Proposal of Channel Estimation Method for ITS systems by using STBC MIMO-OFDM

Tanairat Mata[1], Member, **Katsuhiro Naito**[2], **Pisit Boonsrimuang**[3],
Kazuo Mori[4], and **Hideo Kobayashi**[5], Non-members

ABSTRACT

This paper proposes a new road-to-vehicle communication system for the future ITS by using the STBC MIMO-OFDM technique which can provide the safety and comfortable driving, and collection of variable information from the network in the real-time to the users on the vehicle. To realize the proposed STBC MIMO-OFDM system, it is required to estimate the channel frequency response at every symbol precisely in the time varying fading channel which is the typical operation conditions for the roadto-vehicle communications system. In this paper, we propose a novel channel estimation method by using the scattered pilots and null sub-carriers inserted into the data sub-carriers both in the frequency and time axes which enables the accurate channel estimation even in the higher time varying fading channel. From the computer simulation results, this paper demonstrates the effectiveness of proposed system which can achieve the higher transmission data rate with keeping the higher signal quality even under the higher mobile ITS environments.

Keywords: OFDM, MIMO, STBC, ITS, RVC

1. INTRODUCTION

Intelligent Transport Systems (ITS) have been expanding with the popularization of Electrical Toll Collection System (ETC) and the Vehicle Information communication Systems (VICS) which enable the drivers for the safety and comfortable driving, and collection of variable information from the network in the real-time [1-3]. Various transmission techniques for the communications systems in the ITS are currently studying in the various projects and some of them have already been standardized in the ITS systems.

From the above backgrounds, the ITS could become an advanced information network systems for the transportation infrastructures which are essential to greatly improve our social activities and the quality of our social life. The Communications systems for the ITS can be classified into the road-to-vehicle communication (RVC) and the vehicle-to-vehicle communication (VVC). The communication services through the RVC has been investigated to provide various kinds of information to the users on vehicles. In the RVC, the received signal power at the vehicle decreases as increasing the distance from the base stations located along the road. The received signal is also fluctuated in the short time period due to the time varying multipath fading when the vehicles are moving at high speed. These conditions cause the fatal degradation of bit error rate (BER) performance in the RVC. From this fact, the achievable transmission data rate in the current RVC is insufficient to provide the mobile multimedia communications services to the users on the vehicles.

The IEEE 802.11p is adopted as the standard specifications for the VVC and RVC in the ITS [4]. The IEEE 802.11p employs the Orthogonal Frequency Division Multiplexing (OFDM) as the transmission technique in the 5GHz band used by the IEEE 802.11a. Although the OFDM technique can achieve high signal quality in the multipath fading channel, this standard is insufficient to achieve the higher transmission data rate with the higher signal quality especially in the higher time varying fading channels which are typical operation environments in the ITS.

To solve the above problems, this paper proposes a new RVC system by using the STBC (Space Time Block Coding) MIMO (Multiple Input Multiple Output)-OFDM [5-6] technique for the future ITS which can provide the mobile multimedia communications services to the users on the vehicle. To realize the proposed STBC MIMO-OFDM systems, the channel estimation method is required as the key technique which enables the accurate channel estimation at every symbol in the higher time varying fading channels. This paper proposes a channel estimation method by using the scattered pilot and null sub-carriers which enables the demodulation of multiplexed signal encoded with the STBC. The proposed STBC MIMO-OFDM system in conjunction

Manuscript received on July 15, 2013 ; revised on November 7, 2013.
Final manuscript received December 8, 2013.
[1,2,4,5] The authors are with Electrical and Electronic Engineering, Graduate School of Engineering, Mie University, Tsu-shi, 514-8507 Japan., Email:tanairat@com.elec.mie-u.ac.jp, naito@elec.mie-u.ac.jp, kmori@elec.mie-u.ac.jp, and koba@elec.mie-u.ac.jp
[3] The author is with Telecommunication Engineering, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, 10520 Thailand., Email:kbpisit@kmitl.ac.th

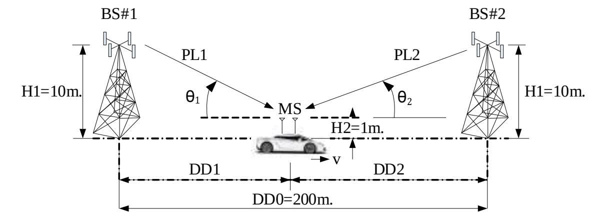

Fig.1: *Overview of proposed system model*

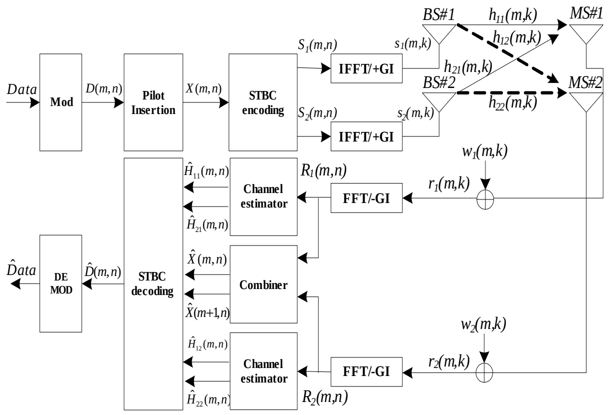

Fig.2: *Block diagram of proposed STBC MIMO-OFDM transceiver*

with the proposed channel estimation method can achieve higher transmission data rate with keeping the higher signal quality even in the time varying fading channels.

This paper is organized as follows. Section 2 shows the proposed STBC MIMO-OFDM system model, and Section 3 proposes a channel estimation method for the proposed system by using the scattered pilot sub-carriers assignment method. Section 4 presents the various computer simulation results to verify the effectiveness of the proposed method as compared with the conventional methods. Finally Section 5 draws some conclusions.

2. PROPOSED SYSTEM MODEL

Figure 1 shows the proposed STBC MIMO-OFDM system model to be used in this paper. The vehicle (*MS*) with two receiving antennas receives the OFDM signals with STBC encoded by Alamounti scheme [5] from both base stations (*BS#1* and *BS#2*) located along the road. The communication channel is modelled by the Rician fading including one direct path and several reflected paths which follows the Rayleigh fading. In Fig.1, *PL* represents the propagation loss between the *BS* and *MS*, θ is the signal arrival angle from the *BS* to the *MS*, and *DD1* and *DD2* are the distances from the *BS#1* and *BS#2* to *MS*, respectively.

Figure 2 shows the block diagram of proposed STBC MIMO-OFDM transceiver. In Fig.2, *D(m,n)* is the modulated information signal at the *n-th* sub-carrier of *m-th* symbol in the frequency domain, *X(m,n)* is the modulated signal after insertion of scattered pilot signals, and $S_1(m,n)$ and $S_2(m,n)$ are transmission signals from *BS#1* and *BS#2* which are encoded by STBC. The STBC encoded signals $S_1(m,n)$ and $S_2(m,n)$ are converted to the time domain signal by using IFFT, and the guard interval (GI) is added to avoid the inter-symbol-interference (ISI). The time domain signal is transmitted to the *MS* receiver through the Rician fading channel with having the time impulse response $h_{ij}(m,k)$ at the *k-th* time sampling of *m-th* symbol. At the receiver, $r_1(m,k)$ and $r_2(m,k)$ including the additive white Gaussian noise *w(m,k)* are received at the *MS* receiving antenna *MS#1* and *MS#2*, respectively. The received time domain signals are converted to the frequency domain signal $R_1(m,n)$ and $R_2(m,n)$ by FFT after removing the GI. The received frequency domain signal inputs to the channel estimator to estimate the channel frequency response (CFR) for $\hat{H}_{ij}(m,n)$ which represents the channel response from *BS#i* to *MS#j* link at the *n-th* sub-carrier of *m-th* symbol. The received signal also inputs to the combiner to detect the modulated signals $\hat{X}(m,n)$ and $\hat{X}(m+1,n)$ at the *n-th* sub-carrier of *m* and *(m+1)-th* symbols, respectively.

In the STBC MIMO-OFDM system with the Alamounti coding, the modulated information data *X(m,n)* is encoded into two signals S_1 and S_2 as given by the following equation;

$$\begin{aligned} S_1(m,n) &= X(m,n), \\ S_1(m+1,n) &= -X^*(m+1,n), \\ S_2(m,n) &= X(m+1,n), \\ S_2(m+1,n) &= X^*(m,n). \end{aligned} \tag{1}$$

To easily understand the process at the receiver, we divide the processes into *4* parts as follows;

PART 1: Received Signal

The frequency domain received signal $R_1(m,n)$ and $R_2(m,n)$ at *MS#1* and *MS#2* can be given by;
At *MS#1*,

$$\begin{aligned} R_1(m,n) &= H_{11}(m,n)S_1(m,n) \\ &\quad +H_{21}(m,n)S_2(m,n). \\ R_1(m+1,n) &= H_{11}(m+1,n)S_1(m+1,n) \\ &\quad +H_{21}(m+1,n)S_2(m+1,n). \end{aligned} \tag{2}$$

At *MS#2*,

$$\begin{aligned} R_2(m,n) &= H_{12}(m,n)S_1(m,n) \\ &\quad +H_{22}(m,n)S_2(m,n). \\ R_2(m+1,n) &= H_{12}(m+1,n)S_1(m+1,n) \\ &\quad +H_{22}(m+1,n)S_2(m+1,n). \end{aligned} \tag{3}$$

Substituting (1) into (2) and (3), they can be rewritten by the following equation;

At *MS#1*,

$$\begin{aligned} R_1(m,n) &= H_{11}(m,n)X(m,n) \\ &\quad +H_{21}(m,n)X(m+1,n). \\ R_1(m+1,n) &= -H_{11}(m+1,n)X^*(m+1,n) \\ &\quad +H_{21}(m+1,n)X^*(m,n). \end{aligned} \tag{4}$$

At *MS#2*,

$$\begin{aligned} R_2(m,n) &= H_{12}(m,n)X(m,n) \\ &\quad +H_{22}(m,n)X(m+1,n). \\ R_2(m+1,n) &= -H_{12}(m+1,n)X^*(m+1,n) \\ &\quad +H_{22}(m+1,n)X^*(m,n). \end{aligned} \tag{5}$$

PART 2: Channel Estimator

The details of the CFR estimation method is proposed in Section 3.

PART 3: Combining Scheme

From (4) and (5), *X(m,n)* can be rewritten into the following equations by using the CFR $\hat{H}_{ij}(m,n)$ estimated in Part 2;

At *MS#1*,

$$\begin{aligned} X_{MS\#1}(m,n) &= \hat{H}^*_{11}(m,n)R_1(m,n) \\ &\quad +\hat{H}_{21}(m+1,n)R^*_1(m+1,n). \\ X_{MS\#1}(m+1,n) &= \hat{H}^*_{21}(m,n)R_1(m,n) \\ &\quad -\hat{H}_{11}(m+1,n)R^*_1(m+1,n). \end{aligned} \tag{6}$$

At *MS#2*,

$$\begin{aligned} X_{MS\#2}(m,n) &= \hat{H}^*_{12}(m,n)R_2(m,n) \\ &\quad +\hat{H}_{22}(m+1,n)R^*_2(m+1,n). \\ X_{MS\#2}(m+1,n) &= \hat{H}^*_{22}(m,n)R_2(m,n) \\ &\quad -\hat{H}_{12}(m+1,n)R^*_2(m+1,n). \end{aligned} \tag{7}$$

From (6) and (7), we obtain the combined received signals as follows;

$$\begin{aligned} \hat{X}(m,n) &= \hat{H}^*_{11}(m,n)R_1(m,n) \\ &\quad +\hat{H}_{21}(m+1,n)R^*_1(m+1,n) \\ &\quad +\hat{H}^*_{12}(m,n)R_2(m,n) \\ &\quad +\hat{H}_{22}(m+1,n)R^*_2(m+1,n). \end{aligned} \tag{8}$$

$$\begin{aligned} \hat{X}(m+1,n) &= \hat{H}^*_{21}(m,n)R_1(m,n) \\ &\quad -\hat{H}_{11}(m+1,n)R^*_1(m+1,n) \\ &\quad +\hat{H}^*_{22}(m,n)R_2(m,n) \\ &\quad -\hat{H}_{12}(m+1,n)R^*_2(m+1,n). \end{aligned} \tag{9}$$

PART 4: STBC decoding

The information data after the STBC decoding can be given by;

$$\begin{aligned} \hat{D}(m,n) &= \tfrac{d(m,n)\hat{X}(m,n)-b(m,n)\hat{X}(m+1,n)}{a(m,n)d(m,n)-b_1(m,n)c_1(m,n)} \\ \hat{D}(m+1,n) &= \tfrac{a(m,n)\hat{X}(m+1,n)-c(m,n)\hat{X}(m,n)}{a(m,n)d(m,n)-b(m,n)c(m,n)} \end{aligned} \tag{10}$$

where

$$\begin{aligned} a(m,n) &= A_i(m,n)+A_{i+1}(m,n), \\ b(m,n) &= B_i(m,n)+B_{i+1}(m,n), \\ c(m,n) &= C_i(m,n)+C_{i+1}(m,n), \\ d(m,n) &= D_i(m,n)+D_{i+1}(m,n). \end{aligned}$$

$$\begin{aligned} A_i(m,n) &= \left|\hat{H}_{1i}(m,n)\right|^2 + \left|\hat{H}_{2i}(m+1,n)\right|^2, \\ B_i(m,n) &= \hat{H}^*_{1i}(m,n)\hat{H}_{2i}(m,n) \\ &\quad -\hat{H}^*_{1i}(m+1,n)\hat{H}_{2i}(m+1,n), \\ C_i(m,n) &= \hat{H}_{1i}(m,n)\hat{H}^*_{2i}(m,n) \\ &\quad -\hat{H}_{1i}(m+1,n)\hat{H}^*_{2i}(m+1,n), \\ D_i(m,n) &= \left|\hat{H}_{1i}(m+1,n)\right|^2 + \left|\hat{H}_{2i}(m,n)\right|^2. \end{aligned}$$

3. PROPOSAL OF CHANNEL ESTIMATION METHOD

In this section, we propose the channel estimation method for the proposed STBC MIMO-OFDM system. Firstly, we define the Rician fading channel which consists of one direct path and several reflected paths which follows the Rayleigh distribution. Secondly, we propose the scattered pilot and null subcarriers assignment method both in the frequency and time axes which enables the estimation of CFR for the multiplexed signal with STBC coding transmitted from both *BSs*. Finally, we propose the CFR estimation method by using the the Maximum Likelihood (ML) method in the frequency axis and the cubic spline interpolation method which enables the demodulation of received signal with the STBC coding.

3.1 Fading Channel Model

The channel impulse responses $h_{tr}(m,k)$ in the Rician Fading Channel between the *t-th* transmitting antenna at the *BS#t* and the *r-th* receiving antenna at the *MS#r* can be given by;

$$\begin{aligned} h_{tr}(m,k) &= \sum_{l=1}^{NP} \rho^{(l)}_{tr}(m)\cdot\delta(k-l) \\ \rho^{(l)}_{tr}(m) &= \sum_{s=1}^{C_l} \mu_{ls}\cdot e^{j2\pi f_D\cos(\varphi_{ls})m} \end{aligned} \tag{11}$$

where *t (=1,2)* and *r(=1,2)* represent the *Tx* antenna and *Rx* antenna numbers, $\rho^{(l)}_{tr}$ is the channel impulse response in the time domain between the *t-th* transmitting antenna and the *r-th* receiving antenna for the *l-th* delay path, *NP* is the number of delay paths, μ_{ls} is the coefficient of scattered path for the *s-th* arrival angle of *l-th* delay path, C_l is the number of scattered paths for the delay path *l*, and f_D is the maximum Doppler frequency spread at the speed of the vehicle v (km/hr) in the radio frequency (f_c).

By using (11), the time domain received signal $r_1(m,k)$ and $r_2(m,k)$ at each receiving antenna at the *MS* can be given by;

At *MS#1*,

$$\begin{aligned} r_1(m,k) &= \{h_{11}(m,k)\otimes s_1(m,k)\}\cdot PL1 \\ &\quad +\{h_{21}(m,k)\otimes s_2(m,k)\}\cdot PL2 + w_1(m,k). \end{aligned} \tag{12}$$

At *MS#2*,

$$\begin{aligned} r_2(m,k) &= \{h_{12}(m,k)\otimes s_1(m,k)\}\cdot PL1 \\ &\quad +\{h_{22}(m,k)\otimes s_2(m,k)\}\cdot PL2 + w_2(m,k). \end{aligned} \tag{13}$$

where $\otimes$ denotes the convolution operation. Here, the channel frequency response $H_{tr}(m,n)$ can be obtained by converting the channel impulse response given in (11) to the frequency domain by FFT which is given by;

$$H_{tr}(m,n) = \sum_{l=1}^{NP} \rho_{tr}^{(l)}(m) \cdot e^{\frac{-j2\pi(l-1)(n-1)}{N}}. \qquad (14)$$

3.2 Scattered Pilot Sub-carrier Assignment Method

From (14), it can be seen that the channel frequency response under the high mobile environments is required to estimate at every symbol for the frequency domain equalization of received signal. From this fact, this paper proposes three types of pilot sub-carrier assignment methods to be used in the estimation of channel frequency response. Figure 3 shows the pilot sub-carriers assignment method for *Type I* [7], *Type II* and *Type III.* In the figure, *FIP* and *TIP* represent the interval of sub-carriers in the frequency axis and interval of pilot symbols including the pilot sub-carriers in the time axis. The followings are the details for these three types of pilot sub-carriers assignment methods.

Type I: As shown in Fig.3(a),every symbol in the time axis includes the pilot sub-carriers and null sub-carriers inserted into the data sub-carrier with the interval of *FIP* in which the locations of all pilot sub-carriers for the *BS#1* are assigned by the null sub-carriers for the *BS#2* so as to avoid the collision of pilot sub-carriers between the received signals at the *MS* from *BS#1* and *BS#2*. From this assignment method, the *MS* can estimate the CFRs at the pilot sub-carriers for both links from the *BS#1* and *BS#2*, separately. By using the estimated CFR at the pilot sub-carriers, the CFR over the OFDM frequency bandwidth can be estimated at every symbol based on the ML method which is presented in Section 3.3.

Type II: As sown in Fig.3(b), consecutive two symbols with the interval of *TIP* include both the pilot and null sub-carriers or two null sub-carriers inserted into the data sub-carrier with the interval of *FIP*. The pilot sub-carriers assignment method for the pilot symbols including both the pilot and null sub-carriers with the interval *TIP* is the same as *Type I.* The null sub-carriers for the pilot symbols including only the null sub-carriers are assigned at the consecutive two sub-carriers with the interval of *FIP*. All data sub-carriers except the pilot and null sub-carriers are encoded by the STBC over the consecutive two symbols. The estimation of CFR both for the frequency and time axes for the *Type II* is the same as the *Type I.* Here it should be noted that the null sub-carrier is assigned at the location of pilot sub-carrier in the first pilot symbol within the consecutive two pilot symbols from the reason that the consecutive two symbols are encoded by the STBC.

Type III: As shown in Fig.3(c), the consecutive two pilot symbols in which the pilot and null sub-carriers assignment method are the same as the *Type I*, are inserted into the data symbols with the interval of *TIP* in order to improve the CFR estimation accuracy. From this assignment method, it is possible to use the estimated CFR over the consecutive two pilot symbols for improving the CFR estimation accuracy.

Table 1: *Transmission Efficiency η (%)*

Type	Transmission Efficiency η (%)
I	50.0%
II	85.2%
III	85.2%

Table 1 shows the transmission efficiency η for the above three types of pilot sub-carriers assignment methods. In the evaluation, the *FIP* and *TIP* are 4 and 1 for *Type I* and 4 and 8 for *Type II* and *Type III.* From the table, it can be observed that *Type II* and *Type III* show the higher transmission efficiency than the *Type I.*

3.3 Channel Estimation method

In the previous section, we propose three types of scattered pilot sub-carriers assignment methods. In this section, we propose the channel estimation (CE) method by using the scattered pilot sub-carriers for the STBC MIMO-OFDM system. The CFR can be estimated in both the frequency and time axes separately. For the frequency axis, the CFR over the OFDM frequency bandwidth can be estimated by applying the Maximum Likelihood (ML) method [7-9] for the estimated CFR at the pilot sub-carriers. For the time axis including the data symbols, the CFR over one frame can be estimated by applying the cubic spline interpolation method for the estimated CFR over the OFDM frequency bandwidth at the pilot symbols. In this section, the ML method for the frequency axis and interpolation method for the time axis are presented.

The time domain signals given in (12) and (13) are converted to the frequency domain signals $R_1(m,n)$ and $R_2(m,n)$ by FFT which can be expressed by the following;
At *MS#1*,

$$\begin{aligned} R_1(m,n) &= H_{11}(m,n)S_1(m,n)PL1 \\ &+H_{21}(m,n)S_2(m,n)PL2 + W_1(m,n). \end{aligned} \qquad (15)$$

At *MS#2*,

$$\begin{aligned} R_2(m,n) &= H_{12}(m,n)S_1(m,n)PL1 \\ &+H_{22}(m,n)S_2(m,n)PL2 + W_2(m,n). \end{aligned} \qquad (16)$$

By dividing (15) and (16) by the known pilot sub-carrier data, the CFRs $S_{P1}(mp(k),np_1(i))$ and $S_{P2}(mp(k),np_2(i))$ at the location of pilot sub-carriers can be estimated as follows;

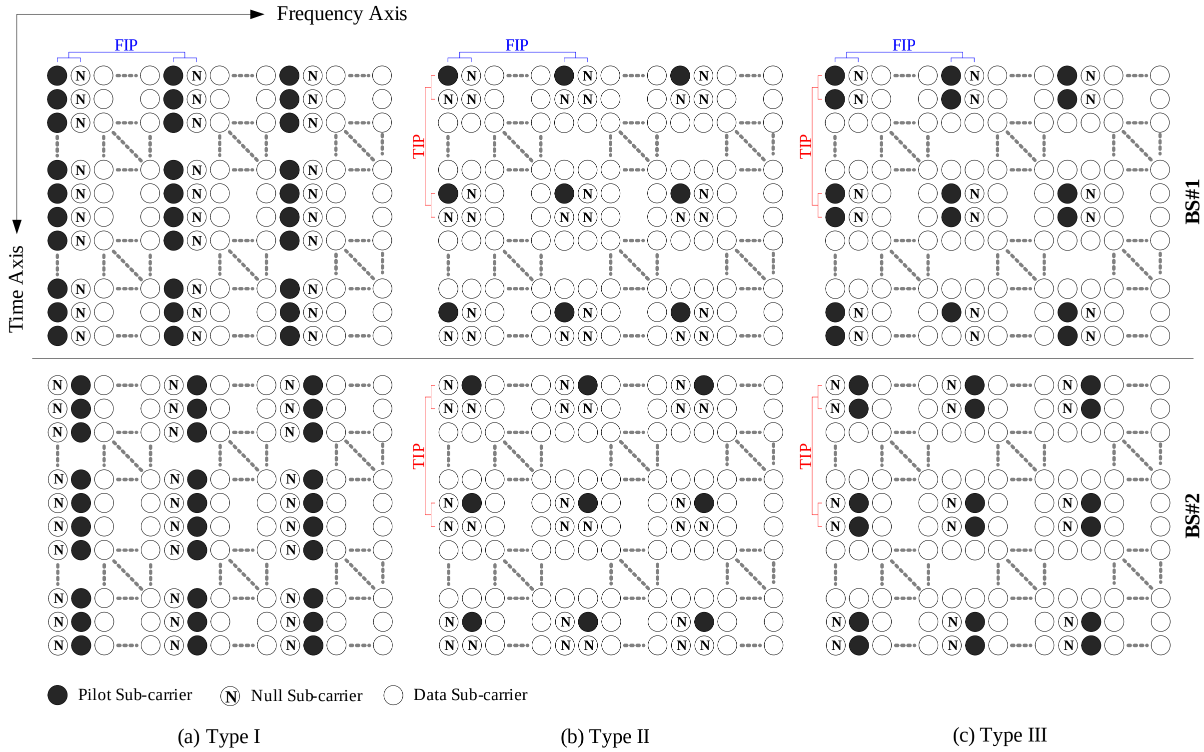

Fig.3: *Three types of scattered pilot sub-carriers assignment methods*

At *MS#1*,

$$\begin{aligned}\hat{H}_{11}(mp(k),np_1(i)) &= \frac{R_1(mp(k),np_1(i))}{S_{P1}(mp(k),np_1(i))} - \frac{W_1(mp(k),np_1(i))}{S_{P1}(mp(k),np_1(i))},\\ \hat{H}_{21}(mp(k),np_2(i)) &= \frac{R_1(mp(k),np_2(i))}{S_{P2}(mp(k),np_2(i))} - \frac{W_1(mp(k),np_2(i))}{S_{P2}(mp(k),np_2(i))}.\end{aligned} \quad (17)$$

At *MS#2*,

$$\begin{aligned}\hat{H}_{12}(mp(k),np_1(i)) &= \frac{R_2(mp(k),np_1(i))}{S_{P1}(mp(k),np_1(i))} - \frac{W_2(mp(k),np_1(i))}{S_{P1}(mp(k),np_1(i))},\\ \hat{H}_{22}(mp(k),np_2(i)) &= \frac{R_2(mp(k),np_2(i))}{S_{P2}(mp(k),np_2(i))} - \frac{W_2(mp(k),np_2(i))}{S_{P2}(mp(k),np_2(i))}.\end{aligned} \quad (18)$$

where the pilot symbol number $mp(k)$ and pilot sub-carrier number $np_1(i)$ for the *BS#1* and $np_1(i)$ for the *BS#2* are given by;

$$\begin{aligned}&mp(k) = (k-1)TIP + 1 \; if \; k = 1 \sim L/TIP + 1,\\ &np_1(i) = (i-1)FIP + 1, \text{ and}\\ &np_2(i) = (i-1)FIP + 2 \; if \; i = 1 \sim N/FIP.\end{aligned}$$

Since W_1 and W_2 are uncorrelated Gaussian variable in (17) and (18), the ML solution of both equations comes into the minimum square error (MSE) optimization problem. To estimate the CFR precisely, the number of guard interval length (Ng) must be taken by larger than NPi. The unknown parameters for the channel impulse response (CIR) $\hat{\rho}^{(l)}_{xr}(mp(k))$, where x is *BS#1* or *#2*, can be obtained by;

$$\begin{aligned}&L_{ML}(\hat{\rho}^{(l)}_{xr}(mp(k)))\\ &= \arg\min_{\hat{\rho}^{(l)}_{xr}(mp(k))} \left[\sum_{i=1}^{NPi} \left| \begin{array}{l} H_{xr}(mp(k),np_x(i)) \\ - \sum_{l=1}^{Ng} \left\{ \begin{array}{l} \hat{\rho}^{(l)}_{xr}(mp(k)) \\ \cdot e^{\frac{-j2\pi(l-1)(np_i(i)-1)}{N}} \end{array} \right\} \end{array} \right|^2 \right]\\ &\hat{\rho}^{(l)}_{xr}(mp(k)) = \left[\hat{\rho}^{(1)}_{xr}(mp(k)),....,\hat{\rho}^{(Ng)}_{xr}(mp(k))\right]\end{aligned} \quad (19)$$

Taking $\partial(19) \Big/ \partial \hat{\rho}^{*(l)}_{xr}(mp(k)) = 0$, where $(*)$ denotes conjugate, (19) can be expressed by the following;

$$\begin{aligned}&\sum_{i=1}^{NPi} [\{H_{xr}(mp(k),np_x(i))\\ &\quad - \sum_{l=1}^{Ng} \hat{\rho}^{(l)}_{xr}(mp(k)) \cdot e^{\frac{-j2\pi(l-1)(np_x(i)-1)}{N}}\}\\ &\qquad \cdot \sum_{ll=1}^{Ng} e^{\frac{j2\pi(ll-1)(np_x(i)-1)}{N}}] = 0.\end{aligned} \quad (20)$$

From (20), it can be rewritten as following;

$$\begin{aligned}&\sum_{i=1}^{NPi} \sum_{ll=1}^{Ng} H_{fromBS\#x}(mp(k),np_x(i)) \cdot e^{j\frac{2\pi(np_x(i)-1)(ll-1)}{N}}\\ &= \sum_{i=1}^{NPi} \sum_{l=1}^{Ng} \sum_{ll=1}^{Ng} \hat{\rho}^{(l)}_{xr}(mp(k)) \cdot e^{-j\frac{2\pi(np_x(i)-1)(l-ll)}{N}}.\end{aligned} \quad (21)$$

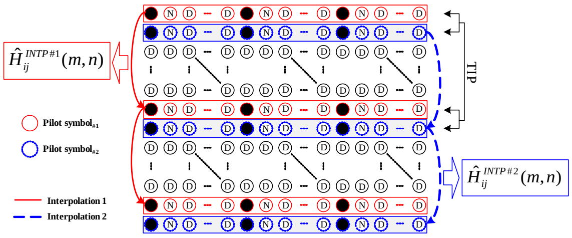

Fig.4: *Proposed CFR estimation method for Type III*

From (21), since the dependence from optimization parameters $\hat{\rho}^{(l)}_{xr}(mp(k))$ is linear in (21), its solution can be realized by the Moore-Penrose generalized matrix inversion which can be given by;

$$\left[\hat{\rho}^{(l)}_{xr}(mp(k))\right] = \dagger\, [D] \bullet [B(mp(k), np_x(i))] . \qquad (22)$$

where $\left[\hat{\rho}^{(l)}_{xr}(mp(k)\right]$ is the (Ngx1) matrix of the $\hat{\rho}^{(l)}_{xr}(mp(k)$, $[B(mp(k), np_x(i))]$ is the(Ngx1) matrix of the $R_r(mp(k), np_x(i))/S_{Px}(mp(k), np_x(i))$,$[D]$ is the (NgxN) matrix of the $exp(-j2\pi(np_x(i)-1)(l-ll)/N)$. † denotes the Moore-Penrose inverse and • denotes matrix multiplication. Because the matrix $[D]$ depends on the locations of pilot sub-carriers and they are known at the receiver, the Moore-Penrose inverse matrix can be calculated in advance at the receiver. From this fact, the computation complexity for the estimation of CFR can be reduced relatively. The frequency channel response over the OFDM frequency bandwidth can be obtained by converting the CIR given in (22) to the frequency domain by FFT.

As for the estimation of CFR in the time axis, the cubic spline interpolation method is applied to the estimated CFR which is given by using ML method as mentioned above. As for the *Type III*, the CFRs of *pilot symbol*$_{\#1}$ and *pilot symbol*$_{\#2}$ with the interval of *TIP* are estimated by performing two interpolations separately as shown in Fig. 4. From Fig. 4, it can be seen that the CFR for the *pilot symbol*$_{\#1}$ and *pilot symbol*$_{\#2}$ are interpolated every $mp(k) = (k-1)TIP+1$ and $mp(k) = (k-1)TIP+2$, respectively. Then $\hat{H}^{INTP\#1}_{ij}(m,n)$ and $\hat{H}^{INTP\#2}_{ij}(m,n)$ can be estimated for each interpolation. Where i and j are the index of *BS* and the receiving antenna, and *INTP#1* and *INTP#2* denote the interpolations *1* and *2*, respectively. By using two estimated CFR, the estimation accuracy of CFR can be improved by taking the average of them which is given by,

$$\hat{H}_{ij}(m,n) = mean\left[\hat{H}^{INTP\#1}_{ij}(m,n) + \hat{H}^{INTP\#2}_{ij}(m,n)\right] . \qquad (23)$$

Figure 5 shows the estimation results of CFR $\hat{H}_{ij}(m,n)$ which is given by (23). From the figure,

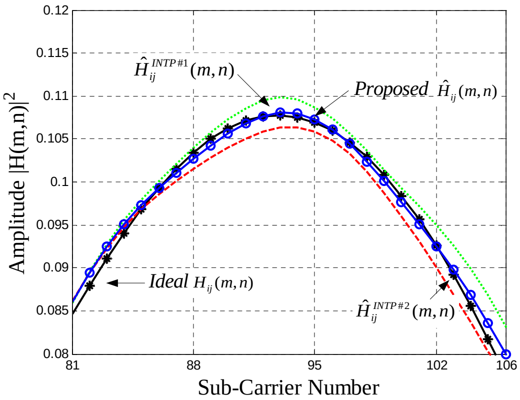

Fig.5: *Example of the average estimated signal $[\hat{H}_{ij}(m,n)]$ in (23)*

it can be observed that the estimation accuracy of CFR for the proposed method is better than those of using $\hat{H}^{INTP\#1}_{ij}(m,n)$ and $\hat{H}^{INTP\#2}_{ij}(m,n)$ separately and the estimation accuracy for the proposed estimation method given in (23) is closed to the ideal CFR.

4. PERFORMANCE EVALUATION

This section presents the various computer simulation results to select the best pilot sub-carriers assignment method and to verify the effectiveness of the proposed STBS MIMO-OFDM system in conjunction with the proposed CFR estimation method. The simulation parameters used in the following evaluations are listed in Table 2.

Figure 6 shows the CFR estimation accuracy for three types of pilot sub-carriers assignment methods as shown in Fig.3 when changing the distance from both base stations *BS#1* and *BS#2* to the vehicle (*MS*). In the figure, the normalized minimum mean square error (NMSE) is employed in the evaluation of estimation accuracy of CFR. From Fig.6, it can

Table 2: *Simulation parameters*

Information	**Parameter**
Modulation for data sub-carriers	64QAM
Demodulation	Coherent
Number of Sub-carriers (N)	128
Symbol Duration (Ts)	12.8μSec
Guard Interval Duration (Tsg)	1.2μSec
Number of Sample points in GI (Ng)	12
Modulation of Pilot sub-carriers	QPSK
Interval of Pilot Symbol (TIP)	1,4,8,16
Interval of Pilot Sub-carrier (FIP)	1,4,8,16
OFDM Occupied Bandwidth (W)	10MHz
Radio Frequency (fc)	5.4GHz
Rician fading channel model	
Rice Factor(K)	6dB
CNR at BS#1 and BS#2	50dB
Delay Profile	Exponential
Decay Constant	-1dB
Number of delay paths (NP)	4
Number of scattered paths (C_l)	20

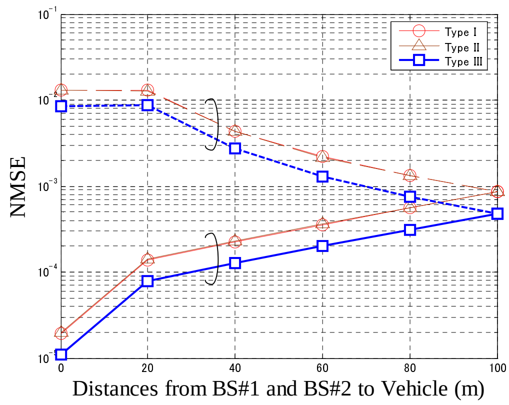

Fig.6: *The channel estimation accuracy for three types of pilot sub-carriers assignments methods*

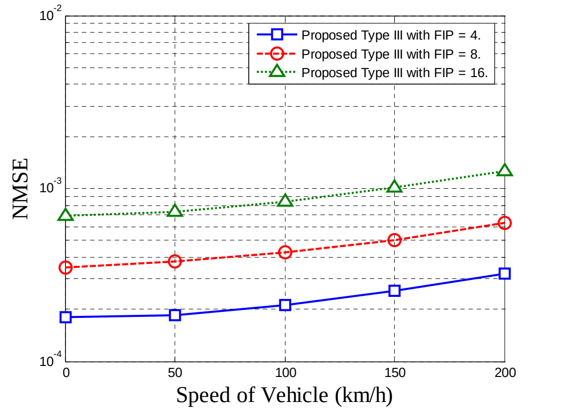

Fig.7: *Channel estimation accuracy for the proposed Type III method (FIP= 4, 8 and 16, and TIP=8)*

be seen that the channel estimation accuracy of the CFRs for the *BS#1* to *MS* link and *BS#2* to *MS* link are degraded and improved, respectively, until at the center of location between both base stations (*DD1* is 100m). It can be also observed that the channel estimation accuracy of proposed *Type III* is better than that for both *Type I* and *Type II*. From these results and the transmission efficiency as shown in Table 1, it can be concluded that the *Type III* with the channel estimation method given in (23) is the best pilot sub-carrier assignment method for the proposed STBC MIMO-OFDM system.

In the following, we optimize the parameters for the intervals of *FIP* and *TIP* under the typical RVC environments. The selection of these parameters is much dependent on the fading conditions which includes the number of delay paths and vehicle speed. In this paper, we employ the Rician fading model which is the typical operation conditions for the RVC. The Rician fading model employed in this paper consists of one direct path and 4 reflected paths which follow the Rayleigh distribution. The vehicle speed is considered in this paper up to 200km/h. Under these operation conditions, we conduct the computer simulations and decide the parameters of *FIP* and *TIP* which can achieve the better estimation accuracy even under the higher mobile environments up to 200km/h.

Figure 7 shows the channel estimation accuracy for the proposed CFR estimation method with *Type III* when the intervals of *FIP* are 4, 8, and 16, and the interval of *TIP* is fixed by 8. In the figure, the channel estimation accuracy is evaluated by the NMSE when changing the speed of the vehicle (km/h). From the figure, it can be observed that the estimation accuracy for the proposed method can achieve the better performance when the *FIP* is 4 even at 200km/h vehicle speed.

Figure 8 shows estimation accuracy for the proposed CFR estimation method with *Type III* when the intervals of *TIP* are 4, 8, and 16, and the interval

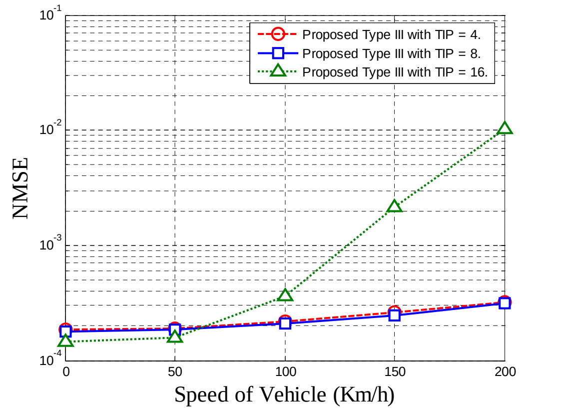

Fig.8: *Channel estimation accuracy for the proposed Type III method (TIP = 4, 8 and 16, and FIP=4)*

of *FIP* is fixed by 4 which is obtained from the results of Fig.7. From the figure, it can be seen that the estimation accuracy can keep the better performance when the interval of *TIP* is less than 8. From the results in Figs.7 and 8, it can be concluded that the proposed CFR estimation method by using *Type III* can achieve the better estimation accuracy with keeping the better transmission efficiency when *FIP* is 8 and *FIP* is 4 even under higher mobile environments. The following evaluations for the BER performance employs 8 and 4 for the intervals of *TIP* and *FIP*, respectively.

Figure 9 shows the BER performance of the proposed *Type III* method of using one and two receiving antennas at the *MS* when changing the carrier-to-noise ratio (CNR). In the simulation, the vehicle is located at the center of two base stations (*DD1* is 100m as shown in Fig.1) which corresponds to the worst condition for the road-to-vehicle communication. The operation CNR is 50dB which is defined at the right beneath of *BS#1*. The vehicle speed is 200km/h, and the *FIP* and *TIP* intervals are 4 and 8, respectively. The conventional-OFDM employs the

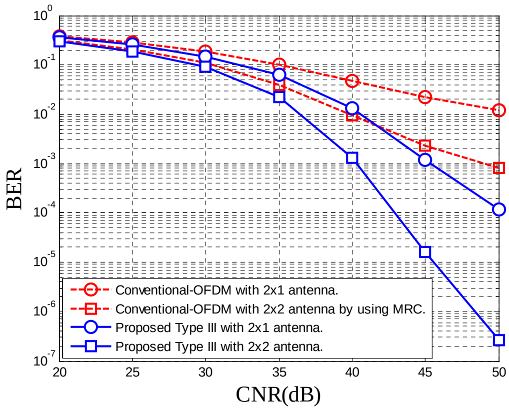

Fig.9: *BER performance of the proposed Type III method when changing CNR*

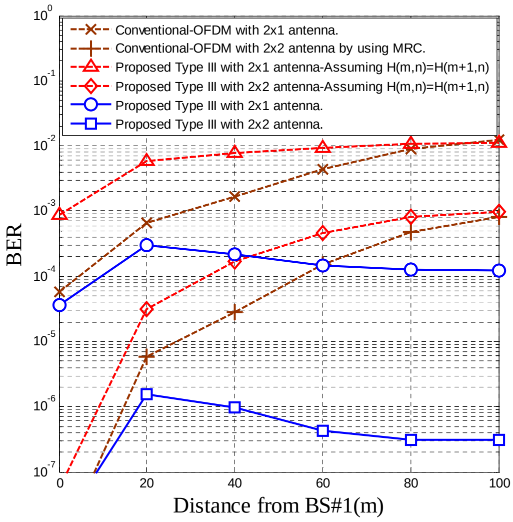

Fig.10: *BER performance of the proposed method when changing the distance from the base station#1 (BS#1) to the vehicle (MS)*

Single Frequency Network technique (SFN) [10] in which both base stations transmit the same OFDM data information and the *MS* can demodulates the data information correctly from the multiplexed received signal when the maximum delay time deference for two received signals from the *BS#1* and *BS#2* is within the guard interval length Ng. The SFN technique is employed in the terrestrial digital TV system of using OFDM method. In the figure, the BER performances for both conventional-OFDM with and without the *Maximum Ratio Combining* (MRC) [11] technique are also shown as for the purpose of comparison with the proposed method. From the figure, it can be observed that the proposed method with 2x2 antennas shows much better BER performance than that for the conventional OFDM of using SFN and MRC techniques.

Figure 10 shows the BER performance of the proposed method of using one and two receiving antennas at the *MS* when changing the distance from *BS#1* to the *MS*. In the simulation, the operation CNR is 50dB which is defined at the right beneath of *BS#1* and the vehicle speed is 200km/h. In the figure, the BER performances for the conventional OFDM method of using SFN and MRC techniques, and the proposed method when assuming the *H(m,n)=H(m+1,n)* are also shown. From the figure, it can be observed that the proposed method with two receiving antennas shows much better BER performance than the other methods especially when the vehicle is located at the center of two base stations (*DD1* is 100m) which corresponds to the worst case in the road to vehicle communications. The BER performance of proposed method when assuming *H(m,n)=H(m+1,n)* is worse than the conventional OFDM methods. From these results, the channel estimation is required at every symbol for the proposed STBC MIMO-OFDM system under higher mobile environments. From these results, it can be concluded that the proposed STBC MIMO-OFDM method with the pilot sub-carriers assignment method of *Type III* has a big advantage on the road to vehicle communication systems (RVCs) because the higher transmission data rate with better BER performance can be achieved at any place of vehicle between two base stations.

5. CONCLUSIONS

This paper proposed the new road-to-vehicle communication system for the future ITS which can provide the mobile broadband multimedia wireless communications. The salient features of the proposed method are to employ the STBC MIMO-OFDM techniques and channel estimation method of using the scattered pilot sub-carriers both for the frequency and time axes. From the various computer simulation results, this paper demonstrated the effectiveness of the proposed STBC MIMO-OFDM system with *Type III* pilot sub-carriers assignment method even in the higher time varying fading channel.

ACKNOWLEDGEMENT

The authors would like to thank to the Japanese Government (Monbukagakusho:MEXT) Scholarships who has supported this research.

References

[1] W.-Y. Shieh, C.-C.J. Hsu, S.-L. Tung, P.-W. Lu, T.-H. Wang, and S.-L. Chang, "Design of Infrared Electronic-Toll-Collection Systems With Extended Communication Areas and Performance of Data Transmission," *Intelligent Transportation Systems, IEEE Trans*, Vol.12, pp.25-35, Mar. 2011.

[2] Y. Hattori, T. Shimoda, and M. Ito, "Development and Evaluation of ITS Information Communication System for Electric Vehicle," *in Proc. of VTC Spring 2012*, pp.1-6, May 2012.

[3] A. Ono, K. Naito, K. Mori, and H. Kobayashi, "Roadside to Vehicle Communication System with OFDM Cooperative Transmission," *in Proc. of APWCS2011*, MP2-7, Aug.2011.

[4] D. Jiang, and L. Delgrossi, "IEEE 802.11p: Towards an International Standard for Wireless Access in Vehicular Environments," *in Proc. of VTC Spring 2008*, pp.2036-2040, May 2008.

[5] S.M.Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE J. Select. Areas Commun*, Vol.16, pp.1451-1458, Oct.1998.

[6] T. Mata, P. Boonsrimuang, P. Boonsrimuang, and H. Kobayashi, "Proposal of Improved PTS Method for STBC MIMO-OFDM Systems," *IEICE Trans. Comm. Lett.*, Vol.E93B, no.10, Oct.2010.

[7] T. Mata, K. Naito, P. Boonsrimuang, K. Mori, and H. Kobayashi, "Proposal of STBC MIMO-OFDM for ITS Systems," *in Proc. of ECTI-CON2013*, May 2013.

[8] G. Mkrtchyan, "Estimation, Parameter learning and Prediction of Time-varying communication channels," *Ph.D dissertation, Mie university*, Sep. 2006.

[9] H. Kobayashi and K. Mori, "Proposal of channel estimation method for OFDM systems under Time-varying fading environments,"*IEICE Trans Comm.*, Vol.J90B, no.12, Dec. 2007.

[10] G. Santella, R. De Martino, and M. Ricchiuti, "Single frequency network (SFN) planning for digital terrestrial television and radio broadcast services: the Italian frequency plan for T-DAB," *in Proc. of VTC Spring 2004*, Vol.4, pp.2307-2311, May 2004.

[11] K. S. Ahn, and R.W. Heath, "Performance analysis of maximum ratio combining with imperfect channel estimation in the presence of cochannel interferences," *IEEE Wireless Commun*, Vol.8, pp.1080-1085, Mar. 2009.

Tanairat MATA received the B.Eng (1st class honors) and M.Eng degrees in Telecommunications Engineering from King Mongkut's Institute of Technology Ladkrabang(KMITL),Thailand in 2007,and 2010,respectively.And He worked in Strong Brothers1961 Co.,Ltd., Thailand from 2007 to 2012.He is currently a Ph.D candidates at the Mie University,Japan.He research interests include mobile communications,wireless LAN systems, MIMO-OFDM system,and the next generation ITS communication systems.

Katsuhiro NAITO was born in Tokyo, Japan in 1977. He received the B.S. degree in Electronics Engineering from Keio University, Japan in 1999, and received the M.S. and Ph.D. degrees in Information Engineering from Nagoya University, Japan in 2001 and 2004, respectively. From 2001 to 2004, he was a research fellow of the Japan Society for the Promotion of Science. Since 2004, he has been an Assistant Professor of the Department of Electrical and Electronic Engineering at Mie University, Japan. He was a visiting scholar at University of California, Los Angeles in 2011. His current research interests include the packet radio networks, wireless internet access, and ad hoc network. Dr.Naito is a member of IEEE and IPSJ.

Pisit Boonsrimuang received the B.Eng, M.Eng,and Doctor degrees in Telecommunications Engineering, in 1997,2000,and 2007 respectively.He is currently an associate professor at the King Mongkut's Institute of Technology Ladkrabang(KMITL),Thailand.His research interests include transmission techniques for future multimedia wireless LAN systems and next generation of mobile communication systems. He received the Student Award of Young Research's Encouragement Award from IEICE Tokai branch and Doctor Thesis Award for information technology from Nation Research Council of Thailand(NRCT) in 2005 and 2008,respectively.

Kazuo Mori received the B.E. degree in computer engineering from Nagoya Institute of Technology, Japan, in 1986 and received the Ph.D. degree in information electronics engineering from Nagoya University, Japan in 2000. In 1986, He joined the Hyper-media Research Center, SANYO Electric Co., Ltd. and was engaged in research and development on telecommunication systems. From 1995 to 2000, he was a research engineer at YRP Mobile Telecommunications Key Technology Research Laboratories Co., Ltd., where he was engaged in research on mobile communication systems. Since August 2000 he has been with Mie University, Japan, where he is currently a Professor in the division of Electrical and Electronic Engineering, Graduate School of Engineering. During 2005–2006, he was a Visiting Research Fellow at King's College London, UK. His research interests include mobile communication systems, wireless sensor networks, radio resource management, and teletraffic evaluation. Dr. Mori is a member of IEEE.

Hideo Kobayashi received the B.E., M.E., and Dr.E. degrees in 1975, 1977 and 1989, respectively from Tohoku University. He joined KDDI in 1977, and engaged in research on digital fixed satellite and mobile satellite communications systems. From 1988 to 1990, he was with INMARSAT as a Technical Staff and involved in the development of future INMARSAT systems. Since 1998 he has been a Professor of Mie University. His current research interests include mobile communications and wireless LAN systems.