Correction of Tunnel Wireless Propagation Model Based on TD-LTE

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Abstract. Because WLAN uses the open frequency band of 2.4GHz or 5.8GHz and does not need to be approved by the radio management department, it is inevitable that it will interfere with the wireless transmission of rail transportation vehicles. The rail transit system of some cities introduces TD-LTE into the CBTC system, but the path loss generated during the transmission has a non-negligible impact on the urban rail transit network propagation plan. Therefore, the accuracy of the radio wave transmission model has an impact on the urban rail transit system. The importance of transportation is self-evident. This paper selects the SPM propagation model for correction, and uses the PSO algorithm to make up for the problem of BP easily falling into local optimality, and obtains the corrected propagation model and the measured data is closer.

1. Introduction

At present, the Wireless Local Area Network (WLAN) is widely used in CBTC (Communication Based Train Control) system of urban rail transportation in China. However, WLAN technology has many shortcomings. For example, when used in open frequency bands, interference is difficult to avoid. The system lacks anti-interference technology and no anti-frequency offset algorithm, so WLAN technology can only be applied to indoor network coverage and low-speed scenarios. With the continuous improvement of subway train speed, WLAN technology is increasingly unable to guarantee the train ground communication demand. When the train speed exceeds 120km/h, it may even lead the train to stop urgently. Time Division Long Term Evolution (TD-LTE) technology has higher speed and more stability than WLAN technology in data transmission. TD-LTE uses the special frequency band for transmission and uses anti-interference technologies such as ICIC and IRC. TD-LTE’s anti-interference capability is stronger. Meanwhile, the algorithm of anti-frequency offset is adopted to support the speed of 430km/h, which meets the demand of high-speed urban rail transit. TD-LTE system network is flatter and simpler. TD-LTE has higher security. Therefore, LTE technology has been applied to urban rail transportation field in major cities at home and abroad [1].

In the transmission process, radio waves are easily affected by the environment, such as path loss, multipath fading, slow fading, and fast fading, etc. Path loss, multipath fading, slow fading, and fast fading will cause different attenuation of signal intensity. In order to make the planning of urban rail transportation wireless network more reasonable, the coefficient of the transmission model is adjusted by the correction of the propagation model with the fitting algorithm. So that the predicted value of the adjusted model is closer to the loss value measured in practice.
The paper [2] proposes that the Time division Long Term Evolution network of 3.7GHz in rural areas is measured, and various transmission models are checked and corrected, and the SPM model has the best performance. The paper [3] presents a path loss prediction of TD LTE propagation at sea by the Weighted Least Square method. The paper [4] proposes that the TD LTE model in hot spot area of Shanghai is corrected by The Weighted least square method. In literature [5], the SPM model is corrected by the Genetic algorithm, but Genetic algorithm is easy to fall into local optimal. Compared with other civil systems, the urban rail transportation system requires higher accuracy of the communication model. This paper proposes the PSO-BP algorithm to correct the SPM propagation model. And then the propagation model after corrected can be used in urban rail transit environment. Finally, the simulation analysis shows that the transmission model based on PSO BP is closer to the actual measurement value than the former one. The corrected propagation model is used to estimate the isolation degree between adjacent cells, and it can make the network planning of urban rail transit system more reasonable.

2. TD-LTE Wireless Communication

Long Term Evolution (LTE) is formulated by the third-generation partnership project (3GPP). In order to improve spectrum efficiency and provide more than 100kbits access service for high-speed mobile users, it adopts OFDM (orthogonal frequency division multiplexing) and MIMO (Multiple-input Multiple-output) two key technologies. OFDM technology divides the effective signal transmission bandwidth into many orthogonal narrow bands that carrier’s information streams independently or in groups. The technology of OFDM reduces the interference come from two carriers greatly. MIMO technology improves the transmission rate and system capacity of LTE system by using multiple antennas at the transmitter and receiver.

LTE system defines FDD-LTE (Frequency Division Duplex) and TD-LTE (Time Division Duplex) two standards. Because TDD is more flexible and has higher spectrum utilization than FDD, TD-LTE is mainly used in urban rail transit in China. In the 20 MHz bandwidth networking, the downlink peak rate can reach 100 Mbit/s, and the uplink peak rate can reach 50 Mbit/s.

The urban rail transit wireless communication system based on TD-LTE technology adopts A / B dual network redundancy structure and works independently without affecting each other. Due to the commercial LTE technology using the structure that co-frequency network, adjacent cells use the same frequency. So that the adjacent cells have a greater co-frequency interference. The interference between two adjacent cells affects the real-time and reliability of urban rail transit communication. Therefore, corresponding measures must be taken to reduce the co-frequency interference.

3. SPM Propagation Model

The SPM model is the standard propagation model. It is an empirical model. The propagation environment is different and the parameter values are different. It is based on the COST-231 model. The applicable frequency of SPM Model is 1500-3500MHz. The main advantage of SPM model is that it can consider a set of parameters ignored in Okumura Hata model, such as diffraction loss or clutter attenuation, in the case of digital topographic map. This uncertain model provides considerable flexibility for the model by considering the correction coefficient of each parameter. Determining the SPM model parameters by performing measurement and fitting correction in different propagation environments, can make the SPM model more suitable for specific transmission environments The SPM model formula is given by formula (4), where d is the distance, Ht represents the effective height of transmitter and Hr means the effective height of receiver. Distance, Ht and Hr are defined in meters. The correction coefficient Ki is generated by the fitting process, and diff is the diffraction loss in decibels.

\[ L_s = K_1 + K_2 \log(d) + K_3 \log(Ht) + K_4 \text{diff} + K_5 \log(d) \log(Ht) + K_6 Hr + K_7 \text{clutter} f \left( \text{clutter} \right) \]  

4. Tunnel Propagation Model Calibration

The communication model is an objective reflection of the communication environment. When the
communication environment changes, the communication model suitable for the original environment may not be suitable for the new communication environment. In real life, the environment of radio wave propagation is diverse, which determines that the existing deterministic model cannot cover all propagation models, and the uncertain model also needs to modify some parameters to adapt to the deterministic propagation environment. The basic process of general model calibration is as follows:

A): Initial preparation work;
B): Point selection and route determination;
C): Collecting data;
D): Processing data;
E): Correcting model;
F): Get the answer;

The frequency of electromagnetic wave \( F_c = 1.8 \text{GHz} \), \( H_b = 28.5 \text{m} \), \( H_m = 1.5 \text{m} \).

4.1. Sampling Data
According to Lee's theorem, when the distance is 40 wavelengths, 36 ~ 50 data points need to be collected. Therefore, the speed requirements of the test vehicle are shown in equation (2):

\[
36 \leq \frac{40 \times \lambda}{v} \times n \leq 50
\]  

(2)

4.2. Model Correction Based on PSO-BP Algorithm
In order to improve the accuracy of the prediction of the loss of radio waves in urban rail transit environment, the appropriate algorithm is corrected for the selected propagation model. This paper proposes the correction of SPM model by PSO-BP algorithm.

PSO-BP algorithm uses BP algorithm to train sample set and then combines PSO algorithm to find the optimal solution through multiple iterations. The correction of propagation model is to modify the coefficient of the propagation model, so it can be more in line with the real communication environment. Therefore, PSO BP algorithm can be used for wireless propagation model correction.

4.2.1. PSO Algorithm
PSO (Particle Swarm Optimization) is a kind of intelligent algorithm for biological groups. Dr. Eberhart and Dr. Kennedy established the particle swarm algorithm model by simulating the movement law of biological groups. The algorithm mainly includes two core parameters, speed and space [6].

The possible solution after optimization in particle swarm optimization is corresponding to each particle. The position vector of particles in space is expressed by setting position vector and velocity vector. If the population is composed of M particles, the space dimension is N dimension, then the particle space is expressed as \( X = (X_1, X_2, \ldots, X_n) \), the position of the M particle in n-dimensional space is expressed as \( X_M = (X_{M1}, X_{M2}, \ldots, X_{MN}) \), the individual optimal solution is recorded as \( p_{best} = (P_1, P_2, \ldots, P_{MN}) \), the group optimal solution is recorded as \( g_{best} = (P_{G1}, P_{G2}, \ldots, P_G) \).

In iteration, the coordinates of particles are updated as follows:

\[
V_{M,N}^{k+1} = V_{M,N}^{k} + c_1 r_1 (P_{M,N}^{k} - X_{M,N}^{k}) \\
+ c_2 r_2 (P_{G,N}^{k} - X_{M,N}^{k}) \\
X_{M,N}^{k+1} = X_{M,N}^{k} + V_{M,N}^{k+1}
\]  

(3)

4.2.2. PSO-BP algorithm
The particle swarm optimization algorithm has fast convergence speed and simple operation, and it does not need too many parameters to adjust, but its local search ability is weak. Combining with the BP algorithm which have stronger local search ability, the weights of neural network are initialized by PSO algorithm. The global optimization ability of PSO is combined with the local search ability of BP,
which makes the corrected propagation model more consistent with the actual communication environment \[7\]. The algorithm flow is shown in Figure 1:

First, establish the topology structure corresponding to the prediction model. According to SPM model and main factors affect path loss, the number of input layer and output layer node is determined. The output is path loss, and the output layer is determined to be 1, the transmitter antenna height \(H_t\), receiver antenna height \(H_r\) and propagation distance \(d\) are set as input layer.

Then, the PSO algorithm is used to initialize the weights and thresholds of the network, and the coding form of particles in PSO-BP algorithm is corresponding to the regression coefficient of SPM model \[8-10\]. The regression coefficient vector of SPM model is as follows (4):

\[
X_{\text{position}} = \left[ K_1, K_2, K_3, K_4, K_5, K_{\text{Clutter}(i)} \right]
\]  

(4)

Rewrite equation (1) to equation (5):

\[
L_e = K_1 + K_2 \log (d) + K_3 \log (H_t) + K_4 \text{diff} + K_5 \log (d) \log (H_t) + K_6 H_r + \sum_{i=1}^{n} W_i K_{\text{Clutter}(i)}
\]  

(5)

Figure 1. Flow chart of PSO-BP algorithm

Rewrite it to a simplified form:

\[
y(i) = b_0 + X_{ij} B_{ij} + \delta (i = 1, 2,...,n; j = 1, 2,...,m)
\]  

(6)

Where \(x\) is the independent variable matrix, so the optimal \(K\) value of SPM model can be obtained by finding the optimal solution of regression coefficient matrix \(B\).

The optimization objective of SPM model is to minimize the standard deviation between the actual path loss value and the predicted path loss value. The objective function and fitness function are calculated as follows:

\[
\min f(j) = \frac{\sum (Y_i - \hat{Y}_i)^2}{N-1} \quad i = 1,2,...,N; j = 1,2,...,M
\]  

(7)

The expression of particle fitness is as follows:

\[
F(j) = \frac{\sum (Y_i - \hat{Y}_i)^2}{N-1} \quad i = 1,2,...,N; j = 1,2,...,M
\]  

(8)

...
5. Matlab Simulation and Performance analysis

5.1. Simulation Results of Propagation Model Path Loss

The curve comparison of the propagation model corrected by PSO-BP algorithm with that before correction is shown in Figure 2 below.

![Figure 2. Comparison of propagation model before and after correction](image)

The coefficient values of SPM model before and after correction are shown in Table 1.

| Propagation model coefficients | Before correction | After correction |
|-------------------------------|-------------------|-----------------|
| $K_1$                         | 12.4              | 23.88           |
| $K_2$                         | 31                | 32.43           |
| $K_3$                         | 5.83              | 5.46            |
| $K_4$                         | 0                 | 0.44            |
| $K_5$                         | -6.55             | -5.05           |
| $K_6$                         | 0                 | 1.3             |
| $K_{clutter}$                 | 1                 | 1.15            |

The corrected expression is shown in equation (9):

$$L_s = 23.88 + 32.43 \cdot \log(d) + 5.46 \cdot \log(H_t) + 0.44 \cdot \text{diff} - 5.05 \cdot \log(H_t) \cdot \log(d) + 1.3 \cdot H_r + 1.15 f(clutter)$$  \hspace{0.5cm} (9)

Take $H_t$, $H_r$, $\text{diff}$ and $f(clutter)$ as 28.5, 1.5, 1 and 1, respectively. It is simplified to (10):

$$L_s = 35.36 + 25.08 \log d$$  \hspace{0.5cm} (10)

According to figure 2, the propagation model corrected based on PSO-BP algorithm is more accurate and less error. The propagation model after corrected is closer to the measured data than the propagation model before correction.

5.2. Application of correction propagation model

Because TD-LTE oriented urban rail transit system adopts the same frequency networking mode, there is a certain degree of same frequency interference between the up tunnel and down tunnel on both sides of the station. The interference diagram is shown in Figure 3 below:

Taking the following link as an example, the distance between user u and base station a and B is 2m and 10m respectively, and there is 10dB penetration loss between user and base station B. according to the calculation formula (11) of the same frequency isolation, the isolation is 17.56db.
Through the isolation degree, the isolation distance can be calculated reasonably, which can not only avoid the space waste caused by too large a distance setting but also avoid the mutual interference between cells caused by insufficient distance setting.

6. Conclusion

Through the isolation degree, the isolation distance can be calculated reasonably, which can not only avoid the space waste caused by too large a distance setting but also avoid the mutual interference between cells caused by insufficient distance setting. Based on PSO-BP algorithm, this paper uses CW test data in urban rail transit environment to predict and correct the SPM model, so that the corrected propagation model is more suitable for TD-LTE urban rail transit environment than the corrected propagation model. The availability and rationality of the corrected propagation model can be reflected by the isolation degree of the uplink and downlink cells in the tunnel. Through the accurate estimation of isolation degree, the isolation distance is set to avoid the same frequency interference between different districts. Therefore, it is self-evident that the accuracy of the propagation model is important to the safety of urban rail transit.

Acknowledgments

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