Wireless Communication Characteristics for Tunnels with and without Traffic

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Abstract

The bit error rate performance for high-speed personal communication service in tunnels with and without traffic is investigated. The impulse responses of tunnels with and without traffic for any transmitter-receiver location are computed by shooting and bouncing ray/image techniques. By using the impulse responses of these multipath channels, the bit error rate performance of BPSK (binary phase shift keying) system with phase and timing recovery circuits are calculated. Numerical results have showed that the multipath effect by the vehicles in the tunnel is an important factor for bit error rate performance. In addition, the effect of space diversity techniques on mitigating the multipath fading is also investigated.

I. Introduction

In the North Second Superhighway in Taiwan, there are twenty-three tunnels with a total length of 15880 meters. It is necessary to have a good understanding of radio wave propagation mechanisms to establish high-speed personal communication service (PCS) in tunnels. However, relatively few information is available on the wide-band propagation characteristics in such environments [1]. The propagation characteristics due to the heavy wave-guiding and multipath effects are much different from those of open-area mobile systems. In tunnel environments, propagation is dominated by multiple reflection from walls, floor and obstruction resulting in frequency selective multipath fading. Delay distortion due to multipath fading is a serious cause of channel degradation and imposes an upper limit on signal symbol rate.

Many studies have been concentrated on leaky coaxial cable in tunnel communication systems [1]-[3]. However, at the PCS frequency (1-2 GHz), the attenuation of coaxial cables becomes excessive and the cost is high. An alternative way to establish communication in tunnels is building a relay antenna at the entrance of tunnels. Some researches on the narrow-band propagation characteristics in empty tunnels have been presented [4]-[5]. Nevertheless, only a few investigations have been made on narrow-band propagation characteristics for tunnels with traffic [6]-[8]. To our knowledge, no wide-band propagation characteristics that take into account the effects of vehicles have been analyzed.

In this paper, the bit error rate (BER) performance of PCS in complex tunnels with and without traffic is investigated. The space diversity techniques to reduce the fading effect are also presented. Theoretical part of the method is presented in section II. Section III shows the numerical results. Finally, some conclusions are drawn in section IV.

II. Theoretical Part

(A)Calculation of the channel characteristics

The equation used to model the multipath radio channel is a linear filter with an equivalent baseband impulse response given by

$$h_b(\tau)=\sum_{k=0}^{N}\beta_k e^{j\theta_k}\delta(\tau-\tau_k) \qquad (1)$$

where k is the path index, β_k is the path gain, θ_k is the phase shift and τ_k is the time delay of the kth path. $\delta(\,)$ is the Dirac delta function. The goal of channel modeling is to determine the β_k's, θ_k's, and τ_k's for any transmitter-receiver location in the building.

Let us consider a curved arched tunnel as shown in Fig. 1. The boundary of tunnel is composed of triangular facets and consists two straight segments and a curved one. The impulse response function of each building for any transmitter - receiver location is computed by modified shooting and bouncing ray/image (SBR/Image) techniques [8],[9]. The SBR/Image method can deal with high frequency radio wave propagation in complex indoor environments. It conceptually assumes that many triangular ray tubes (not rays) are shot from the transmitter and each ray tube bouncing and penetrating in the environments is traced. If the receiver is within a ray tube, the ray tube will have contribution to the received field and the corresponding equivalent source (image) can be determined. In addition, the first order wedge diffraction is included, and the diffracted rays are attributed to corresponding images. By using these images and received field, the impulse response of the channel, $h_{rf}(t)$, can be obtained. As a result, the parameters β_k, θ_k, and τ_k in Eq. (1) for the equivalent baseband impulse response, $h_b(t)$, can be obtained. Note that $h_{rf}(t)$ is equal to $h_b(t)e^{i\omega_c t}$, where ω_c is the angular carrier frequency.

A squaring-enveloped scheme is used for timing recovery circuit, [10], [11]. In the phase recovery circuit, the near optimum remodulation scheme suggested in [12] is used. In this method, the phase of the overall complex baseband channel impulse response is used as the phase reference.

(C) Space diversity techniques

Diversity reception is usually regarded as a means of combating fading in radio wave transmission. In dual space antenna diversity system, the dual diversity structure has two receiver sections that process the incoming signals independently. Each section is the cascade of a receiver filter and an adaptive equalizer, and the diverse signals are equalized at separate receiver sections as shown in Fig. 2. After demodulation and equalization of the two diversity channels, the selector pick the channel with lower error rate. In other word, $P_e = \min\ [P_e \text{ for channel } 1,\ P_e \text{ for channel } 2]$.

III. Numerical Results

Let us consider a curved arched tunnel as shown in Fig. 1(a). The top view and cross section of the tunnel are plotted in Fig. 1(b) and Fig. 1(c) respectively. The relative dielectric constant and the conductivity of the lossy material outside the tunnel are 5.5 and 0.03 S/m, respectively, according to Chiba [5]. The transmitting and receiving antennas are both half-wave dipoles and vertically polarized. The transmitting antenna Tx is located at the center of the tunnel entrance with the height of 5 meters. The locations of receiving antenna with a fixed height of 1.5 meters are uniformly distributed in the tunnel and they are total 1000 receiving points. For dual space antenna diversity, the two receiving antennas are separated by 1/4 wavelength. The impulse response of the tunnel was calculated at 1.9 GHz by SBR/Image method. The number of ray tubes shooting from transmitter is 800,000. The maximum number of bounces setting beforehand is twenty, and the convergence is confirmed. Tunnels with and without vehicles are considered in the simulation. Vehicles are simulated by metallic rectangular boxes which are modeled with triangular facets. Two type of vehicles are considered. One is a small car with the dimension of 1.3m (high) x 1.5m (wide) x 4.5m (long), and the other is a truck with 2.8m high, 2m wide and 7.5m long. The cars and trucks are located 0.2m above the ground. The top view of the tunnel with vehicles is shown in Fig. 1(b). Figs. 3(a)-(b) show the impulse responses of the empty tunnel at Rx(59m,108m,1.5m) and Rx(107m,50m,1.5m). Similarly, the impulse responses of the tunnel with vehicles are plotted in Figs. 4(a)-(b) to correspond the receivers at Rx(59m,108m,1.5m) and Rx(107m,50m, 1.5m). Note that the locations of receivers for the tunnel with vehicles are the same as those for the empty tunnel. The prominent peak found at the delay time of 180 ns in plots of Fig. 3(a) and Fig. 4(a) is the peak corresponding to the wave arriving directly from the transmitter, other less prominent peaks are considered to be multipath components reflected from the walls and floor. Fig. 3(b) and Fig. 4(b) are out-of-sight cases. Note that the first peaks are not always the largest ones. From Fig. 3, it is seen that the multipath effect is not severe for the case of empty tunnel. This is due to the fact that the arched shape tunnel causes "focusing" effects and results in constructive interference. Comparison of Fig. 3 and Fig. 4 reveals that the multipath effect is more severe for the case of the tunnel with vehicles than that of the empty tunnel. This can be explained by the fact that the "focusing" effects in arched shape tunnel has been destroyed when the vehicles exist.

In order to observe the statistical properties of these environment more detail, the cumulative distributions of the rms delay spreads for tunnel with and without traffic are plotted in Fig. 5. In addition, the mean values and the standard deviations of the rms delay spreads are depicted in Table 1. It is found that the mean rms delay spread for the empty tunnel is smaller than that for the tunnel with traffic. This indicates that the multipath effect for tunnel with traffic is very severe.

Next, let us consider the BER performance for the following three different receiver structures:

(i) BPSK receiver without DFE

(ii) BPSK receiver with DFE

(iii) Dual space diversity BPSK receiver with DFE

The optimal size of an equalizer depends on the delay spreads of the channels. A channel with a large mean rms delay spread value needs an equalizer with more taps. Here DFE with four forward and three feedback taps are used. Two receiving antennas separated 4cm (about 1/4 wavelength) are used for dual space antenna diversity. The BERs at unfaded SNR (signal to noise ratio)=160dB for tunnels with and without traffic are calculated. Here unfaded SNR is defined as the ratio of the transmitted signal power to the noise power at the front end of the receiver. The BERs are used to calculate the outage probability. Outage probability is the average performance criteria for digital transmission system. Outage occurs whenever the system error rate equals or exceeds a threshold P_{th}. Usually for voice circuits $P_{th} = 10^{-3}$ and for data $P_{th} = 10^{-5}$. For the BER requirement of BER $P_{th} = 10^{-5}$, the outage probabilities versus different transmission rate for tunnels with and without traffic are shown in Fig. 6. From Fig. 6, it is obvious that the BER performance is still good for the case of the empty tunnel even the transmission rate is up to 100Mbps. On the contrary the outage probability for the tunnel with traffiic is more than 5% when the transmission rate is as low as 15Mbps. This phenomena indicate that the multipath effect by the vehicles in the tunnel is an important factor for bit error rate performance. In addition, for aiming the transmission rate above 10MHz, dual space diversity receiver with DFE is more suitable than the other two receiver structures.

IV. Conclusions

The BER performance for high-speed BPSK

communication in tunnels with and without traffic has been investigated. The impulse response of the tunnel is calculated by SBR/Image method. By using the impulse response of the multipath channel, the BER for high-speed communication in tunnel has been calculated. It is found that the BER performance for the tunnel without traffic is better than that with traffic. This is due to the fact that the multipath effect is severe when vehicles exist in the tunnel. Moreover, the effect of dual space diversity techniques and decision feedback equalizer on mitigating multipath fading is also investigated. Numerical results show that diversity techniques and decision feedback equalizer can combat the multipath fading.

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References

[1] P. Delogne, "EM propagation in tunnels", *IEEE Trans. Antennas Propagat.*, vol. 39, pp. 401-406, March 1991.

[2] P. Delogne, "Basic mechanisms of tunnel propagation," *Radio Science*, vol. 11, no. 4, pp. 295-303, April 1976.

[3] P. Delogne, *Leaky Feeders and Subsurface Radio Communications*, Stevage, U.K.,1982.

[4] A. G. Emslie, R. L. Lagace and P. F. Strong, "Theory of the propagation of UHF radio waves in coal mine tunnels", *IEEE Trans. Antennas Propagat.*, vol. 23, no. 2, pp. 192-205, Mar. 1975.

[5] J. Chiba, T. Inaba, Y. Kuwamoto, O. Banno and R. Sato, "Radio communication in tunnels," *IEEE Trans. Microwave Theory Tech.*, vol.26, no. 6, pp. 439-443, June 1978.

[6] T. Klemenschits and E. Bonek, "A radio coverage of road tunnels at 900 and 1800 MHz by discrete antenna", *5th IEEE Symposium on Personal, Indoor and Mobile Radio Communications*, pp. 411-415, Sept. 1994.

[7] Y. Yamaguchi, T. Abe and T. Sekiguchi, "Radio wave propagation loss in the VHF to microwave region due to vehicles in tunnels", *IEEE Trans. Electromagn. Compat.*, vol. 31, no. 1, pp. 87-91, Feb. 1989.

[8] S. H. Chen and S. K. Jeng, "SBR/Image approach for radio wave propagation in tunnels with and without traffic," *IEEE Trans. Veh. Technol.*, vol. 45, pp. 570-578, Aug. 1996.

[9] S. H. Chen and S. K. Jeng, "An SBR/Image approach for radio wave propagation in indoor environments with metallic furniture," *IEEE Trans. Antennas and Propagat., vol. 45, pp. 98-106, Jan 1997.*

[10] N. Amitay and L. J. Greenstein, "Multipath outage performance of digital radio receivers using finite-tap adaptive equalizers," *IEEE Trans. Commun.*, vol. 32, pp. 597-608, May 1984.

[11] L. J. Greenstein and B. A. Czekaj-Augmn, "Performance comparisons among digital radio technologies subjected to multipath fading," *IEEE Trans. Commun.*, vol. 30, pp. 1184-1197, May 1982.

[12] J. C. Chuang, "The effects of multipath delay spread on timing recovery," *IEEE Tran. Veh. Technol.*, vol. 35, pp. 135-140, Aug. 1987.

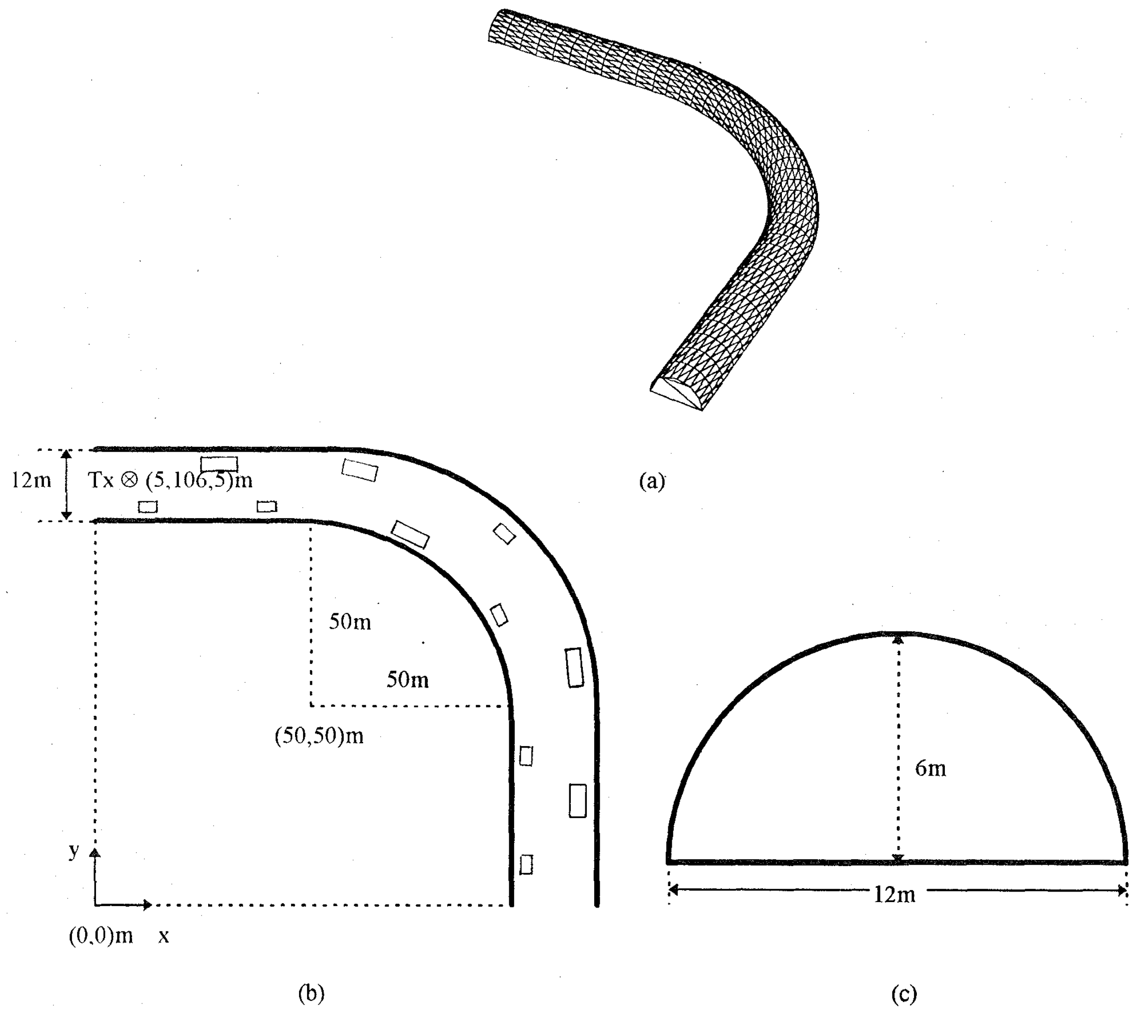


Fig. 1 A tunnel modeled by triangular facets. (a)Tunnel structure (b) Top view of the tunnel with vehicles (c) Cross section of the tunnel

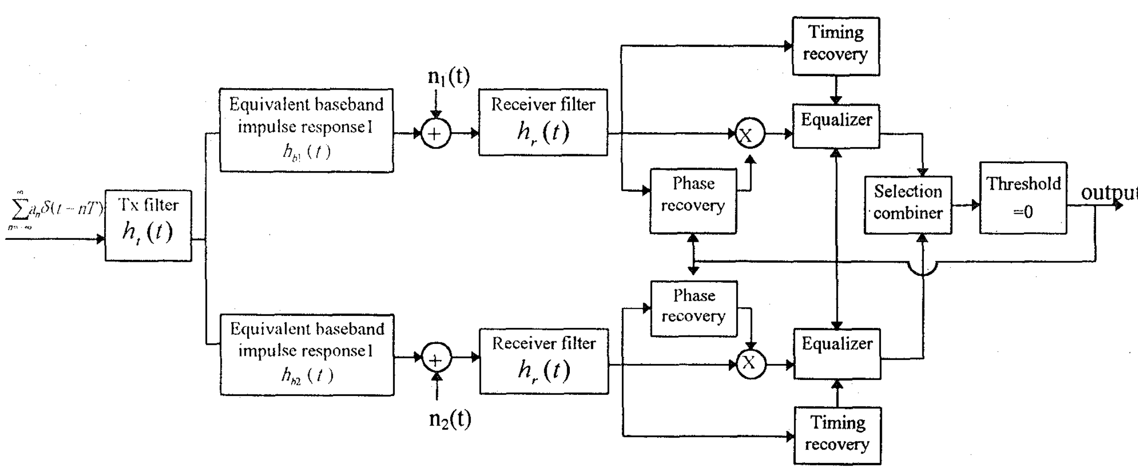
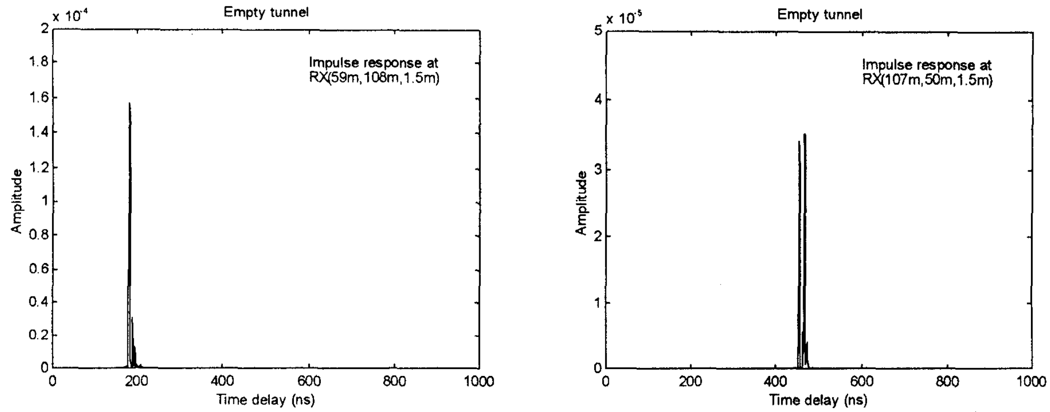
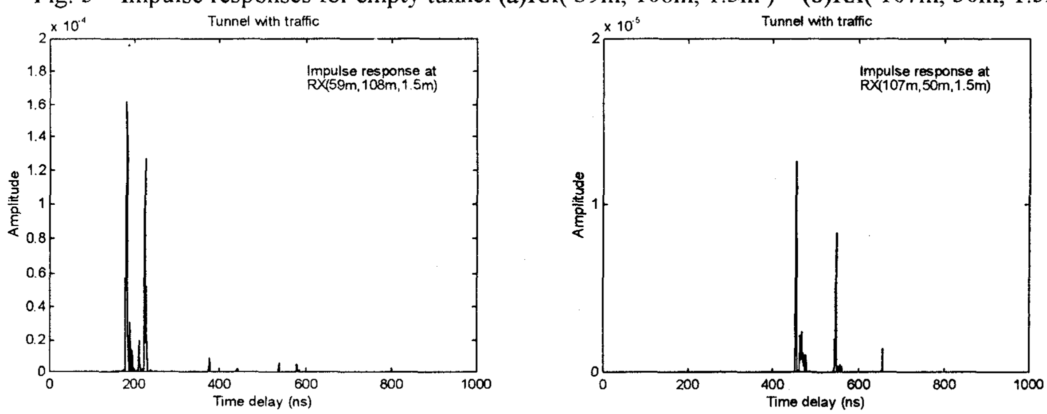


Fig. 2 Block diagram of equivalent baseband communication system with dual space antenna diversity.



(a) (b)

Fig. 3 Impulse responses for empty tunnel (a)Rx(59m, 108m, 1.5m) (b)Rx(107m, 50m, 1.5m)



(a) (b)

Fig. 4 Impulse responses for tunnel with traffic (a)Rx(59m, 108m, 1.5m) (b)Rx(107m, 50m, 1.5m)

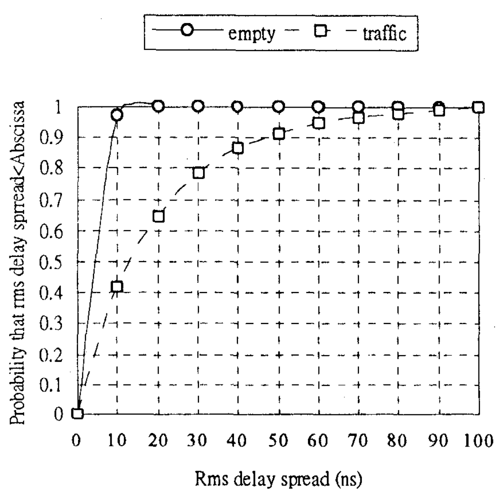
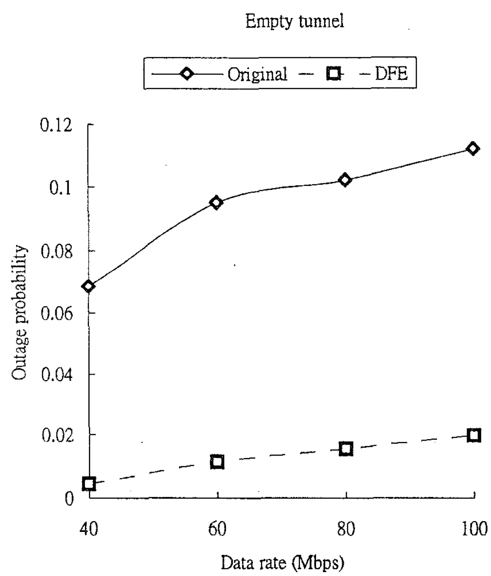
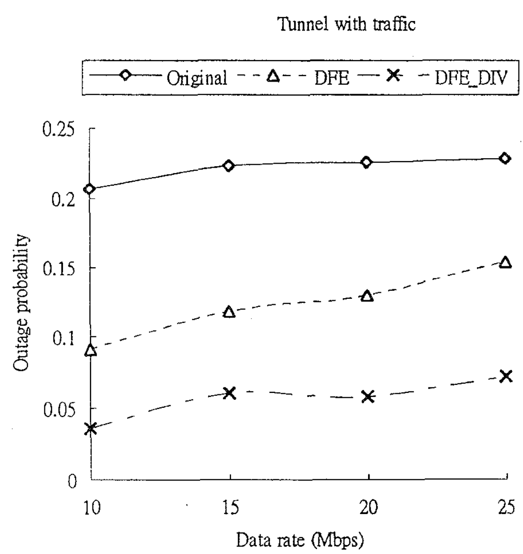


Fig. 5 Cumulative distributions of rms delay spreads for tunnels with and without traffic.



(a)



(b)

Fig. 6 Outage probabilities versus transmission rate for tunnels with and without traffic and three different receiver structures. (a) for the empty tunnel (b) for tunnel with traffic

Parameters / Shapes	Rms delay spread τ_{rms}	
	mean	standard deviation
Empty tunnel	4.23 ns	2.72 ns
Tunnel with traffic	19.8 ns	19.64 ns

Table 1 Mean and standard deviation of the rms delay spreads for tunnels with and without traffic.