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RELIABILITY EVALUATION FOR VHF AND UHF BANDS UNDER DIFFERENT SCENARIOS VIA PROPAGATION LOSS MODEL

OCENA NIEZAWODNOŚCI PROPAGACJI FAL RADIOWYCH PASM VHF I UHF W RÓŻNYCH WARUNKACH TERENOWYCH Z WYKORZYSTANIEM MODELU UTRATY MOCY SYGNAŁU

The significant effect of path loss on the reliability of very high frequency (VHF) and ultrahigh frequency (UHF) bands propagation has drawn much attention. Previous works mainly focus on the reliability evaluation for infrastructures and basic equipment, however, its propagation reliability has not been taken into full consideration. This paper proposes a new method for evaluating the reliability of the wireless communication based on the analysis of the traditional outdoor wave propagation loss models. In the reliability evaluation of the radio communication, we firstly consider the transmission frequency, the antenna height, the cell type and the communication distance. Then, we use a lognormal distribution to fit the random distribution curve of the communication distance so that the relationship between the path loss value and the reliability can be analysed. We further derive the probability distribution function (PDF) and the cumulative distribution function (CDF) of the path loss value from different antenna correction factors, cell type correction factors and terrain correction factors. Finally, we calculate the radio communication reliability values at different frequencies based on the threshold of the propagation loss value. Compared with the reliability degree only considering the communication distance threshold, the influence of environmental factors on the reliability of the VHF and the UHF radio propagation has been analysed.

Keywords: *Propagation, reliability estimation, lognormal distribution, VHF radio propagation, UHF radio propagation.*

W literaturze przedmiotu, wiele uwagi poświęca się ostatnio znaczącemu wpływowi utraty mocy sygnału (ang. path loss) na niezawodność rozchodzenia się fal tworzących pasma o bardzo wysokiej częstotliwości (VHF) i ultra wysokiej częstotliwości (UHF). Wcześniejsze prace koncentrują się głównie na ocenie niezawodności infrastruktury i podstawowego wyposażenia, nie uwzględniając w pełni niezawodności propagacji fal. W niniejszym artykule zaproponowano nową metodę oceny niezawodności komunikacji bezprzewodowej opartą na analizie tradycyjnych modeli utraty mocy sygnału podczas propagacji fal radiowych w środowisku zewnętrznym. Oceniając niezawodność komunikacji radiowej, w pierwszej kolejności rozważano częstotliwość transmisji, wysokość anteny, typ komórki oraz odległość komunikacyjną. Następnie, za pomocą rozkładu lognormalnego, dopasowano krzywą rozkładu losowego odległości komunikacyjnej, co pozwoliło na analizę związku między wartością utraty mocy sygnału a niezawodnością. W dalszej kolejności, z wartości różnych współczynników korekcji anteny, typu komórki oraz terenu wyprowadzono funkcję rozkładu prawdopodobieństwa oraz dystrybuantę wartości utraty mocy sygnału. Na koniec obliczono wartości niezawodności komunikacji radiowej dla różnych zakresów częstotliwości w oparciu o próg wartości utraty mocy sygnału. Przedstawiona analiza wykracza poza elementarne obliczenia niezawodności na podstawie maksymalnej odległości komunikacyjnej biorąc także pod uwagę wpływ czynników środowiskowych na niezawodność propagacji fal radiowych VHF i UHF.

Słowa kluczowe: *propagacja, ocena niezawodności, rozkład lognormalny, propagacja fal radiowych VHF, propagacja fal radiowych UHF.*

Acronyms and Abbreviations

CDF	Cumulative distribution function.
FM	Frequency modulation.
FS	Free-space.
GPS	Global position system.
LCCS	Linear consecutively connected system.
LPM	Large-scale propagation model.
PDF	Probability distribution function.
PM	Propagation model.
RMa	Rural macrocell.
RS	Receiving station.
SPM	Small-scale propagation model.
TRG	Two-ray ground propagation model.
BS	Base station.
UHF	Ultrahigh frequency.
UMa	Urban macrocell.
UMi	Urban microcell.
VHF	Very high frequency.
3GPP	3rd Generation Partnership Project.

Notations

$h(t)$	Fading factor.
d	Transmission distance.
$\delta(i)$	Shadow fading factor.
$g^2(t)$	Small-scale fading factor.
L	Path loss value.
L_{bs}	Path loss in free space.
A_{mu}	Median attenuation.
$G_T(h_{te})$	Gain factor of the transmitting station antenna height.
G_{AREA}	Correction factor associated with the type of environment.
f_c	Frequency of transmission.
h_b	Effective height of base station antenna.
h_{re}	Effective height of receiving station antenna.
$\alpha(h_{re})$	Receiving station antenna height correction factor.
C_{cell}	Cell type correction factor.
$C_{terrain}$	Terrain correction factor.
$f_{\ln d}$	PDF of $\ln d$.
$\mu_{\ln d}$	Mean value of $\ln d$.
$\sigma_{\ln d}$	Standard deviation of $\ln d$.
$f_{c\max}$	Maximum of the frequency.
d_T	Threshold of distance.
L_T	Threshold of path loss.
R	Reliability.

1. Introduction

With the advantages of long distance communication and high transmission rate, VHF band (30-300MHz) [13] and UHF band (300MHz-3GHz) [40] are widely used in military and commercial communications, such as radio astronomy, mobile phones, Bluetooth and GPS [25]. Reliable radio communication is very important for the military to perform tasks or for normal civil operation. Under different propagation scenarios, such as small city, large city, suburban, and rural environments, the reliability of VHF and UHF communications is largely influenced by the path loss [6]. As the popularization of the VHF and UHF bands, many research groups pay attention to reliability evaluation method for the radio communication.

Fig.1 shows two research directions for the reliability evaluation on wireless communication. One of the ways to calculate the reliability is to analyze the communication channels between two-terminal nodes [18, 20]. Chen [4] proposed a simulation approach to calculate two nodes reliability of a mobile ad hoc network (MANET) in a $[0, 1]^2$ topology with N nodes. In Ref. [26], the propagation-based link reliability of the MANET was calculated by using the Monte Carlo Simulation. Currently, the researchers focused on the connectivity analysis of the linear consecutively connected system (LCCS), which can be applied to assess the reliability of the radio communication system. Levitin modeled the LCCS considering the nodes allocation such as service nodes [16], series parallel nodes [14] and standby nodes [15]. Other researchers also studied the radio communication LCCS optimization methods by considering different situations, such as random repair time as well as different repair polices [42], multi-state components [44] and topological structures [39].

Another way to assess the reliability of radio communication is to evaluate the devices. Park [27], Mi [23, 24] and Zadehparizi [45] assessed the reliability of wireless communication based on the evaluation of the communication devices [7, 19], such as the antennas and the controllers [17]. However, the environmental factors have not been taken into account in these models, so that these models are only suitable for free space communication environments. The link capacity and the path loss of radio propagation in each communication scenarios should not be ignored.

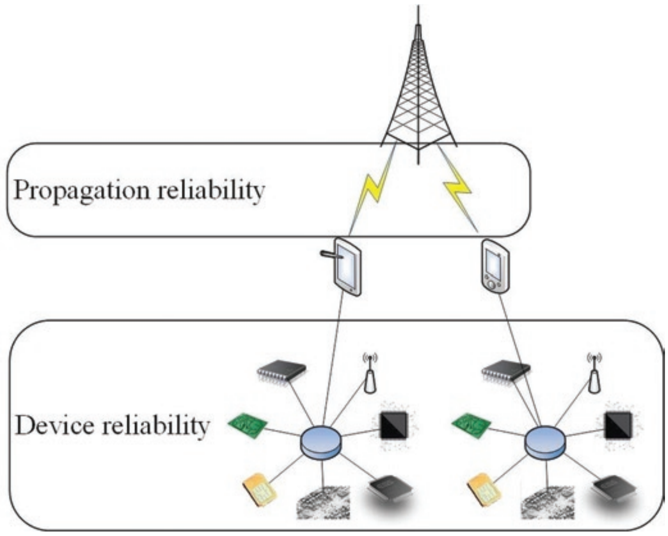

Fig. 1. Reliability evaluation methods for wireless communication

Propagation loss is one of the most important and the greatest affective factors to evaluate the reliability of the radio communication. Some international telecommunications unions including the 3rd Generation Partnership Project (3GPP) [8] and the International Telecommunications Union-Radio communication Sector (ITU-R) [35] have released their study on path loss models for VHF and UHF bands. Many influence factors in the propagation loss models for radio communications that were investigated including the prediction accuracy [37], different scenarios such as small city [38], large city [5], suburban and rural environments [21], line-of-sight (LOS) and non-LOS (NLOS) [22,43].

Based on the propagation loss models, this paper proposes a new evaluation method on radio communication reliability. The organization of this paper is: In Section II, the propagation models, including the fading characteristics, the Okumura model and the Okumura-Hata model, are introduced briefly. In Section III, the proposed methodology and corresponding evaluation method of the link reliability are presented. In Section IV, an example of reliability evaluation for the radio communication links is used to illustrate this method. Finally, main conclusions and relevant future research are drawn in the last section.

2. Propagation Model (PM)

2.1. Fading characteristics

The prototype of radio wave propagation originated from the research work of scientist James Clerk Maxwell [34, 9], who established the electromagnetic field theory and predicted the existence of electromagnetic waves. Subsequently, his predictions were proved by Heinrich Hertz. A prelude to the study of wireless communication was led by the work of Maxwell and Hertz, and radio communication attracts people's eyes [32]. After nearly a century of development, mobile communication has brought people a free and convenient way in transmitting information. With the growing use of smart phones in daily life, consumers are increasingly demanding the speed and quality of mobile communication. The reliability of radio communication in the process of electromagnetic radio propagation has also attracted people's interest. Research on the reliability of wireless communication has become a hot issue [41].

In general, for the environment, radio waves propagation includes geographical environment, climatic characteristics, electromagnetic interference, and so on [11, 3]. The radio waves transmitting in this environment mainly manifest in following modes: reflection, diffraction and scattering, and their synthesis [28]. Due to the complexity of the mobile working environment, the impacts on radio wave communication can be mainly summarized as:

1) Transmission loss [36]: transmission loss caused by different propagation distance of radio waves;
2) Shadow fading [1]: being faded radio waves due to the topographical features (buildings and other obstacles) in the propagation environment, i.e. shadow fading;
3) Multipath fading [12]: Radio waves are reflected, diffracted, and scattered by the terrain or buildings through the propagation path, so that the received signal is a superposition of different signals from multiple paths. This multipath propagation will result in a random variation in the amplitude, phase, and arrival time of the receiver signal, i.e., multipath fading.

The scientists who study on mobile propagation models usually predict the average received signal intensity at a specific communication distance, and the PM is often divided into a large-scale propagation model (LPM) and a small-scale propagation model (SPM) [37].

Fig.2 shows these effects. In addition, if the mobile terminal (communication station) moves in the direction of the radio propagation path, the Doppler shift [33] will occur at the receiving signal, that is, the received signal will spread in the frequency domain, and this effect will generate additional frequency modulation (FM) noise, resulting in distortion of the signal.

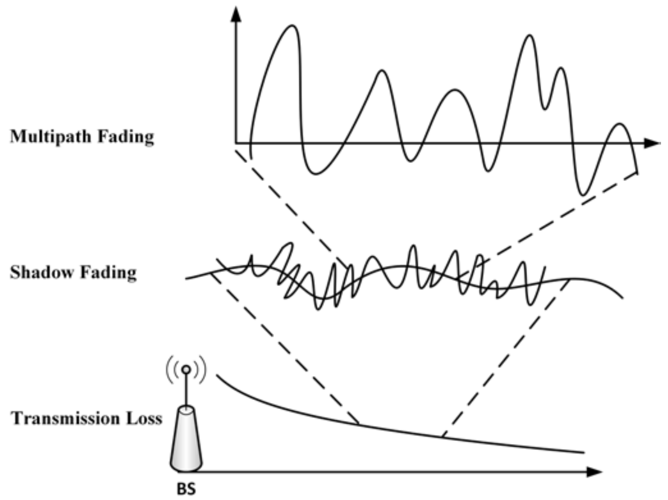

Fig. 2. Propagation loss in wireless channels

The LPM [37] is applied to analyse the variety of the receiving signal intensity under long communication distances (several hundred meters or several kilometres), such as the transmission loss and shadow fading. It characterizes the changes of the received signal strength that occur slowly with the changes of the propagation distance and the environment in a certain period. The SPM is mainly applied to analyse the rapid fluctuation of the receiving signal intensity in several wavelengths or several seconds, the rapid fluctuation is mainly caused by multipath transmission of wireless channels, and its effects are described as follows: signal intensity changes rapidly after short distance propagation, random signal caused by time-varying Doppler shift of different multipath signals, and multipath propagation delay. However, these fading characteristics are not independent, and both involved in the same radio propagation.

Let $h(t)$ be the fading factor of the channel. The radio propagation loss characteristics of communication links can be described as follows:

$$h(t)=\left(\text{const}\times d^{-\alpha}\times 10^{-\frac{\delta(t)}{10}}\right)\times g^2(t) \tag{1}$$

where $d^{-\alpha}$ is the influence of the path transmission loss and is inversely proportional to the transmission distance d, α is generally between $2\sim 5$; $10^{-\delta(t)/10}$ denotes the influence of shadow fading, and the shadow fading $\delta(t)$ follows lognormal distribution; $g^2(t)$ indicates the effects of small-scale fading, including multipath fading. The fading characteristics of the communication channel are the combination of path transmission loss, shadow fading, and small-scale fading.

In a general radio communication system, the environment and the topography which the nodes worked in is complex, the characteristics of the transmission channel may change at any time and place, and thus radio communication system is a typical variable parameter communication channel. In the mobile channel, the signal will be affected by the LPM and SPM: LPM include transmission loss and shadow fading; SPM mainly refers to multipath fading, including Doppler shift [33].

For the radio communication system, the transmission environment is more complex than the free space, and the impact of wireless transmission environment on the propagation loss of the radio waves is the principal influence factor. Therefore, in most cases, a realistic model is often built based on different environment according to the test data, and the amendment in that way can make the models more realistic and accurate. In this paper, we will evaluate the reliability of radio communication reference to the following propagation models.

2.2. Okumura model

The Okumura model [29] is built by Japanese scientist Okumura based on the measurement data of radio transmission loss in Tokyo. The Okumura model can be formally expressed as the following formula:

$$L = L_{bs} + A_{mu}(f,d) - G_T(h_{te}) - G_R(h_{re}) - G_{AREA} \tag{2}$$

where L is the median of the propagation loss value; L_{bs} is the propagation loss in free space; A_{mu} is the median attenuation; $G_T(h_{te})$ is the gain factor of the transmitting station antenna height; $G_R(h_{re})$ is the receiving station antenna height gain factor; G_{AREA} is the correction factor associated with the type of environment.

The Okumura model is the most widely used empirical model in PMs. Many subsequent analysis models are derived from the Okumura model.

2.3. Okumura-Hata model

The Okumura-Hata model [10] is one of the PMs which are derived from the Okumura model under different scenarios, applied to f_c from 150 to 1500MHz. The model includes the essence elements of Okumura model and further derives a more applicable model to reflect the effects of propagation fading caused by different scenarios. Its formulation is given as:

$$L = 69.55 + 26.16\lg f_c - 13.82\lg h_b - \alpha(h_{re}) + (44.9 - 6.55\lg h_b)\lg d + C_{cell} + C_{terrain} \tag{3}$$

where f_c is the frequency of transmission; h_b is the difference between the actual altitude of the BS and the average ground altitude within the actual distance of the BS along the propagation direction; $\alpha(h_{re})$ is the RS antenna height correction factor. For small city, the factor is:

$$\alpha(h_{re}) = (1.11\lg f_c - 0.7)h_{re} - (1.56\lg f_c - 0.8) \tag{4}$$

For a large city, suburban and rural environments, the factor is:

$$\alpha(h_{re}) = \begin{cases} 8.29(\lg 1.54h_{re})^2 - 1.1, & f_c \le 300\text{MHz} \\ 3.2(\lg 11.75h_{re})^2 - 4.97, & f_c > 300\text{MHz} \end{cases} \tag{5}$$

C_{cell} is the cell type correction factor, and it is expressed as:

$$C_{cell} = \begin{cases} 0 & \text{cities} \\ -2\left[\lg(f_c/28)\right]^2 - 5.4 & \text{suburban} \\ -4.78(\lg f_c)^2 + 18.33\lg f_c - 40.98 & \text{rural} \end{cases} \tag{6}$$

$C_{terrain}$ is the terrain correction factor and its unit is decibel (dB).

3. Methodology

3.1. The PDF and CDF of the propagation loss

The scenarios of the radio communication system in this study are described as follows [10]: large city, small city, suburban and rural areas. The terrain correction factor $C_{terrain}$ reflects the influence of some important terrain environmental factors on path loss, such as buildings. The reasonable terrain correction factor values are obtained by testing and correcting the propagation model, and can also be set by humans; the range of terrain correction factor $C_{terrain}$ is: $-1 \sim -8$dB . In this paper, we assume that the terrain correction factor $C_{terrain}$ is -5dB [2, 30, 31].

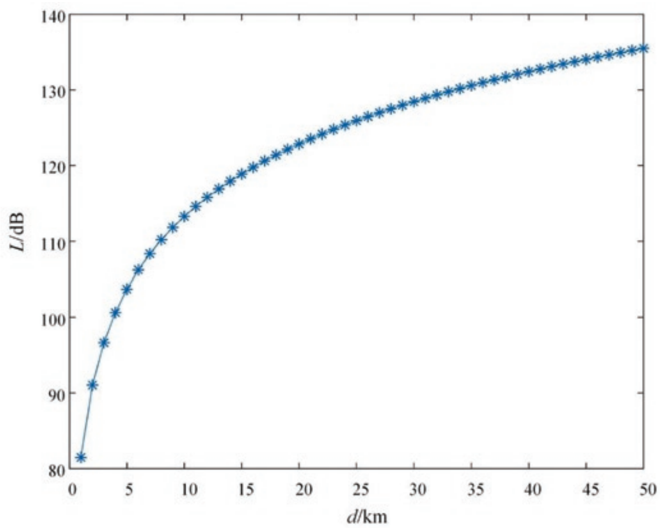

Fig. 3. The effect of d on the path loss

It can be seen from Eq. (3) that the L of the communication channel is mainly affected by the electromagnetic wave carrier frequency f_c and d between the BS and the RS. Through investigation and analysis, it can be concluded that d follows lognormal distribution, the path loss L follows the normal distribution, and the original model can be rewritten as:

$$L = 69.55 + 26.16\lg f_c - 13.82\lg h_b - \alpha(h_{re}) + (44.9 - 6.55\lg h_b)\frac{\ln d}{\ln 10} + C_{cell} + C_{terrain} \tag{7}$$

When the frequency f_c is 100MHz, the L of the radio communication and d exhibits logarithmic relation as shown in Fig. 3.

According to Eq. (7), we can observe that since the effective antenna correction factor $\alpha(h_{re})$ and the cell type correction factor C_{cell} are not affected by the communication distance d . The coefficient of $\ln d$, $\frac{(44.9 - 6.55\lg h_b)}{\ln 10} = (19.5 - 2.84\lg h_b)$, is only affected by h_b . d is the horizontal distance between the BS and RS, because the position of the mobile station antenna changes at any time, and f_c is the frequency of transmission, the f_c is determined value within a certain range, and it can be assumed that d follows the lognormal distribution, let $\ln d \sim N\left(\mu_{\ln d}, \sigma_{\ln d}^2\right)$.

$$f_{\ln d}(d) = \begin{cases} \frac{1}{d\sqrt{2\pi}\sigma_{\ln d}} e^{-\frac{(\ln d - \mu_{\ln d})^2}{2\sigma_{\ln d}^2}}, & d > 0 \\ 0, & d \le 0 \end{cases} \tag{8}$$

The communication scenario is set by the modelling assumptions described at the beginning of this section. The mean value of the communication distance of different carrier frequency is shown in Table 1.

Table 1. The parameters for the radio communication

Parameter	value
Effective height of base station antenna h_b	100m
Effective height of receiving station antenna h_{re}	2.5m
Terrain correction factor $C_{terrain}$	-5dB
$\mu_{\ln d}$ ($f_c = 150$MHz)	2.3
$\mu_{\ln d}$ ($f_c = 550$MHz)	1.6
$\sigma_{\ln d}$	0.3

When $\mu_{\ln d}$ =2.3, it means that the distance approximately equals 10 km. the PDF and CDF of the distance are shown in Fig.4.

From Eqs. (7) and (8), we can conclude that L follows the normal distribution, i.e.

$$L \sim N\left((19.5 - 2.84\lg h_b)\mu_{\ln d} + 69.55 + 26.16\lg f_c - 13.82\lg h_b - \alpha(h_{re}) + C_{cell} + C_{terrain}, (19.5 - 2.84\lg h_b)^2\sigma_{\ln d}^2\right)$$

Its PDF is given by:

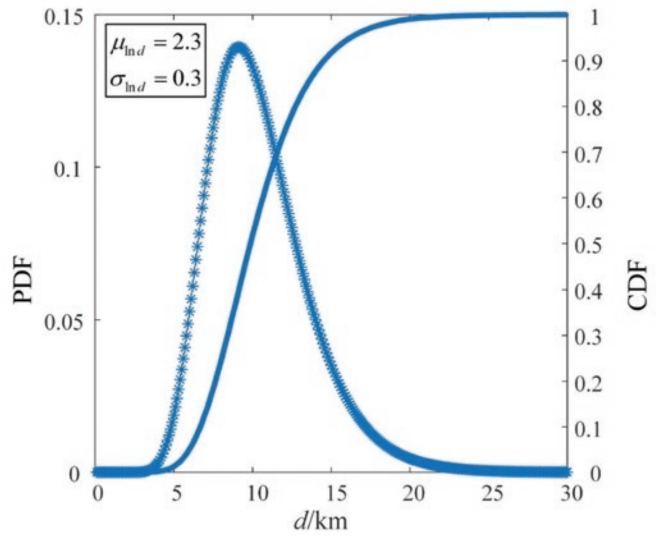

Fig. 4. The PDF and CDF of the distance

$$f_L(l) = \frac{1}{(19.5 - 2.84\lg h_b)\sqrt{2\pi}\sigma_{\ln d}} e^{-\frac{\left[l - \left((19.5 - 2.84\lg h_b)\mu_{\ln d} + 69.55 + 26.16\lg f_c - 13.82\lg h_b - \alpha(h_{re}) + C_{cell} + C_{terrain}\right)\right]^2}{2(19.5 - 2.84\lg h_b)^2 \sigma_{\ln d}^2}}$$

In order to prove the correctness of this PDF, we use the Monte Carlo simulation [9] to calculate the distribution of the path loss under the small city which the $f_c = 150\text{MHz}$. Compare with the calculation results shown in Fig. 5, the closed-form solution of the path loss distribution proves to be proper.

It is noted that the variance of the path loss threshold does not change regardless of the environment, and is only affected by h_b. The only parameter that is affected by environmental change is μ_L.

The μ_L under different communication scenarios is shown in Table 2.

From the equations listed in Table 2, we can obtain the PDF curve and the CDF curve of the propagation path loss values of the VHF bands with a frequency of 150 MHz and the UHF bands of 550 MHz under different communication scenarios. The results are shown in Figs. 6 and 7.

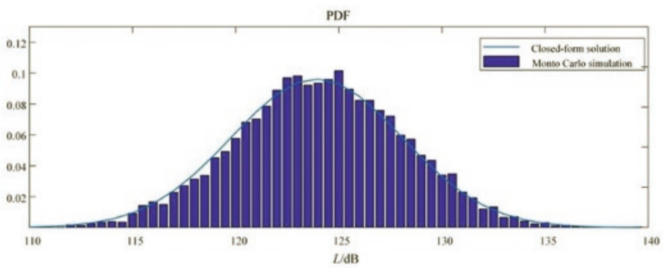

Fig. 5. The results of the Monte Carlo simulation compared with the closed-form solution

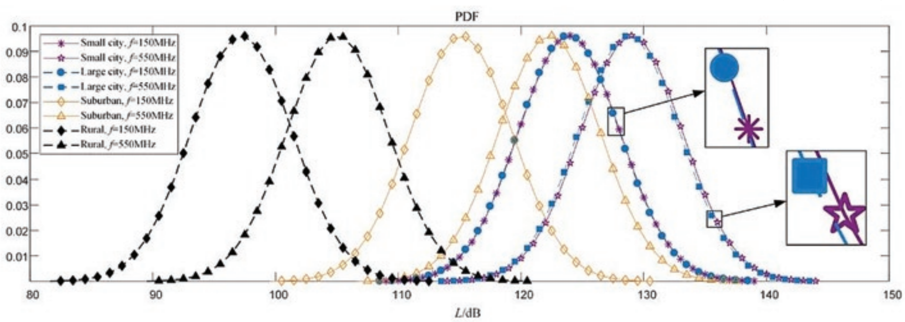

Fig. 6. The PDF curve of the path loss in each communication scenarios

In Figs. 6 and 7, when $f_c = 150\text{MHz}$, the effect of the city size on L is slight, the μ_L in the small city and the large city are 123.9286 dB and 123.8810 dB, respectively. It can be concluded that in the communication situation of cities, the path loss is mainly affected by the communication distance. When the distance difference is not large, the path loss values of the large city and small city are similar.

3.2. The threshold of the path loss

To evaluate the reliability of the communication, the threshold of the path loss value should be firstly calculated. As the practical path loss threshold is determined by the experiment or test, and in different scenarios, the test result is changed. In this study, we suppose that the path loss threshold L_T can be obtained through the following equation:

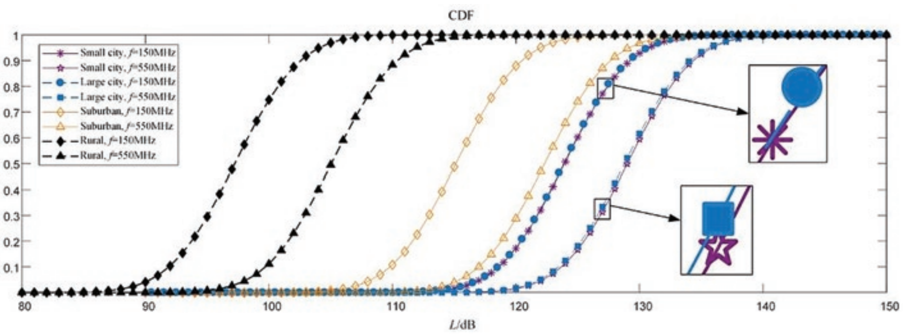

Fig. 7. The CDF curve of the path loss in each communication scenarios

$$L_T = 69.55 + 26.16\lg f_{c\max} - 13.82\lg h_b - \alpha(h_{re})\Big|_{f_c = f_{c\max}} + (19.5 - 2.84\lg h_b)\ln d_T + C_{cell}\Big|_{f_c = f_{c\max}} + C_{terrain} \quad (9)$$

where $f_{c\max}$ is the maximum of the frequency, and d_T is the threshold distance. After L_T has been obtained, the reliability can be calculated according to Eq. (10):

$$R = \int_0^{L_T} \frac{1}{(19.5 - 2.84\lg h_b)\sqrt{2\pi}\sigma_{\ln d}} e^{-\frac{\left[l - \left((19.5 - 2.84\lg h_b)\mu_{\ln d} + 69.55 + 26.16\lg f_c - 13.82\lg h_b - \alpha(h_{re}) + C_{cell} + C_{terrain}\right)\right]^2}{(19.5 - 2.84\lg h_b)^2 \sigma_{\ln d}^2}} dl. \quad (10)$$

4. Case Study

The reliability of the radio communication system is mainly affected by the distance. In the real world, the communication distance is mainly affected by the transmission power of the radio, and the receiving power is mainly affected by the communication scenarios. Through survey and data fitting, a random distribution which the communication distance is

Table 2. The μ_L under each communication scenarios

Communication scenario	f_c	μ_L
small city	——	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-13.82\lg h_b$ $-\left[(1.11\lg f_c-0.7)h_{re}-(1.56\lg f_c-0.8)\right]+C_{terrain}$
large city	≤ 300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-13.82\lg h_b$ $-\left[8.29(\lg 1.54h_{re})^2-1.1\right]+C_{terrain}$
	>300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-13.82\lg h_b$ $-\left[3.2(\lg 11.75h_{re})^2-4.97\right]+C_{terrain}$
suburban	≤ 300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-13.82\lg h_b$ $-\left[8.29(\lg 1.54h_{re})^2-1.1\right]-2\left[\lg(f_c/28)\right]^2-5.4+C_{terrain}$
	>300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-13.82\lg h_b$ $-\left[3.2(\lg 11.75h_{re})^2-4.97\right]-2\left[\lg(f_c/28)\right]^2-5.4+C_{terrain}$
rural	≤ 300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-\left[8.29(\lg 1.54h_{re})^2-1.1\right]$ $-13.82\lg h_b-4.78(\lg f_c)^2+18.33\lg f_c-40.98+C_{terrain}$
	>300MHz	$(19.5-2.84\lg h_b)\mu_{\ln d}+69.55+26.16\lg f_c-\left[3.2(\lg 11.75h_{re})^2-4.97\right]$ $-13.82\lg h_b-4.78(\lg f_c)^2+18.33\lg f_c-40.98+C_{terrain}$

Table 3. Each communication channels' frequency

Communication channel	Frequency
A-VHF	100-150MHz
B-UHF	550-700MHz

Table 4. Thresholds of path loss under different communication scenarios

Communication scenario	$f_{c\max}$/MHz	d_T/km	L_T/dB
small city	150	23	135.5
	700	9	139.2
large city	150	23	135.4
	700	9	139.8
suburban	150	25	130.1
	700	10	131.9
rural	150	30	115.3
	700	12	116.2

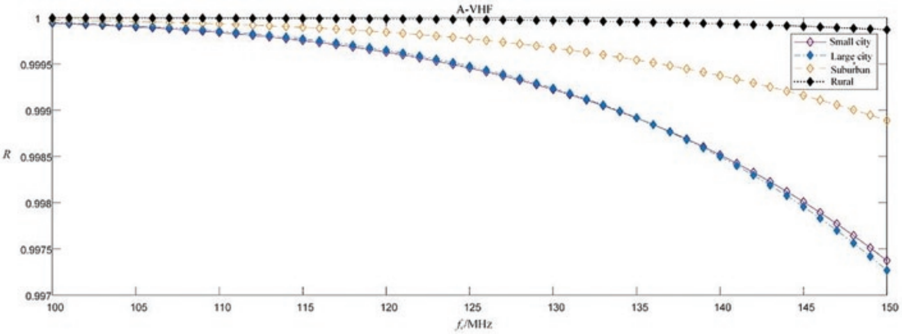

Fig. 8. The effect of the A-VHF's f_c on the reliability

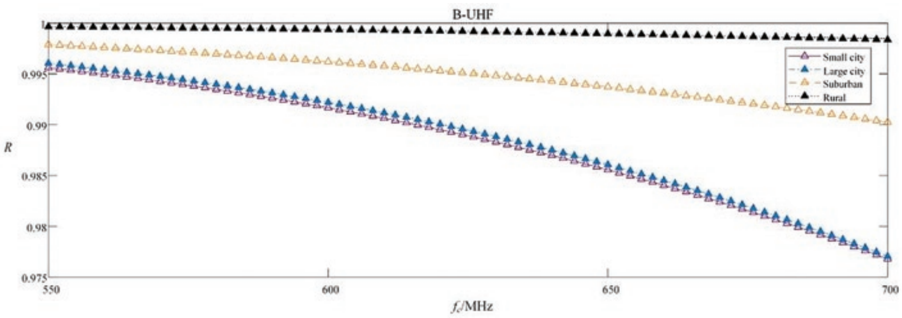

Fig. 9. The effect of the B-UHF's f_c on the reliability

following can be abstained. Under different environmental conditions, the path loss of the radio changes when the communication distance is different. Through the iterative solution of the distribution function, the PDF of the path loss can be obtained. According to the research, when the path loss exceeds a certain threshold, the wireless communication will become unreliable. The research objects of this study are two radio channels shown in Table 3.

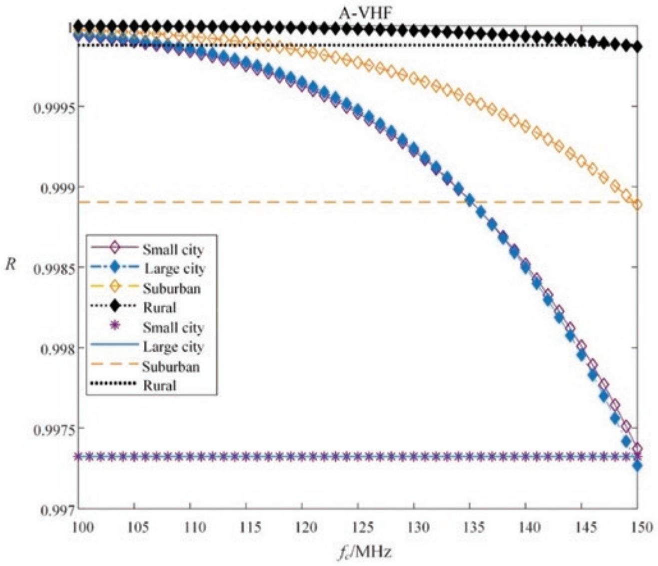

Fig. 10. The effect of the A-VHF's f_c *on the reliability*

According to Eq. (9), when the maximum of the frequency $f_{c\max}$ and the threshold distance d_T is reached, the thresholds of the transmission channel path loss L_T corresponding to different communication scenarios can be calculated. The thresholds of the path loss under different communication scenarios are shown in Table 4.

When the path loss threshold L_T has been obtained, the reliability can be calculated according to Eq. (10), the effect of f_c on the radio communication reliability is shown in Figs. 8 and 9.

Through our calculation, the path loss of various communication channels of the radio can be obtained. By studying the relationship between L and the communication reliability, the reliability of radio communication under a particular loss threshold can be obtained.

If we only consider the maximum distance in calculating the reliability value of the radio communication, the results are shown in the Fig. 10, corresponding to the horizontal lines. As shown in the Fig.10, because the communication distance and the maximum distance of the small and large cities in this case are the same, so the horizontal reliability values of the small and large cities are overlapped. It can also reflect the advantages of the proposed method compared to the results that do not change along with the carrier frequency.

5. Conclusions

Based on the investigation of existing path loss models, this paper comprehensively considers some important factors in communication systems, including the carrier frequency, operating environment, communication distance and equipment performance parameters of the radio communication system. Accordingly, the Okumura-Hata path loss model is adopted as the basic tool for radio transmission reliability evaluation. After using the simplified processing of the model, the communication distance is treated as a random variable which is fitted by the logarithmic normal distribution. Based on the solution of communication distance's PDF and CDF, we can inference that the path loss follows the Gaussian distribution, and the explicit model of the PDF is derived subsequently. By setting the path loss threshold, the reliability of various communication channels with different carrier frequencies can be evaluated.

Though in this paper the path loss threshold of various communication channels is not accurately measured but calculated through the maximum communication distance, the result of this method also reflects the effect of the communication scenarios on the radio communication. In the future work, the problem of the path loss threshold could be addressed by experimental test or simulation. The PM in this paper is also an empirical model. With the development of radio communication, the popularity of 5G and the increase of radio wave communication frequency, the empirical models of the propagation loss model is also constantly updated. If the basic propagation loss model is being updated, whether the proposed parameter fitting method is still applied to the reliability evaluation of the radio communication. This deserves further investigation in our future work.

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