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Research on Wireless Signal Coverage in Metro Station

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Abstract: In this paper, Firstly, we analyzed metro platform types and the basic principle of radio frequency (RF) technology. Secondly, we proposed an application method of radio frequency technology in metro. Then, by studying the wireless signal coverage in metro station, we got results of relationships of reflection coefficient Γ with angle θ, and with phase shift ζ. Finally, we studied an example of signal coverage for wireless network in metro station, three kinds of path difference ΔL_i ($i = 2, 3, 4$) between the reflected wave and incident wave are calculated. This work could provide certain theoretical and practical research value for studying the security transmission of wireless signal in metro station. *Copyright © 2014 IFSA Publishing, S. L.*

Keywords: Metro station, Electromagnetic waves, Wireless signal, Propagation, Coverage.

1. Introduction

With the development of society, metro construction showing a rapid development trend. As an important technology in metro - wireless signal coverage is to get a great deal of attention to us. Wireless signal coverage in metro can effectively ensure the safe operation of the train and improve the operating efficiency of the train, and facilitate the general public to travel.

Metro station not only provides the basic functions for passengers to get on and off, but also accommodates the major technical equipment and operations management systems, in order to protect the safe operation of metro. Metro station has an internal wireless dispatch system, and the normal public wireless communications network is essential [1-3].

The study of propagation conditions and coverage solutions for tunnel environments have been studied in several previous publications [4-6], whereas not much attention has been given to understand the wireless signal coverage in metro stations. An example of studying the covering type of electromagnetic wave field strength in the concourse from the theory to reduce the blind spot of signal and guide the design antenna arrangement is given in [7], the paper studied design of antenna arrangement. The study of discussing the modelling and analyzing of the initial radio coverage design in underground stations of the New Copenhagen metro system by way of a commercial ray-tracing tool is given in [8]. Instead, in this paper our aim is to discuss the wireless signal coverage in metro station and calculate path difference of electromagnetic waves between the reflection waves and the incident wave by the way of studying reflected wave and transmitted wave of electromagnetic field at interface of two media.

In order to improve the operational efficiency and operational safety for metro system, the modern train control system is moving in the direction of

automation, intelligent, systematic, network and information technology. Communication based train control (CBTC) technology is currently the most advanced train control technology. The CBTC system using wireless communication technology to achieve real-time and bi-directional communication between train and trackside equipment through an open data communication network [9-14].

We will analyze metro platform types in the following Section 2 and basic principle of radio frequency (RF) technology that we have analyzed in Section 3. In Section 4, we propose a method of radio frequency technology application in metro. Wireless signal coverage in metro station that we have analyzed in Section 5. Based on this we select an example of analyzing the signal coverage for wireless network in metro station in Section 6. Finally, section 7 concludes this paper.

2. Metro Platform Types

Metro station is divided into several types, such as island platform station and side platform station, as well as station hall. According to different needs, there are a variety of categories that can be classified according to the operations nature, the platform forms and transfer mode.

According to station's operations nature, metro station can be divided into intermediate stations, regional stations, transfer stations, hub stations, transport stations and terminal stations.

According to station's platform, metro station can be divided into island platform, side platform as well as island and side hybrid platform.

Island platform station is located between the upper and downlink. Island platform station is a common platform form, with a platform area of high utilization, improve facilities are shared, flexible passengers transfer, easy to use, more concentrated management, generally used in large passenger stations.

Side Platform station is located on both sides of uplink and downlink. Side platform station is also a common platform form, although its platform area utilization is low, and adjusts the uplink and downlink passenger traffic and other aspects do not like island platform station, but the elevated station of side platform enables more reasonable range.

Island and side hybrid platform is island platform and side platform co-located in a station.

Island platform station is located between two tunnels and narrow shape, so generally shared leaky cables with tunnels to meet the needs of coverage for wireless signal. If strength of wireless signal is not enough in metro platform station, an omni-directional antenna will be installed, meanwhile can provide signal handoff and updated positions.

Side platform station is located on the both sides of rail line area, the station hall and side platform station are at the same level, in most cases, omni-directional antenna is used for wireless signal coverage.

Generally station hall uses the antenna system with RF cable, if strength of wireless signal is not strong enough in some places, we can use fiber optic repeater or repeater to enhance the wireless signal.

3. The Basic Principle of Radio Frequency Technology

The propagation mechanism of electromagnetic waves is very complex, usually with incident propagation, reflection propagation, transmission propagation. In any types of wireless far field, the radiated waves are a spherical waves, and the electric and magnetic fields can be shown by the following two formulas (1) and (2)

$$\vec{E} = \vec{a}_E ZI \frac{e^{-jkt}}{r} f(\theta,\phi), \tag{1}$$

$$\vec{H} = \frac{1}{\eta}\vec{a}_r \times \vec{E}, \tag{2}$$

where $\vec{a}_r$ is the unit vector of $\vec{H}$ direction; $\vec{a}_E$ is the unit vector of $\vec{E}$ direction; r is the radius of sphere; I is the current on the antenna; Z is the reactance; k is the coefficient, $k = \omega / \lambda f$ (ω is the angular frequency, λ is wavelength, f is frequency); η is the coefficient, $\eta \approx 377$.

Therefore, the radiation power density is

$$p = \frac{1}{2} R_e \mid \vec{E} \times \vec{H} \mid = \vec{a}_r \frac{1 \mid ZI \mid}{2\eta r^2} \mid f(\theta,\phi) \mid^2, \tag{3}$$

Meanwhile, the total power of the spherical surface is

$$p_r = \oiint_S \vec{p} \times \vec{a}_r dA, \tag{4}$$

$$p_r = \int_{-\pi}^{\pi} \int_0^{\pi} \frac{\mid ZI \mid}{2\eta r^2} \mid f(\theta,\phi) \mid^2 r^2 \sin\theta n d\phi, \tag{5}$$

For purposes of calculation and analysis, assuming antenna considered a point source, and within the range considered, every direction of the antenna is the same nature. Then, in the free space, sine wave emitted by a point source will propagate radially, for the isotropic antenna, if the power delivered to the antenna is p_t, antenna gain is G_t, then the antenna transmitting power is

$$P_{r \wedge d} = P_t G_t, \tag{6}$$

The wave power per unit area from the point source at r is

$$P_{fs} = \frac{P_{r\wedge d}}{4\pi r^2}, \quad (7)$$

In order to derive the desired, using electric field strength of root mean square can be written

$$E_{fs} = \sqrt{Z_{fs} P_{fs}}, \quad (8)$$

where Z_{fs} is the impedance of free space, it can be shown as

$$Z_{fs} = \sqrt{\mu_{fs}\varepsilon_{fs}} = 120\pi \approx 377\Omega, \quad (9)$$

where μ_{fs} is the permeability of free space, $\mu_{fs} = 4\pi \times 10^{-7} H/m = 4\pi \times 10^{-7} V_{-s}/A_{-m}$; ε_{fs} is the permittivity of free space, $\varepsilon_{fs} = (10^{-9}/36\pi) F/m = (10^{-9}/36\pi) A_{-\sec}/V_{-m}$

4. The Applications of Radio Frequency Technology in Metro

Due to the limited space in metro station, the metro station hall is generally no longer than 200 m, and its width is about 40 m. In process of wireless signal propagation, apart from the incident wave of electromagnetic waves from the antenna to the receiver, the power of reflected wave is also very large. Metro is composed of station and tunnel. Most metro station reinforced concrete structure, which is generally divided into two parts of the concourse level and platform layer. Concourse level is mainly composed of the station control room, equipment room, as well as Sale and check tickets area. Platform layer is mainly waiting area and equipment rooms. Tunnels of metro typically use concrete structure, tunnels of metro with respect to the road and rail tunnels are to narrow. The narrow space makes the incident angle of wireless signal is small, uneven distribution of signals inside the tunnel. When a train through the tunnel in metro, the tunnel remaining space becomes smaller, at this time there is a great difference between the wireless signal propagation through the train body with no, the wireless signal is blocked very easily and create shadow effects. Train itself also has a greater impact on the wireless signal propagation in metro, because the train body is metal, the wireless signal can only be injected into the train from the window section. At the same time, windows also have some signal attenuation. There are a lot of columns supporting at the platform layer, which also formed a wireless signal propagation block. Meanwhile, concrete materials and aluminum construction of the body on the sites with the absorption of the signal loss and penetration loss. In order to improve operational efficiency and operational safety of metro system, studying on wireless signal coverage in metro station is particularly important.

5. Research on Wireless Signal Coverage in Metro Station

In metro station, electromagnetic waves propagation from the transmitting antenna to the receiver antenna is incident wave, reflected wave and transmitted wave. When the electromagnetic waves incident upon the walls of the metro station hall, because permittivity and conductivity of the walls are not same in free space, therefore, there are reflected wave and transmitted wave at the interface of two media. The schematic diagram of reflected wave and transmitted wave for electromagnetic field is shown in Fig. 1.

In Fig. 1, μ_1, ε_1, δ_1 and μ_2, δ_2, ε_2 represent the permittivity and conductivity of the two substances, respectively.

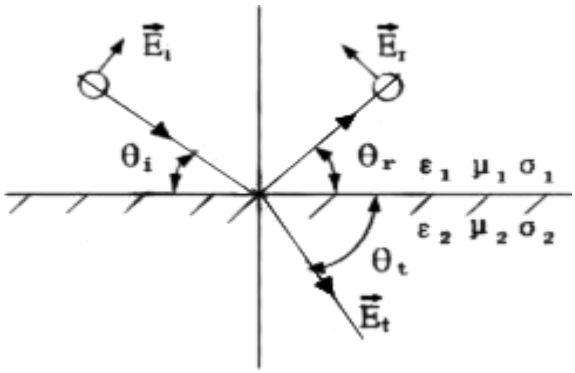


Fig. 1. The schematic diagram of reflected wave and transmitted wave for electromagnetic field.

If the reflection coefficient vector is Γ , relationships between incident wave and reflected wave, incident wave and transmitted wave can be expressed as below

$$E_r = \Gamma E_i, \quad (10)$$

$$E_t = (1-\Gamma) E_i, \quad (11)$$

$$\Gamma = \frac{\sin\theta_i - Z}{\sin\theta_i - Z} = |\Gamma| e^{j\varsigma}, \quad (12)$$

$$Z = \sqrt{\varepsilon_g - \cos^2\theta_i}, \quad (13)$$

(Horizontal polarization)

$$Z = \sqrt{\varepsilon_g - \cos^2 \theta_i} / \varepsilon_g , \quad (14)$$

(Vertical polarization)

Outside the walls of metro is the soil, the typical parameter values of walls are taken as follows: ε=10(F/m), δ=0.01(S/m),

$$\varepsilon_g = 10 - j\frac{179.8}{f(MHz)}, \quad (15)$$

If it is assumed frequency of mobile communication is 900 MHz, then the above equation (15) can be written as

$$\varepsilon_g = 10 - \mathrm{j}0.19981, \quad (16)$$

Equation (15) is substituted into equation (13), and then substituted into the equation (12), we can obtain function of reflection coefficient Γ.

$$\Gamma = |\Gamma(\theta)| e^{j\varsigma}, \quad (17)$$

We made a curve of reflection coefficient Γ of horizontally polarized changing with θ, as shown in Fig. 2.

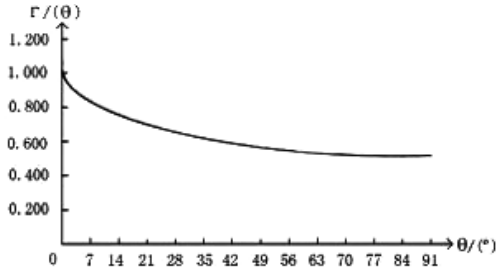


Fig. 2. Curve of reflection coefficient Γ of horizontally polarized changing with θ.

We made a curve of phase shift ς of Γ changing with θ, as shown in Fig. 3. From Fig. 2 and Fig. 3, We can get results that the amplitude of Γ varies between 0.6 and 1, the phase shift of Γ varies between 0 and -0.35^0.

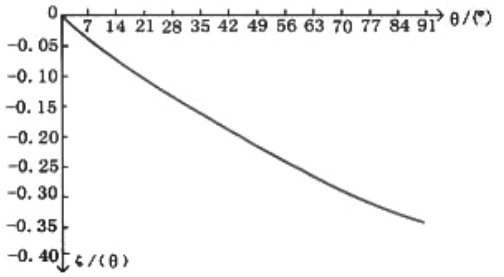


Fig. 3. Curve of phase shift ς of Γ changing with θ.

6. Research on Signal Coverage for Wireless Network in Metro Station

A metro station hall is shown in Fig. 4. An antenna is installed on the roof, a mobile phone is located at L from the antenna.

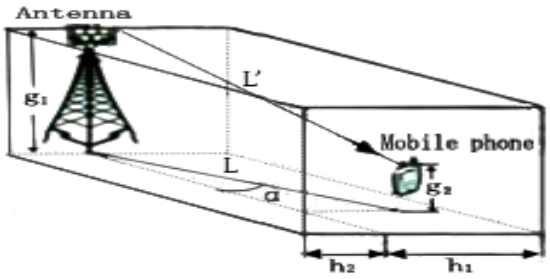


Fig. 4. Three-dimensional graphics of metro station hall.

Wireless signals are received by the mobile phone, not only incident wave from the antenna, but also reflected wave from wall and ground. There are three main ways of reflected wave, the first way is reflected wave from the ground as shown in Fig. 5, the second way is reflected wave from the right wall as shown in Fig. 6, the third way is reflected wave from the left wall.

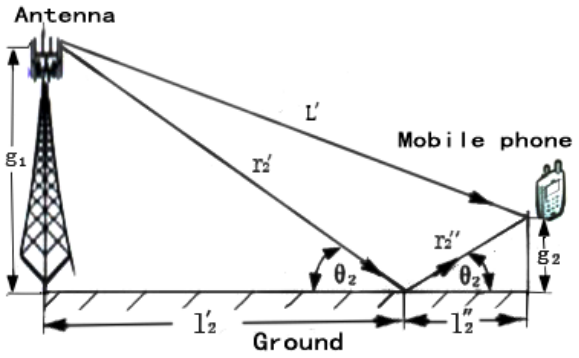


Fig. 5. Schematic diagram of reflected wave from the ground.

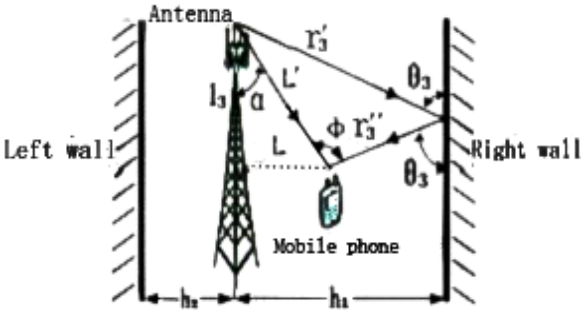


Fig. 6. Schematic diagram of reflected wave from the right wall.

Each path length of the reflected wave is different, amplitude and phase shift of Γ are not the same, thus resulting in the multipath effects generated at the receiving point are not same. Here, three kinds of path difference ΔL_i ($i = 2, 3, 4$) between the reflected wave and the incident wave are calculated.

For reflected wave from the ground

$$\sin\theta_2 = \frac{g_1}{r_2'} = \frac{g_2}{r_2''}, \tag{18}$$

We can obtain

$$g_1 = \sin\theta_2 r_2', \tag{19}$$

$$g_2 = \sin\theta_2 r_2'', \tag{20}$$

$$\therefore tg\theta_2 = \frac{g_1}{l_2'} = \frac{g_2}{l_2''} = \frac{g_1+g_2}{l_2'+l_2''} = \frac{g_1+g_2}{L}, \tag{21}$$

Then

$$\Delta L_2 = (r_2' + r_2'') - L'$$

$$\Delta L_2 = g_1\sqrt{1+\frac{L'^2-(g_1-g_2)^2}{(g_1+g_2)^2}} + g_2\sqrt{1+\frac{L'^2}{(g_1+g_2)^2}} - L', \tag{22}$$

The reflected wave from right wall

$$l_3 = r'\cos\theta_3 + r_3''\cos\theta_3, \tag{23}$$

$$l_3 = (r_3' + r_3'')\cos\theta_3 = L'\cos\alpha, \tag{24}$$

$$r_3' + r_3'' = \frac{\cos\alpha}{\cos\theta_3}L', \tag{25}$$

$$\sin\theta_3 = \frac{h_1}{r_3'} = \frac{h_1}{L'}\bullet\frac{2\sin\theta_3\cos\theta_3}{\sin(\theta_3+\alpha)}, \tag{26}$$

$$\cos\theta_3 = \frac{\cos\alpha}{\sqrt{(\frac{2h_1}{L'})^2 - 2(\frac{2h_1}{L'})\sin\alpha + 1}}, \tag{27}$$

Therefore

$$\Delta L_3 = (r_3' + r_3'') - L' = L'(\frac{\cos\alpha}{\cos\theta_3} - 1), \tag{28}$$

$$\Delta L_3 = L'[\sqrt{(\frac{2h_1}{L'} - \sin\alpha)^2 + \cos^2\alpha} - 1], \tag{29}$$

The reflected wave from left wall, similar as reflected wave from right wall

$$r_4' + r_4'' = L'\bullet[\frac{\cos\alpha}{\cos\theta_4}], \tag{30}$$

Then

$$\cos\theta_4(\frac{2h_1}{L'} + \sin\alpha) = \sin\theta_4\cos\alpha, \tag{31}$$

$$tg\theta_4 = \frac{\sin\theta_4}{\cos\theta_4} = \frac{[\frac{2h_1}{L'} + \sin\alpha]}{\cos\alpha}, \tag{32}$$

We can obtain

$$\Delta L_4 = L'\bullet[\frac{\cos\alpha}{\cos\theta_4} - 1], \tag{33}$$

$$\Delta L_4 = L'\bullet[\cos\alpha\sqrt{tg^2\theta_4 + 1} - 1], \tag{34}$$

$$\Delta L_4 = L'\bullet[\sqrt{(\frac{2h_1}{L'} + \sin\alpha)^2 + \cos^2\alpha} - 1], \tag{35}$$

6. Conclusions

This paper presents a method of studying wireless signal coverage in metro by the way of studying incident wave, reflected wave and transmitted wave of electromagnetic waves at the interface of two media. This work could provide certain theoretical and practical research value for studying wireless signal coverage in metro station. With the popularity of communications technology applications in metro, the issue of security transmission for wireless signal has been caused concern [15]. In the future, we will focus on research the security transmission of wireless signal in metro.

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