The Influence of Noise Environment upon Voice and Data Transmission in the RF-CBTC System

Minseok Kim*, Sanghyeok Lee**, and Jongwoo Lee†

Abstract

The RF-CBTC (Radio Frequency-Communication Based Train Control) System is a communication system in railroad systems. The communication method of RF-CBTC system is the wireless between the wayside device and on-board device. The wayside device collects its location and speed from each train and transmits the distance from the forwarding train to the speed-limit position to it. The on-board device controlling device controls the speed optimum for the train. In the case of the RF-CBTC system used in Korea, transmission frequency is 2.4 [GHz]. It is the range of ISM (Industrial Scientific and Medical equipment) band and transmission of voice and data is performed by CDMA (Code Division Multiple Access) method. So noises are made in the AWGN (Additive White Gaussian Noise) and fading environment. Currently, the SNR (Signal to Noise Ratio) is about 20 [dB], so due to bit errors made by noises, transmission of reliable information to the train is not easy. Also, in the case that two tracks are put to a single direction, it is needed that two trains transmit reliable voice and data to a wayside device. But, by noises, it is not easy that just a train transmits reliable information. In this paper, we estimated the BER (Bit Error Rate) related to the SNR of voice and data transmission in the environment such as AWGN and fading from the RF-CBTC system using the CDMA method. Also, we supposed the SNR which is required to meet the BER standard for voice and data transmission. By increasing the processing gain that is a ratio of chip transmission to voice and data transmission, we made possible voice and data transmission from maximally two trains to a wayside device, and demonstrated it by using Matlab program.

Keywords: Bit error rate, Code division multiple access, Processing gain, Radio frequency-communication based train control, Signal to noise ratio

1. Introduction

Like the train controlling system, in the system necessary for safety, it is important that the transmission of train controlling information is accurate. The RF-CBTC system is a communication system in railroad systems. The communication method of RF-CBTC system is the wireless between the wayside device and on-board device. The wayside device collects its location and speed from each train and transmits the distance from the forwarding train to the speed-limit position to it [1].

In case of the RF-CBTC system used in Korea, transmission frequency is 2.4 [GHz]. It is the range of ISM band and transmission of voice and data is performed by CDMA method. So noises are made in the environment such as AWGN and fading. Currently, the SNR is about 20 [dB], so due to bit errors made by noises, transmission of reliable information to the train is not easy. Also, in the case that two tracks are put to a single direction, it is needed that two trains transmit reliable voice and data to a wayside device. But, by noises, it is not easy that just a train transmits reliable information [2].

In this paper, we estimate the BER related to the SNR of voice and data transmission in the environment such as AWGN and fading from the RF-CBTC system using the
CDMA method. Also, we suppose the SNR which is required to meet the BER standard for voice and data transmission. By increasing the processing gain that is a ratio of chip transmission to voice and data transmission, we make possible voice and data transmission from maximally two trains to a wayside device, and demonstrated it by using Matlab program.

2. BER Calculation

2.1 AWGN Environment

Equation (1) is a signal reaching to a receiver of the standard train, under the condition that as the standard train, \( j \) in cell is set up [3,4].

\[
r(t) = s^{(j)}(t) + \sum_{m=1,m \neq j}^{K_i} s^{(m)}(t-\tau_{im}) + \sum_{n=1}^{K_q} s^{(n)}(t-\tau_{qn}) + n(t)
\]

Equation (2) is the determinant variable after passing through the correlation receiver of the standard train (i, j).

\[
z_0^{(j)} = \sqrt{P_0^{(j)}} + \sqrt{F} \sum_{m=1,m \neq j}^{K_i} I_m + \sqrt{F} \sum_{n=1}^{K_q} \sqrt{L_{mn}} \eta + \eta
\]

where \( s^{(j)}(t) \) means a transmitting signal of the \( j \) in the \( i \) cell, and \( n(t) \) means AWGN with \( N_0 \) as the electric density. Equation (2) is the determinant variable after passing through the correlation receiver of the standard train (i, j).

\[
V\text{ar}[z_0^{(j)}] = \frac{P_T}{3N}[K_i-1+ \sum_{n=1}^{K_q} E[|L^{(n)}|^2]] + \frac{N_0 T_b}{2}
\]

Because in \( b_0^{(j)} \), the possibility of transmission in 1 and -1 is the same, equation (4) is related to the BER [6].

\[
P_b - P_x(z_0 < 0) = Q\left(\frac{1}{2}\right)
\]

\[
\gamma_b = \frac{P_o T_b}{N_0}
\]

\[
Q(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} dx
\]

\[
\gamma_b \text{ means SNR, and } f \text{ means the re-use of frequency. If there are trains as many as } K \text{ under the standard wayside device, and moreover, there are trains as many as } K_i \times K, \text{ the BER of a train in the standard wayside device can be presented as equation (7).}
\]

\[
P_b = Q\left(\frac{K(1+f_i K_i)-1}{3N_{\text{voice}}} + \frac{1}{2\gamma_b}\right)
\]

Equation (8) is related to the BER of the voice transmission using equation (7), and equation (9) is related to the BER of data [7].

\[
P_c = P_x(z_c < 0) = 1 - Q\left(\frac{A_{\text{voice}} K_{\text{voice}}(1+f_i K_i)-1}{3N_{\text{voice}}} + \frac{1}{2\gamma_b}\right)
\]

\[
N_{\text{voice}} = \frac{R_e}{R_{\text{voice}}}
\]

\[
N_{\text{data}} = \frac{R_e}{R_{\text{data}}}
\]

where \( N_{\text{voice}} \) and \( N_{\text{data}} \) mean the processing gain that is the ratio between a chip and data transmission rate. \( A_{\text{voice}} \) and \( A_{\text{data}} \) mean the transmission activity between voice and data.

2.2 Fading Environment

The electric power \( P \) reached under controlling of the wayside device in the standard train is established as a unit power. And the propagation delay of each transmission signal is presented as a relative value about a transmission signal from the standard user. Equation (12) is the signal \( r(t) \) received from the train of the standard wayside device [8].

\[
r(t) = \sum_{m=1,m \neq j}^{K_i} s^{(m)}(t-\tau_{im})
\]

\[
E[|z_0^{(j)}|^2] = \frac{P_T}{3N}[K_i-1+ \sum_{n=1}^{K_q} E[|L^{(n)}|^2]] + \frac{N_0 T_b}{2}
\]

\[
\gamma_b \text{ means SNR, and } f \text{ means the re-use of frequency. If there are trains as many as } K \text{ under the standard wayside device, and moreover, there are trains as many as } K_i \times K, \text{ the BER of a train in the standard wayside device can be presented as equation (7).}
\]

\[
P_b = Q\left(\frac{K(1+f_i K_i)-1}{3N_{\text{voice}}} + \frac{1}{2\gamma_b}\right)
\]

Equation (8) is related to the BER of the voice transmission using equation (7), and equation (9) is related to the BER of data [7].

\[
P_c = P_x(z_c < 0) = 1 - Q\left(\frac{A_{\text{voice}} K_{\text{voice}}(1+f_i K_i)-1}{3N_{\text{voice}}} + \frac{1}{2\gamma_b}\right)
\]

\[
N_{\text{voice}} = \frac{R_e}{R_{\text{voice}}}
\]

\[
N_{\text{data}} = \frac{R_e}{R_{\text{data}}}
\]

where \( N_{\text{voice}} \) and \( N_{\text{data}} \) mean the processing gain that is the ratio between a chip and data transmission rate. \( A_{\text{voice}} \) and \( A_{\text{data}} \) mean the transmission activity between voice and data.
\[ y^{(m)}(t) = \sum_{k=1}^{L} c_k^{(m)}(t) \times \mu^{(m)}(t-kT_c) \]  

(13)

where \( \mu(t) \) means an equivalent expression of the transmission signal \( s(t) \) and \( z(t) \) is an equivalent expression of AWGN \( n(t) \). The reference signal \( a(t) \) made from the code tracking loop of a receiver confronted with the standard train is motivated with the code signal \( a^{(\beta)}(t-\rho T_c) \) that is the strongest No. \( \rho \) of signaling element \( y^{(\beta)} \) as many as \( L \).

\[ \phi_\beta(t-\rho T_c), \]  

(20)

As \( S_f \) in equation (14) is a signaling element of the standard user appeared with the fading condition, it can be presented as equation (18), using the random variable \( a \) of the Rayleigh distribution [9].

\[ S_f^{(\beta)}(t) = \left[ \sum_{\beta=1}^{L} \sum_{m=1}^{K} f^{(\beta)}(m)(t) \mu^{(\beta)}(t-kT_c) \times a^{(\beta)}(t-\rho T_c) \right] dt \]  

(21)

\[ \eta^{\alpha} = \sum_{n=1}^{L-1} a^{(\alpha)}(t-\rho T_c) \]  

(19)

By using equation (18) and equation (19), the determinant variable can be presented as equation (20) [10].

\[ z^{(\beta)} = a_p T_b b_0^{(\beta)} + \sum_{n=1}^{L} \frac{\kappa_n}{n} + \sum_{n+i} N_f \]  

(20)

Under the central limit theorem, \( N_f \) becomes a random variable in the normal distribution with zero as the mean and equation (21) as the standard deviation [11].

\[ \text{Var}[N_f] = \frac{1}{2} \left[ \frac{3(L-1)}{2} + (K_2-1) + L \sum_{n=1}^{N} a^{(\alpha)}(t-\rho T_c) \right] \]  

(21)

where \( L \) means the multipath. In case that there are trains as many as \( K \) under the standard wayside device, and moreover, there are users as many as \( K \times K \), the BER of a train in the standard wayside device can be presented as equation (22) [12].

\[ P_b = \frac{1}{2} \left[ 1 + \sum_{m=1}^{L} \left( \frac{L}{m} \right)^m (1+m\mu)^{-\frac{m}{2}} \right] \]  

(22)

\[ \mu = \frac{2}{3N} \left[ \frac{3(L-1)}{2} + L(K_f-1) + f_i K_f \right] \]  

(23)

Equation (24) is one converted using equation (23) for the voice transmission, and equation (25) is one converted for the data transmission.

\[ \mu = \frac{2A_{\text{voice}}}{3N_{\text{voice}}} \left[ \frac{3(L-1)}{2} + L(K_f-1) + f_i K_f \right] + \frac{L}{\gamma_b} \]  

(24)

\[ \mu = \frac{2A_{\text{data}}}{3N_{\text{data}}} \left[ \frac{3(L-1)}{2} + L(K_f-1) + f_i K_f \right] + \frac{L}{\gamma_b} \]  

(25)
3. Calculation for Maximum Number of Train

In case that self-interference of the wayside device is \( I_{sc} \), and the average interference from the around trains is \( I_{av} \), frequency re-use, is equation (26) [13].

\[
f_c = \frac{I_{sc}}{I_{sc}} = \frac{E}{\sum \sum A_i j_i} = \frac{1}{(K-1)(K+1)} \tag{26}
\]

In case that the transmission activity from trains of the wayside device, is perfect from the electric power control is an standard, the value of \( L \) under the fading environment is computed as 1.

When using equation (31), the maximum number of trains except to standard train(\( K_r \)) can be deduced.

\[
K_m \approx \left( \frac{N}{E_b / I_0} \right)^{1/(1+f_c)} + 1 \tag{32}
\]

When using equation (32), the maximum number of trains under the environment mixed with voice and data is made, then, equation (33) can be deduced. \( x \) and \( y \) mean voice and the ratio of data transmission, respectively, and it is met the requirement that \( x + y = 1 \) [15].

\[
K_{max} = \frac{N_{avg} \left( I_{av} / I_0 \right) + 1}{f_c} \tag{33}
\]

\[
N_{avg} = N_{voice} x + N_{data} y \tag{34}
\]

\[
R_{avg} = A_{voice} x + A_{data} y \tag{35}
\]

\[
(E_b / I_0)_{avg} = 10^{0.1 x (E_b / I_0)} x + 10^{0.1 x (E_b / I_0)} y \tag{36}
\]

4. Simulation

The standard of simulation is the environment of RCF-CBTC, currently used in Korea [16]. The Table 1 is related to the parameters of the simulation standard. We compute the possibility of bit error related to the SNR under the AWGN and fading environment, and we calculate the maximum number of trains. When there is no train except to the standard train, there is a train on the only one of two tracks. And when there is one train except to the standard train, there is each one train on two tracks. Because one wayside device is a standard, the value of \( L \) under the fading environment is computed as 1.

Table 1 Parameters of Simulation Standard

<table>
<thead>
<tr>
<th>Division</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio of chip transmission(( R_c ))</td>
<td>64[Mcps]</td>
</tr>
<tr>
<td>Frequency re-use(( f_c ))</td>
<td>0.547</td>
</tr>
<tr>
<td>Speed of voice transmission(( R_{voi} ))</td>
<td>1[Mbps]</td>
</tr>
<tr>
<td>Speed of data transmission(( R_{dat} ))</td>
<td>11[Mbps]</td>
</tr>
<tr>
<td>Voice processing gain(( N_{voice} ))</td>
<td>64</td>
</tr>
<tr>
<td>Data processing gain(( N_{data} ))</td>
<td>5.8182</td>
</tr>
<tr>
<td>Voice activity(( A_{voice} ))</td>
<td>0.5</td>
</tr>
<tr>
<td>Data activity(( A_{data} ))</td>
<td>0.5</td>
</tr>
<tr>
<td>Number of standard train(( K_r ))</td>
<td>1</td>
</tr>
<tr>
<td>Train number except to standard train(( K_r ))</td>
<td>0–1</td>
</tr>
</tbody>
</table>

4.1 BER under AWGN Environment

4.1.1 Voice transmission

Fig. 1 is the plot of BER versus SNR under the AWGN.
The Influence of Noise Environment upon Voice and Data Transmission in the RF-CBTC System

To transmit voice reliably during transmitting voice.

To transmit voice reliably during transmission under the AWGN environment, it should be satisfied that the BER is about $10^{-2}$. According to analyzing the Fig. 1, in case of $K_r=0$, the SNR shall be about 8.3 [dB]. In case of $K_r=1$, the SNR shall be about 8.5 [dB].

4.1.2 Data transmission

Fig. 2 is the plot of BER versus SNR under the AWGN environment during transmitting data.

To transmit data reliably during transmission under the AWGN environment, it should be satisfied that the BER is about $10^{-4}$. According to analyzing the Fig. 2, in case of $K_r=0$, the SNR shall be about 10 [dB]. In case of $K_r=1$, the SNR shall be about 27 [dB].

4.2 BER under Fading Environment

4.2.1 Voice transmission

Fig. 3 is the plot of BER versus SNR under the fading environment during transmitting voice.

To transmit voice reliably during transmission under the fading environment, it should be satisfied that the BER is about $10^{-2}$. According to analyzing the Fig. 3, in case of $K_r=0$, the SNR shall be about 23 [dB]. In case of $K_r=1$, the SNR shall be about 24 [dB] or more.

4.2.2 Data transmission

Fig. 4 is the plot of BER versus SNR under the fading environment during transmitting data.

To transmit data reliably during transmission under the fading environment, it should be satisfied that the BER is about $10^{-4}$. According to analyzing the Fig. 4, in case of $K_r=0$, the SNR shall be about $2 \times 10^3$ [dB]. But in case of $K_r=1$, it shall be not possible. By increasing up to ten times of data activity throughout using the rake receiver, the SNR should be about 40 [dB] or more, under $K_r=1$.

4.3 Maximum Number of Trains

We compute the maximum number of trains meeting the standard value of the SNR by the transmission ratio of voice and data. We use the SNR of voice and data transmission satisfactory for the standard value of the BER as $K_r=1$. And we represent the maximum number of trains by the voice transmission ratio as the graph. When the voice transmission ratio is 1, it means that only
voice is transmitted. And when 0, it means that only data is transmitted. Therefore, for the simulation, in the condition that the transmission ratio of voice and data is 50\%, respectively, we compute the maximum number of trains.

4.3.1 AWGN environment

Fig. 5 is the maximum number of trains under the AWGN environment. It meet the standard value of the BER, and in case of \( K_r = 1 \), the SNR of voice and data transmission is 8.5 [dB] and 27 [dB], respectively. Because in the condition of voice transmission compared with data transmission, the SNR is lower, the maximum number of trains is better in the condition that the ratio of voice transmission usage is 1 rather than in the condition that the ratio of data transmission usage \( 1 \) (ratio of voice transmission usage=0). In the condition that the used transmission ratio of voice and data is 50\%, the maximum number of trains is 0.45.

Fig. 6 is the result that to make the maximum number of trains two by using equation (31), the processing gain of voice and data is increased up to 5 times.

4.3.2 Fading environment

Fig. 7 is the maximum number of trains the fading environment. It meet the standard value of the BER, and in case of \( K_r = 1 \), the SNR of voice and data transmission is 24 [dB] and 40 [dB], respectively. The SNR during transmitting data is deduced by using the rake receiver.

The maximum number of trains is 0.02 in the condition that the used ratio of the voice and data transmission is 50\%. We also demonstrate that the maximum number of trains can be over 2 during transmitting data in the condition that the ratio of the voice transmission is 1.

Fig. 8 is the result that to make the maximum number of trains two by using equation (31), the processing gain of voice and data is increased up to 100 times.

The maximum number of trains is 2.24 in the condition that the used ratio of the voice and data transmission is 50\%. We also demonstrate that the maximum number of trains can be over 2 during transmitting data in the condition that the ratio of the voice transmission is 1.
5. Conclusion

In this paper, when voice and data are transmitted in the RF-CBTC using the CDMA method, we demonstrate that the BER has been affected by AWGN and fading environment.

As the result of computing the BER to the SNR in the AWGN environment in the case that a wayside device is related to two trains, the SNR which is required to meet the BER standard which is $10^{-2}$ in case of the voice transmission is $8.5\, \text{dB}$. The SNR of met on the BER standard which is $10^{-4}$ in case of the data transmission situation is $27\, \text{dB}$. In case of the voice transmission, the SNR which is required to meet the BER standard which is $10^{-2}$ is $24\, \text{dB}$ in the fading environment. In case of the data transmission, the SNR which is required to meet the BER standard which is $10^{-4}$ is $27\, \text{dB}$ by using the rake receiver in the fading environment. To meet the BER standard, the SNR shall be changed from $20\, \text{dB}$ to $40\, \text{dB}$ or above. As the result of computing the maximum number of trains about a wayside device by using the SNR which is required to meet the BER standard, it is $0.45$ in the AWGN environment and $0.02$ in the fading environment. It means that the transmission is not reliable for meeting the BER standard. Therefore, it is necessary that the processing gain is heightened by increasing the chip transmission. By increasing the processing gain up fivefold in the AWGN environment and up hundredfold in the fading environment, reliable voice and data transmission up to maximally two trains can be possible.

The current paper can be used for the ETCS Level 2 system on the RF-CBTC under the environment of the AWGN and the fading. Also, it can be used for the video call system applicable to the current Korean subway.

Nomenclature

- AWGN : Additive White Gaussian Noise
- BER : Bit Error Rate
- CDMA : Code Division Multiple Access
- ISM : Industrial Scientific and Medical equipment
- RF-CBTC : Radio Frequency-Communication Based on Train Control
- SNR : Signal to Noise Ratio

Reference