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Proposal of Power and Modulation Level Controlled Radio Entrance Network for Wireless ATM Access

Masahiro NISHI†, *Student Member*, Katsutoshi TSUKAMOTO†, *and* Shozo KOMAKI†, *Members*

SUMMARY This paper proposes the radio ATM entrance network with radio links connecting between access points and wired backbone ATM networks for wireless ATM access. In order to reduce the interference power among the radio entrance links, the Power and Modulation Level Controlled Radio method is newly proposed, the method controls not only modulation level but also the transmission power according to the ATM cell traffic intensity. Theoretical analysis shows that the proposed method can increase the carrier to noise plus interference power ratio and can reduce the average cell loss rate compared with the conventional Modulation Level Controlled Radio method in case that there is the interference power among the radio ATM entrance links.

key words: *wireless ATM access, radio entrance link, power and modulation level controlled radio method, interference*

1. Introduction

Asynchronous transfer mode (ATM) technique has been extensively studied and developed to efficiently provide multimedia services such as voice, data, and video communications through Broadband - Integrated Services Digital Network (B-ISDN). In mobile communication networks, a demand for a multimedia service is increasing and wireless ATM system has been developed and standardized [1]–[3].

In order to construct the access networks for mobile multimedia communications, at first, we should construct the entrance links connecting between access points (AP) and ATM backbone networks, and the entrance links can support ATM transmissions because the ATM technology can increase the network efficiency [4]. We call the access networks using ATM entrance links the ATM entrance networks [5]–[7].

The ATM entrance networks will be constructed with micro-cellular/pico-cellular radio to improve frequency utilization efficiency. Furthermore, since high frequency such as SHF or millimeter wave band will be used to provide high speed multimedia radio services, the cell size will be reduced more and more, consequently the number of access points (AP) such as cell stations and base stations will increase and the number of entrance links will also increase. Therefore, if the entrance link is constructed with wired channels such as optical fiber, it will require a large cost and time investment due to a regulation for digging. On the other hand, radio method will be a strong candidate for the entrance link, since the radio entrance link can be constructed more cost-effectively and quickly for rapid increase of AP than wired method. Figure 1 illustrates the radio ATM entrance networks. To realize the radio ATM entrance networks, we should solve many problems including the channel assignment for radio entrance links, the configuration of radio cell, the network topology, the hand-off control and so on.

This paper focuses on the effective transmission method on the radio ATM entrance link which can support ATM services. When constructing radio entrance link, the ATM cell traffic fluctuation should be considered sufficiently. ATM service in the class of variable bit rate (VBR) transmits ATM cells at various rates. In order to effectively accommodate the traffic fluctuation of ATM cells, we have proposed the modulation level controlled radio (MLCR) method which changes the modulation level according to traffic intensity [8]–[10]. However, the transmission power per symbol in the MLCR method is same for each modulation level [11]. The radio signal with low modulation level will become a strong interference noise to radio signals with high modulation level in other radio entrance links. For example, If an entrance link uses the 256-QAM modulation scheme and an other entrance link uses the QPSK modulation scheme, the 256-QAM signal is interfered by the QPSK signal while the QPSK signal is not almost influenced.

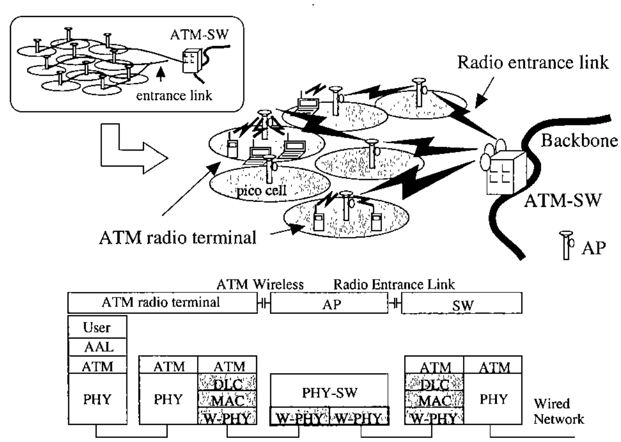

Fig. 1 Concept of radio ATM entrance networks.

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†The authors are with the Faculty of Engineering, Osaka University, Suita-shi, 565–0871 Japan.

To solve such problems, we newly propose Power and Modulation Level Controlled Radio (PMLCR) method for radio ATM entrance networks. This system can control not only the modulation level but also the transmission power according to cell traffic intensity [6]. When the traffic intensity is small, the proposed method can reduce the transmission power satisfying the required quality of service (QoS). This paper theoretically analyzes the cell loss rate and the required carrier to noise power ratio of PMLCR method and show that the PMLCR method has the improvement effect of the interference reduction compared with MLCR method.

The rest of paper is organized as follows. In Sect. 2, we describe the proposed radio ATM entrance network architecture. In Sect. 3, we describe the principle of PMLCR method. We also describe the modulation level decision rule in this section. In Sect. 4, we describe the analysis model about cell loss rate of PMLCR method and show the numerical results and the improvement effect of the PMLCR method in Sect. 5. Finally, we draw conclusions in Sect. 6.

2. System Description

Figure 1 illustrates the radio ATM entrance networks where some APs are connected to the ATM switch node (ATM-SW) with some radio entrance links.

In conventional ATM access networks, the standard ATM protocol is used on the wired entrance links and converted to the wireless ATM protocol for mobile ATM services at an AP in order to improve the radio channel quality by use of the data link control (DLC) layer and to effectively assign a radio bandwidth to mobile users by use of the medium access control (MAC) layer. On the other hand, since all channels from mobile ATM terminals to ATM backbone network are constructed with radio channels in the proposed radio entrance networks, the standard ATM protocol can be converted to the wireless ATM protocol at an ATM-SW, not at an AP, as shown in Fig. 1. In order to establish more and more APs in the ATM entrance networks achieving a large channel capacity, we should reduce a cost for an AP and increase a reliability of AP. Therefore, we assume that AP is a non-regenerative repeater which provides only a few functions such as a transmission power control and a frequency conversion. On the up-link in our system, at first, the radio signal is transmitted on the access link from a radio terminal to an AP. The AP converts the frequency, controls the power of the radio signal and transmits it to an ATM-SW via the entrance link. Finally the radio signal is demodulated at an ATM-SW. Then, the modulation method used on the access links is the same one used on the entrance link. Moreover, the connection can be dynamically established between APs by use of physical switch at an AP in order to avoid the traffic concentration on one radio entrance link.

Since we can cost-effectively establish wireless ATM access networks by use of radio entrance links and low-cost APs, we can increase the number of APs to cover more areas.

However the interference signal power among radio entrance links degrades the received performance of the desired signal and its degradation becomes large as the number of APs increases. Therefore, to realize the radio ATM entrance networks, it is necessary to develop the transmission method which can achieve high performance without high received power and reduce the interference power.

3. Principle of Proposed PMLCR Method

3.1 Concept of PMLCR Method

In radio channels, there are following two kinds of the cell loss.

(a) Traffic cell loss: The traffic amount fluctuates and exceeds over the capacity of the buffer in the transmitter.

(b) Radio cell loss: The cell header information is lost due to the bit error on radio channels.

Therefore, the cell loss rate (CLR) in radio channels P_c is given

$$\begin{aligned} P_c &= 1-(1-P_t)(1-P_r) \\ &= P_t + P_r - P_t \cdot P_r, \end{aligned} \tag{1}$$

where P_t is the traffic cell loss rate (TCLR) and P_r is the radio cell loss rate (RCLR). Therefore, when the service requires the desired CLR P_d, we should satisfy that $P_t < 0.5 \cdot P_d$ and $P_r < 0.5 \cdot P_d$ to guarantee the required quality of service (QoS).

The MLCR method uses 2^{2n}-QAM ($n = 1,2,3,4$) modulation scheme and dynamically changes its modulation level according to cell traffic fluctuation with the average transmission power fixed as shown in Fig. 2. When the ATM cell traffic amount is large, the MLCR method selects the high modulation level to increase the

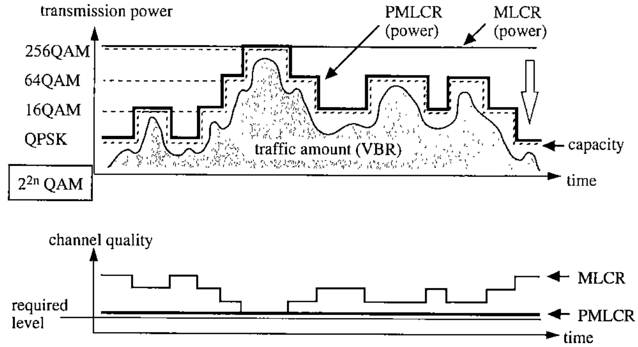

Fig. 2 Principle of PMLCR method.

channel capacity with a radio bandwidth fixed. On the other hand, when the ATM cell traffic amount is small, the MLCR method selects a low modulation level to enhance the durability to an abnormal propagation such as fading. However, the MLCR method doesn't require a large received power to keep a small RCLR in case of using a low modulation level. Then it is wasted to use a large transmission power required with a high modulation level.

To solve this problem, we newly proposed power and modulation level controlled radio method. This method can control not only a modulation level but also a transmission power and can reduce an average transmission power keeping the radio channel quality required by services as shown in Fig. 2.

3.2 Modulation Level Decision Rule

The modulation level is decided in the transmitter according to traffic amount. The transmitter observes incoming cells to the buffer in itself and obtains the information of the arrival cell rate. According to the observed cell rate, we use the minimum modulation level, n_0, with which the TCLR $P_t(n_0)$ can be smaller than the half of desired cell loss rate of service P_d as follows;

$$n_0 = \min_i\{i; P_t(i) < 0.5 \cdot P_d, (i = 1, 2, 3, 4)\}, \qquad (2)$$

3.3 Transmission Power Design

While an average transmission power is fixed in the MLCR method, the PMLCR method controls the transmission power according to the modulation level so as to fix the minimum Euclidean distance as shown in Fig. 3. Then the PMLCR method controls the transmission power so as to satisfy

$$\gamma_{req}(n_0) = \frac{2^{2n_0} - 1}{255}\gamma_{256}, \qquad (3)$$

where γ_{req} is the required received carrier to noise power ratio (CNR) in PMLCR method and γ_{256} is the required received CNR to satisfy that the RCLR is less than the half of desired CLR P_d of service when 256QAM ($n = 4$) method is used.

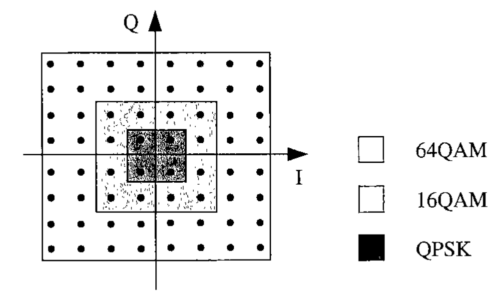

Fig. 3 Signal point of PMLCR method.

4. Theoretical Analysis

4.1 Traffic Cell Loss Rate

Using the buffer model shown in Fig. 4, the traffic cell loss rate with modulation level of n, $P_t(n)$ is the probability that the number of cell is K in the buffer and approximately given by

$$P_t(n) = \frac{\left(\frac{a \cdot N_c}{C_r(n)}\right)^{K+1}\left(1 - \frac{a \cdot N_c}{C_r(n)}\right)}{1 - \left(\frac{a \cdot N_c}{C_r(n)}\right)^{K+1}} \quad \left(\tfrac{a \cdot N_c}{C_r} < 1\right), \qquad (4)$$

where a is the cell arrival rate [cell/s], N_c is the number of bit per a cell [bit], K is the buffer size [cell] and $C_r(n)$ is the radio channel capacity with modulation level of n given by

$$C_r(n) = \frac{2n}{T} = \frac{2nW}{1+\alpha} \quad \text{[bps]}, \qquad (5)$$

where T is the symbol duration, W is the radio bandwidth α is the roll off factor and n is the modulation level.

4.2 Radio Cell Loss Rate in Fading Channel

Each radio signal received at an ATM-SW is faded due to the fading occurred in the access link. The delay spread of the access link is very small because of small cell size, or it can be equalized by used of an equalizer at the demodulator of ATM-SW. So we ignore a frequency selectivity in the access link. On the other hand, the entrance link is assume to be an AWGN (Additive White Gaussian Noise) link because it is a line-of-sight path. Hence we employ the frequency-non-selective Rayleigh fading channel model for the total link constructed with an access link and an entrance link.

We assume to apply the forward error correction (FEC) technique to the wireless cell header in order to improve the RCLR P_r on radio channels. In case that FEC technique can correct t bits, the radio cell loss is occurs if the number of erroneous bit in the header is more than t bits. Then, the radio cell loss rate with modulation level of n, $P_r(n)$, is written by

$$P_r(n) = \sum_{i=t+1}^{n_h} {}_{n_h}C_i \,(1 - \beta(n))^{n_h - i} \cdot \beta(n)^i, \qquad (6)$$

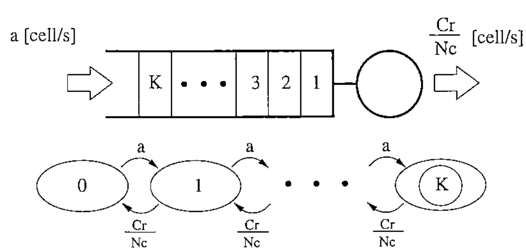

Fig. 4 Model of buffer in the transmitter.

where n_h is the number of wireless ATM header and $\beta(n)$ is a bit error rate (BER) with modulation level of n in Rayleigh fading channel written by

$$\beta(n) = \int_0^\infty \left(1 - \frac{1}{2^n}\right) \cdot \mathrm{erfc}\left(\sqrt{\frac{3}{2(2^{2n}-1)} \cdot \gamma}\right) p(\gamma) d\gamma, \quad (7)$$

where $p(\gamma)$ is the probability density function (p.d.f.) of the received CNR, given by

$$p(\gamma) = \frac{1}{\gamma_{req}} \exp\left(-\frac{\gamma}{\gamma_{req}}\right), \quad (8)$$

and $\mathrm{erfc}(x)$ is the complementary error function given by

$$\mathrm{erfc}(x) = \frac{2}{\sqrt{\pi}} \int_x^\infty e^{-t^2} dt. \quad (9)$$

From (7), (8) and (9), the BER in Fading channel is written by

$$\beta(n) = \left(1 - \frac{1}{2^n}\right)\left(1 - \left(1 + \frac{2(2^{2n}-1)}{3\gamma_{req}}\right)^{-\frac{1}{2}}\right). \quad (10)$$

4.3 Cell Loss Rate with Interference Power

Figure 5 shows the analysis model of the interference among the radio entrance links. We assume that there exists two radio entrance links (link 1 and link 2) and the ATM-SW receives the interference power from an undesired AP with the interference coupling ratio ρ as shown in Fig. 5. When we assume that the used radio bandwidth on the link 1 is equal to that on the link 2 and that the interference power is white noise, the CNIR Γ at the ATM-SW is given by

$$\Gamma(n_1, n_2) = \frac{C}{N+I} = \frac{C/N}{1 + I/N} = \frac{M\gamma_1(n_1)}{1 + M\rho\gamma_2(n_2)}, \quad (11)$$

where M is the power margin, n_1 and n_2 are the modulation level used in the link 1 and link 2, respectively and $\gamma_1(n_1)$ and $\gamma_2(n_2)$ are the CNR at the ATM-SW in the link 1 and link 2, respectively. $\gamma_1(n_1)$ and $\gamma_2(n_2)$ are given by (3).

When using PMLCR method, the transmission power is changed according to the used modulation level found from (3). Since the used modulation level is selected according to the cell arrival rate as found from (2) and (4), when the cell arrival rate is fluctuated, the transmission power is changed according to the cell arrival rate. Then the average received CNIR at the AP_r1 using a modulation level n_1 is written by

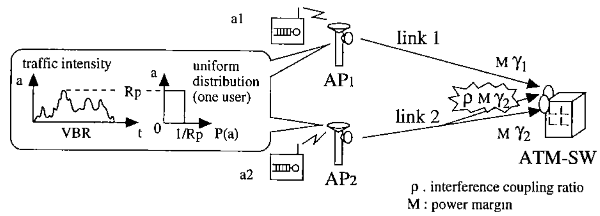

Fig. 5 Interference model among the radio entrance links.

$$\Gamma_{ave}(n_1) = \int_0^{R_p} \Gamma(n_1, n_2) p(a_2) da_2, \quad (12)$$

where R_p is the peak rate of service, a_2 is the cell arrival rate in the link 2 and $p(a_2)$ is the p.d.f. of the arrival cell rate a_2.

On the other hand, the BER with interference power on the link 1, $\beta'(n_1, n_2)$ is written by

$$\beta'(n_1, n_2) = \int_0^\infty \left(1 - \frac{1}{2^{n_1}}\right) \cdot \mathrm{erfc}\left(\sqrt{\frac{3}{2(2^{2n_1}-1)} \cdot \gamma}\right) p(\gamma) d\gamma, \quad (13)$$

where n_1, n_2 is the modulation level used in the link 1 and link 2, respectively and $p(\gamma)$ is the p.d.f. of the received CNR, given by

$$p(\gamma) = \frac{1}{\Gamma(n_1, n_2)} \exp\left(-\frac{\gamma}{\Gamma(n_1, n_2)}\right). \quad (14)$$

We assume to apply the forward error correction (FEC) technique to the wireless cell header in order to improve the P_r on radio channels. In case that FEC technique can correct t bits, the radio cell loss occurs if the number of erroneous bit in the header is more than t bits. Then the RCLR $P_r(n_1, n_2)$ is written by

$$P_r(n_1, n_2) = \sum_{i=t+1}^{n_h} {}_{n_h}C_i \cdot \beta'(n_1, n_2)^i \cdot (1 - \beta'(n_1, n_2))^{n_h - i}. \quad (15)$$

Finally, taking the traffic fluctuation both on the link 1 and link 2 into consideration, the average cell loss rate with the interference power on the link 1 is written by

$$P_{c_{ave}} = \int_0^{R_p} \int_0^{R_p} P_c(n_1, n_2) p(a_1) p(a_2) da_1 da_2, \quad (16)$$

where $P_c(n_1, n_2)$ is the CLR on the link 1 written by

$$P_c(n_1, n_2) = 1 - (1 - P_t(n_1)) \cdot (1 - P_r(n_1, n_2)). \quad (17)$$

As shown in Fig. 5, we assume that both p.d.f. $p(a_1)$ and $p(a_2)$ are uniform distribution functions.

5. Numerical Results

Table 1 shows the parameters used in following theoretical analysis. The wireless ATM cell (N_c bits) consists

Table 1 Parameters used in theoretical analysis.

radio bandwidth	W	10 MHz
service peak rate	R_p	10 Mbps
buffer size	K	5 cells
Wireless ATM cell length	N_c	446 bits
compressed cell header length	n_h	32 bits
FEC collect bit	t	5 bits
Roll off factor	α	0.0

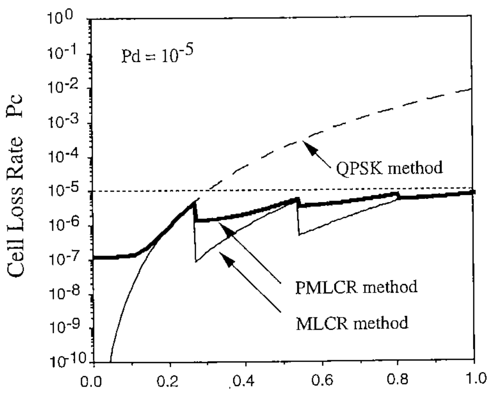

Fig. 6 Cell loss rate versus the normalized cell arrival rate.

of a compressed header (4 bytes), a payload (48 bytes) and redundancy bits (30 bits) as a result from using BCH(62,32) code as a FEC technique which can correct 5 erroneous bits.

5.1 Cell Loss Rate and CNR of PMLCR Method

This section shows the improvement effect on CLR and CNR of PMLCR method without interference power. Figure 6 shows the CLR P_c versus the normalized arrival cell rate a when the desired cell loss rate of service P_d is 10^{-5}. The CLR of QPSK, MLCR mehtod and PMLCR method are shown in this figure. We can see that the QPSK method cannot satisfy the required CLR if the traffic intensity becomes large using the transmission power as large as the MLCR method uses, while the PMLCR and MLCR method can satisfy. The CLR of proposed PMLCR is larger than that of conventional MLCR method because the received CNR of PMLCR method is lower than that of MLCR when the cell arrival rate a is small and the used modulation level is small. From Fig. 6 we can see that the CLR is the worst value in the case of using the maximum modulation level. However, the CLR of PMLCR is about the desired CLR of service (10^{-5}) for any a and can achieve high quality received performance for wireless ATM transmissions.

Figure 7 shows the required CNR γ_{req} [dB] versus the normalized arrival cell rate a when the desired cell loss rate of service P_d is 10^{-5}. When using conventional MLCR method, the γ_{req} is same for different values of a. On the other hand, when using proposed PMLCR method, since the γ_{req} is changed according to the used modulation level, the γ_{req} is reduced as the a decreases. It is found from Figs. 6 and 7 that the PMLCR method can reduce the transmission power keeping the CLR as same as P_d when the ATM traffic amount is small.

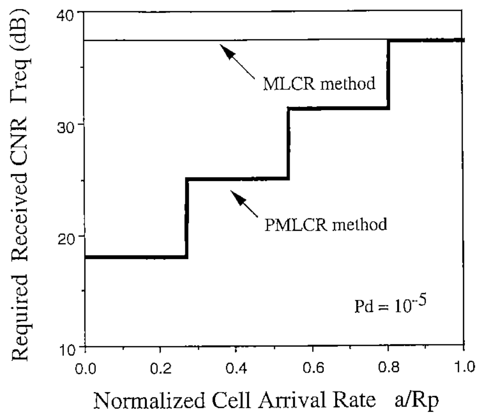

Fig. 7 Required received CNR versus the normalized cell arrival rate.

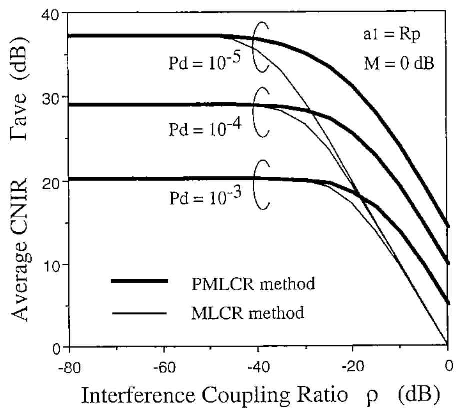

Fig. 8 Average CNIR as a function of the interference coupling ratio.

5.2 Improvement Effect of PMLCR Method with Interference Power

Figure 8 shows the average CNIR Γ_{ave} as a function of the interference coupling rate ρ for each value of the desired CLR of service P_d when the modulation level n_1 is the maximum level and the power margin $M = 0$. When the ρ is -100 dB and the interference power is extremely small, the average CNIR of PMLCR method is equal to that of MLCR method. However, when the ρ is large and the interference power is large, PMLCR method can improve the average CNIR compared with MLCR method. This reason is that the interference power of PMLCR method is variable according to the used modulation level n_2 and is small in the case of using low modulation level while the interference power of MLCR method is fixed for any values of n_2.

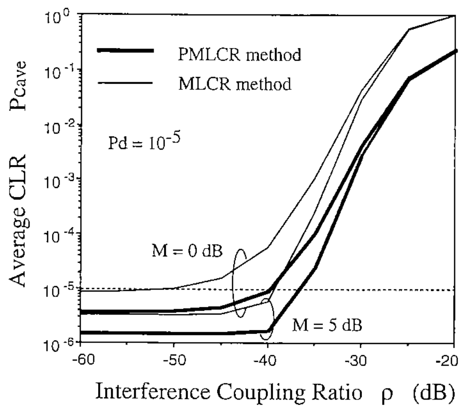

Fig. 9 Average CLP as a function of the interference coupling ratio.

Figure 9 shows the average cell loss rate $P_{c_{ave}}$ as a function of the interference coupling ratio ρ for each values of the power margin M when the desired cell loss rate is 10^{-5}. From this figure we can see that the PMLCR method can increase the interference coupling ratio compared with MLCR method satisfying that the average cell loss rate is less than the desired cell loss rate for any values of the power margin M. When the power margin M is 0 dB, the PMLCR method can obtain about 10 dB improvement of the interference coupling ratio and when M is 5 dB, the PMLCR method can obtain about 4 dB improvement of ρ compared with MLCR method. Finally, the PMLCR method can increase the allowable interference coupling ratio and is stronger method against the interference than MLCR method. Consequently, in case of applying the MLCR method, we can reduce the size of antenna to achieve a high antenna directivity or establish more APs and radio entrance links to increase the frequency utilization efficiency.

6. Conclusion

In this paper, we proposed the radio ATM entrance networks with radio links connecting the APs and the ATM backbone networks to cost and time investment. and proposed the power and modulation level controlled radio method which changed not only a modulation level and but also the transmission power to reduce the interference power among radio entrance links. Theoretical analysis clarified improvement effects of PMLCR method as follows;

- When ATM service class is VBR, the PMLCR method can reduce the required received CNR keeping the cell loss rate required by ATM service.
- The PMLCR method can increase the carrier to noise plus interference power ratio and improve the cell loss rate compared with MLCR method when there exist an interference power among radio entrance links.
- The PMLCR method can increase the allowable interference coupling ratio and is strong for the interference power.

Consequently, in case of applying the PMLCR method, the size of antenna can be reduced, or the number of APs and radio entrance links can be more established to increase the frequency utilization efficiency.

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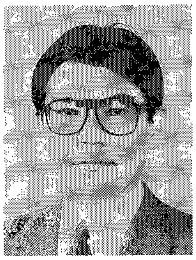
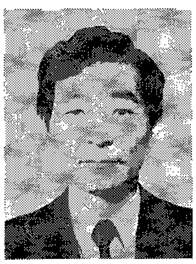
Masahiro Nishi was born in Osaka, Japan, in 1972. He received the B.E. and M.E. degrees in Communications Engineering from Osaka University, Osaka, Japan, in 1995 and 1997 respectively. He is currently pursuing the Ph.D. degree at Osaka University. His current research includes the access network design and the modulation method for wireless ATM systems.



Katsutoshi Tsukamoto was born in Shiga, Japan in 1959. He received the B.E., M.E. and Ph.D. degrees in Communication Engineering from Osaka University, in 1982, 1984 and 1995 respectively. He is currently a Associate Professor in the Department of Communications Engineering at Osaka University, engaging in the research on radio and optical communication systems. He is a member of IEEE.



Shozo Komaki was born in Osaka, Japan, in 1947. He received B.E., M.E. and Ph.D. degrees in Electrical Communication Engineering from Osaka University, in 1970, 1972 and 1983 respectively. In 1972, he joined the NTT Radio Communication Labs., where he was engaged in repeater development for a 20-GHz digital radio system, 16-QAM and 256-QAM systems. From 1990, he moved to Osaka University, Faculty of Engineering, and engaging in the research on radio and optical communication systems. He is currently a Professor of Osaka University. Dr. Komaki is a senior member of IEEE, and a member of the Institute of Television Engineers of Japan (ITE). He was awarded the Paper Award and the Achievement Award of IEICE, Japan in 1977 and 1994 respectively.