Performance Characteristic of satellite Wibro system in the high-speed Railroad Channel Environment

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요 약

본 논문은 고속철도 채널환경에서의 위성을 통한 Satellite Wibro 시스템의 성능열화특성과 이에 따른 보상기법에 대해 서술하였다. 고속철도 채널환경은 LOS채널 과 터널환경으로 구분되고 LOS 환경에서서는 고속철도 파워 급전선에 의한 신호블로킹에 의한 문제와 터널내 에서는 Optic Fiber내에서와 같은 다중경로 간섭문제가 발생한다. 이러한 전형적인 두 채널 공간에서의 위성 와이브로 시스템 성능열화 특성을 해석적으로 규명하고 컴퓨터 시뮬레이션을 통하여 확인 하였다. 아울러 300 ㎞/h 이상으로 이동하는 고속철도에서 발생되는 OFDM 시스템의 도플러 효과에 의한 ICI 현상과 이를 보상할 수 있는 기법을 해석적 ,실험적 결과를 통하여 증명하였다.

키워드: 위성통신, 와이브로, 도플러 효과

ABSTRACT

In this paper, we describe the performance degradation of satellite Wibro system and compensation method in the high-speed railroad channel environment. High-speed railroad channel environment is divided into LOS channel and tunnel. In the LOS channel, signal blocking caused by railroad power feeder structures can be a critical problem which is can be solved with antenna diversity. On the other hand, multi path interference phenomenon, representable by propagation model of Optic Fiber, occurred in the tunnel may be another obstacle. These satellite Wibro system performance degradations in railroad channel environment are addressed and adequate compensation methods are proposed and verified through computer simulation. In addition, the ICI caused by Doppler shift in OFDM system is analyzed with its compensation method.

Key Words : Satellite communications, Wibro, Doppler effect

I. Introduction

Mobile broadband satellite multimedia connection system which provides continuous rapid speed internet connecting service in high speed moving vehicles, such as an express train, is called a highly moving vehicle system. When the train is moving, the duplex active antenna receives the satellite signal directly in the LOS(Line Of Sight) environment. However, in N-LOS environment like a tunnel or inside of a station, the satellite signal relay equipment like duplex gap filler or the ground wireless net same as wireless LAN or Wibro net is used to offer continuous service. To provide a ceaseless service, it is necessary to develop a special technique for N-LOS environment like a tunnel or inside of a station. Moreover in LOS circumstance, a conquest skill is necessary for the Shadow effect and Doppler effect that are caused by Electric Power Post and Power Bridge on the railroad. In this paper, this conquest technique system is introduced.

2. Propagation property in LOS channel environment

2.1 The General Approach

The fluctuation of signal in LOS channel environment changes because of the surroundings. This kind of phenomenon is called fading and it is divided into short-term fading and long-term fading. Long-term fading means a slow and large fluctuation caused by an obstacle such as a relatively tall building or a hill. In mobile communication environment, the standard deviation of long-term fading is about 8dB. Short-

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term fading is a brief fading which occurs in multi-path signals. This signal gets reflected from the obstacle, and it is within the circumference of the receiver. The envelop of received signal is Rayleigh distributed.

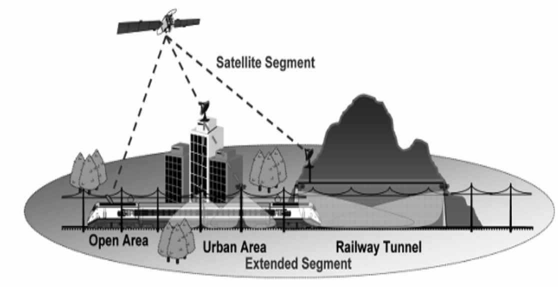

Figure 1. The railway environment

Another propagation property in LOS channel environment is the path loss occurred in long term of the total path. As the signal is reduced depending on the topography of the total path, the received power is changed gradually.

2.2 The Antenna Gain

The gain of parabola antenna established in high-speed railroad can be acquired by this formula.

$$G_{\max} = \eta \left(\frac{4\pi}{\lambda^2} \right) A_{eff} \qquad (1)$$

A_{eff} is the effective aperture of the antenna, λ =c/f, where c is the light speed ($3*10^8$m/s), f is the frequency of radio wave and η is the antenna efficiency. In case, the exact surface area is $A=\pi D^2/4$ in a round shape reflection antenna, A_{eff} is η A and the gain of the antenna is,

$$G_{\max} = \eta \left(\frac{\pi D}{\lambda} \right)^2 = \eta \left(\frac{\pi D f}{c} \right)^2 \qquad (2)$$

The products of diverse part can express the antenna efficiency η.

$$\eta = \eta_1 \eta_2 \eta_3 \eta_4 \eta_5 \eta_6 \qquad (3)$$

Total efficiency of η is about 55% to 77%. Figure 2 shows the parabola antenna model, which is located in a central railroad car.

2.3 The Shadow Effect

If there is an obstacle between the transmission point and receive point, the strength of microwave-received signal will be decreased. This is known as shadow effect.

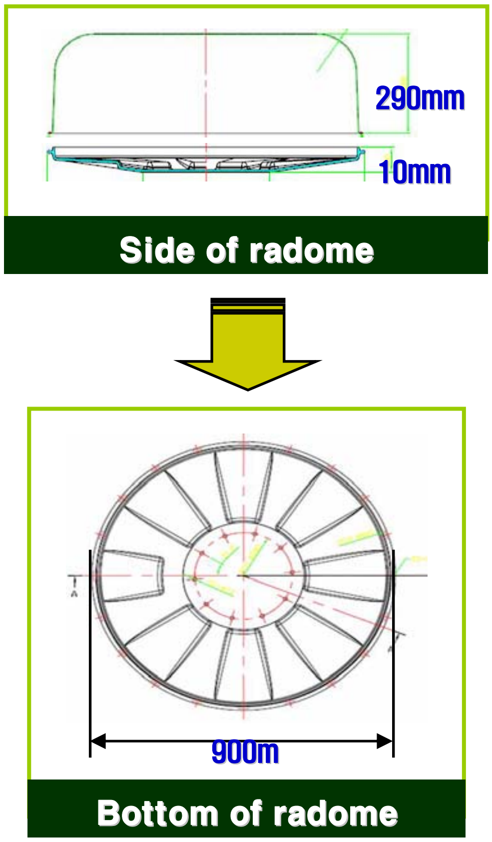

Figure 2. Radome(parabola antenna) standard

In the KTX (Korea Train Express) railroad environment, the railroad power feeder line's width is 13m and the feeder's gap of length is 63m. Suppose that the average of KTX speed is 300km, and then the loss occurs at intervals of 0.8second when the train passes the power supply line.

Figure 3 illustrates the simulation result which is the extent of loss (3/10, 1/2, 3/4) when the feeder line hides the antenna. By Figure 3, we can confirm the shaded signal about 1/2 degree and 3/4 degree, which reveal the capacity of about lower 3dB and 6dB. The simplest method of compensation for the loss is spatially arranged with more than two parabola antenna and then receives the independent fluctuating signal.

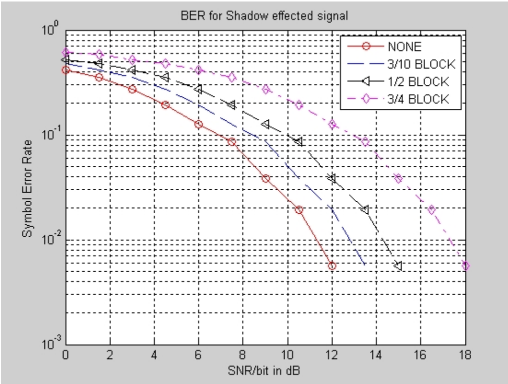

Figure 3. BER for Shadow effected signal

Suppose that each of received signal in antenna is $r_1(t)$, $r_2(t)$.

$$r_1(t) = A_1 S(t-\tau_1) + n_1(t)$$
$$r_2(t) = A_2 S(t-\tau_2) + n_2(t) \qquad (4)$$

To make the random phase of each branch for the same position, the correlation of $r_1(t)$ and $r_2(t)$ are calculated which are formed L samples and M samples and then the difference value τ_1 and τ_2 which from $r_1(t)$ and $r_2(t)$ are compensated. Correlation of $r_1(t)$ and $r_2(t)$ is

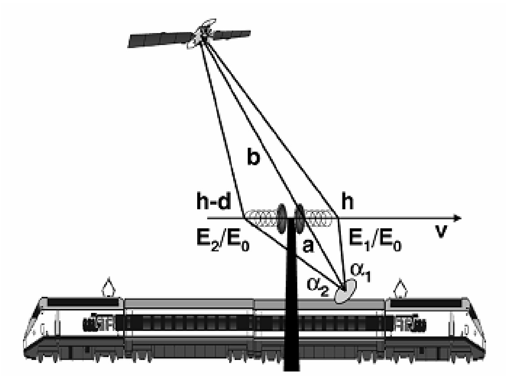

Figure 4. Geometry of the power feeder structures

$$r_{hx}(k) = \frac{1}{L}\sum_{i=0}^{L-1} r_1(i) r_2(i-k), \qquad 0 \le k \le L \qquad (5)$$

The difference between $r_1(t)$ and $r_2(t)$ is compensated by using the maximum value $r_{hx}(k)$ from equation (5). Two signals by channel tab in combination machine of the final step are combined and the output is obtained. At this time, to get a great composition effect, the contribution about the lower SNR signal is made larger. Finally, received signal in Maximum Ratio Combiner is expressed as following equation (6).

$$r(t) = a_1 r_1(t) + a_2 r_2(t) \qquad (6)$$

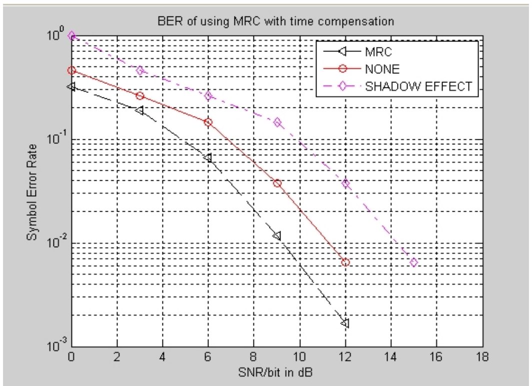

Figure 5. BER for Maximal Ratio Combiner Method (1/2 Blocking)

Figure 5 is the measurement of BER from combination of two antenna signals by using MRC. Compare with the original signal and the shadow affected signal, we can confirm the improvement about 2dB and 5dB.

3. Propagation property in tunnel environment

3.1 The Geometry Approach

In the tunnel environment, we can prospect the propagation characteristic between TX and RX propagation path. With the use of this, the multi-path channel parameters like path loss, RMS delay spread mean excess delay and coherent bandwidth can be obtained. The procedure to predict the propagation is shown in Fig.6.

3.2 Ray Tracing Scheme

Ray tracing method is based on the electromagnetic wave theory and the expression technique of the indoor propagation characteristic [1][2]. This method is mainly applicable to tunnel circumstance. Geometrical planimetry is used to obtain the sum of rays at some kind of point those come from every path.

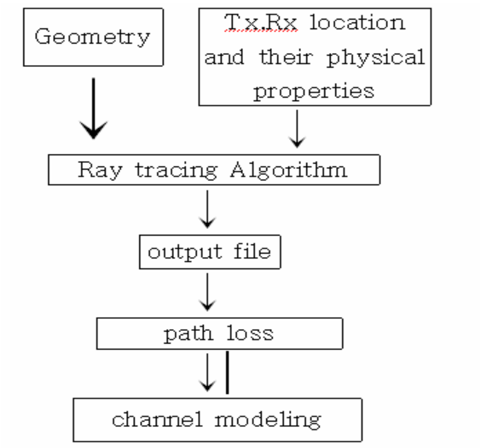

Figure 6. The block diagram for simulation

In KTX channel environment, there are only straight tunnels, no curved tunnel. Therefore the line of sight is guaranteed, we can change the received signal to original signal sufficiently only using ray-tracing method. Finding the paths between RX and TX are the requirement matter. In propagation-path, they include all of the direct, reflection and diffraction propagation. Information of physical properties is required to simulate these multipath phenomenons between Rx and Tx. There are two ways to find the propagation path, images algorithm and brute force ray tracing algorithm. In this paper, we use images algorithm method. Using these information and algorithm, propagation paths emitted from the transmitter and arrived at the receiver are calculated.

3.3 Path Loss Calculation

Propagation radiated from Tx is separated to several rays and appeared various propagation phenomenon. Mathematical formula utilized by rays are represented [3][4][5]. The following rays have considered in this algorithm:

1. Direct line of sight(LOS) ray
2. Reflected rays(in any order)
3. Diffracted rays(single and double)
4. Diffracted-reflected rays

The electric field of a ray reaching the receiver can be calculated as follows:
for the direct ray

$$E_{direct} = \frac{e^{-jkr_{direct}}}{r_{direct}} E_0 \qquad (7)$$

E0 is free-space field strength, r is the total path length for the directed ray and k is propagation constant. The electric field of the reflected ray at the receiver antenna is obtained as:

$$E_{reflected} = \frac{e^{-jkr_{reflected}}}{r_{reflected}} E_0 R \qquad (8)$$

Where r is the total path length for the reflected ray length from the reflection point to the source point. R is the reflection coefficient given by

$$R = \frac{jk\sin\phi + \xi_{1,2}}{jk\sin\phi - \xi_{1,2}} \qquad (9)$$

Where values of ξ_1 and ξ_2 are chosen to represent an impedance wedge with the complex relative dielectric constants $\varepsilon_{1,2}$=($\varepsilon_{1,2}$-j60λσ):

$$\xi_{1,2} = -jk\sqrt{\varepsilon_{1,2} - 1} \qquad (10)$$

for an incident plane wave of horizontal polarization or

$$\xi_{1,2} = -jk\frac{\sqrt{\varepsilon_{1,2} - 1}}{\varepsilon_{1,2}} \qquad (11)$$

for an incident wave of vertical polarization. The electric field of the diffracted ray at the receiver antenna is obtained as:

$$E_{diffracted} = \frac{e^{-jks'}}{s'}\sqrt{\frac{s'}{s(s+s')}}e^{-jks}E_0 D \qquad (12)$$

Where s’ is the total path length from the source to the diffraction wedge and s is the total path length from the wedge to the receiver. D is the dyadic single-diffraction coefficient for a finite conductivity wedge [6]. Equation (12) is divergent when s becomes zero and the diffracted fields are inaccurate near edges. If a single diffraction is combined with multiple reflections the electric field has the form

$$E_{d-r} = \frac{E_0}{s'}e^{-jks'}\sqrt{\frac{s'}{s(s+s')}}e^{-jks}DR \qquad (13)$$

The received power is

$$P_{received} = P_t(\frac{\lambda}{4\pi})^2 \left|\frac{E_{total}}{E_0}\right| \quad (14)$$

The total received field at the mobile antenna is obtained by adding the contribution of each individual ray. For each ray, transmitter and receiver antennas power gain GTj and G_{Rj} must be taken into account

$$E_{total} = \sum_{i=1}^{m} E_j \sqrt{G_{Tj}} \sqrt{G_{Rj}} \quad (15)$$

From equation (14), the path loss in decibels is calculated as follows:

$$L = 20\log(\frac{\lambda}{4\pi}\left|\frac{E_{total}}{E_0}\right|) \quad (16)$$

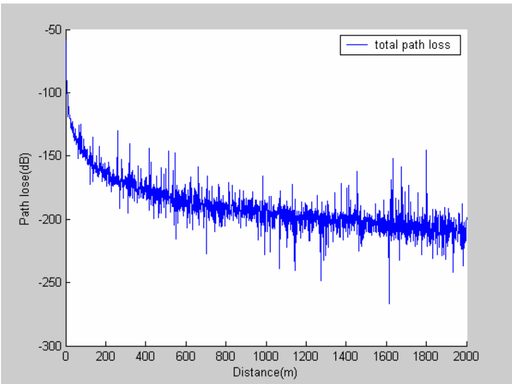

Figure 7. PathLoss in 2km tunnel

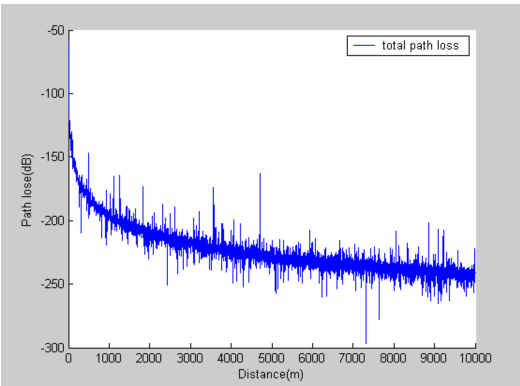

Figure 8. PathLoss in 10km tunnel

Figure 7 and 8 are the simulation result of pathloss using the equation (16). At present, the longest KTX tunnel is Hwang-hak tunnel which length is about 10km. So we have considered maximum length of tunnel is 10km and minimum length of tunnel is 2km for the purpose of simulation.

3.4 RMS Delay Spread

RMS delay spread, which provides information about the tunnel wide-band channel characteristics, is another important parameter. Delay spread gives an indication of the potential for the inter symbol interference (ISI) in digital communications. Time dispersion of the wideband multipath channel can be split into two portions; rms delay spread and means excess delay. The mean excess delay is the first moment of the power delay profile and is defined to be [7]

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \quad (17)$$

The RMS delay spread is the square root of the second moment of the power delay profile and is defined to be:

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} \quad (18)$$

Where,

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)} \quad (19)$$

Figure 9 presents the Multipath delay profile. Mean Excess Delay and RMS Delay Spread computed by numerical value of figure are usefulness to determine the data rate in non-equality channel. Figure 9 also shows that until 0.1*10-5sec, about five signals exist fallen off from -10dB to -30dB and after that, about -35dB detracted several signals are in existence.

Figure 10 shows the received signal in antenna. The amplitude of received signal fading is similar to Rayleigh fading distribution.

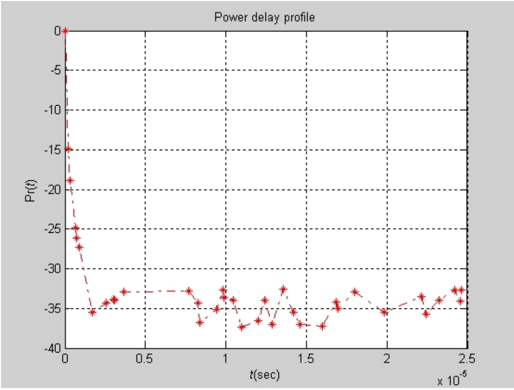

Figure 9. Multipath delay profile

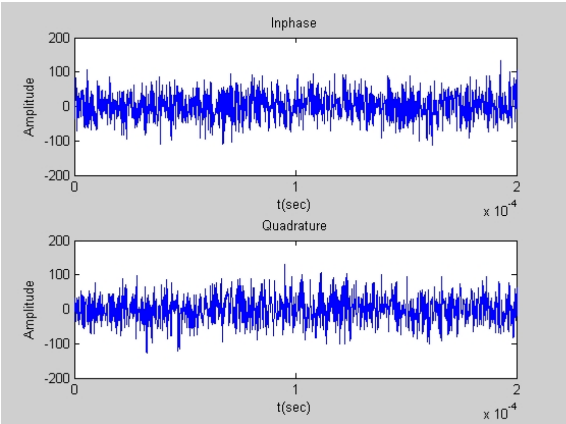

Figure 10. Inphase and Quadrature component of Received signal

4. New OFDM Scheme

4.1 The General Approach

OFDM system is an adapted method to high-speed data communication but the system has a serious ICI problem caused by DFS. A thing this ICI problem, we can explain that bit error becomes saturated not by random noise but by sensitive to frequency offset [8] [9].

ICI self-canceling scheme which using correlative coding to reduce the distortion of ICI involves a huge reduction of bandwidth efficiency [10]. Moreover, in case of ICI elimination finding frequency offset and frequency response of channel, there are searching time and handing problem of large dimension interference matrix [11]. In Doppler spread channel, OFDM system for Low-complexity MMSE(minimum mean square error) has an computational complexity problem up to now[12][13].

If we can cancel the ICI from DFS successfully, necessity of channel estimator and adaptive equalizer will be not required in the design for OFDM system. Good conditioned Rician channel like Satellite or DSRC (Dedicate Short Range Communication) [14], DFS compensation method is suitable to obtain a strict BER requirement without a special advanced equalizer[15].

4.2 Doppler Shift Compensation

To clarify the exact effects of the Doppler shift on the received data symbol is expressed as $X(l)$, excluding any other interferences and noise, then the received signal on l th subcarrier in the channel of Doppler shift can be expressed as [9]

$$Y(l) = X(l)H(0) + \sum_{j=0, l\neq j}^{N-1} X(j)H(j-l) \tag{20}$$

Since the significant interferences to the l th subcarrier are coming from the neighboring few subcarriers equation (20) can be approximated with four adjacent ones,

$$\begin{aligned} Y(l) &\cong X(l)H(0) + X(l-1)H(-1) + X(l+1)H(+1) \\ &+ X(l-2)H(-2) + X(l+2)H(+2) \end{aligned} \tag{21}$$

To simplify the equation (21) further, the first and second terms of $H(j-l)$ are manipulated using basic trigonometric equations and approximations into equation (22).

$$\begin{aligned} \frac{\sin(\pi(j-l+\varepsilon))}{N\sin\left(\frac{\pi}{N}(j-l+\varepsilon)\right)} &\cong \frac{\sin \pi\varepsilon}{N\sin\left\{\frac{\pi}{N}(j-l)\right\}} \\ &\cong \frac{\varepsilon}{j-l} \quad (j-l\neq 0) \end{aligned} \tag{22}$$

$$\begin{aligned} &\exp(i\pi(1-1/N)(j-l+\varepsilon)) \\ &\cong \exp(i\pi(l-k))\cdot\exp(i\pi\varepsilon) \end{aligned} \tag{23}$$

After substituting equation (22), (23) into (21) and dividing both sides by $X(l)$, equation (21) becomes equation (24).

$$\frac{Y(l)}{X(l)} \cong \exp(i\pi\varepsilon) + \left\{\frac{-X(l-1)-X(l+1)}{X(l)}\right\}\varepsilon\exp(i\pi\varepsilon) + \left\{\frac{X(l-2)+X(l+2)}{X(l)}\right\}\frac{\varepsilon}{2}\exp(i\pi\varepsilon) \qquad (24)$$

Two composite random sequences are defined as

$$Z_1 = \{(-X(l-1)-X(l+1))/X(l)\} \qquad (25)$$

$$Z_2 = \{(X(l-2)+X(l+2))/X(l)\} \qquad (26)$$

Since $E[Z_1]=0$, $E[Z_2]=0$, the expectation value of equation (24) will be

$$E\left[Y(l)/X(l)\right] \cong \exp(i\pi\varepsilon) \qquad (27)$$

Therefore the center of constellation of $Y(l)$ will be shifted $(\pi\varepsilon)$ radian from that of $X(l)$ on complex unit circle and the depressiveness of $Y(l)$ is determined by the variance of another composite random sequence defined as

$Z_1\varepsilon\exp(i\pi\varepsilon)+Z_2(\varepsilon/2)\exp(i\pi\varepsilon)$, that is also proportional to ε and $\exp(i\pi\varepsilon)$.

Based on the result of statistical estimation as in equation (24), Doppler effects compensation can be performed in frequency domain as well as time domain. Frequency domain compensation, classified as post-FFT compensation technique, can be done by the equation as follows:

$$Y_c(l) = \frac{Y(l)}{E\left[Y(l)/X(l)\right]} \cong \frac{Y(l)}{\exp(i\pi\varepsilon)} \qquad (28)$$

With this compensation, the center of constellation of $Y(l)$ move to that of $X(l)$ however the depressiveness of $Y(l)$, still dominated by $Z_1\varepsilon+Z_2(\varepsilon/2)$, can not be diminished. The other compensation technique performed in time domain (Pre-FFT) as in equation (29) is able to correct not only the biased constellation center but also the depressiveness of constellation.

$$x(n) = y(n)\cdot\left\{IFFT[E[Y(l)/X(l)]^{-1}\right\} \cong y(n)\cdot\left\{IFFT[\exp(-i\pi\varepsilon)]\right\} \qquad (29)$$

Naturally this time domain approach shows better performance than frequency domain since Doppler frequency shift is fundamentally corrected in time domain before FFT demodulator which actually brings the bias and depressiveness of constellations because of frequency offset.

4.3 Simulation Result

Figure 11 shows the compensated constellation by frequency domain and time domain compensation methods for QPSK signal.

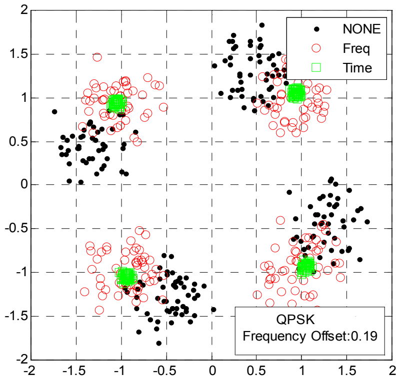

Figure 11. Compensated Constellation (QPSK)

The result of 'NONE' shows the constellation without compensation. By frequency domain compensation method, designate by 'FREQ', only the constellation center is corrected wile both constellation center and the depressiveness are corrected by the time domain method designated by 'TIME".

5. Conclusions

This paper showed the performance degradation of satellite WIBRO system and compensation method in the high-speed railroad channel environment. The BER results presented MRC(Maximum Ratio Combine) technique that solves the signal-blocking problem which is caused by power feeder line in LOS channel environment. The path loss results show the multi-path interference problem in tunnel circumstance. The compensation method which solves ICI problems is not only simple but effective as well. Using these techniques, we can take advancement of super-high speed internet service ceaselessly in high-speed railroad environment.

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