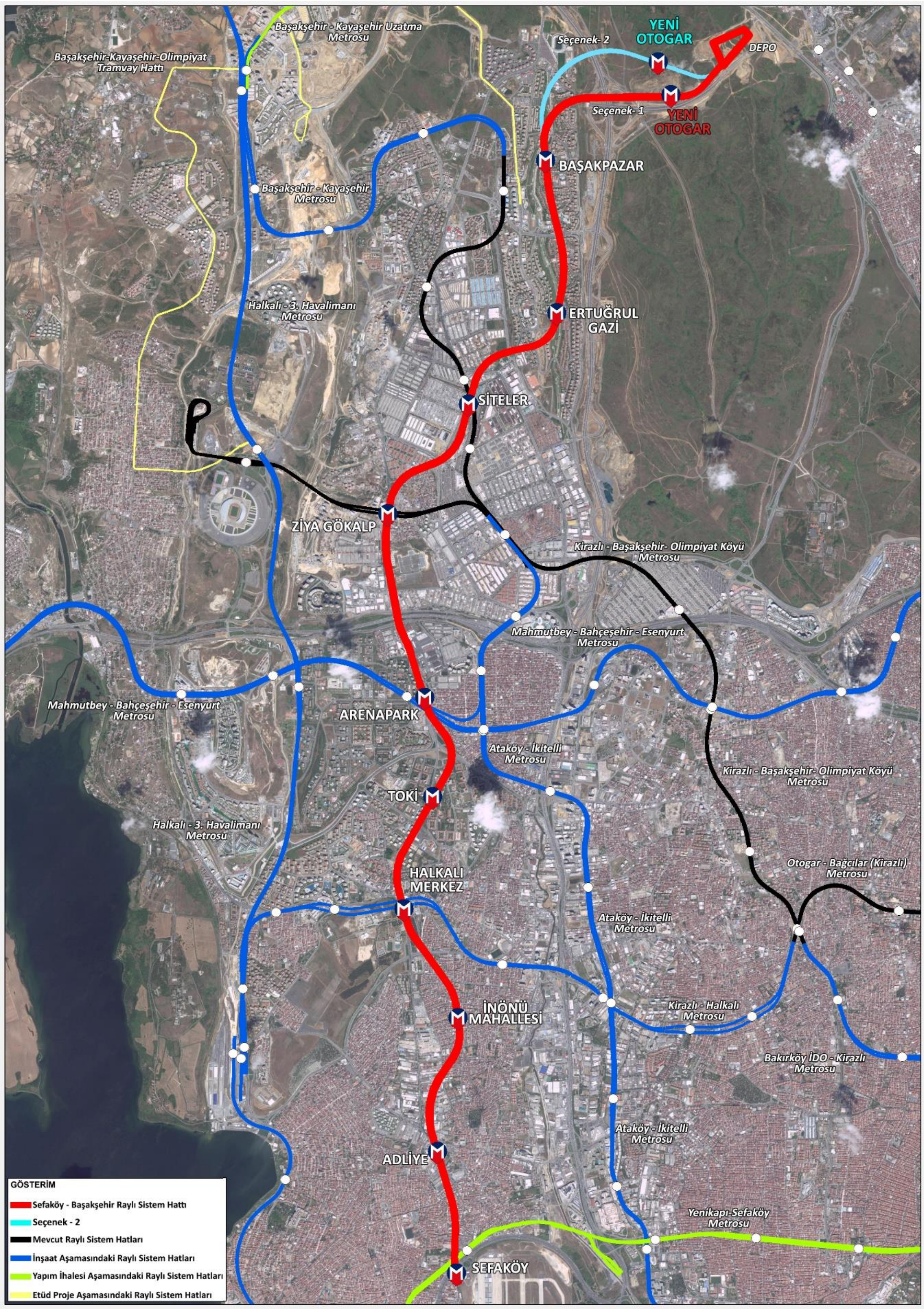

Figure 29: Integration of Sefakoy - Basaksehir Railway System Line with other lines [12]

5.1.2. Inonu Neighborhood Station

Inonu Neighborhood Station; It is the third station of Sefakoy - Basaksehir Rail System Line. The district of Kucukcekmece is located in Inonu District. The location of Inonu Neighborhood Station is shown in Figure 30.

Inonu Station is planned as a central platform with a 14.5 m line span and the station is planned to be built on and off. The slope of the station is 0.00% and the elevation above the rail is 37.00 m.

After the station, the line span of 14.5 m R: narrowed to 13 m with a horizontal curve of 600 m. The line continued up to the scissor zone with a vertical curve of R: 9000 m with a slope of + 1.10% and the line span of the scissor zone narrowed to 9.8 m.

Along the 1/7 R-190 type scissors, the line span was 9.8 m. Scissor slope is 0.5%. After the scissors area, the route R: reaches the Halkali Central Station with a vertical curve of 3300 m and an inclination of + 5.00%. [13]

Figure 30: Location of Inonu Neighborhood Station [13]

Sefakoy-Basaksehir Metro Line Inonu Neighborhood Station Architectural Drawing

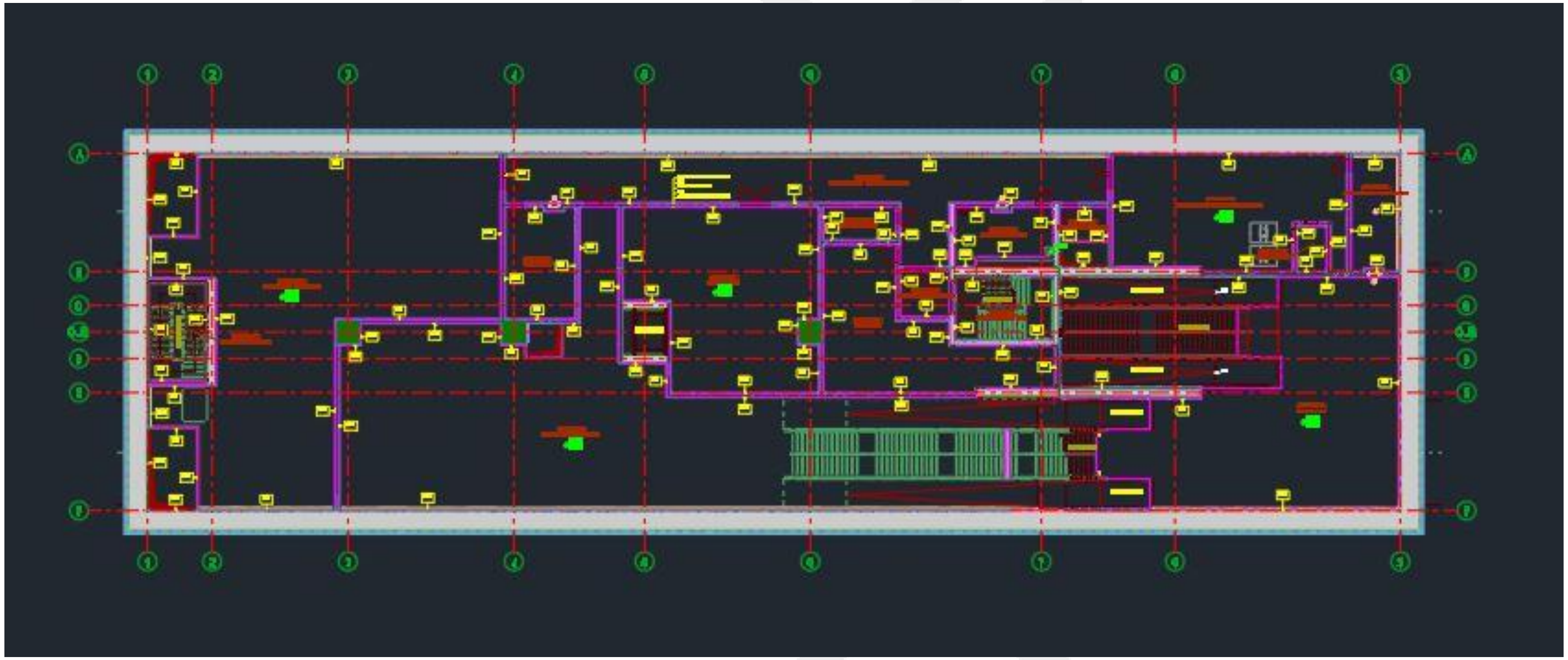

Figure 31: Architectural sketch of Inonu neighborhood metro station inter floor

Inonu Neighborhood Station

Figure 32: Drawing of Inonu neighborhood station with Revit program

5.2. Inonu Neighborhood Metro Station Architectural Sketch

- Antenna output power 83 dB

Figure 33: Antenna transmissions at technical volume

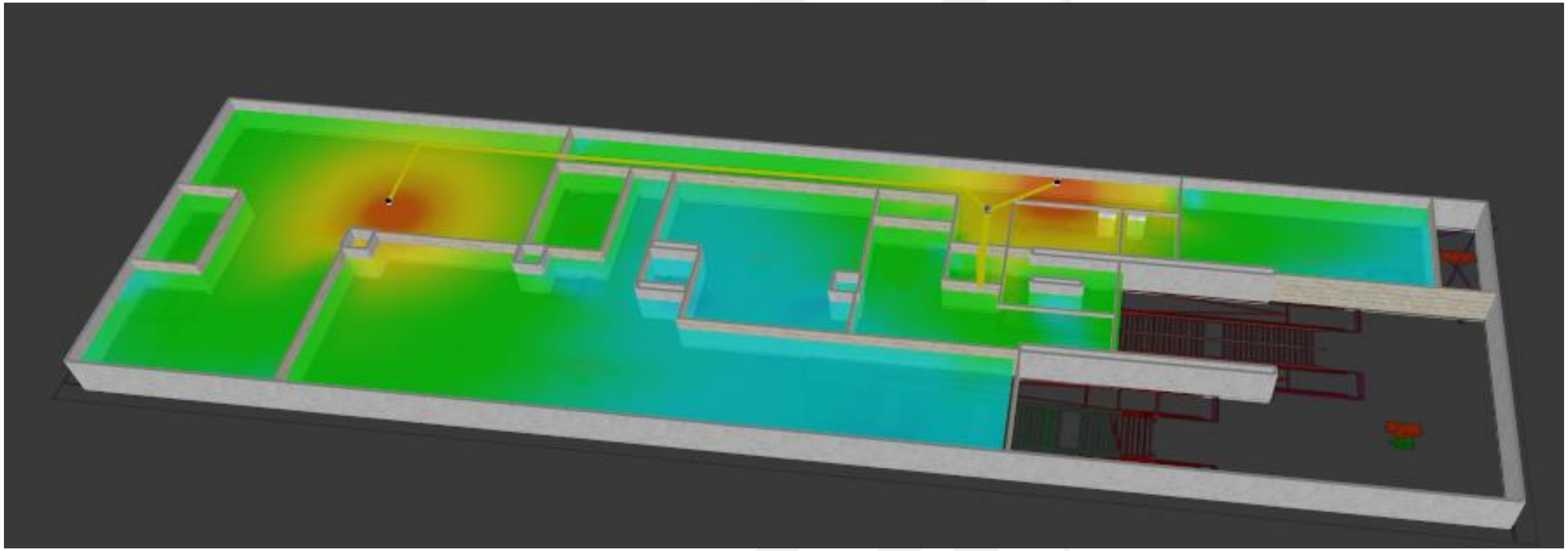

Figure 34: 3D view of antenna transmissions in technical volume

Results From Placing the Metal Plate/Reflector İn Front of the Antenna

Measurement Results of Propagation Models and 2D View

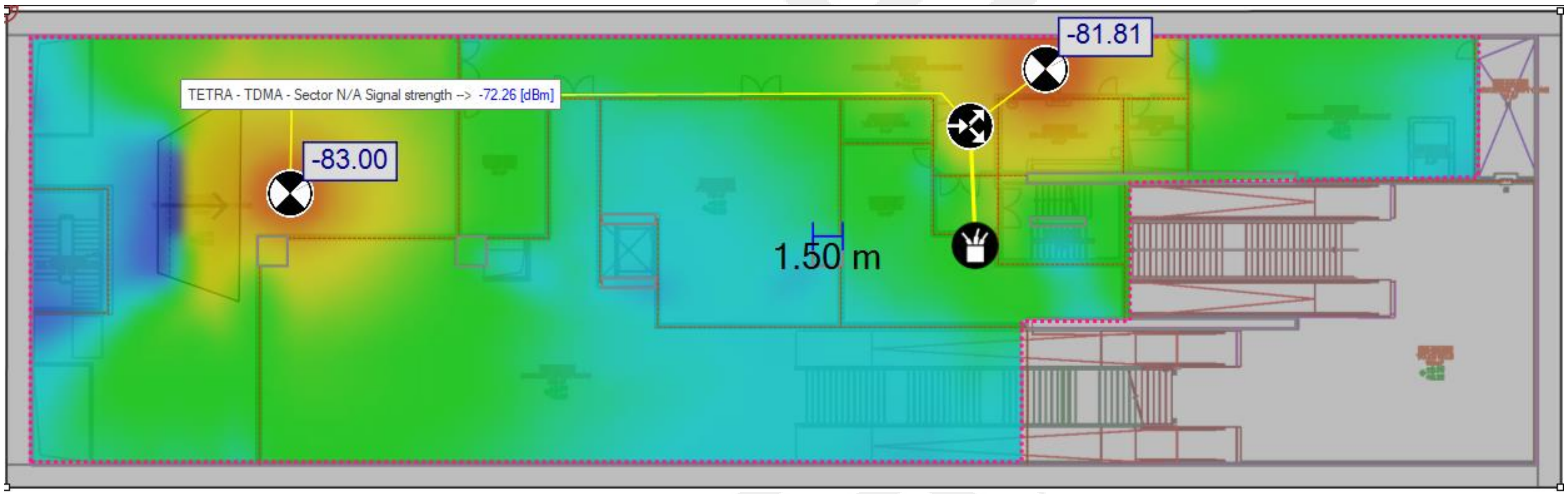

Figure 35: 2D Simulation result with a metal plate/reflector in front of the antenna

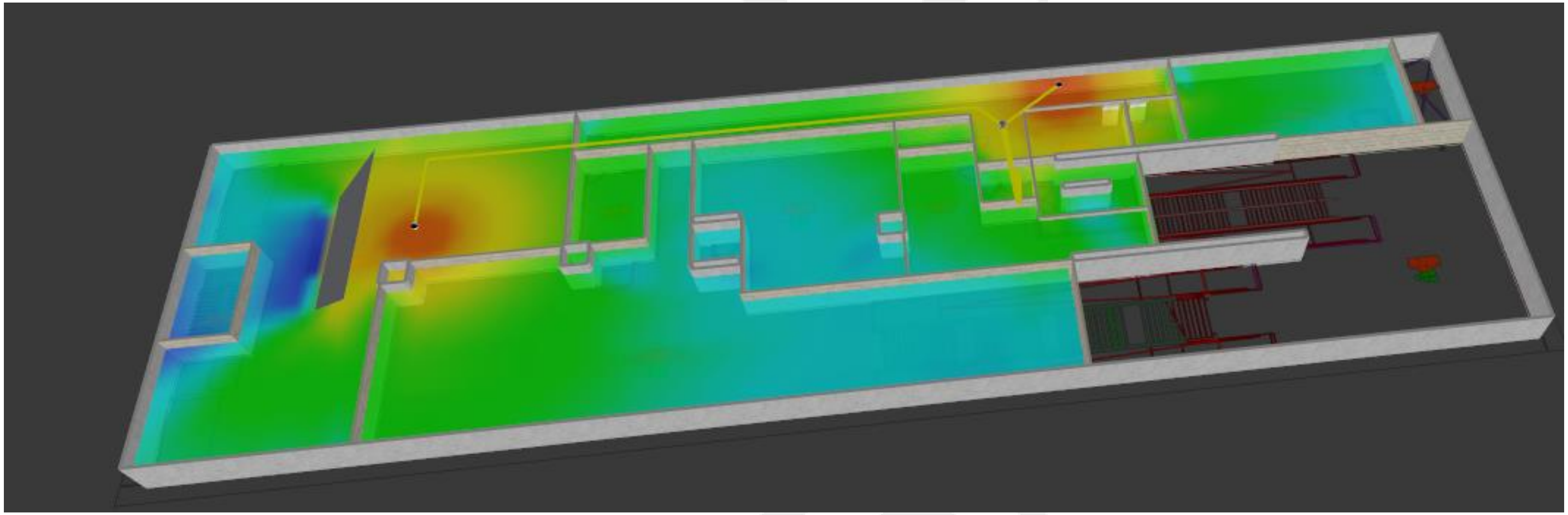

Figure 36: 3D simulation with a metal plate/reflector in front of the antenna

Results From Placing the Metal Plate/Reflector on the Floor

Measurement Results of Propagation Models and 2D View

Figure 37: 2D Simulation result with a metal plate/reflector on the floor

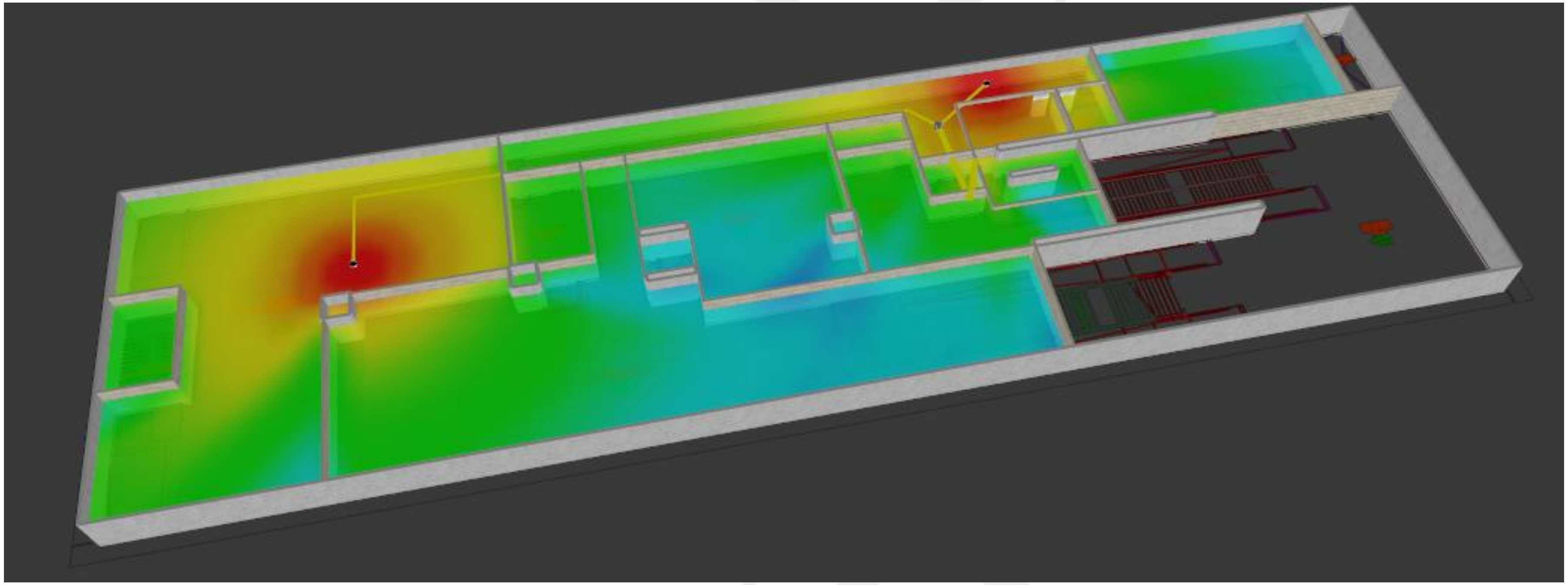

Figure 38: 3D Simulation result with a metal plate/reflector on the floor

Results of Placing the Metal Plate / Reflector on the Side Two Walls

Measurement Results of Propagation Models and 2D View

Figure 39: 2D Simulation result with a metal plate/reflector on the side two walls

Measurement Results of Propagation Models and 3D View

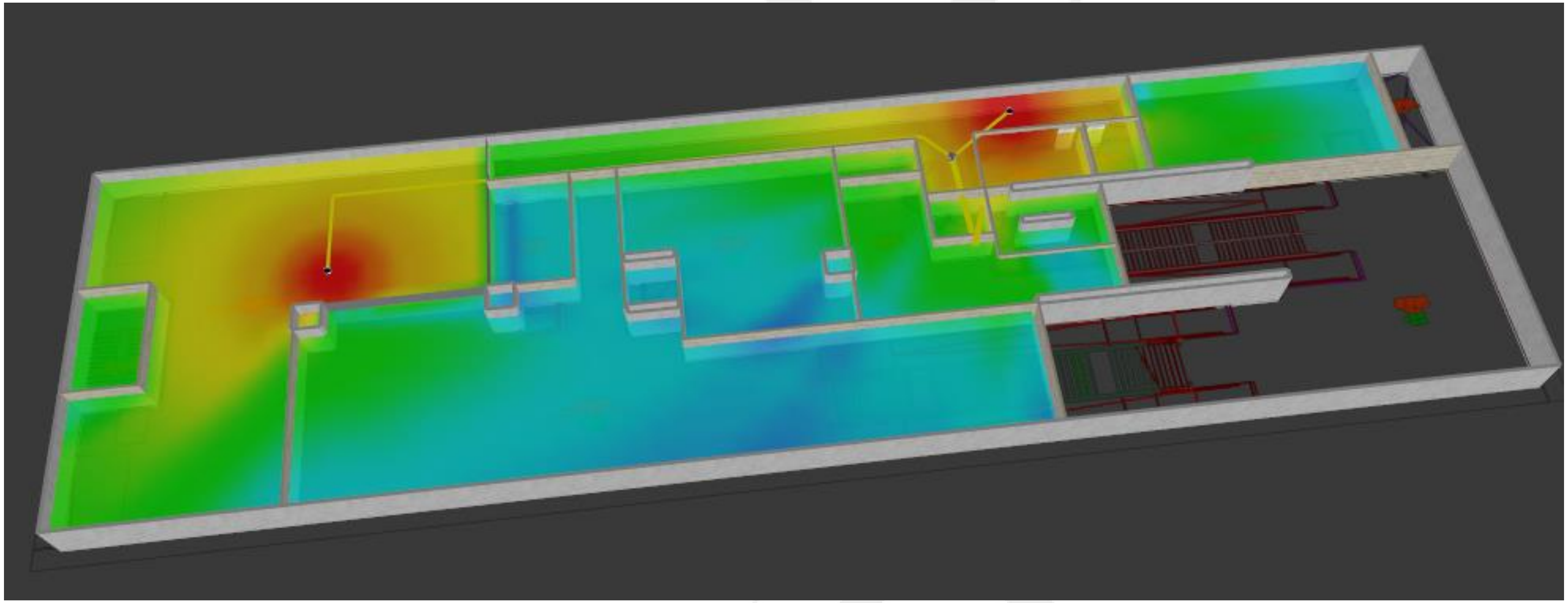

Figure 40: 3D Simulation result with a metal plate/reflector on the side two walls

The Result of the Simulation When the Inner Wall Is Turned with Metal Plate/Reflector

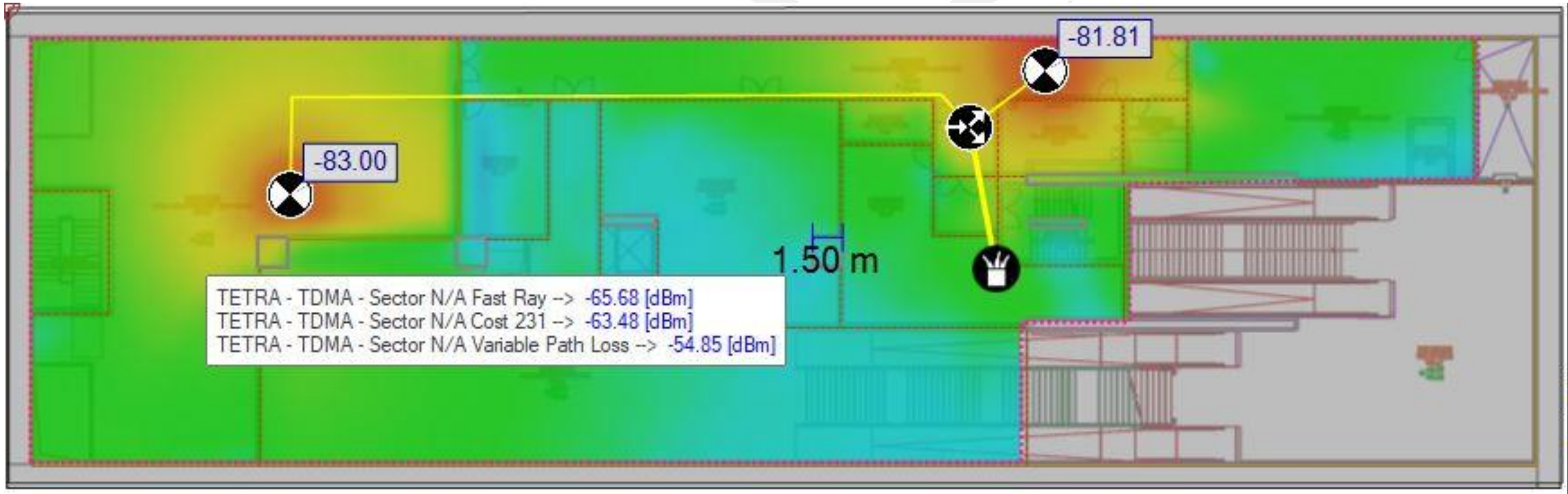

Figure 41: Measurement results from the same point for three propagation models

CHAPTER 6

6. RESULTS AND CONCLUSIONS

In this thesis, radio propagation areas at Umitkoy and Inonu Neighborhood metro stations were analyzed at different distances and surfaces. At the same time, path losses in the radio propagation area were investigated. Following the modeling of the radio coverage area in the metro stations that vary in different distances and conditions, applications were made at the Umitkoy metro station on the Ankara Koru metro line and at the Inonu metro station on the Sefakoy-Basaksehir metro line planned for Istanbul. First of all, suitable propagation models have been determined by considering 450 MHz frequency band and closed area in metro lines. Path losses were calculated with the code written in MATLAB program by using empirical formulas. Then the results of the models are shown graphically. TETRA radio and spectrum analyzer were used in Umitkoy station in order to examine how theoretically the calculations are parallel with the measurements taken in the field. The Motorola radio used in the measurements has a clearer range because the frequency range is in the 380-450 MHz band and the frequency in the metro station is 450 MHz. The frequency range of the Freedom Communication Technologies R8100 spectrum analyzer used was 1MHz - 1GHz, and fluctuations were observed, although the measurements taken by radio were close to the average 5 MHz differences depending on the distance. The results are shown in Table 5. The measurements taken in the field and the calculations and analyses made with empirical formulas coincide. The margin of error was calculated as ± 5%. Within the scope of improvement works, İnonu metro station has been studied. The most important factor in choosing this station is that it is still in the project stage. In this context, primarily architectural drawings were studied. Then, the station was modeled in 3D. After modeling, antenna communication was made, and radio communication infrastructure was established. Afterwards, two dimensional and three-dimensional simulation studies were performed (Figure 33-34). In order to observe the improvement studies more clearly, the intermediate floor which is shown in Figure 32 with less coverage was preferred. First, a reflector panel was placed in front of the antenna and the coverage area was examined in Figures 35,36. However, this application did not make any difference in the measurements taken. Secondly, the floor was completely covered with reflective material and the coverage area was examined in Figures 37,38. Although this application is very small, it has reduced path loss. Thirdly, the two side walls were covered with a reflector material and the coverage area was examined. In this application, path loss is reduced even if it is very small in Figures 39,40. Finally, the frame inner wall of the subway station was completely covered with reflector material and the coverage area was examined in Figure 41. This application did not make any difference in the measurements taken.

Within the scope of this thesis, as a result of the losses observed depending on the ambient conditions, materials used and installation points, a method that can provide optimization before installation is developed. In line with the observed and calculated results, necessary simulation-modeling and arrangements were made for the Inonu neighborhood metro station, which is a new project, and the ideal design for radio coverage area was avoided, avoiding radio-pulling problems and unnecessary material usage.

Preliminary design modeling has not been performed in many metro stations designs so far, and coverage problems have been encountered. In this thesis, the comparison of empirical calculations and field measurement results is supported by simulation studies because it shows parallelism. Simulation studies allowed us to obtain the preliminary design and the results were found to give the same results with ± 5% error in field applications. In this context, the preliminary design of the next subway station design works, wireless communication infrastructure; avoiding unnecessary material usage and ensuring installation at the right points.

REFERENCES

[1] Purnima K. Sharma, R.K.Singh "Cell Coverage Area and Link Budget Calculations in GSM System" International Journal of Modern Engineering Research (IJMER) vol.2, Issue.2, pp-170-176, Mar-Apr 2012.

[2] Stutzman, W. L., & Thiele, G. A. (2013). Antenna theory and design (3rd ed.). Hoboken, NJ: Wiley. p. 10.

[3] Balanis, C. A. (2005). Antenna theory: analysis and design (3rd ed.). Hoboken, NJ: John Wiley. p.44-45.

[4] Sharma, H.K., Sahu, S.K., & Sharma, S. (2016). Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss and Signal Strength.

[5] Stutzman, Warren; Thiele, Gary (1981). Antenna Theory and Design. John Wiley & Sons, Inc. p. 60.

[6] Yılmaz, Ö. (2002). Propagation Simulation For Outdoor Wireless Communications In Urban Areas, unpublished Master's Thesis, Department of Electrical and Electronics engineering, University of Bilkent, Ankara.

[7] Stutzman, W.L., Thiele, G.A. (2012), Antenna Theory and Design (3rd ed.), Wiley, Westford. (pp.10-11)

[8] EGO General Directorate, Department rail systems; M2 Ankara Metro Kizilay Cayyolu, from https://www.ego.gov.tr/tr/sayfa/2108/m2-ankara-metrosu2-kizilay-cayyolu

[9] G.Fischer, F.Pivit, W.Wiebeck," Link Budget comparison of different Mobile Communication Systems based on EIRP and EISL", Advances in Radio Science (2004) 2:127- 133.

[10] Rappaport, T.S., "Wireless Communications", Prentice-Hall, Upper Saddle River, New Jersey,Ch. 3 and 4, 1996.

[11] Istanbul-General Rail System Lines Project Design Services Work; Sefakoy-Basaksehir Rail System Line Application Primary Project Services (2019), p.20-21

[12] Istanbul-General Rail System Lines Project Design Services Work; Sefakoy-Basaksehir Rail System Line Application Primary Project Services (2019), p.22

[13] Istanbul-General Rail System Lines Project Design Services Work; Sefakoy-Basaksehir Rail System Line Application Primary Project Services (2019), p.26

[14] EGO General Directorate, Department rail systems, from https://www.ego.gov.tr/tr/sayfa/1075/rayli-sistem

[15] Singh, Y. (2012). Comparison of Okumura, Hata and COST-231 Models on the Basis of Path Loss and Signal Strength. International Journal of Computer Applications, 59(11), 37–41. doi: 10.5120/9594-4216

[16] GÜMÜŞ, Ö. F. (n.d.). Antenler ve Çeşitleri. Retrieved 2012, from https://www.elektrikport.com/teknik-kutuphane/antenler-ve-cesitleri/16763#ad-image-0.

[17] Metro Tasarım Kriterleri. (2018, November 30). Retrieved January 7, 2019, from https://rayhaber.com/2014/04/metro-tasarim-kriterleri/. p. 91.

[18] Metro Tasarım Kriterleri. (2018, November 30). Retrieved from https://rayhaber.com/2014/04/metro-tasarim-kriterleri/. p. 95-97.

[19] Stutzman, W. L., & Thiele, G. A. (2013). Antenna theory and design (3rd ed.). Hoboken, NJ: Wiley. p. 107.

[20] Stutzman, W. L., & Thiele, G. A. (2013). Antenna theory and design (3rd ed.). Hoboken, NJ: Wiley. p. 116.

[21] Bevelacqua, P. (n.d.). The Friis Equation. Retrieved 2015, from http://www.antenna-theory.com/basics/friis.php.

[22] Wikipedia, Path Loss. (2019, August 16). Retrieved from

https://wikizeroo.org/index.php?q=aHR0cHM6Ly9lbi53aWtpcGVkaWEub3JnL3dpa2kvUGF0aF9sb3Nz

[23] Yılmaz Özgür. (2002). Retrieved from http://www.thesis.bilkent.edu.tr/0002065.pdf

[24] iBwave Design. Retrieved from file:///C:/Program%20Files/iBwave/iBwave%20Design/Documentation/WebHelp/Home/Propagation Module/Propagation models/ Empirical (COST 231)

[25] iBwave Design. Retrieved from file:///C:/Program%20Files/iBwave/iBwave%20Design/Documentation/WebHelp/Home/Propagation Module/Propagation models/ Fast Ray Tracing

[26] iBwave Design. Retrieved from file:///C:/Program%20Files/iBwave/iBwave%20Design/Documentation/WebHelp/Home/Project Properties/Propagation models/Variable Path Loss Exponent