Millimeter-wave Technologies for ITS Wireless Communications

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Abstract

CRL (Communications Research Laboratory, Independent Administrative Institution, Japan) is developing ITS wireless communication technologies in millimeter-wave frequency region. Technologies are categorized for inter-vehicle communications (IVC) and road-vehicle communications (RVC). In this paper, system concepts and the experimental facilities are introduced. The experimental facility for inter-vehicle communications is gotten ready in 60 GHz frequency region and the experimental system for road-vehicle communications is based on RoF (Radio on Fiber) technology in 36-37GHz frequency region.

1. Introduction

In the ITS, Inter-Vehicle Communications (IVC) and Road-to-Vehicle Communications (RVC) are expected to play an important role for assisting safe driving, and supporting automatic driving in such as the Advanced Cruise-Assist Highway Systems (AHS). Furthermore, multimedia information contents such as moving picture and music etc. are useful for relaxing the persons sitting in the back seat in a vehicle.

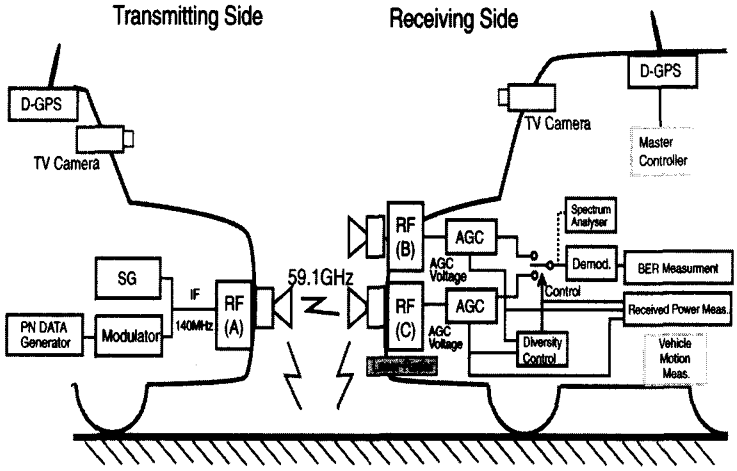


Fig. 1. Block diagram of experimental facility for IVC.

CRL is studying the millimeter-wavein-ter-vehicle communications technology and millimeter-wave radio-on-fiber road-to-vehicle communications technology intensively in cooperation with many private companies.

As for the IVC, we are focusing on the utilization of 60 GHz millimeter wave frequency band and have carried out experiments for the measurement of propagation characteristics between two vehicles on the practical road. On the other hand, as for the road-to-vehicle communications, we are interested in millimeter-wave short range communi-cations along the road. Radio-on-fiber (ROF) technology is also very interesting not only for its simple network architecture but also for its high poten-tiality to transmit multiple-service radio signals. We have proposed the common frequency band ROF transmission system for ITS and have executed a basic experi-ment. In this paper, we present these IVC

Fig. 2. experimental vehicles and RF unit.

and RVC studies including experimental results and finally mention the applications of ROF technology for the future wireless communications.

2. Inter-vehicle communications

2-1. Experimental facilities for IVC

Millimeter-wave propagation characteristics between vehicles are affected by environmental changes as traveling of vehicles: To investigate the behavior of propagation characteristics comprehensively, we executed experiments for IVC system in millimeter wave.

Fig. 1 shows the block diagram of our experimental system. Fig. 2 shows the experimental vehicles and RF units. The front vehicle has a transmitter (A), and the successive vehicle is equipped with two receivers (B and C) for the space diversity. The propagation experiments are executed by using these unit A, B and C. The data transmission experiment is also available by using these unit in order to demonstrate transmission rate up to 10 Mbps. The RF center frequency is 59.1 GHz.

In the transmitting side, signal generator makes the IF carrier of 140 MHz. In data transmission experiment, PN code at 1, 5 or 10 Mbps is generated by the data generator, and the IF carrier is modulated by the Manchester-DFSK modulator. The IF signal is up-converted to RF signal at 59.1 GHz by RF unit using MMIC devices. The RF signal is radiated from a horn antenna. The RF unit with the horn antenna is housed in a waterproofing radome with a temperature control.

In the receiving side, two receivers are mounted at the constant heights in front of a vehicle. The down-converted 140 MHz IF signals are controlled by the AGC. One of these two IF signals are selected alternatively depending upon the con-

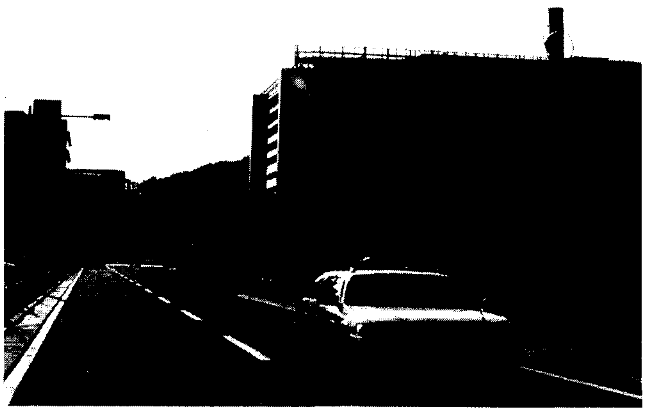


Fig 3. Scenery of test course

trolled level.

2-2. Experiments

Data transmission of 1 Mbps with a carrier frequency of 59.1 GHz has been examined. Fig. 3 shows the experimental scenery. The test site is a straight public road. The precede vehicle was stopped at the end of the course, and the successive vehicle was moved at the constant speed of 2.5 m/s from the other end of the course. Table 1 shows the experimental setup for the measurement. The transmitting power is -4 dBm. The antennas for the transmitter and the receiver are standard horn antennas with the gain of 24 dBi, and these were mounted at the height of 46 cm in the transmitting side and 85 cm and 38 cm in the receiving side respectively.

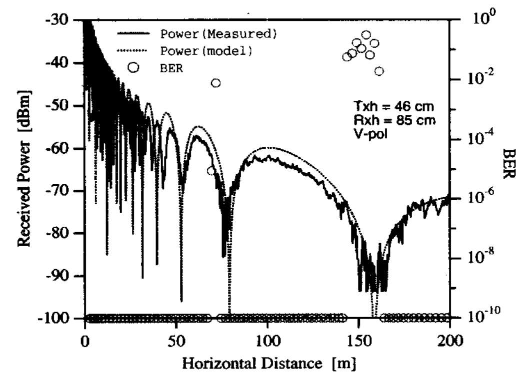
The bit error rates (BERs) were measured every one-second and the received powers were also measured simultaneously at the rate of 18.75 KHz.

Table 1. Experimental parameters

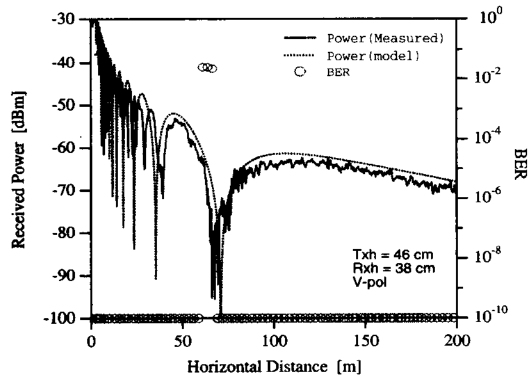
Center freqency	59.1 GHz
Transmitted power	-4 dBm
Data rate	1 Mbps
Modulation	DFSK (manchester code)
Symbol rate	2 Msymbol / s
Detection	Quadrature
Antenna	Standard Horn
Antenna gain	24 dBi
Polarization	Vertical or Horizontal

2-3. Results

Fig. 4(a) and (b) shows the measurement results of the received power and the BER at two different antenna heights. In Fig. 4, the theoretical received power estimated by two-ray model is indicated with dashed line and BER is shown with circular markers. The results of measured receiving power give fairly good agreement with those obtained by the two-ray model. This result shows that the height diversity is effective for IVC system using millimeter-wave for data transmission.



(a)



(b)

Fig. 4. Experimental results in each height of receiver.

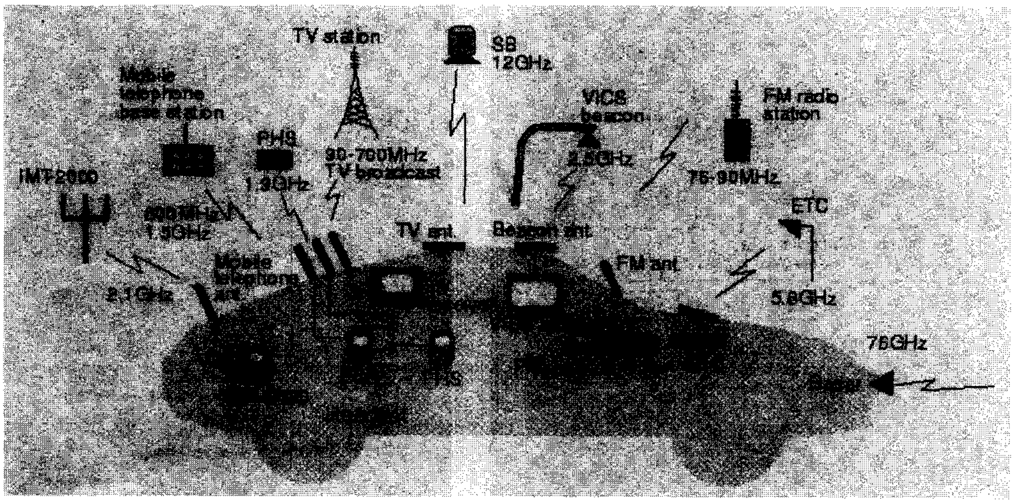


Fig. 5. Current surroundings for vehicle communications, broadcasting, and radar.

3. Road-Vehicle Communications

3-1. Millimeter-wave Radio on Fiber Technologies

As one scheme for the ITS (Intelligent Transport Systems) broadband communication system, a road-to-vehicle communication system using 36-37 GHz millimeter-wave band based on the RoF (Radio on Fiber) technology has been studied and the experimental test bed is under the construction [1], [2]. The experimental system has adopted a scheme which can provide multiple wireless services by integrating mobile communications and broadcasting, besides the ETC which was developed for a dedicated ITS service.

The RoF technology has been practically used in the cellular phones as the blind zone cover technology, since radio wave is hard to reach to the deep place of the tunnel or the underground arcade [3]. The RoF has also been considered as a low loss transmission technology in a high frequency region such as millimeter-wave frequency [4], since the transmission loss is large when millimeter wave is transmitted through the cable or the waveguide. Furthermore, the interference with the radio waves which propagate in the air is avoided, because RF signal converted to optical signal is transmitted confinedly in the optical fiber. In addition to that, the analog modulation of lightwave can make the transmission system very simple.

On the other hand, the external optical modulator should have characteristics of good linearity and fast response and the amplifier in RF unit also should have a good linearity. The costs of these com-

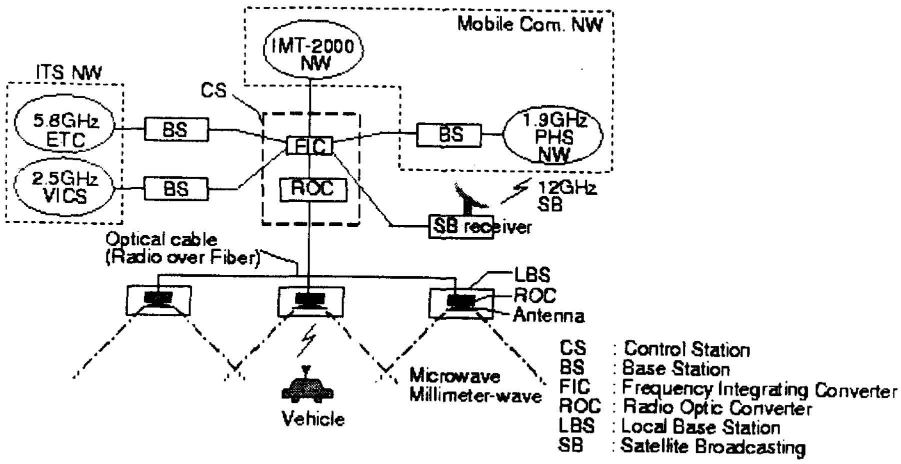


Fig. 6. Concept of the ITS multiple-service network based on common frequency band RoF.

ponents are required to be low for the practical use. At present, research and development for overcoming these problems are extensively carried out and the optical fiber is expected as a transmission medium of radio wave.

3-2. New Concept for Multiple Wireless Services

Fig. 5 shows the radio environment that surrounds the vehicle. As shown in this figure, present vehicle runs while transmitting and receiving various kinds of radio waves. As examples of the ITS services, there are VICS (Vehicle Information and Communication System) and ETC. The VICS service is offered by FM multiplexed broadcasting, 2.5 GHz radio beacon and infrared beacon. While, ETC service is offered as a scheme of DSRC (Dedicated Short Range Communication) using 5.8 GHz band. On the other hand, mobile telephones are offered by 800 MHz and 1.5 GHz band. The next generation mobile communication system IMT-2000 will use 2.1 GHz band, which is under the development with the aim of the start in 2001.

Although the vehicle is enjoying the various radio services mentioned above, the vehicle might become a vehicle looks like a hedgehog with many antennas if a new service is introduced one after another in this manner in the future. This is a problem since the space for mounting antennas is limited. Moreover, the interior of the vehicle is gradually oppressed, if radio communication equipment and mobile terminal are set individually for each service. In order to avoid such situation, a concept of ITS road-to-vehicle

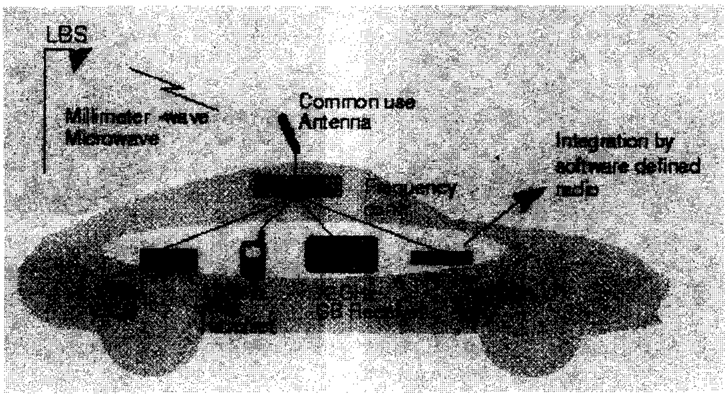


Fig. 7. Integration of mobile communications link in vehicle.

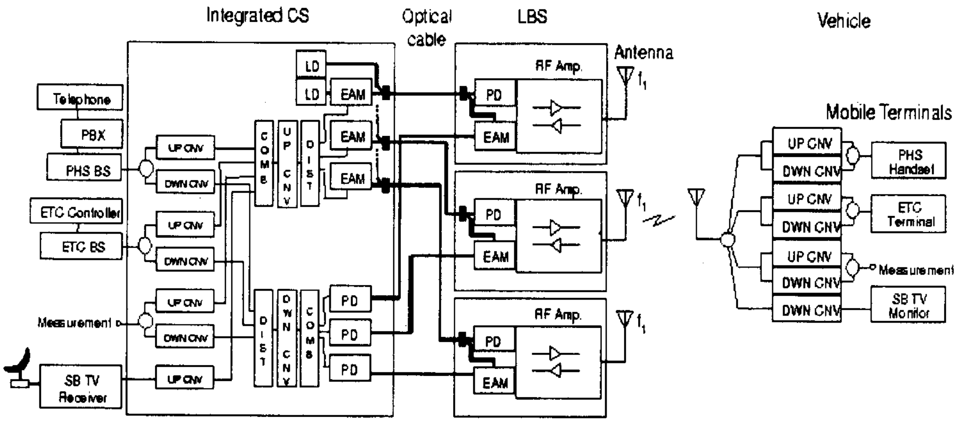
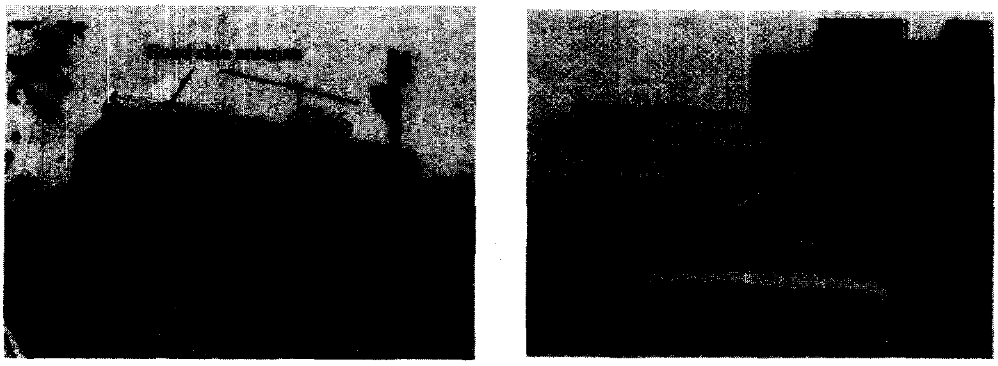


Fig. 8. Configuration of the experimental facilities for the multiple service common frequency band RoF transmission system in millimeter-wave band.

communication by a new communication scheme using RoF was proposed, and the research and development have been approached by CRL.

The proposed concept is shown in Fig. 6. As shown in this figure, various RF signals such as existing mobile communications, or next generation mobile communication, ITS communications and satellite broadcasting are fed into the CS (Control Station) from each service BS (Base Station). Then each radio frequency is converted and integrated into some commonly used frequency band. Then, the lightwave emitted from a laser diode is modulated by the integrated radio signal and is transmitted to the LBS (Local Base Station) through the optical fiber cable. At the LBS, the received optical signal is restored into the radio signal, which is amplified and emitted into the air from an antenna. In this process, FDM (frequency



(a) (b)

Fig. 9. (a) Test course and experimental vehicle at YRP and (b) Vehicle on-board equipment.

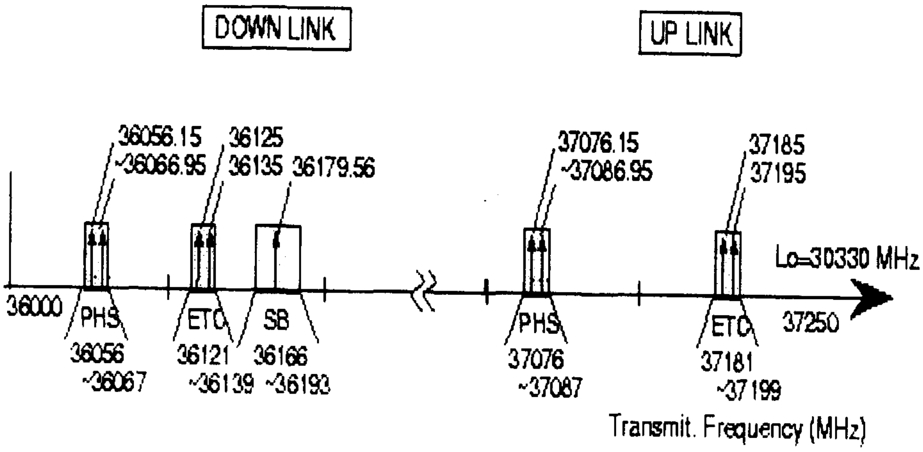


Fig. 10. Frequency allocation of the multiple service in the common frequency band.

division multiplexing) can be employed as a multiplexing technique. Here, in order to transmit such an integrated broadband radio signal, microwave or millimeter wave frequency band is preferable. As shown in Fig. 7, at the vehicle, the integrated radio signal is received by a broadband antenna and divided into several original radio service signals. By constituting the down-link of the multiple service like this, radio interface between vehicle and LBS can be unified. The up-link from the vehicle to CS can be realized by the scheme which is reverse to the down-link.

3-3. 36-37 GHz band experimental facility

A realization of the system that can

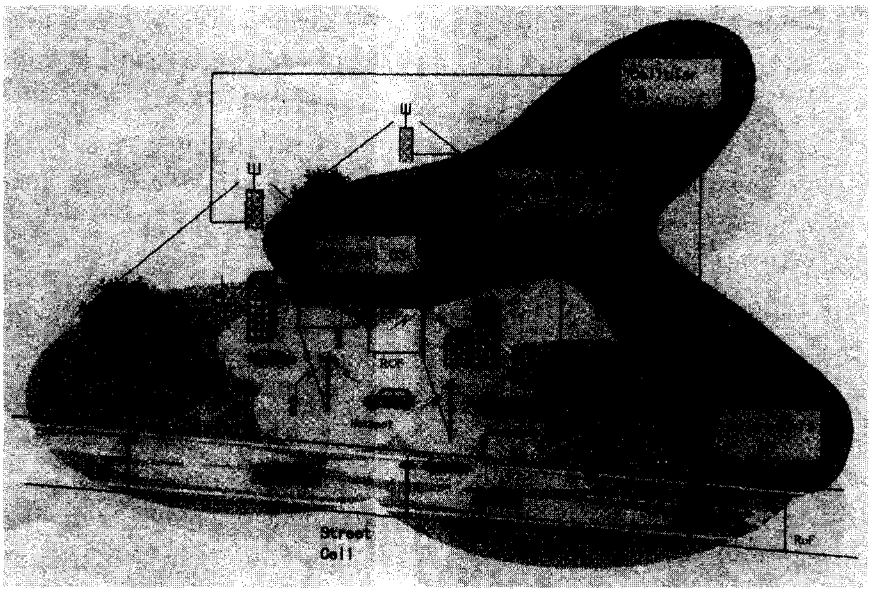


Fig. 11. Concept of a seamless mobile network consisting of macro-cell, micro-cell, and street-cell.

provide large-capacity multi-media information in a short time is desired for the future ITS telecommunication systems. Then, millimeter-wave RoF road-tovehicle communications system which ensures the broadband transmission capability is considered to be developed.

As shown in Fig. 8, we are establishing an experimental facility based on a scheme of a street cell RoF multiple service transmission in a millimeter-wave frequency region. This experimental facility consists of integrated CS, optical cables, LBS, and mobile terminals in the vehicle. The integrated CS is installed in the laboratory room in the YRP (Yokosuka Research Park) center building, and the LBSs are located along with ITS test course, which is about 240 m long public road at YRP. The integrated CS and the LBSs are connected with the optical fiber cables. The distance between the LBSs is 20 m and six local base stations have been established at present. The experimental test course and the vehicle on-board equipment are shown in Fig. 9(a) and (b), respectively.

In this experimental system, the RF signal is integrated and converted into a millimeter-wave common frequency band and the integrated RF signal modulates the lightwave, which is transmitted through the optical fiber cable. Then, the LBSs receive the optical signal and restore it into the radio signal, which is emitted toward the street after amplified. By adopting such a scheme, unification of radio interface can be obtained. It is drastically advantageous that multiple service can be provided through only one antenna and RF unit mounted on the vehicle.

The frequency allocation of the multiple service in the common frequency band is shown in Fig. 10. Frequency bands of 36.00-36.50 GHz and 36.75-37.25 GHz are used for the down-link and for the up-link, respectively. In this system, we have introduced ETC as one of the typical ITS services, PHS as one of the mobile communication services, and SB as one of the broadcasting services. Table 2 shows the specification of three services. ETC and PHS have different modulation schemes of ASK and π/4-DQPSK and transmission rates of 1.024 Mbit/s and 384 Kbit/s, respectively.

Table 2. Specifications of three services Service

Service	PHS	ETC	SB
Freq. Band (GHz)	1.90	5.80	1.16 (IF)
Input signal level	19 dBm	10 dBm	-47 dBm
Access scheme	TDMA/ TDD	TDMA/ FDD	------
Modulation scheme	π/4-QPSK	ASK	FM
Transmission rate	384kbit/s	1024kbit/s	------

There are two major ways of 36 GHz radio signal generation. One is the scheme that transmits the optical signal modulated directly by 36 GHz radio signal. Another scheme transmits the optical signal modulated by the integrated IF signal of each service. In the latter case, the transmitted IF signal is up-converted into 36 GHz frequency band at the LBS. Our experimental system adopts both schemes.

4. High mobility and high data rate mobile communications

As for the beyond IMT-2000 mobile communications, compatibility of high mobility and high data rate is required. To satisfy the compatibility, we hereby propose a seamless wireless system concept based on the RoF transmission technology shown in Fig. 11, which consists of macro-cells and micro-cells and street cells. In this concept, microwave is used for macro-cell and millimeter wave is used for micro-cells and street-cells, since propagation loss of microwave is smaller than that of millimeter wave. However, millimeter wave is suitable for the high data rate transmission since it can supply broad frequency band. Within a macro-cell, vehicle can transmit or receive relatively low data rate signal to or from the base station while running fast. Within a micro-cell or street-cells, vehicle can transmit or receive high data rate signal while running on the urban road or stopping at the parking lot called hotspot area. Among macro-cells, micro-cells and street cells, seamless connection is maintained by the traverse management station. Therefore, the vehicle makes use of macro-cells, micro-cells and street-cells seamlessly and unconsciously.

In such a system, millimeter-wave RoF plays an important role for connecting local base stations and a control station in micro-cell system or in street-cell system. In such a wireless network, it may be thought that micro-cells or street-cells under one control station constitute a large cell topologically. This network scheme is reasonable and smart, since if modulation and access schemes of macro-cell are used in micro-cell, we have only to up-convert the microwave frequency band into millimeter-wave frequency band. Furthermore, we have only to adopt a homogeneous parallel transmission scheme for the higher transmission rate in the micro-cell. In addition to that, we can make use of a same mobile terminal in micro-cells as well as in macro-cell.

5. Conclusion

In this paper, we have described research activities of millimeter-wave communications technologies for the IVC and the RVC. Millimeter-wave IVC will become more useful if we integrate radar function and communication function into one unit. We focus on this technology for further study.

On the other hand, millimeter-wave RoF transmission technology makes a great contribution to realization of an ITS infrastructure or a new mobile communication infrastructure. The broadband transmission capability of the optical fiber is suitable for the case that the new service is additionally introduced. In the network structure introduced or proposed in this paper, facilities such as the control station and the local base station can be used flexibly for additional wireless services, if the transmission bandwidth and the gain of the RF units and the antenna are good enough. The RoF network structure is more flexible and easy to be expanded in comparison with conventional radio network structure. RoF may be called a key technology for the telecommunications in the 21st century, which has the possibility to open the door for a new paradigm in new mobile communications and ITS communications.

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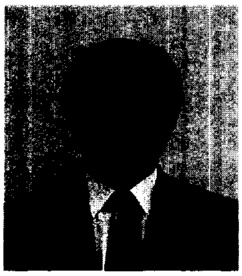

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was born in Fukuoka, Japan in 1950. He received the B.S., M.S. and Dr. Eng. degrees, in communication engineering from Kyushu University, Fukuoka, Japan, in 1973, 1975 and 1987, respectively and the M. Eng. degree in electrical engineering from Cornell University, Ithaca, NY, in 1980. He joined KDD in 1975 and was with the R&D Laboratories being engaged in research on optical fiber measurement technologies for optical fiber transmission systems. In 1990, he joined ATR Optical and Radio Communications Research Laboratories as a department head, where he managed research on optical inter-satellite communications and active array antenna for mobile satellite communications. In 1997, he joined Communications Research Laboratory (CRL), Independent Administrative Institution, Japan. He is now the research supervisor of Yokosuka Radio Communications Research Center of CRL and is interested in radio on fiber, software defined radio, ITS telecommunications and ad-hoc wireless communications technologies. Dr. Fujise is the recipient of the Jack Spergel Memorial Award of the 33rd International Wire & Cable Symposium in 1984 and he is a member of the IEEE and the IEICE.