Autonomous Decentralized Synchronization System for Inter-Vehicle Communication in Ad-hoc Network

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Abstract

This paper proposes an autonomous decentralized synchronization system for Inter-Vehicle Communication Network (IVCN). We have to consider the future of IVCN: "time variant" about the number and the location of vehicles in IVCN, frame timing, and fading. Proposed scheme is different from other decentralized synchronization systems that have association with a fixed base station, and from centralized Personal Communication Systems. This system includes an autonomous decentralized synchronization scheme for IVCN, a high-speed algorithm, a protocol for a coming subscriber in IVCN, and a utilization of spread spectrum ranging for frame timing error. Computer simulation evaluates the performance of the system under highway conditions. It is shown that IVCN can be carried out among one and surrounding vehicles in such environment.

1. Introduction

As road traffic has increased more and more recently, much research has been done for short range Inter-Vehicle Communication Networks (IVCN) and systems to increase road traffic safety and to support drivers [1]-[7].

The main purpose of the system is to communicate between vehicles, which move within a short-range zone and to get various information from about car type, velocity, acceleration, deceleration, follow spacing and direction, etc.

Nowadays, drivers can get traffic information only from eyesight, the sense of hearing, and limited medium such as radios, signposts, etc. Especially, they depend largely on eyesight. Thus, they will be able to get higher road traffic safety under IVCN. For example, we will be able to run with another vehicle just behind own one in safety to keep automatic driving.

The problem of the system is how to design the network. Considering the mobility of the terminals, the network should be modeled as a number of terminals approaching and separating each other randomly. So its operations and management should be done in a decentralized manner, not in a central control manner [1][6]. IVCN needs frequent and regular communication to avoid collision and keep safety. Thus a TDMA system seems to be useful for such a system. In a TDMA type protocol, it is very important for each vehicle to get a common TDMA frame timing. In conventional systems, a central control station usually gets the frame timing. However there are some problems about central control manner in IVCN.

If its synchronization is done in a central control manner like conventional TDMA systems, a lot of base stations have to be built beside each road. While one of vehicles stands for the IVCN, it is difficult which representative vehicle to select.

But in an IVCN system, the best choice for the frame timing operation is to be done in a decentralized manner. One of the studies about autonomous decentralized frame synchronization is Autonomous Decentralized Inter-Base-Station Synchronization for TDMA Microcellular Systems. In this system, the timing of each base station deriver is based on a weighted sum of the timing differences (timing error) with respect to all other stations in the entire network.

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All base stations perform and iterate this averaging process autonomously to reach a time synchronous state for the network.

In this paper, we have applied an autonomous decentralized synchronization system for Microcellular system to the IVCN. This system includes a new method of autonomous decentralized frame synchronization for IVCN, a high-speed algorithm for the method, a protocol for coming subscriber of IVCN, and a utilization of Spread Spectrum ranging for frame timing error. Computer simulations evaluate these performances of the methods under highway conditions. Therefore gotten frame synchronization, IVCN can be carried out among one and surrounding vehicles in such an environment.

In chapter 2, the model of the system is shown. In chapter 3, proposed system and some improvements to the system are proposed. In chapter 4, the performance of the systems is evaluated by computer simulation. In chapter 5, this paper is summarized.

2. Model

2.1. Vehicle flow model

The model of IVCN is very difficult if we take account of different aspects such as geometry condition and man-made environment. To simplify, we assumed the model of IVCN from a highway situation. Its model is used in traffic engineering. When it is not so congested, the traffic flow obeys the Poisson point process [7].

Thus it is appropriate to assume that every vehicle has its own network within a certain area and each network is different from the other. This is one of the features of IVCN.

For the above assumption, the probability density function (pdf) of the number k of vehicles $f_{x,k}(x,k)$ within a certain area x is as follows.

$$f_{x,k}(x,k) = \frac{(\lambda x)^k}{k!}\exp\{-\lambda x\}(k = 0,1,2\cdots) \qquad (1)$$

Then the pdfs of the head spacing $f_{hs}(r)$ of the vehicle becomes an exponential distribution.

$$f_{hs}(r) = \lambda \exp\{-\lambda r\} \qquad (2)$$

Based on statistical research, the velocity of the vehicle obeys a normal distribution. The pdf of the speed of the vehicle is as follows,

$$f_v(v) = \frac{1}{\sqrt{2\pi\sigma_v^2}}\exp\{-\frac{(v-m_v^2)}{2\sigma_v^2} \qquad (3)$$

Here, λ represents the spatial density of the vehicle, $f_v(v)$ is the velocity of the vehicle, m_v is the expected value of the velocity, and σ_v is the variance of the velocity. In a free-moving situation such as the highway, vehicles organize groups. It is assumed that a network is organized with the vehicles that pay attention to each other. Thus it is appropriate to assume that every vehicle has its own network within a certain area and each network is different from the other. This is one of the features of IVCN.

2.2 . TDMA System

To obtain traffic security, it needs to exchange its data period in IVCN. Therefore it is best to choose this system, which operates TDMA (Time Division Multiple Access) as IVCN's multiple access. TDMA causes two problems on IVCN. One is slot assignment, and the other is frame synchronization. In conventional communication systems, the Master-Slave technique is employed as slot assignment and frame synchronization. But it is difficult to use the Master-Slave technique for IVCN. If this technique is employed, the base station(BS) has to be placed on every street and distance. Therefore a lot of BS has to be prepared for IVCN. The other technique is to make one of the vehicles in the network to be selected as the control station. It is not only difficult how to select control station, but also when control station is away from the network. Thus, IVCN it is important that these problems are considered.

2.3. Autonomous Decentralized Network

IVCN is to point unspecified multipoint communication network. And each vehicle moves independently unlike in an inter-base-station communication network. Each vehicle subscribes or secedes from IVCN because of the mobility of the vehicles and IVCN.

In addition, we have to consider the problem of slot assignments and frame synchronizations in TDMA systems.

Thus, the network needs to be modeled as a number of terminals approaching each other randomly, and its operations and management should be done in a decentralized base station-less manner [1][5-6].

Reservation-ALOHA(R-ALOHA) is suitable for the network as decentralized and flexible for the mobility of the vehicles. The protocol is explained as follows: Each vehicle listens to determine whose slots are being used by other vehicles. If it finds whose slots are not used, it reserves the slot its own send slot. As it listens to other slots, it realizes the state of slots per frame.

2.4. Autonomous Decentralized Inter-Base-Station Synchronization for TDMA Microcellular System

One of the studies about autonomous decentralized frame synchronization is Autonomous Decentralized Inter-Base-Station Synchronization for TDMA Microcellular Systems [2]-[4][6]. The system algorithm, which was explained as follows: A base station monitors TDMA signals from other base stations to measure the timing and the received power levels. The frame timing errors, which are defined as differences in timings among other base stations and the measuring base station, are averaged with the received power level as weighting factors. The result is used to correct the frame timing of the base station. This process is repeated periodically, and is performed at each base station.

The system parameter is shown in Table 1, and its process can be mathematically expressed as follows,

$$\Delta T(i,n) = \frac{\sum_{j=1}^{N} P(i,j,n)\Delta T(i,j,n)}{N\sum_{j=1}^{N} P(i,j)} \quad (4)$$

$$\Delta T_{(i,j,n)} = T_{(j,n)} - T_{(i,n)} + 2\cdot t_0 \quad (5)$$

$$T_{(i,n+1)} = T_{(i,n)} + \varepsilon \Delta T_{(i,n)} \quad (6)$$

Where ε and $2\cdot t_0$ are constant numbers.

Table 1. System Parameter

Own station	*i*	Number of base station	N
Other station	*j*	Iteration number	*n*
Timing error	ΔT(*i,n*)	Received power	P(*i,j*)
External frame timing		T(*i,n*)	

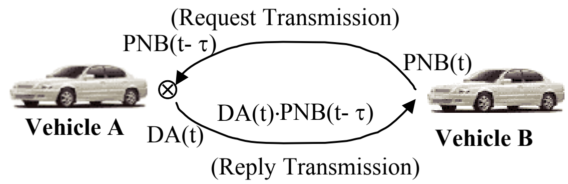
2.5. Spread Spectrum Ranging and Boomerang Communication Method

Spread Spectrum (SS) communication systems are known by

- Anti-interference
- Multiple access capability
- High concealment
- Simultaneous ranging capability

Especially, it is convenient to range simultaneously for IVCN. Thus it is advantageous to apply the spread spectrum techniques to the IVCN [1][6].

Fig. 1 shows the principle of the SS simultaneous ranging method



PNB(t) : PN sequence of Vehicle B
DA(t) : data of Vehicle A

Fig. 1 Principle of SS Ranging

In this figure, vehicle A and Vehicle B are running together. Vehicle B sends spreading sequence PNB(t) to vehicle A. Vehicle A received signal PNB(t-τ) delayed propagation time τ. Vehicle A send back its sequence PNB(t-τ) to vehicle B. Vehicle B detect the peak signal by the PN matched filter. As compared with time difference, the propagation time was gotten from vehicle A to vehicle B.

And when vehicle A transmits spreading sequence, vehicle A can transmit its own data D(t) to vehicle B by multiplying the spreading sequence: D(t) · PN(t-τ). It is called as SS Boomerang Communication method. Thus inter-vehicle communication can be established by using it.

3. Proposed System

We have proposed that an autonomous decentralized synchronization system for IVCN. This system includes an autonomous decentralized synchronization scheme for IVCN, a high-speed algorithm, and a protocol for a coming subscriber in IVCN, and a utilization of Spread Spectrum ranging for frame timing error. The methods of the system are proposed as follows.

3.1. Fixed Conventional Network and Inter-Vehicle Communication Network

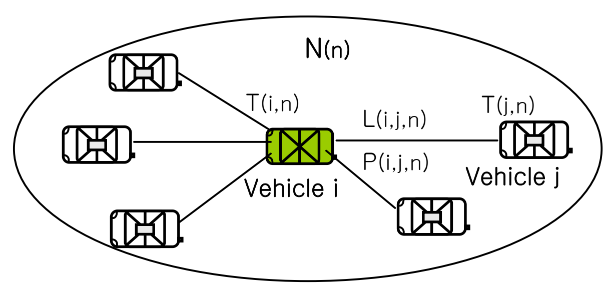


Fig. 2 Model Inter-Vehicle Communication Network

While the number of stations and distance among them are fixed in conventional systems, the number of

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stations and distance among them are unfixed and unknown in IVCN. Fig. 2 shows the network model.

3.2. Improvement of Frame Synchronization

When they are not in a stable state, each vehicle should need to be influenced by other vehicles to fasten convergence speed. Thus ε must be set on as a large value to depend on $\Delta T(i,n)$.

While in stable state, there could be a case such that a coming subscriber will take part in an IVCN with difference of timing error. If such a case occurs, the subscriber notifies the network and the network loses frame synchronization. Moreover if a vehicle cannot catch frame timing for some reason, the network becomes an unstable state, too.

Thus ε should set as follows:

- ε sets large value in an unstable state
- ε sets small value in an stable state

The way to carry out it easily, the value is changed by the difference of past two own frame timing, $\Delta T(i,n - 1)$ and $\Delta T(i,n)$. And in the actual conditions, the propagation time of two vehicles should be substituted for $2 \cdot t_0$. Thus under the condition, the equations are rewritten as follows:

$$\Delta T(i,n) = \frac{\sum_{j=1}^{N_{(n)}} P(i,j,n)\Delta T(i,j,n)}{N_{(n)}\sum_{j=1}^{N} P(i,j,n)} \quad (7)$$

$$\Delta T_{(i,j,n)} = T_{(j,n)} - T_{(i,n)} + L_{(i,j,n)} \quad (8)$$

$$T_{(i,n+1)} = T_{(i,n)} + \varepsilon \Delta T_{(i,n)} \quad (9)$$

$$\varepsilon = \alpha \,|\, T_{(i,n-1)} - T_{(i,n-2)} \,|\, + \beta \quad (10)$$

Where $L_{(i,j,n)}$ is the propagation time, $N_{(n)}$ is the number of vehicles, and $P(i,j,n)$ is the received power.

3.3. Protocol for coming Subscriber

It is necessary to consider multiple accesses for IVCN. For such a condition, R-ALOHA is must suitable for IVCN. Furthermore, the new subscriber obeys the protocol that is explained later to maintain a stable network state. Fig. 3 shows its protocol and the protocol is explained as follows:

- A coming subscriber finds the network
- It listens to all vehicles in the network if it takes part in the network
- Compare own frame timing with frame timing of the network
  - Calculate equations and revision own frame timing without transmitting my signal
  - Transmit my signal when the difference that own frame timing and frame timing of the network is less than a threshold value
- Calculate equations and revision own frame timing all over the network

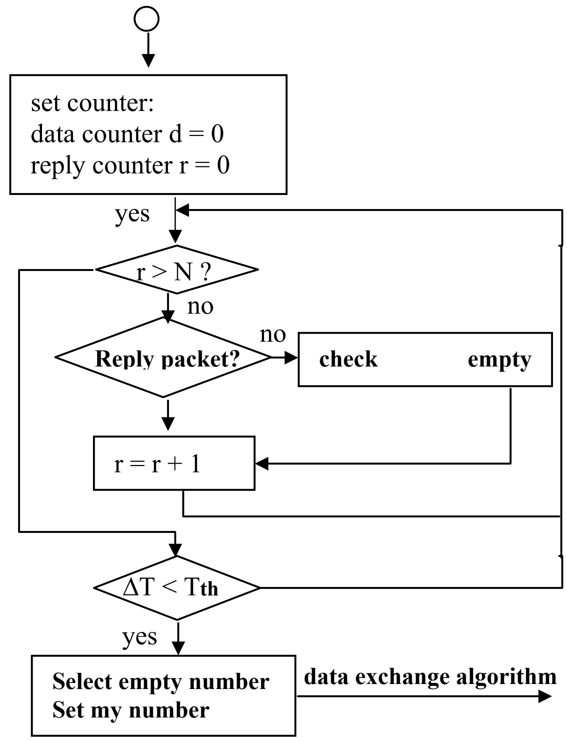

Fig. 3 Protocol for a Coming Subscriber

While the difference that own frame timing and frame timing of the network is more than a threshold value, the subscriber doesn't send own signal.

And about a leaving subscriber, it is possible to make the protocol for it as follows:

- Each vehicle has left the slot of the leaving subscriber untouched and ignored if not listen to the signal while several frames
- Each vehicle sets the slot "empty-slot" if not listens to the signal after several frames

Thus fluctuation of the network frame timing is small, compared with conventional system.

3.4. Utilization of SS Ranging

In this proposed system, there is a problem about residual timing error. The residual timing error causes the network swerving from frame timing as mentioned the equations. As far as in the network, it is offset. Bu it is not a desirable situation as the network acts in harmony with other networks and has communication to fixed-point station.

Thus each vehicle should need to observe propagation time among other vehicles and eliminate the residual timing error. To measure the propagation time, Spread Spectrum with ranging is used. Using SS and in the stable state, it is possible to use SS Boomerang communication system.
Computer simulation evaluates the performance of the methods proposed above.

4. Computer Simulation

In this paper, the highway situation is assumed, the road traffic flow obeys Poisson point process. Head spacing *hs* sets 80[m], average vehicle sets 25[m/sec], and each vehicle sends an equal power signal.
Simulation conditions are shown in Table 2.

Table 2. Simulation Conditions

Path loss	$\propto r^{-2}$
Number of vehicles	5[car]
Transmission range	200[m]
Fading	Rayleigh Fading
Modulation method	DPSK
Modulation frequency	1200[MHz]
Multiple access	R-ALOHA
Transmission rate	384[kbps]
1[slot]	200[bit]
1[frame]	15[slot]
Head spacing	80[m]
α	1.0
β	1.0

4.1. Protocol for Coming Subscriber

Fig. 4 shows the protocol for a coming subscriber compared with conventional system is applied to the network under the high-speed algorithm.
It is assumed that when four vehicles are in stable state, the coming subscriber takes part in the network by offset 20[bit]. In conventional system, the coming subscriber influences frame timing of the network. But the proposed protocol prevents the frame timing from being out of stable state because the subscriber is not able to send own signal while the difference of the frame timing is within ±1.0[bit].
In conventional one, it takes 300 times' iteration to converge within ±0.1[bit]. But in proposed one, it takes 68 times' iteration to converge within ±0.1[bit].

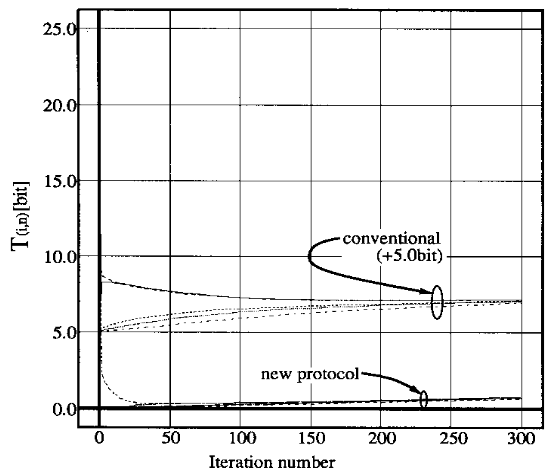

Fig. 4 Protocols for Coming Subscriber

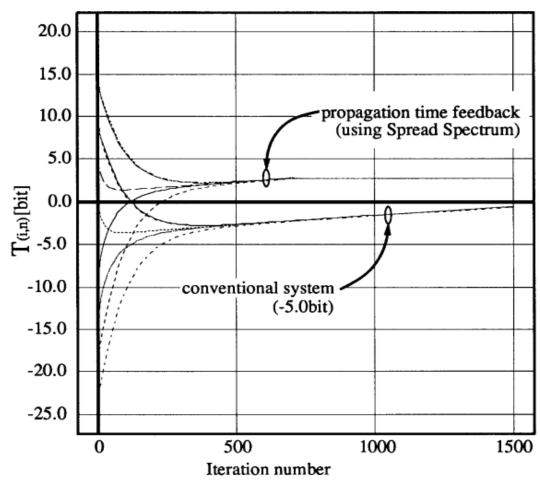

Fig. 5 Feedback propagation time by SS

4.2. Utilization of SS Ranging

The more calculated the equations are, the more frames timing error increases because of propagation time. Thus using SS ranging, driver can measure propagation time of each vehicle and solve the problem that increases the frame timing error. It is not a problem to use SS ranging after getting synchronized state, as propagation time is less than the fluctuation of the frame timing error before getting synchronized state. System a condition for SS is shown on Fig. 5 is shows that conventional system and the proposed system. Where modulation method is DS-DPSK, spreading sequence is PN-Code and code length is 31[chip].
User can measure propagation time of each vehicle after getting synchronized state, so its results the

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feedback to the equations. Thus it solves the problem by using SS ranging that increases frame-timing error after getting synchronized state.

5. Conclusions

In the paper, we proposed that an autonomous decentralized synchronization system for IVCN. We considered the future of IVCN: "time variant" about the number and the location of vehicles in IVCN, frame timing, and fading. This system includes an autonomous decentralized synchronization scheme for IVCN, a high-speed algorithm, a protocol for a coming subscriber in IVCN, and a utilization of spread spectrum ranging for frame timing error under highway conditions.

From the results of the computer simulation, the high-speed algorithm makes possible the convergence from stable state the speedy state. And a protocol for a coming subscriber of IVCN prevents its stable state from noise or jamming. Also the frame timing error fluctuation is suppressed by using spread spectrum ranging. This IVCN can be carried out between one and surrounding vehicles in such environment as highway.

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