Bit Error Rate Performance of High-Speed Tunnel Communication

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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 response of the tunnel is computed by shooting and bouncing ray/image techniques. Binary data with phase shift keying modulation are transmitted over the multipath channel and coherent match filters are used as receivers. The bit error rate for communication in tunnels with and without traffic is 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]. 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 [2]. Nevertheless, only a few investigations have been made on narrow-band propagation characteristics for tunnels with traffic [3]-[5]. 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.

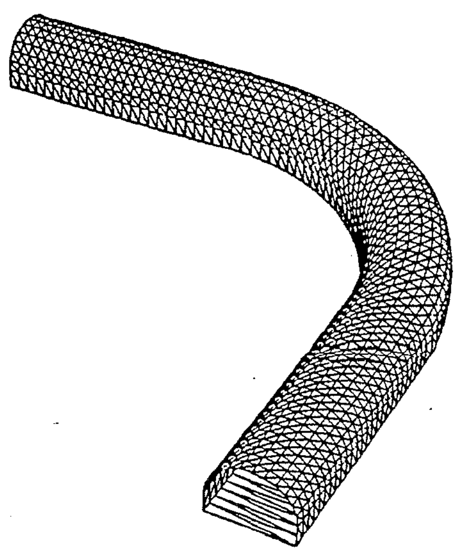


Fig. 1 A tunnel modeled by triangular facets.

II. Theoretical part

(A) Calculation of the channel characteristics

Let us consider a curved arched tunnel as shown in Fig.1. The boundary of the tunnel is composed of triangular facets. The tunnel is composed of two straight segments and a curved one. The impulse response of the tunnel is computed by modified shooting and bouncing ray/image (SBR/Image) techniques [5]. This method can deal with the high frequency radio wave propagation in complex indoor environments. It conceptually assumes that many triangular ray tubes (not rays) are shooting 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 summing all the contribution of these images, we can obtain the total received field at the receiving antenna for any given carrier frequency.

(B) System block diagram

The block diagram of the simulated system is shown in Fig. 2. Binary data with biphase shift keying (BPSK) modulation are transmitted over the multipath channel. A coherent demodulation without synchronization error is assumed. In Fig. 2, $h_{rf}(t)$ is the impulse response of multipath propagation channel between the transmitter and receiver. $h_t(t)$ and $h_r(t)$ represent the transmitted waveform and the receiving filter respectively. They are both chosen as the impulse response of the square root of the raised cosine function with rolloff value 0.5. n(t) is zero-mean additive Gaussian noise. a_n is the binary data and T is the transmitted interval of binary data. The carrier frequency is denoted by ω_c. BER of the simulated communication system can be calculated by the method described in [6].

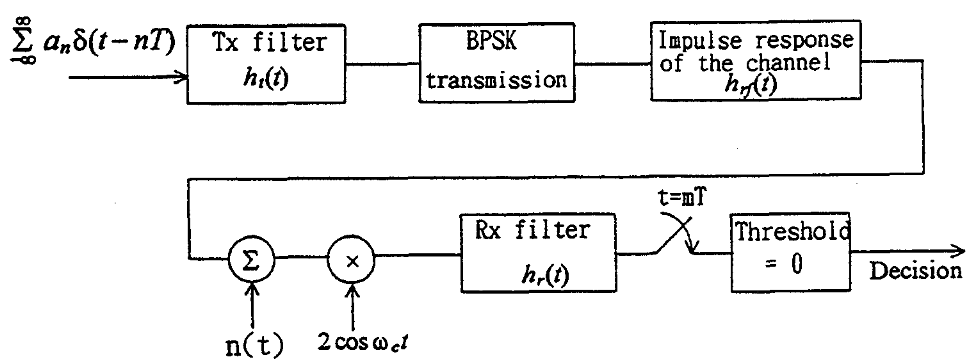


Fig. 2 Block diagram of the simulated communication system.

(C) Space diversity techniques

Diversity reception is usually regarded as a means of combating fading in radio wave transmission. In space diversity, several antennas separated in space are used to process the various received signals. The basic idea behind this concept is that the received signals on different antennas are statistically independent (or at least highly uncorrelated) and therefore there is a good chance that they will not all fade at the same time. Post detection and selection combining is used in the dual space antenna system. That is, after demodulation, the two receiving signals are compared and the one with larger envelope is selected at the sampling time. For simplicity, the BER is calculated by the method described in [6] under the assumption that the selection is made in noise free environments. This selection assumption is reasonable when SNR is high.

III. Numerical Results

Let us consider a curved arched tunnel as shown in Fig. 1. 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 [2]. 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 are plotted in Fig.3 with the fixed height of 1.5 meters. For dual space antenna diversity, the two receiving antennas are separated by 1/4 wavelength. 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) $\times$ 1.5m (wide) $\times$ 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. 4. Figs. 5(a)-(b) show the impulse responses of the empty tunnel at Rx2 and Rx15 respectively. Similarly, the impulse responses of the tunnel with vehicles are plotted in Figs. 6(a)-(b) to correspond the receivers at Rx2 and Rx15 respectively. Note that the locations of receivers for the tunnel with vehicles are the same as those for the empty tunnel. From Fig. 5 and Fig. 6, 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. 5 and Fig. 6 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.

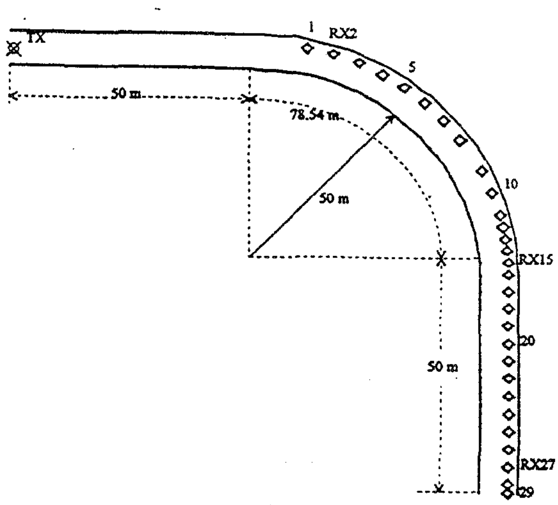


Fig. 3 Top view of the tunnel . TX denotes the transmitter. ◆ denotes the receiver.

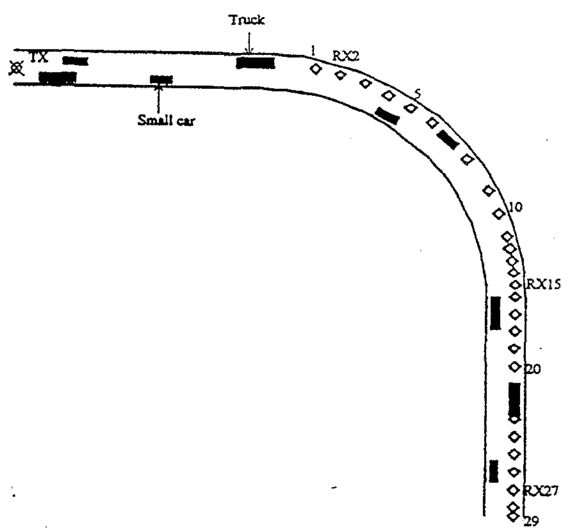
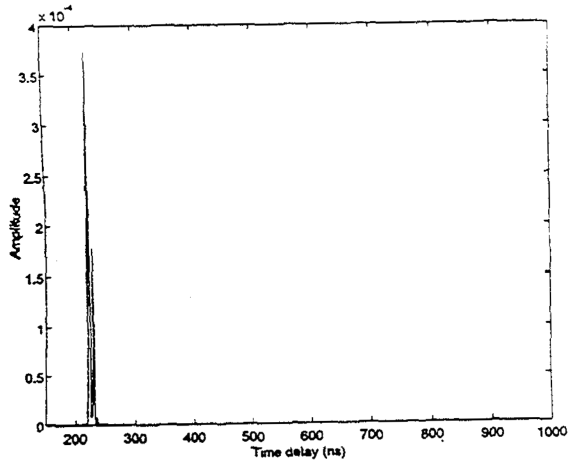
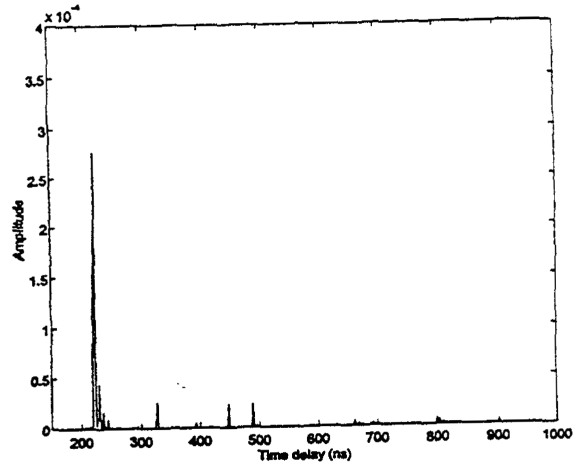


Fig. 4 Top view of the tunnel with traffic. The black rectangles represent the vehicles. TX denotes the transmitter. ◆ denotes the receiver.

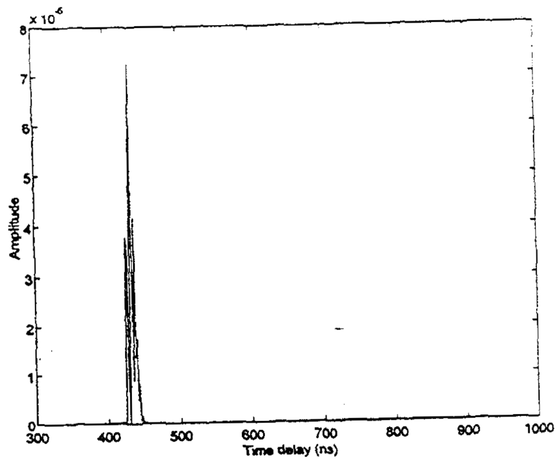


(a)

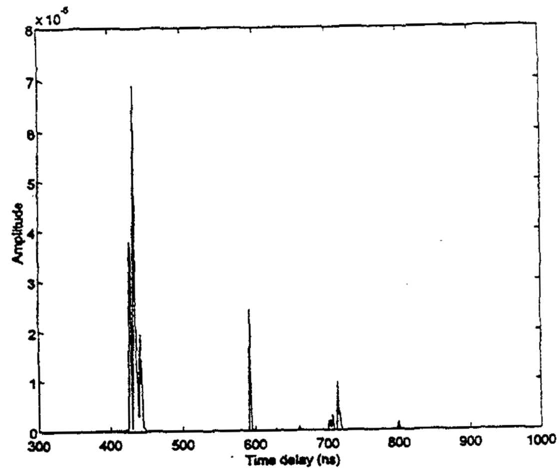


(b)

Fig. 5 Impulse responses for the empty tunnel
(a) Receiver at RX2
(b) Receiver at RX15



(a)



(b)

Fig. 6 Impulse responses for the tunnel with traffic
(a) Receiver at RX2
(b) Receiver at RX15

Now, let us consider the BER performance for the communication systems shown in Fig. 2. The BER at 100 Mbps transmission rate versus signal to noise ratio (SNR) for the cases of tunnels with and without traffic is depicted in Fig. 7 for the receiver at RX15. Here SNR is defined as the ratio of the power of the carrier of the first peak to the noise power at the front end of the receiver. From Fig. 7, it is clear that space diversity techniques can reduce the BER. In particular, for the case of the tunnel with traffic, the BER is reduced very much when the space diversity techniques are employed. For the case of the empty tunnel, it is seen that the space diversity gain in SNR for BER=10^{-5} is about 4 dB. It is also found that the BER for the case of the tunnel with traffic is higher than that for the case of the empty tunnel. This can be explained by the fact that the multipath effect is more severe for the case of the tunnel with traffic.

For a SNR of 15 dB, the BER performance as function of transmission rate is shown in Fig.8 for the receivers at and RX27 respectively. Since it is meaningless to plot too small value of the BER, the plotted smallest BER is 10^{-20}. That is, the BER is plotted as 10^{-20} in the figure, while the BER is less than 10^{-20}. The numerical results indicate that the BER for the case of the empty tunnel is lower than that for the case of the tunnel with traffic. In particular, from Fig. 8, when the transmission rate is up to 125 Mbps, the BER for the case of the tunnel with traffic is more than 10%. On the contrary, the BER performance is still good for the case of the empty tunnel.

The BER at 50 Mbps and SNR=15 dB for the case of the tunnel with traffic versus different receiving locations is shown in Fig. 9. It is seen, for lower transmission rate, the space diversity techniques can mitigate the multipath fading to reduce the BER at 6 different receiving locations.

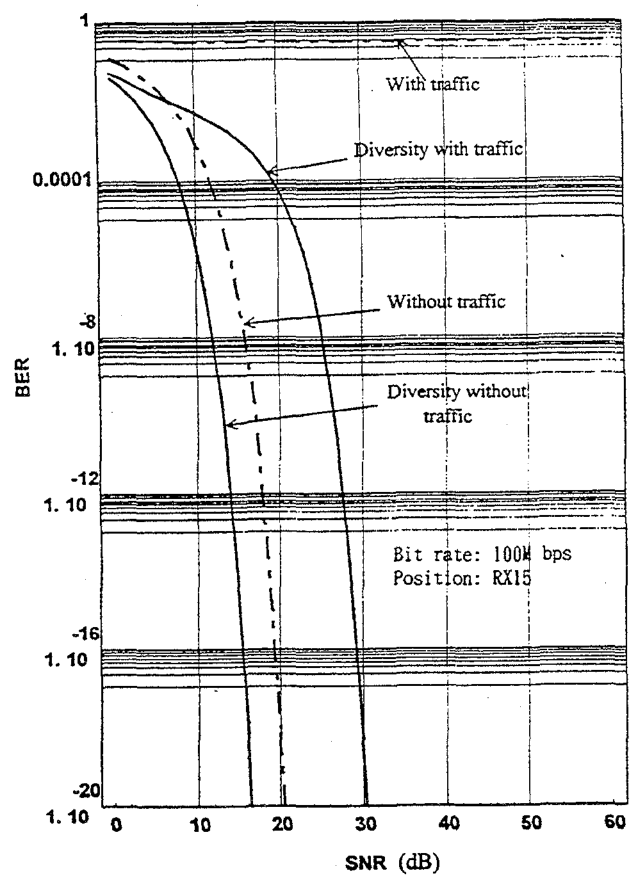


Fig. 7 Dependence of BER on SNR for the cases of tunnels with and without traffic. The transmission rate is 100 Mbps and the receiver is located at RX15.

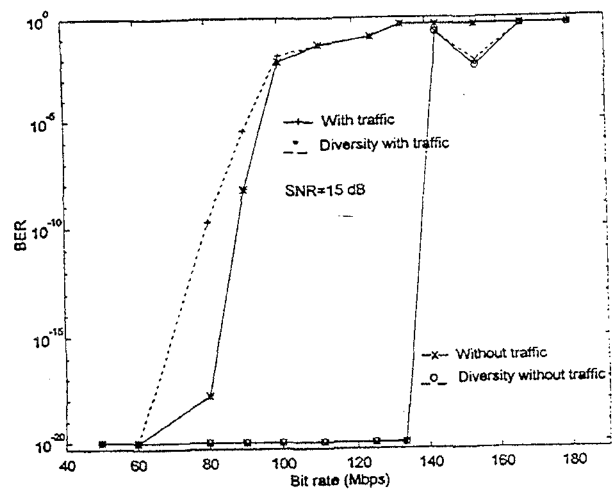


Fig. 8 Dependence of BER on transmission rate for the cases of tunnels with and without traffic. SNR is 15 dB. The receiver is located at RX27.

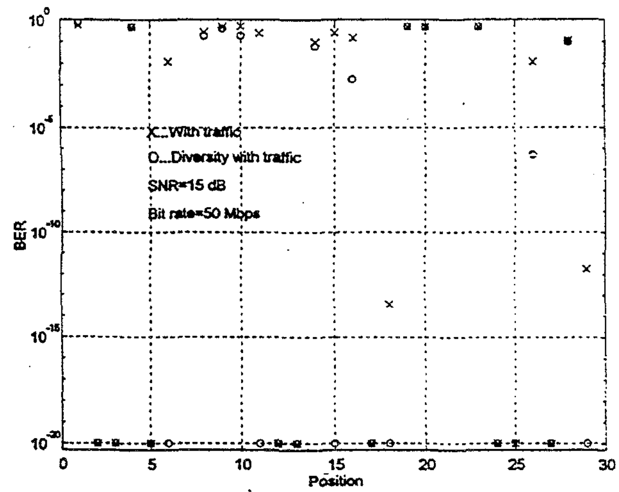


Fig. 9 Dependence of BER on different receiving locations for the case of the tunnel with traffic. SNR is 15 dB and the transmission rate is 50Mbps.

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 space diversity techniques on mitigating multipath fading is also investigated. Numerical results show that diversity techniques can combat the multipath fading.

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