

Radio Channel Modeling and Measurement of a Localization Rescue System

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Abstract—Nowadays with the frequent occurrence of natural disasters, there is a great demand for accurate and fast novel localization technique for rescue. Thanks for the advancements of modern wireless communication technology, lots of people own a mobile phone today, and the most important thing is that the phone is often the only device people carried when such disasters happen, which can send a radio signal to prove their exist. Thus, we can take use of this fact to search and rescue the victims in disaster areas. This paper presents the characterizing radio channel modeling in collapse and measurement experiment, which is a key component for developing a novel passive radio localization system. The behavior of wireless channel can be regarded as a stochastic process, the channel is composed of many complex random obstacles, their influence on the mobile signal propagation is simulated and measured to set up a database, the statistical characteristics of channel can be determined through plenty of simulation and measurement data.

I. INTRODUCTION

Last two decades have witnessed a dramatic boom in the wireless communications industry, hence increasing the number of users of mobile communication devices. Recent survey shows that the majority of buried victims carry their mobile phones in natural disasters like avalanches, earthquakes or landslides, this fact can be taken advantages for smart search and rescue applications when disasters happen. Of course, there are already several localization methods, but many are active, what's more, the victims usually can't do anything when buried and in faint, so they are not always suitable for search and rescue applications [1]. It is necessary to develop a new passive approach for mobile localization. Such development requires that the information of mobile signal attenuation and time delay is measured and modeled, through signal process technique, the position of victim within phone will be determined.

In order to capture the accurate information about the located phones, the characteristics of radio channel between the victim and location system must be determined, which will form the foundation for realization of location algorithm and hardware detection cell in the next rescue system development. Conventional studies have been mostly performed in indoor [2], outdoor-to-indoor environment, except an earthquake rescue

project made in Chengdu University of Technology and the famous "I-LOV" project made in Germany, almost no much study is performed in complex ruin environment after big disasters [3]. In disasters, the radio channel becomes pretty complex due to the complex ruin structures. The reflection, scattering and diffraction of electromagnetic waves introduce the attenuation and frequency dispersion character of the radio channel, even at the same position, the RF signals can become different at the next time interval. This actually yet becomes a challenge problem to deal with.

The method for modeling radio channel propagation can be divided in three main categories. The first one is using the ideal statistical model, typically assumed a complex Gaussian Channel. The second one is using ray-tracing method based on the establishment of geometric distribution of scatters in wireless channel [4], and the third method is based on measurement in actual physical environment. Due to the goodness of reality, simulation based on ray-tracing method and measurement method are employed in our work. Based on high precision measurement of channel response in time and frequency domain, a parametric model of radio channel is established. The channel impulse response power delay spectrum and other physical properties are employed to set channel model with parametric mathematical expressions, then using parameter estimation method to extract the model parameters from large amounts of measured data, thus the statistical character of channel in collapse can be analyzed and determined. As the two important parameters of the channel, the pass loss and the Root-Mean-Spread delay will suffer from different changes in different collapsed structures or at different frequency range, their statistic distribute characteristics can be analyzed in the channel model [5]. Taking account to small scale fading caused by multipath effects, the multipath delay and amplitude characteristics are also analyzed, respectively, spectral estimation techniques can be employed to model the channel [6]. Due to the limitation of our measurement condition, only the signal strength and channel received power are measured in this paper, the delay spread information will be measured and characterized in our future work.

II. CHANNEL MECHANISM

A. Small Scale Fading Mechanism

The channel in collapse first suffers from small scale fading caused by multipath propagation [7]. Our study is mainly performed on the mobile communication channel which works in the frequency range of 890MHz to 960MHz (GSM) and 1805 to 1880MHz in DCS network.

The radio channel in collapse can be regarded as fast time invariant in a extremely short time interval, so the multipath fading channel can be described as follows:

$$h(t) = \sum_{k=0}^{M-1} a_k \cdot \delta(t - \tau_k) \quad (1)$$

where M is the number of significant multipath components, a_k is the complex amplitude of the k 'th component arriving at receiving end. Channel Frequency Response (CFR) can be obtained utilizing the Fourier transform:

$$H(f) = \sum_{k=0}^{M-1} a_k \cdot e^{-j2\pi f \cdot \tau_k} \quad (2)$$

Radio channel is fully determined by $h(t)$ in time domain or by $H(f)$ in frequency domain.

The power delay profile (PDP) is the average of $h(t)$ [8]:

$$p(t) = E(|h(t)|^2) = \left| \sum_{k=0}^{M-1} a_k \cdot \delta(t - \tau_k) \right|^2 \quad (3)$$

where $E(\dots)$ denotes the mathematical expectation. The mean excess delay D and τ_{rms} can be calculated through $p(t)$.

B. Large Scale Fading Mechanism

Considering over a longer time frame, the received signal strength is variable due to different radio channel environment, this fact reflects the large scale fading of the radio channel [9]. Pass loss in collapse can be divided into two loss mechanism.

$$P_L = L_{free} + L_{obstacle} \quad (4)$$

In line-of-sight condition, L_{free} is approximately yielded with the dB form as below:

$$L_{free} = 32.4 + 20 \lg r + 20 \lg f \quad (5)$$

where the units of r and f is km and MHz, respectively.

$L_{obstacle}$ is related to the ruin structure and the material property of obstacles. Research shows that the attenuation constant (α) through obstacle is determined by the complex permittivity and permeability of the material, as well as the frequency of electromagnetic waves:

$$\alpha = f(\mu, \tilde{\epsilon}, \omega) \quad (6)$$

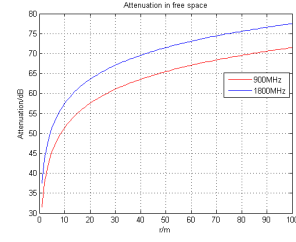


Fig.1. Attenuation in free space

For plane wave incident into obstacles with infinite transverse size, the attenuation factor can be derived from plane wave theory. Simulation can be done based on this result. Research shows that this approximate method is significant if the phone is fully covered with obstacles.

$$\alpha = \omega \sqrt{\frac{\mu \epsilon}{2} \left(\sqrt{1 + \left(\frac{\sigma}{\omega \epsilon} \right)^2} - 1 \right)} \quad (7)$$

where σ is the conductivity of obstacle material.

If the ruin is stratified structure, it can be described as following:

$$L_{obstacle} = \sum_k \alpha_k \cdot h_k \quad (8)$$

h_k is the thickness of k layer barrier. Attenuation constant is studied in many literatures in fact. Thus if the thickness of every obstacle is measured, the total attenuation is calculated.

The received signal strength can be studied from statistical perspective. Let S_n denote the signal strength through n layer obstacle, then

$$S_n = S_0 \cdot e^{-\sum_{k=1}^n \alpha_k h_k} \quad (9)$$

α_k and h_k can be regarded as mutually independent random variables since they are different for different obstacles, and not relevant with each other. In the case of heavy disasters, large numbers of complex obstacles appear in ruins, so according to the Central-Limit-Theorem for independent identical distribution, when the number of obstacles n is large

enough, the sum $\sum_{k=1}^n \alpha_k \cdot h_k$ obeys normal distribution approximately. Thus the logarithm of received signal strength $S = 10 \lg s$ is a normal Gauss process, obeying normal distribution $N(\mu_s, \sigma_s^2)$:

$$p(S) = \frac{1}{\sqrt{2\pi\sigma_s}} e^{-(S-\mu_s)^2/2\sigma_s^2} \quad (10)$$

The statistical characteristic of signal strength suffered from ruin attenuation obeys lognormal distribution in some case, this fact can be validated through future measurement.

III. SIMULATION

In the disaster debris area, mobile phones may be buried or blocked by all sorts of obstacles, such as collapsed wall, ferroconcrete, soil, clay, cement brick, sand, glass, pipes, furniture, etc. Their electromagnetic parameters and distribution structure situation seriously affect the spread of mobile signal, due to penetration, reflection, absorption, diffraction and scattering phenomenon. Through large numbers of simulation experiments and actual measurement, a database which contains the geometry and electromagnetic information of obstacles will be established to analysis their barrier effect.

The electromagnetic parameters of common obstacle materials have been researched by many literatures. Most barrier materials are non-magnetic materials, their complex permittivity, conductivity and loss angle are the main parameters which affect signal propagation.

Ferroconcrete is one of the main material of modern architecture, as well as the most common obstruction material in collapse. Different material of concrete and different number of steel bars make different effect on wireless communication. As a reference, we choose ferroconcrete with relative dielectric constant 6.5 and loss tangent 0.2 (at 900MHz) for simulation. The penetration loss is about 0.46 dB/cm for GSM signal as shown in fig 2. This value is very close to the measurement of ferroconcrete wall in IMTEK buildings in "I-LOV" project [9]. Cement brick with relative dielectric constant 5 and conductivity 0.05 is also simulated.

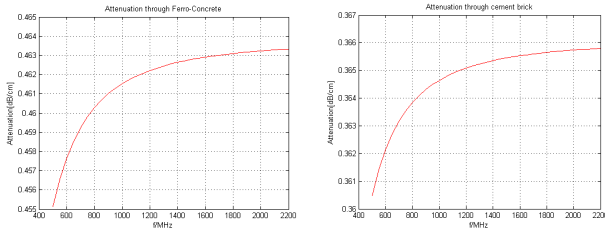


Fig.2. Penetration loss in ferroconcrete and bricks

As a contrast, Table I shows the difference between our simulation and measurement results in "I-LOV" project. Simulation results are higher than measurement value due to the infinite transverse size of obstacle in simulation and the finite obstacle size in actual field measurement, and their electric parameters are not same yet.

TABLE I.
THE ATTENUATION FACTORS FOR GSM900 SIGNAL BETWEEN SIMULATION AND MEASUREMENT

	Our Simulation	Measurement in "I-LOV" project
$\alpha_{ferroconcrete}$ [dB/cm]	0.46	0.42 [9]
α_{brick} [dB/cm]	0.36	0.27 [10]

Simulation shows that the conductivity of obstacle material is the most important parameter which affects the penetration loss of wireless signal. Metal has large conductivity, for metal furniture materials, due to the influence of skin effect of the electromagnetic wave, signal penetration depth is limited,

which causes electromagnetic shielding effect, leading to serious signal attenuation. Other obstacle materials will be investigated in the future.

IV. MEASUREMENT

Field measurement is the most popular mean to estimate and analyze the characteristics of radio channel. Analysis of the radio channel in collapse strongly depends on the original database acquired from measurement [8][9]. Channel measurement can be conducted in both time domain and frequency domain. This paper presents the measurement results conducted in frequency domain as shown in Fig.3. which is set up based on a vector network analyzer or spectrum analyzer.

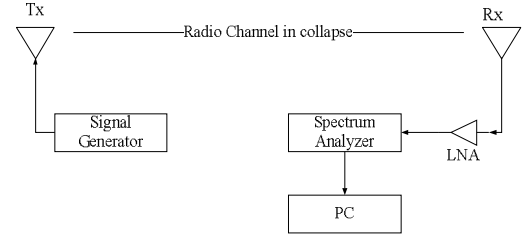


Fig.3. Measurement platform

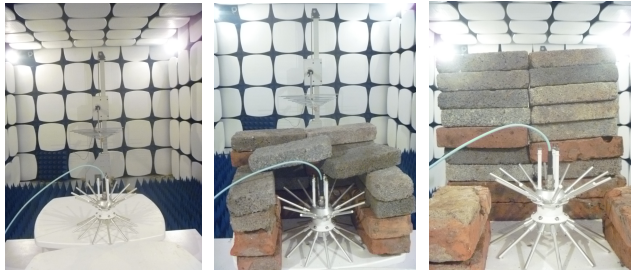
The transmitting antenna is buried in ruins, which simulates the buried phone with weak signal launched, while the receiving antenna is fixed in a certain height. The LNA is utilized to increase the dynamic range of received signal if possible. Taking account of the behavior of antennas, cables, and measurement equipment itself, calibration aimed at reducing the effect of other unexpected channels must be on the way. The method is conducting the same measurement without ruins, after removing this response component, it is the behavior of ruin channel itself.

For the limitation of experimental conditions, experiment is conducted in a $7 \times 4 \times 3$ m electromagnetic shielding absorbing chamber at first stage. Agilent analog signal generator N5183A is used to generate the signal with 1W power. An omnidirectional double-cone antenna with 500MHz to 3GHz bandwidth is employed as transmitting antenna, and a directional log-periodic antenna with 200MHz to 2GHz bandwidth is employed as receiving antenna. Agilent signal analyzer N9020A is utilized to measure the signal strength outside the chamber. Some bricks are used as obstacles. Two frequency band and two polarization mode are conducted. The distance between two antennas is 3m.

Figures 4, 5 and 6 show the measurement environment and results. The measured channel power spectrum density is shown in Tab. II.

The measurement shows two results. Firstly, the signal vertically received is larger than that of horizontally received both at 900MHz and 1800MHz, it is caused by the vertical polarization mode of two antennas. Secondly, obstacles show different effect on 900MHz and 1800MHz. There is an interesting phenomenon that the maximum signal strength with bricks is a little bigger than without bricks at 900MHz, while it doesn't happen at 1800MHz. At 900MHz, the signal wave length is close to the obstacle size, so the diffraction

phenomenon is obvious, while for 1800MHz signal, wave length is smaller, it is more difficult to diffract. As a result, the channel in 900MHz is more stable than in 1800MHz. Channel with obstacles introduces multipath effect, received signal is the superposition of every path signal, coupled with the influence of antenna pattern, the total maximum signal is weaken someplace while it may be enhanced at another place.



(a) No obstacles (b) Bricks surrounding (c) Bricks stop

Fig.4. Measurement environment

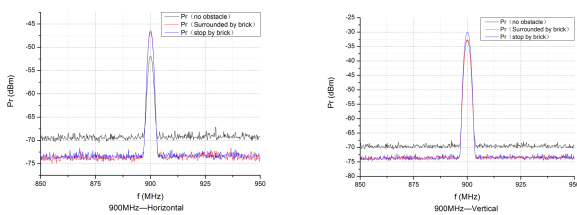


Fig.5. Measured received power at 900MHz

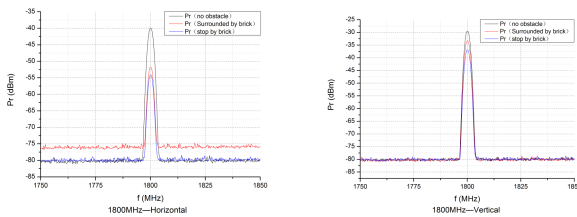


Fig.6. Measured received power at 1800MHz

TABLE II.
CHANNEL POWER SPECTRUM DENSITY (PSD) OF MEASUREMENT

Freq.	Polarization	PSD (dBm/Hz)		
		(a)	(b)	(c)
900MHz	Horizontal	-116	-109.7	-110.1
	Vertical	-96.9	-96.1	-96.5
1800MHz	Horizontal	-103.1	-115.2	-117.5
	Vertical	-93	-96.8	-100

V. CONCLUSION

This paper presents a modeling and simulation method of radio channel in collapse when disasters happen for rescue, which makes up the most important component for our radio

localization system. The channel suffers small scale fading and large scale fading, its behavior can be processed as a stochastic process. As a statistical result in theory, the received signal strength obeys lognormal distribution in some case, future measurement is on the scheme to validate this result. Simulation based on numerical calculation is done to analyze the loss of some typical obstacles in collapse area. Ferroconcrete and bricks are investigated first, simulation results are similar to measurement results in "I-LOV" project. Measurement in dark chamber shows that the radio channel performs different characteristics at different frequency range. Coupled with the multipath effect and diffraction phenomenon, obstacles in channel show quite different effect on 900MHz and 1800MHz frequency. As a result, signal at 900MHz frequency shows diffraction more easier than that of 1800MHz. More field measurement will be conducted in future.

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