Proceedings of the
2007 IEEE Intelligent Vehicles Symposium
Istanbul, Turkey, June 13-15, 2007

Improving Communication Performance of DS/SS Inter-Vehicle Communication System using MMSE Adaptive Array Antenna for Transmission and Reception

Yohei Kawamagari and Shinichi Niihara and Masahiro Fujii and Makoto Itami and Kohji Itoh

Abstract— **Recently, many studies have been being made on ITS (Intelligent Transport System) and IVC (Inter Vehicle Communication) is one of the most important research topics. Improvement of communication is essential for IVC system which communicates incident information and accident information. In IVC, many studies are focused on DS/SS CDMA (Direct Sequence / Spread Spectrum, Code Division Multiple Access) scheme. In this paper, an application using the DS/SS CDMA scheme is studied. In DS/SS CDMA schems, the packet error rate characteristic sometimes degrades under the influence of the near-far problem situation and the increase of PN code interference due to the number of vehicles. In order to improve this degradation, an IVC system that divides the receiving direction is proposed and its performance is evaluated by computer simulation. As the results of simulation good performance was confirmed.**

Keywords: IVC, Array Antenna, Ad hoc network, DS/SS CDMA, MMSE, LMS

I. INTRODUCTION

ITS (Intelligent Transport Systems) is currently attracting much attention for improving traffic congestion and traffic accident, and for realizing a social system which can create a new market. In ITS, IVC (Inter Vehicle Communication) is one of the most important research topics. In IVC system, each vehicle can communicate with other vehicles which happened to be in the same area on the road without base stations. It is possible to increase safety and to reduce traffic congestions by a realization of IVC systems. Especially, improvement of safety is most important purpose of research in ITS and it is expected to provide a great improvement in current traffic situations.

In IVC, each vehicle mutually performs periodic exchanges of navigation and control information such as velocity, acceleration and location information. Therefore, high reliability, real time capability and stability are required to the communication systems in IVC. Moreover, a special autonomous decentralized network that is constructed by two or more vehicles that occasionally approached on the road must be constructed in IVC. Therefore, it is difficult to apply the currently used communication infrastructures (such as cellar phones) and protocols to IVC directly. In this paper, the protocol using DS/SS CDMA (Direct Sequence / Spread Spectrum, Code Division Multiple Access) scheme that is one of the candidates to realize IVC systems is examined. Advantages of the use of DS/SS CDMA communication are that it is possible to use the frequency band efficiently, it is robust to interference and fading and it is possible to realize multiple access communication

However, at the receiver, DS/SS CDMA scheme suffers from the influence of closer user's signal more than that of distant user's signal (near-far problem). There are also problems to allocate unique PN (Pseudo Noise) code to each user in order to realize a DS/SS CDMA communication system in IVC. Very large number of PN codes is required if unique PN code is assigned to each vehicle in the world. Although this is possible theoretically, very long PN code is necessary and this degrades transmission rate. Therefore, sharing limited number of PN codes by vehicles is a realistic solution. To perform this optimally, an appropriate measure to PN code allocation scheme is necessary.

Moreover, even if PN code could be assigned efficiently to each vehicle, characteristic is deteriorated by the increase of users. The reason of this deterioration is that the available length of PN code is actually limited because longer PN code length leads to degradation of transmission speed as above described. The interference caused by PN code collision affects the packet acquisition and packet error rate performance.

On of the schemes to solve this problem is the use of an array antenna. In this paper, in order to improve interference characteristics, the protocol of DS/SS CDMA scheme using common code combined with an array antenna is proposed and its performance is evaluated.

II. MMSE ADAPTIVE ARRAY ANTENNA

In this paper, an MMSE(Minimum Mean Spuare Error) adaptive array antenna is used [3]. The MMSE adaptive antenna determines the optimal weights by minimizing the difference between the reference signal (that has high correlation with the desired signal) prepared in the receiver and the output signal of the array antenna generated from the received signals (error margin signal). Although this scheme has the advantage where it is very simple and is able to perform simultaneous adaptive null steering and beam foaming, the precise reference signal is necessary. However, it is considered that the MMSE scheme is appropriate for DS/SS CDMA system because the PN codes can be used

This work was not supported by any organization

Y.Kawamagari is with the Department of Applied Electronics, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba 278-8510 JAPAN niihara@itamilab.te.noda.sut.ac.jp

as the reference signals. The error margin signal that is the difference between the reference signal and the output signal of the array is expressed by the formula (1).

$$e(t) = r(t) - y(t) = r(t) - \mathbf{W}^H \mathbf{X}(t) \tag{1}$$

Here, X denotes the received signal, W denotes the weight, $e(t)$ denotes the error margin signal, $r(t)$ denotes the reference signal, $y(t)$ denotes the output signal of the array. Then, the mean square error of the error margin signal is expressed by formula (2).

$$E[|e(t)|^2] = E[|r(t) - \mathbf{W}^H \mathbf{X}(t)|^2] \tag{2}$$

Here, $\mathbf{r}_{xr}$ denotes a correlation vector between the reference signal and the input signal vector, that is defined by formula (3).

$$\mathbf{r}_{xr} \triangleq E[\mathbf{X}(t) r^*(t)] \tag{3}$$

In this scheme, the mean square error in formula (2) is minimized by appropriately determining the weight vector. Therefore, the value of the weight vector, $\mathbf{W}$, that minimizes the value of formula (2) (the optimal weight vector) can be derived by making the gradient of formula (2) zero as shown in the following formula.

$$\nabla_W E[|e(t)|^2] = \mathbf{0} \tag{4}$$

As shown above, $\nabla_W E[|e(t)|^2]$ is gradient of the mean square error against the weight vector and optimum weight is expressed by formula (5). Here, the R_{xx} denotes the correlation matrix.

$$\nabla_W E[|e(t)|^2] = -2\mathbf{r}_{xr} + 2R_{xx}\mathbf{W} \tag{5}$$

$$\mathbf{W}_{opt} = R_{xx}^{-1}\mathbf{r}_{xr} \tag{6}$$

A. LMS Algorithm

In this paper, LMS (Least Mean Square) algorithm is used for optimizing the weights of the array iteratively. This algorithm is based on the steepest descent algorithm and is one of the most general and simple algorithms, Moreover, it is easy to implement because of the required number of calculations is not very large. LMS algorithm is expressed by the formula (7).

$$\mathbf{W}(m+1) = \mathbf{W}(m) - \frac{\mu}{2}\nabla_W E[|e(t)|^2] \tag{7}$$

Here, the μ denotes the step size which makes an adjustment of weight Update rate. According to (5), $\nabla_W E[|e(m)|^2]$ expressed in the formula (8) is modified to the form in (8) in LMS algorithm by neglecting the operation of expectation.

$$\nabla_W E[|e(m)|^2] = -2\mathbf{r}_{xr} + 2R_{xx}\mathbf{W}(m) \tag{8}$$

Here, e denotes the error margin signal which the difference between the reference signal and the received signal, and μ is the step size which makes an adjustment of weight update rate. The step size, μ, should satisfy the formula (9) to ensure the stable convergence condition.

$$0 < \mu < \frac{1}{\lambda_{max}} \tag{9}$$

Here, λ_{max} is the maximum eigenvalue of the correlation matrix. However, the maximum eigenvalue of the correlation matrix frequently changes depending the location of vehicles in IVC communication. Therefore, if step size value, μ, is fixed, it may take very long time to converge under very small step size or it may not converge under very large step size. Therefore, the optimal step size is analyzed from the received signal power based on formula (10) and the value is determined.

$$0 < \mu < \frac{1}{Reception\ \ Power} \tag{10}$$

III. System model

A. Packet Structure

In this paper, the packet defined by DOLPHIN (Dedicated Omni-purpose inter-vehicle communication Linkage Protocol for HIghway automatioN) protocol that is one of the IVC protocols is used [5]. Fig. 1 shows the packet format defined in the DOLPHIN protocol.

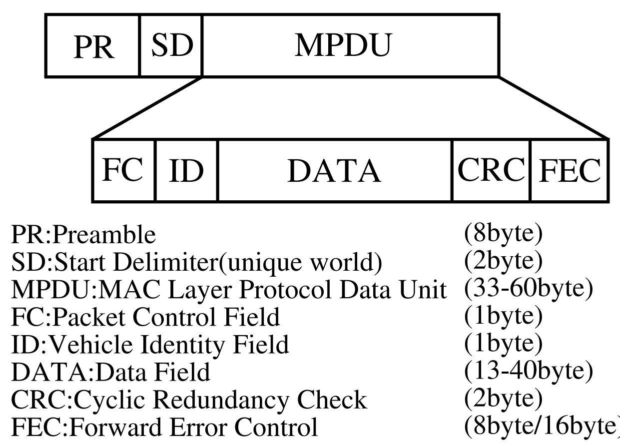

Fig. 1. Channel configuration

B. Link Establishment using Common Code

In this paper, the scheme that use a common PN code for initial link establishment between two vehicles is assumed [1]. After successful link establishment, the vehicles communicate using allocated private PN code in the link establishment procedure. Here, the procedure of communication link establishment between two vehicles is described. It is assumed that a circular array antenna is loaded on each vehicle.

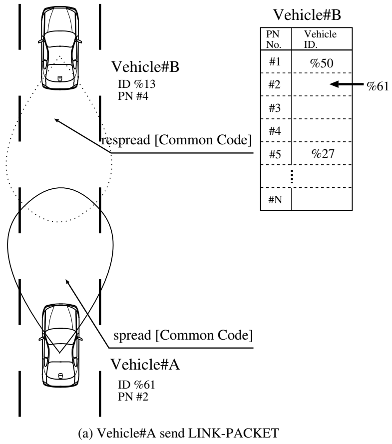

Fig. 2. Link establishment procedure(a)

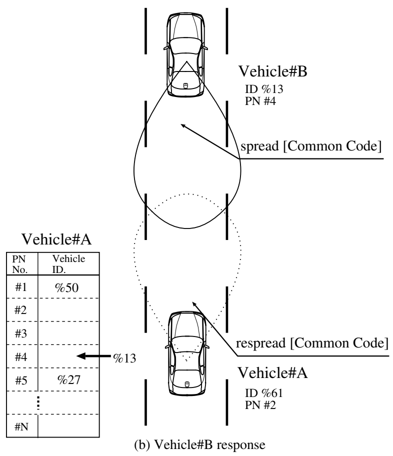

Fig. 3. Link establishment procedure(b)

In the first step of link establishment, the vehicle B receives a link establish request packet from the vehicle A as shown in Fig. 2. Here, the packet contains the private PN code of the vehicle A and is spread and transmitted using the common code. The vehicle B is continuously monitoring reception of the common code. If the vehicle B successfully receives the link establish request packet from the vehicle A, the vehicle B acquires the private PN code of the vehicle A.

In the second step, the vehicle B transmits the link establishment acknowledgment packet backward using the common code as shown in Fig. 3. This packet contains the private code of the vehicle B, and the vehicle A can acquire the private code of the vehicle B if the vehicle A successfully receives the acknowledgment packet. Before transmitting the acknowledgment packet, the vehicle B changes its private code if the received private code of the vehicle A is equivalent to it. The new private code is selected from the PN code usage table and this reduces collision of the equivalent private code. By performing the above link establishment, each other PN codes can be recognized and its code can be used for communication after it.

C. Structure of Array Antenna

Secondly, the system configuration of transmitter and receiver is explained. In this paper, three cases are investigated as shown in the followings.

- Transmitter uses an omni-directional antenna, receiver uses an array antenna.
- Transmitter uses an array antenna, receiver uses an omni-directional antenna.
- Both transmitter and receiver use array antennas.

D. Transmitting Antenna

Fig. 4 shows the structure of the transmitter using the MMSE adaptive array antenna. Before transmission, weight generator prepares the weights that can be used for steering to the target.

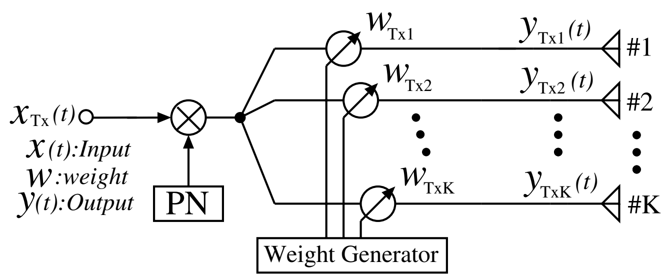

Fig. 4. Structure of the transmitter

E. Recieveing Antenna

Fig. 5 shows the structure of the receiver using the MMSE adaptive array antenna [1]. The initial weights of the array are assumed to be $\mathbf{W}(m) = (1\ \ 0\ \ 0 \cdots 0)$($m$ = iteration). Iterations are performed in every chip timing. At the timing where $m = 0$, the output of the matched filter for the PN code is calculated and the position of synchronization is determined to the position where the output value of the matched filter is largest (correlation peak value). The signal from all directions can be received at the timing where $m = 0$ because only one antenna has gain 1 and other antennas have gain 0 (initially omni directional pattern). After synchronization is performed, the receiver starts iterations using LMS algorithm so that the weight vector converges to the optimal value. This process is completed in the PR part of the DOLPHIN packet in Fig. 1. In this analysis, it is assumed that the reference signal necessary in the receiver is ideally generated from the corresponding PN code.

F. Simulation conditions

In this simulation, use of 5.9GHz frequency band and a free space propagation loss model for transmission channel are assumed [6]. When the distance between two vehicles is denoted by d, a free space basic propagation loss $L(d)$ is expressed by formula (11).

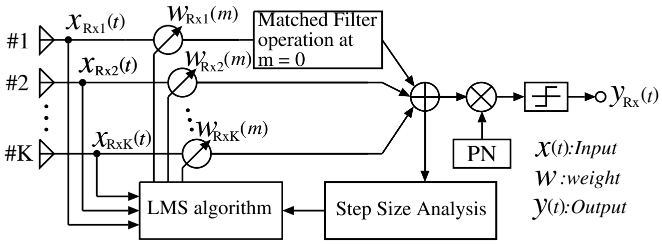

Fig. 5. Structure of the receiver

$$L(d) = 20\log\left(\frac{4\pi d}{\lambda}\right) \qquad \text{[dB]} \qquad (11)$$

Other simulation conditions are shown in TABLE I. In this paper, the additive noise level is set to the value where bit error rate of 10^{-3} is obtained when two vehicles apart by 200m are making a communication under the free space loss channel.

TABLE I
SIMULATION CONDITIONS

The number of lanes	Single-sided 3 lane
Width of lane	5[m]
Speed of Vehicle	80,100,120[km/h]
Evaluation road length	1000[m]
Communication range	200[m]
Length of PN code	Gold seq.63
Chip rate	20.0[Mcps]
Transmission interval	20[msec]
Transmission power	5.0[mW]
Antenna	Array(linear),Omni
Packet	DOLPHIN
SNR	9[dB]

In this paper, simulation result under the situation where multiple vehicles have successfully received the link establishment request packet and the vehicle that have transmitted the link establishment request packet receives multiple acknowledgment packets is shown. Therefore, the procedure of Fig. 2 was not completely performed in this simulation, but it is assumed that packets are successfully received by multiple vehicles because probability of collision between link establishment request packets much less than that of acknowledgement packets. It is assumed that each vehicle has the distance information by receiving a link establishment request packet and transmission timing of the acknowledgement packet is adjusted by using the distance information. In this paper, the contents of the data part of the packet consist of vehicle ID and its private PN code, and location information. For simplicity, influence of shadowing is not considered here.

IV. RESULT OF SIMULATION

A. Packet Error Rate characteristic

At first, packet error rate characteristic is examined. Fig. 6, 7, 8 show the average packet error rate characteristic for all the vehicles on the road. In the figure, the horizontal axis denotes the number of vehicles on the lanes under simulation and the vertical axis denotes realized packet error rate.

Fig.6 shows the average packet error rate where directional antenna is used in the transmitter and array antenna is used in the receiver. As shown in Fig.6, the directional antenna realized by adaptive array antenna has better performance than the omni directional antenna. Moreover, the characteristic improves with increase of the number of the elements. However, the characteristic improvement rate against the increase of the number of the elements becomes worse. Consequently, the characteristic may not be always improved even if the number of the elements is increased.

Fig.7 shows the average packet error rate where array antenna is used in the transmitter and directional antenna is used in the receiver. As in the case of Fig.6, the characteristic improves with increase of the number of the elements. However, the characteristic of Fig.7 is better than the characteristic of Fig.6. The reason of this result is that the side robe signals of the weights which are determined by the weight generator became interference waves to the other vehicles on the road.

Fig.8 shows the average packet error rate under the case where array antennas are used in both transmitter and receiver. The characteristic shown in Fig.8 is best as compared to the characteristics in Fig.6 or Fig. 7.

B. Throughput characteristic

Next, the throughput characteristic is examined. Fig. 9, 10, 11 show the total throughput characteristic for all the vehicles on the road. In the figure, the horizontal axis denotes the number of vehicles on the lanes under simulation and the vertical axis denotes realized throughput.

Fig.9 shows the total throughput characteristic under the case where directional antenna is used in the transmitter and array antenna is used in the receiver. Fig.10 shows the total throughput characteristic under the case where array antenna is used in the transmitter and directional antenna is used in the receiver. As shown in Fig.9, 10, characteristics under the case where array antenna is used becomes equivalent performance to the offered traffic under 50 vehicles on the road. However, characteristics became worse over 50 vehicles on the road and the difference between offered traffic and realized throughput performance increases. As the result, the maximum throughput performance is about 3Mbps.

Fig. 11 shows the total throughput characteristic where array antenna is used both in the transmitter and in the receiver. The characteristic improvement rate is better than the characteristics in Fig. 9, 10. However, the maximum value of throughput is 3Mbps, which is the same as the case of Fig. 9 and 10.

C. Information acquisition rate characteristic

Next, the evaluation of characteristics of the information acquisition rate against the number of the vehicles is shown.

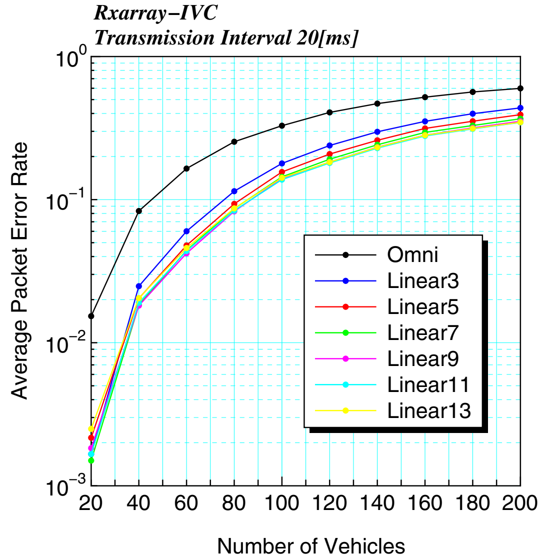

Fig. 6. Average Packet Error Rate using Rx array

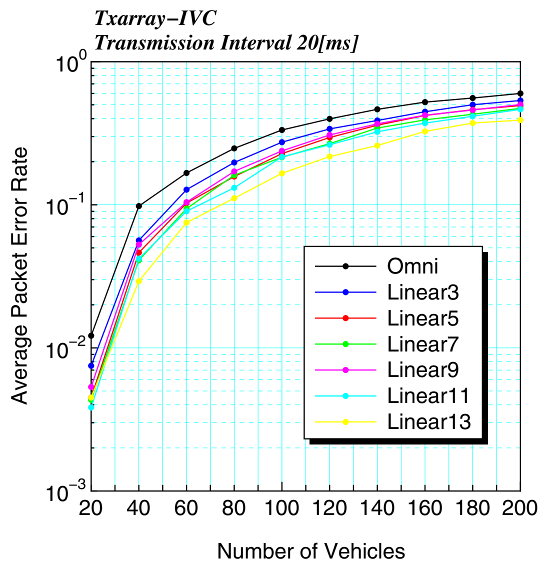

Fig. 7. Average Packet Error Rate using Tx array

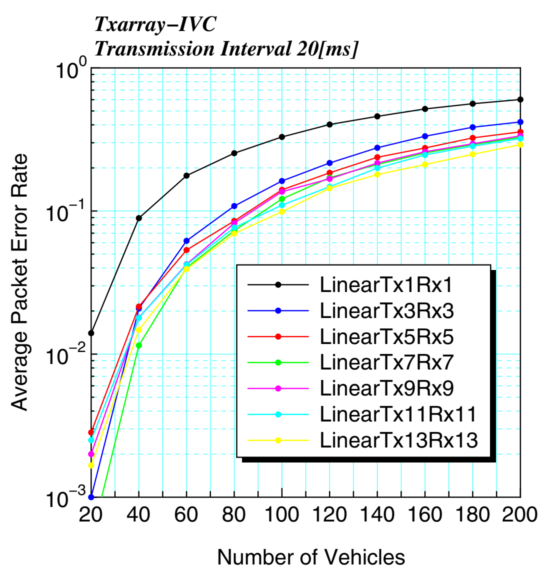

Fig. 8. Average Packet Error Rate using Tx-Rx array

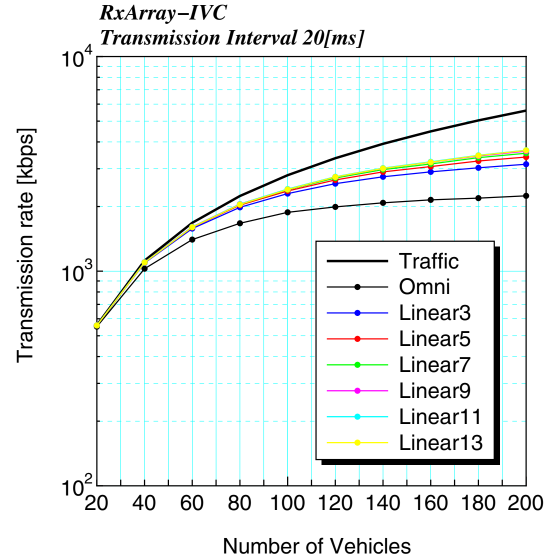

Fig. 9. Throughput Characteristic using Rx array

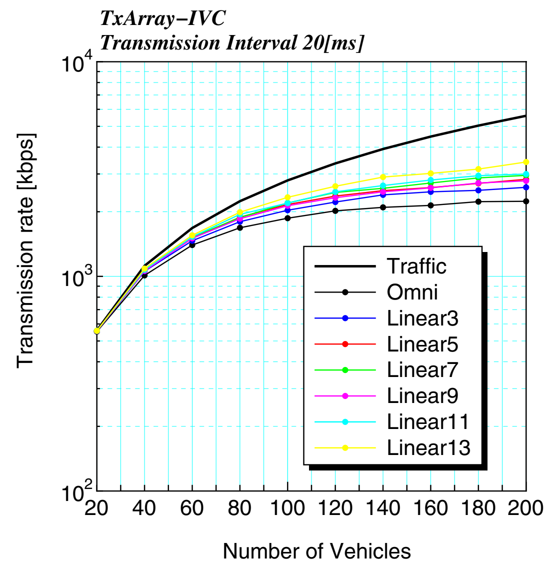

Fig. 10. Throughput Characteristic using Tx array

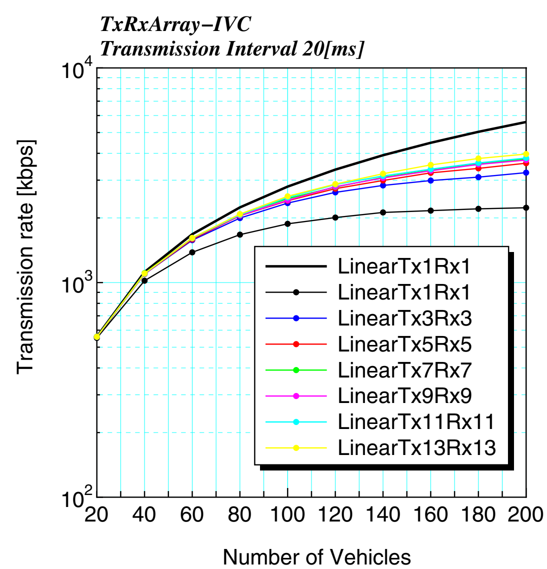

Fig. 11. Throughput Characteristic using Tx-Rx array

In this simulation, information acquisition rate is defined by the following formula (12). In the formula, the information acquisition rate is denoted by P, the number of vehicles that received the acknowledgment packet accurately is denoted by S and the number of vehicles in the communication range vehicles is denoted by N.

$$P = \frac{S}{N} \times 100 \ \ [\%] \tag{12}$$

It is possible to analyze how frequently each vehicle can accurately recognize the ID of another vehicle and information on the private PN code by evaluating the information acquisition rate. As shown in Fig. 12, 13 and 14, more accurate reception of information is possible by using the array antenna.

As shown in Fig. 12,13, the characteristic is improved with the increase of the number of the elements as in the case of packet error rate characteristic.

Moreover, as shown in Fig. 14, the information acquisition rate characteristic is better than characteristics of Fig. 12 and 13. And the information acquisition rate performance beyond 70% against over 200 vehicles on the road is achieved.

V. Conclusion

In this paper, improvement of the performance of the IVC system using DS/SS CDMA scheme in the initial link establishment process was confirmed by using the array antenna. The use of the array antenna improves both information acquisition performance and throughput performance as compared to the case where the omni-directional antenna is used. However, these characteristics have different performance depending on the cases where an array antenna is used only in the transmitter, where it is used only in the receiver and where its is used in both transmitter and receiver. Moreover, under the case where sufficient number of elements is used, throughput and information acquisition rate characteristics is less improved than under the case a few elements are used. In the further researches, more detailed performance under actual traffic situations will be examined. Moreover, total system performance will be also evaluated.

References

[1] Yohei Kawamagari and Masanori Furuya and Makoto Itami and Kohji Itoh: “A Study on DS/SS Inter Vehicle Communication System Using Array Antenna” The 9th IEEE International Conference on Intelligent Transportation Systems 2006.

[2] J.Nagumo and A.Noda: “A learning method for system identification” IEEE Trans. Autom. Control, vol.AC-12, pp.282-287, 1967.

[3] R.T.Compton,Jr: “An Adaptive Array in a Spread-Spectrum Communication System” Proc,IEEE, vol.66, No.3, pp.289-298 (Mar.1978)

[4] B.Widrow and S.D.Stearns: “Adaptive signal processing” Prrentice Hall, Upper Saddle River, USA, 1985.

[5] Kiyohito Tokuda and Msmami Akiyama and Haruki Fujii: “DOLPHIN for Inter-Vehicle Communications System” IEEE Intelligent Vehicles Symposium 2000, Oct.2000.

[6] Lachlan B . MICHAEL and Masao NAKAGAWA: “Interference Characteristics in Inter-Vehicle Communication from Oncoming Vehicles” IEICE Trans. Fundamentals, Vol.j82-B, No.11, pp.2034-2042,

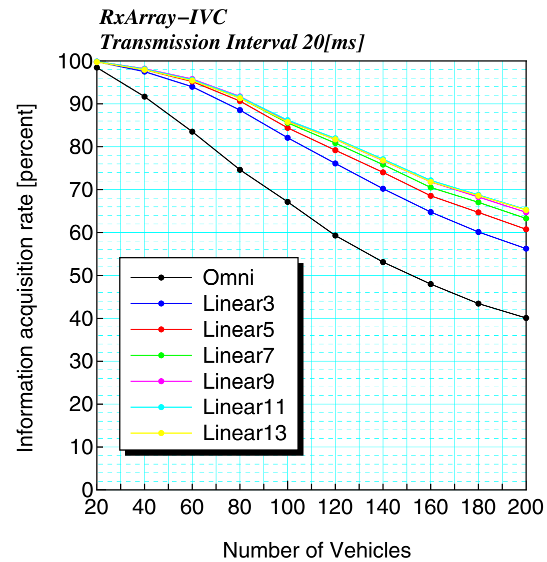

Fig. 12. Information Acquisition Rate Characteristic using Rx array

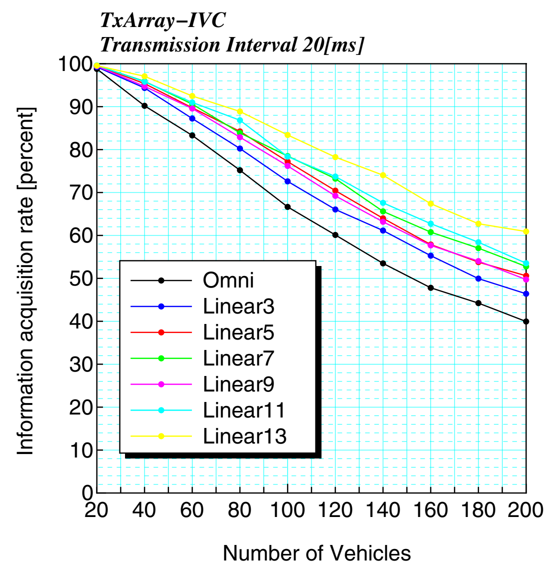

Fig. 13. Information Acquisition Rate Characteristic using Tx array

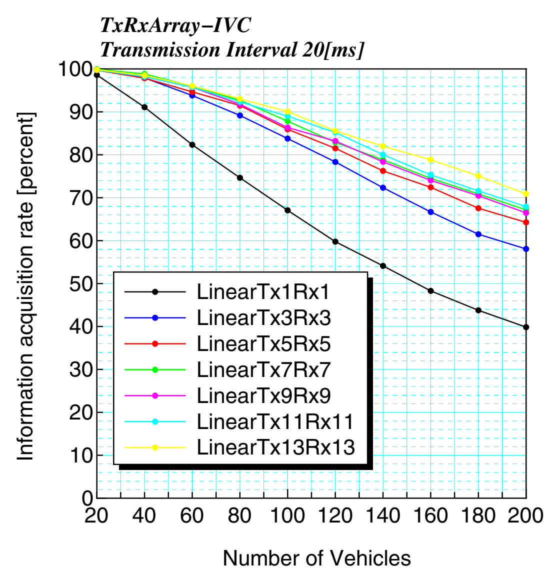

Fig. 14. Information Acquisition Rate Characteristic using Tx-Rx array