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Radio Wave Propagation Characteristics in Coal Mine Workface

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Abstract: Based on the proposed ray-tracing based radio waves propagation (RTRWP) Law for complex coal mine workface tunnels, the energy consumption model evaluation is derived. Theoretical analysis about calculating the multiple reflections of the radio waves in coal mine workface is also provided. Simulations and field tests in coal mine workface tunnels show that the proposed RTRWP law is suitable to describe the actual radio wave propagation in coal mine workface. *Copyright © 2013 IFSA.*

Keywords: Coal mine workface, Ray-tracing based radio waves propagation (RTRWP) law, Multi-path model, Energy loss.

1. Introduction

In order to ensure safety in production on coal face, we have to monitor the operating condition of large scale machines , for example the coal cutter, the scraper conveyer, the hydraulic support, the transfer conveyor, the crusher and so on. Because of the environment of the coal face is complicated and dangerous, we also have to monitor the parameters of the environment such as the gas concentration, rock pressure and coal dust and sometimes the voice and the image are needed also. At present, most of monitoring signals in coal face are transmitted by cables. With the mining of the coal, the majority of machines in the coal face need to be moved separately which makes the cables damaged easily. So there is a reliability problem in coal face communication systems. The application of wireless communication in coal face can solve these problems. In order to analysis the propagation characteristic of wireless radio waves in the coal face, we proposed the coal face radio wave propagation law after analyzing the tent law and comparing the differences between the coal face and mine tunnels.

2. Transmission Law in Coal Mine Tunnels

Ray-tracing method [1] is based on the theory of geometrical optics method. Its basic idea is as follow: at first identify the location of an emission source; and then find out all the transmission paths of each receiver (test points) of the emission source according to the building features and distribution in 3D map; after that, determine the reflection and diffraction losses according to Fresnel equation and

Geometrical Theory of Diffraction/ Unanimous Theory of Diffraction (GTD/UTD); then we will get field strength in the transmission path to each test point; at last, make a coherent superposition of field strength in all the paths to each test point, we will get the total receive field strength of every test point. However, the traditional radio ray method considered only a simple two-dimensional ray (as shown in Fig. 1), while the tent law [2, 3] extended the radio ray to a three-dimensional (as shown in Fig. 2), makes the simulation of multi-path transmission more accurate.

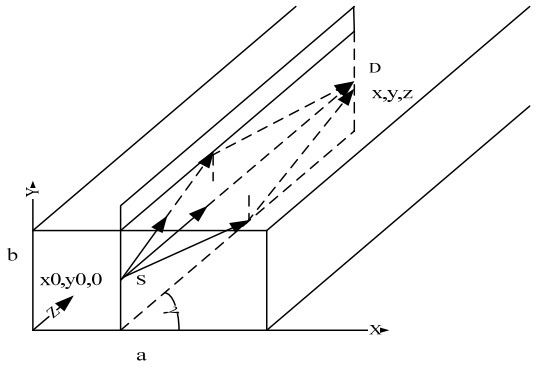

Fig. 1. Schematic diagram of two-dimensional ray.

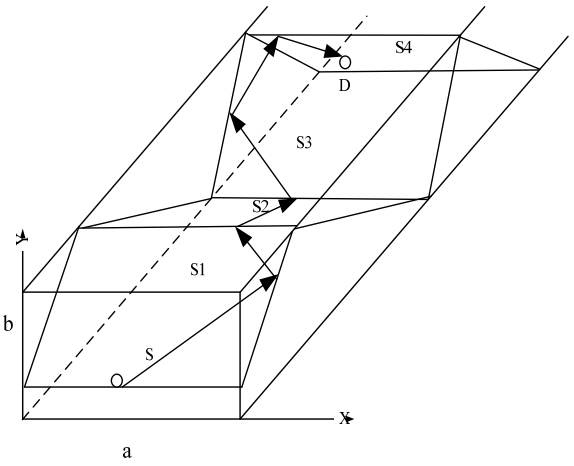

Fig. 2. Schematic diagram of three-dimensional ray.

As is shown in Fig. 2, any radio ray from starting point *S* transmits along the longitudinal direction in incidence plane *S1* will pass through the cross-line of *S1* and *S2* and be reflected to the incidence plane *S2*, and the angle between the *S1* and *S2* satisfy the law of reflection, which is called the surface angle of incidence. Followed by analogy, at the cross-line of *S2* and *S3*, the tent law is still suitable for use.

We called the surface which is perpendicular to the wall as horizontal incidence plane (shows in Fig. 2), and we called the surface which is perpendicular to the roof as vertical incidence plane (shows in Fig. 3). The tent law is a promotion of the Reflection Law in limited space, which applied the Reflection Law for single radio ray to the incidence plane in limited space. That is to say, the Tent Law is a generalized Reflection Law.

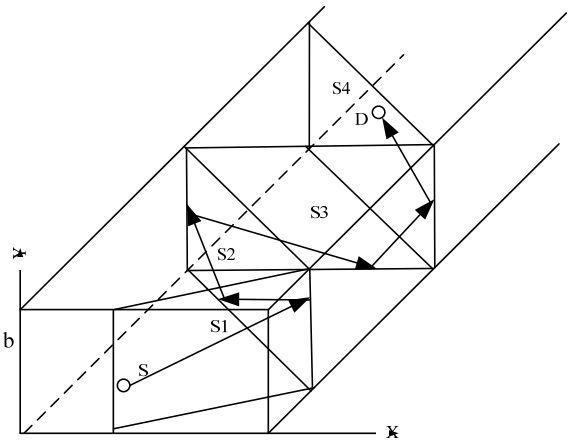

Fig. 3. Vertical incidence plane of tent law.

3. Ray-Tracing Based Radio Waves Propagation (RTRWP) Law

There are lots of hydraulic supports in the coal mine workface, which consist of four walls, threes are metal baffle plates and the residual one is the coal wall [4]. The propagation of wireless radio waves in such special circumstances is different from the general free space. As is shown in Fig. 4, the left side is coal wall, the top and bottom sides are steel baffle plates and in the middle is hydraulic supports. As the existence of the hydraulic supports, the radio rays have energy which have energy loss in the scattering process could not transmit for a long distance.

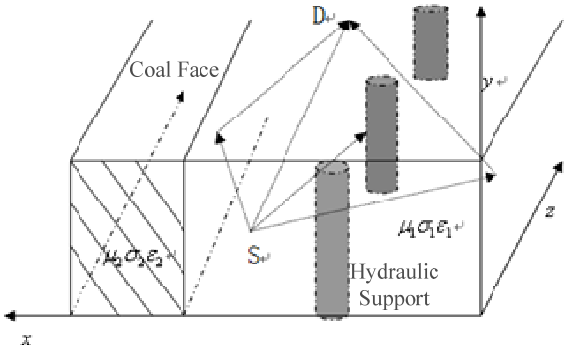

Fig. 4. Schematic diagram of the coal mine workface.

CFRWP Law reveals the radio waves propagation in coal mine workface, and also gives the judgment method that whether the radio ray can transmit cross all hydraulic supports to the destination point.

Fig. 5 is the platform of the roof in coal mine workface, a is the width of the coal mine workface,

k is the distance between the two supports, S is the sending point, D is the receiving point, S1 is the mirror point in the first reflection and S2 is the mirror point in the second reflection.

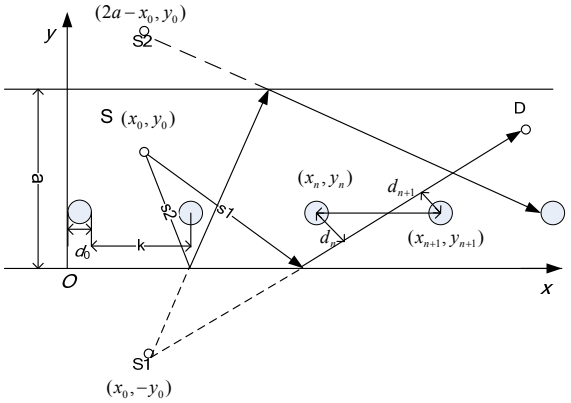

Fig. 5. Vertical incident plane propagating in coal mine workface.

The judgment method is shown as follow:

Step1: According to the characteristic of arithmetic progression (the distance between of hydraulic supports is equal), get the abscissa of the n hydraulic support's circle center:

$$\begin{cases} x_n = (n-\frac{1}{2})d_0 + (n-1)k \\ y_n = y_0 \end{cases} \quad (1)$$

Step2: Gives the equation of S_1D is $y\text{-}K(x+x_s)+y_s=0$, K is the slope of S_1D ($|K|$ is relevant to the number of times of reflection).

Step3: Find out the cross-point of S_1D and line $y=y_0$, whose coordinate is (x'_n, y'_n) located between n and $n+1$ hydraulic support; $n = ceil(x'_n / (d+k))$, $ceil$ is a function means to take the smallest integer which is not less than the independent variable.

Step4: Calculate the distance d_n and d_{n+1} which are the distance between n and $n+1$ hydraulic supports' circle center and ray S_1D.

$$d_n = \frac{|\, y_n - K(x_n + x_0) + y_0 \,|}{\sqrt{1+K^2}} \quad (2)$$

If $d_n > d_0$ and $d_{n+1} > d_0$, ray S1D can go through hydraulic support n between n+1, otherwise, the vertical incidence plane will be hindered by the hydraulic supports.

4. Multi-Path Loss Model Based on CFRWP Law in Coal Mine Workface

The CFRWP Law is helpful to find all the paths that the radio rays propagate cross all hydraulic supports from the transmitter to the receiver. That means CFRWP Law is useful to research the multi-path loss of the radio waves in coal mine workface. So, we propose detail computing method of multi-path energy loss according to RTRWP Law.

Since, we know that the power of receiving point in the direct line of sight is

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \quad (3)$$

P_t, G_t, G_r, λ are the transmit power, transmit gain, receive gain and wavelength; d and L are the path length and system losses (usually the value is 1) [5]. If the radio waves reflect k times in the transmission path, the receive power can be calculated by the equation (4).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d_k^{\,2} L} \rho_k^{\,2} \quad (4)$$

ρ_k is decay factor after reflected k times which is related with reflectivity and the number of reflections [6].

In coal mine workface, the roof and the bottom is metal, while one side is coal wall and the other three sides are metal baffles and they of different reflectivity. So, how can we calculate the power of receiving point after the radio wave reflected k times in this complicated transmission environment? We give the method as follow.

First, calculate decay factor ρ_k.

If the electric field E_i in the incident plane, we call it horizontal incident or vertical polarization; if the electric field E_i perpendicular to the incidence plane, we call it the vertical incident or horizontal polarization. So, we can get the reflection coefficient of the vertical incident wave (5) and horizontal incident wave (6) from the air to the medium [7, 8].

$$\Gamma_v = \frac{E_r}{E_i} = \frac{-\varepsilon_r \cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}}{\varepsilon_r \cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}} \quad (5)$$

$$\Gamma_p = \frac{E_r}{E_i} = \frac{\cos\theta_i - \sqrt{\varepsilon_r - \sin^2\theta_i}}{\cos\theta_i + \sqrt{\varepsilon_r - \sin^2\theta_i}} \quad (6)$$

ε_r is the relative dielectric constant, θ_i is the incidence angle. For the rough reflector, the reflection coefficient needs to be corrected by multiplying the scattering coefficient ρ_s:

$$\rho_s = exp[-8(\frac{\pi\sigma_h \cos\theta_i}{\lambda})^2] I_0[8(\frac{\pi\sigma_h \cos\theta_i}{\lambda})^2] \quad (7)$$

Second, calculate the transmission distance L.

According to Fermat's principle, the 3-dimensional transmission path of the radio waves

can be mapped in two 2-dimension plane (vertically incident plane and horizontal incident plane), as is shown in Fig. 6. Then the transmission distance L can be calculated respectively by the classical image method in the two incident planes.

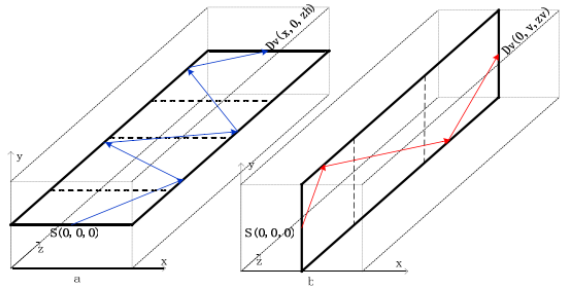

Fig. 6. Propagation paths in incident plane.

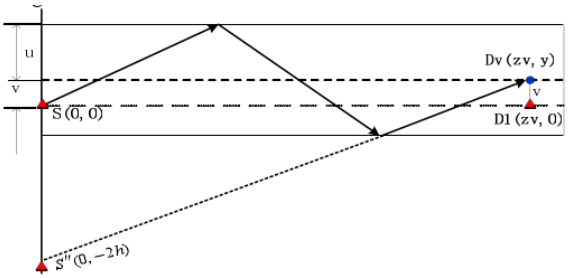

Fig. 7. Calculation of propagation distance.

Third, we the received power can be calculated by formula (4) when get L and ρ_k .

5. Simulation and Experiment

In order to simulate the multi-path loss of 2.4 GHz radio waves, we measured the corresponding parameters in coal mine workface (Jiahe Coal Mine, Xuzhou, China), which are shown as follow:

$$a = 5.13m, d_0 = 0.5m, u = v = 1, \varepsilon_{r1} = 3.2$$
$$\varepsilon_{r2} = 2.4, f = 2.4GHz, e = 0.15$$
$$\sigma_1 = 1.62578 * 10^{-2}, \sigma_2 = 7.7 * 10^6$$

In order to confirm the theoretical model, we also have carried on the scene test in Jiahe coal mine workface, using 2.4 GHz WiFi Access Point whose emissive power is 0 dBm and receive threshold is –90 dBm.

According to experiment result, the effective transmitting range in coal face is about 20 meters; Received signal intensity and packets received rates are shown in Table 1. Fig. 8 shows the relationship between the theoretical calculation result and the actual survey result.

Table 1. Received power in coal mine workface.

Distance/m	RSSI /dBm
1	-64
5	-75
9	-83
15	-82
25	-91
30	-92
35	-93
45	-94

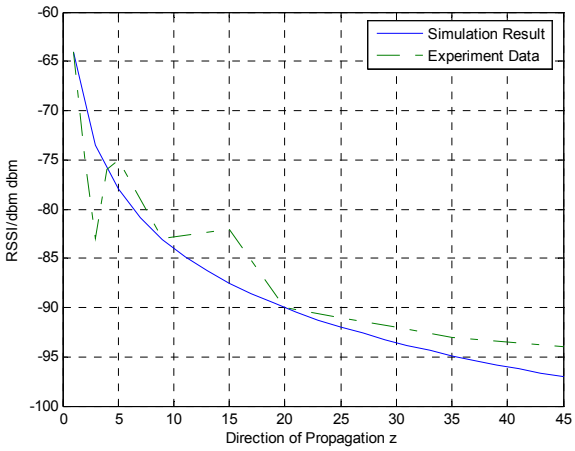

Fig. 8. Experiment results and simulation results.

6. Conclusion

Based on the analysis of proposed CFRWP Law, 2.4 GHz radio waves transmission multi-path attenuation characteristic in coal mine workface is studied. By the comparison of the simulation result and the actual experiment data, it can be concluded that the theoretical model is basically consistent with the actual measurement results. So, this thesis offers a method for wireless transmission research in workface, and the results are helpful for wireless communication in workface.

Acknowledgements

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