Optimum Technique for WATM Error Control in Indoor Environment

Young-Heung Kang*, Song-Sup Shin*

실내환경에서의 WATM 최적화 기법 연구

강 영 흥, 신 송 섭

Abstract

In this paper, we have proposed the optimum technique for wireless ATM (WATM) error control in indoor environment. As the optimum technique, the conventional concatenated FEC only is regarded as the efficient error control method for time-critical ATM traffic in AWGN, and the pilot symbol-added fading compensation with the concatenated FEC is required to optimize the WATM performance in fading environment. Also, the truncated Type-II hybrid ARQ technique will be developed for quality-critical ATM traffic in order to improve its throughput. Therefore, this paper presents the optimization of WATM performance in indoor environment by means of evaluating above techniques using theoretical analysis and simulation.

요 약

본 논문은 실내 환경에서의 WATM 에러 제어를 위한 최적 기술을 제안하였다. 최적 기술에서는, 기존의 concatenated FEC 기법만을 AWGN에서 실시간 서비스가 중요한 ATM 트래픽을 위한 효과적인 에러 제어 기술로 간주될 수 있지만 페이딩 환경에서는 concatenated FEC에 파일롯 심볼을 이용한 페이딩 보상이 WATM 성능을 최적화하는데 필요하다. 또한, truncated Type-II hybrid ARQ 기술은 처리량 개선을 위한 서비스 품질이 중요한 ATM 트래픽을 위해서 개발되어질 것이다. 따라서, 본 논문에서는 이를 각각의 기법에 대한 이론 및 시뮬레이션 평가를 수행하여 실내 환경에서의 WATM 성능의 최적화를 모색하였다.

*군산대학교 전자정보공학부

I. Introduction

Asynchronous transfer mode (ATM) technology will play an important role in the future evolution of global communication networks. In recent years, a lot of interest has been devoted to the possibility of integrating portable wireless access features with wireline ATM networks.

However, the ATM protocol has been designed to be used over high quality transmission links (e.g. optical fiber), which is characterized by high data speed and low bit error rates, and it is evident that wireless links do not satisfy these requirements. Therefore some methods must be applied to make wireless links fit into ATM world as successfully as possible [1] [2].

Because of the fading effects and interference, the wireless links are characterized by burstier error patterns, and higher and time-varying error rates compared to the fiber-based links for which ATM was designed. As a result, such difference leads to error control schemes to improve the error performance from its raw level to the level acceptable to higher layer protocols depending on QoS (Quality of Service) requirements for multimedia traffic. In terms of error control, multimedia traffic can be divided into two traffic types : quality critical traffic such as data and image, time critical traffic such as voice and video[3].

Figure 1 depicts the LECS (Link Error Control System) structure[3], which will be implemented as a separate hardware device to be placed at both ends of each wireless link section.

The LECS system consists of two components depending on the traffic type : FEC (Forward Error Control) for time critical traffic and Hybrid ARQ (Automatic Repeat Request) for quality critical traffic. FEC uses the concatenated code composed of Reed-Solomon and convolutional codes to correct transmission errors. On the other hand, with its low tolerance for transmission errors, a hybrid ARQ

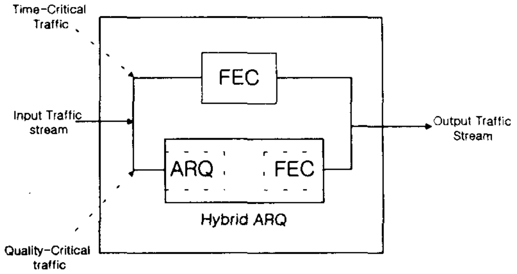

Fig. 1. Structure of link error control system.

scheme is used for quality critical traffic by combining FEC with ARQ.

In this paper, we will simulate the BER and CLP of wireless ATM cells adopting the concatenated FEC technique in indoor wireless environment using the Rician fading channel model. And then, we will contrive the performance improvement in fading channel by introducing the interleaving technique and the fading compensation technique of inserting pilot symbols into the concatenated FEC. Also, we will evaluate the amount of improvement in throughput of wireless ATM systems adopting the truncated Type-Ⅱ hybrid ARQ technique.

The rest of this paper is organized as follows ; Section Ⅱ defines the fading channel model. Section Ⅲ discusses the concatenated FEC technique for WATM systems. Section Ⅳ proposes the truncated Type-Ⅱ hybrid ARQ protocol for WATM systems. Section Ⅴ presents the obtained results from performance analysis. Section Ⅵ provides concluding remarks.

Ⅱ. Fading Channel Model

In this paper, we consider the Rician fading channel model. The Rician probability density function (pdf) is given by [4]

$$p(\gamma) = \frac{(K+1)}{\gamma_0} \exp\left[-K - \frac{\gamma(K+1)}{\gamma_0}\right] \cdot I_0\left[2\sqrt{\frac{\gamma K(K+1)}{\gamma_0}}\right] \quad \cdots\cdots (1)$$

where γ is the instantaneous signal to noise ratio, K is the direct signal power to diffused signal power ratio, $I_0(\cdot)$ is the zero-order modified Bessel function of the first kind, and γ_0 is the average signal to noise ratio.

In indoor building environment, the adequate range of K is 5 to 15 [5].

For example, each bit error probability of QPSK and QAM signals in noise environment can be expressed as[4]

$$P_{e-QPSK/AWGN} = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{\frac{\gamma}{2}}\right) \quad \cdots\cdots (2)$$

$$P_{e-QAM/AWGN} = \frac{2(M-\sqrt{M})}{M}\,\mathrm{erfc}\left(\frac{\sqrt{2\gamma}}{2(\sqrt{M}-1)}\right) \cdot \left[1-\frac{(M-\sqrt{M})}{2M}\,\mathrm{erfc}\left(\frac{\sqrt{2\gamma}}{2(\sqrt{M}-1)}\right)\right] \quad \cdots\cdots (3)$$

where M is the number of symbols.

From the expression of the Rician pdf of γ, it is possible to compute the mean bit error probability of QPSK signal in Rician fading channel.

$$P_e = 1/2 - \frac{2\sqrt{\gamma_0}(K+1)}{\sqrt{\pi}} \cdot \exp[-K] \cdot \sum_{i=0}^{\infty}\frac{(K^2+K)^i}{(i!)^2} \cdot \Gamma\left(i+\frac{3}{2}\right) \cdot (\gamma_0+2K+2)^{-\frac{3}{2}} \cdot \frac{2^i}{(\gamma_0+2K+2)^i}\,{}_2F_1\left(1;i+\frac{3}{2};\frac{3}{2};\frac{\gamma_0}{\gamma_0+2K+2}\right) \quad \cdots\cdots (4)$$

where ${}_2F_1$ represents the Hypergeometric function.

Ⅲ. Concatenated FEC Technique for WATM Systems

For multimedia traffic over wireless links, FEC scheme should provide a large selection of error protection depending on different QoS requirement for multimedia traffic. Moreover, FEC scheme should be powerful enough to support wireless ATM networks, because it is designed as a general solution to support various types of networks. In a recent paper, the concatenated FEC scheme has been proposed [3] for wireless ATM by using a convolutional inner code and an RS(Reed-Solomon) outer code with interleaving as shown in Figure 2.

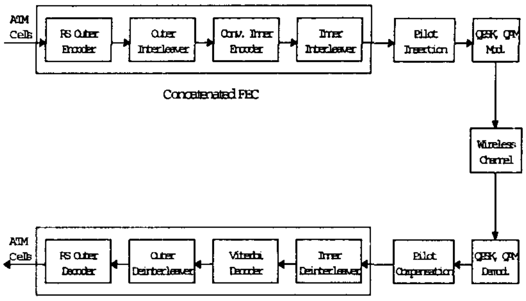

Fig. 2. Block diagram for wireless ATM system.

In particular, a rate 1/2, constraint length 7 convolutional code is used as an inner code, since it is an industry standard in digital cellular systems. When the Viterbi decoder suffers a decoding error, the resulting codeword usually differs from the transmitted word by a few consecutive trellis branches. As a result, although the input to the Viterbi decoder is corrupted by random noise, the output of the decoder tends to have burst errors. Hence, the RS code with its inherent burst error correcting capability is used as an outer code to deal with burst errors out of the Viterbi decoder.

1. RS(Reed-Solomon) Code[6]

The RS codewords are composed of n nonbinary symbols of which k are information symbols and n-k parity symbols. A RS codeword with 2t parity symbols is capable of correcting t symbol errors. The symbol error rate at the output of an RS block decoder, which is capable of correcting t symbol errors can be written as

$$P_{sym} = \sum_{i=t+1}^{n}\frac{i}{n}\binom{n}{i}P_Q^{\,i}(1-P_Q)^{n-i} \quad \cdots\cdots (5)$$

Where P_Q is the channel symbol error rate.

Assuming that each nonbinary RS decoded symbol in error contains bit errors in half of its positions, the bit error rate at the output of the RS decoder is approximately

$$P_b \approx \frac{P_{sym}}{2} \quad \cdots\cdots (6)$$

Figure 3 shows the theoretical results of WATM cells' BER according to the error correcting capability of RS code in AWGN channel.

From the Fig. 3, it is known that 10^{-10} BER of WATM with the concatenated FEC technique using RS code of error correcting capability t=8 in AWGN channel can be achieved with only $E_b/N_o \approx 2.5$ dB which is about 4.5 dB lower than required when using the only R = 1/2, k = 7 convolutional code.

2. Outer/Inner Interleaving Technique

We consider the convolutional interleaving technique as an outer interleaver and the block interleaving technique as an inner interleaver, respectively. In this paper, we have analyzed the BER performance analysis using the convolutional interleaving technique as an outer interleaver, and the bit and symbol interleaving which is the block interleaving technique as an inner interleaver.

Figure 4 shows the simulation results of WATM cells' BER according to the number of interleaver branchs at the output stage of RS decoder in Rician fading channel.

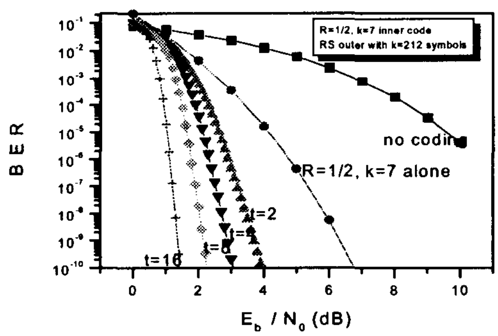

Fig. 3. Theoretical results of WATM cells' BER according to the error correcting capability of RS code in AWGN channel.

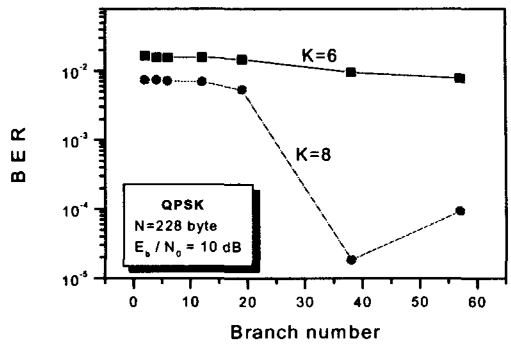

Fig. 4. Simulation results of WATM cells' BER according to the number of interleaver branchs at the output stage of RS decoder in Rician fading channel.

From the Fig. 4, it is confirmed that the best BER performance is obtained at the number of interleaver branchs B=38 in Rician fading channel (K=8).

Figure 5 shows the simulation results of WATM cells' BER according to the block size of interleaver in Rician fading channel.

From the Fig. 5, it is confirmed that the BER performance according to the block size of inner interleaving is similar regardless of the size.

3. Convolutional Code

The performance of convolutional coding with Viterbi decoding can be upper bounded using the

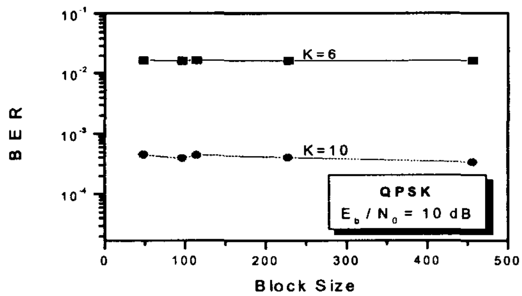

Fig. 5. Simulation results of WATM cells' BER according to the block size of interleaver in Rician fading channel.

union bound technique. The probability of error is upper bounded as the sum of the error probabilities of all incorrect codewords which must be compared with the correct codeword. The union bound on the probability of bit error at the Viterbi decoder output is given by [7]

$$P_{Viterbi} < \frac{1}{m}\sum_{j=0}^{\infty} w_j P_j^{path} \quad \cdots\cdots (7)$$

This bound is valid for a code rate R = m/n convolutional code with weight structure terms w_j. The probability of incorrect decision in comparing a correct codeword with one at a Hamming distance of j away is denoted by P_j^{path}.

Figure 6 shows the simulation results of WATM cells' BER according to coding rate at the output stage of Viterbi decoder in Rician fading channel.

From the Fig. 6, it is confirmed that the best BER performance is obtained at the coding rate R=1/2 in Rician fading channel.

Figure 7 shows the simulation results of WATM cells' BER obtained by various modulation techniques in AWGN channel.

From the Fig. 7, it is confirmed that the performance improvement of 6 dB is obtained in terms

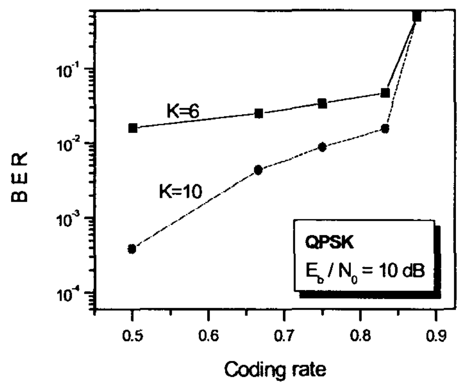

Fig. 6. Simulation results of WATM cells' BER according to coding rate at the output stage of Viterbi decoder in Rician fading channel.

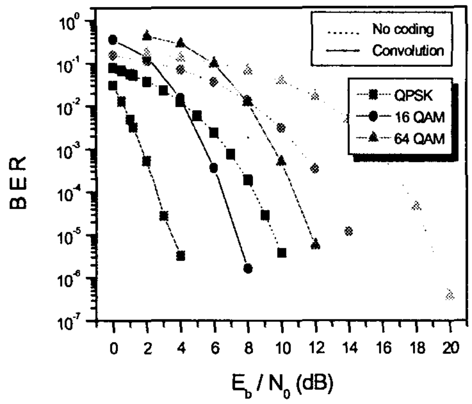

Fig. 7. Simulation results of WATM cells' BER obtained by various modulation techniques in AWGN channel.

of E_b/N_0 by adopting the convolutional coding technique at BER= 10^{-5} of WATM in all cases.

4. Pilot Symbols-Added Fading Compensation Technique

In this paper, we apply a fading estimation and compensation technique proposed by Sampei[8] to a pilot symbol-added fading compensation technique.

Figure 8 depicts the WATM cell format with pilot symbols.

After evaluating the fading degree by using pilot symbols which are already known values, we can compensate for the fading by returning the evaluated values to the information symbols in a cell.

Figure 9 shows the simulation results of WATM cells' BER according to the pilot symbol interval when coding technique is not adopted in Rician fading channel.

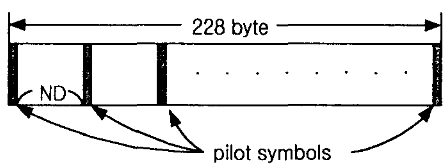

Fig. 8. WATM cell format with pilot symbols.

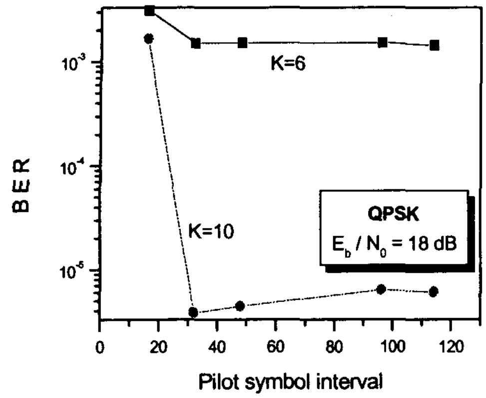

Fig. 9. Simulation results of WATM cells' BER according to the pilot symbol interval when coding technique is not adopted in Rician fading channel.

From the Fig. 9, it is confirmed that the best BER performance is obtained at the pilot symbol interval ND=32 in Rician fading channel.

Ⅳ. Truncated Type-Ⅱ Hybrid ARQ Technique

We consider the truncated Type-Ⅱ hybrid ARQ protocol with a single retransmission. In the truncated protocol, the first transmission of a ATM cell involves error detection coding only. When the data link control (DLC) layer of receiver detects the presence of errors in a received cell, it saves the header and payload in a buffer and requests a retransmission. The retransmission is a block of parity bits, which is obtained by applying a rate 1/2 invertible error correction code to the original cell. If no errors are detected on the first transmission, a received cell is sent to the ATM layer.

Like the Wang-Lin protocol[9], the truncated protocol employs two block codes, C_0 and C_1. C_0 is an (n, k) high rate code used only for error detection, C_1 is a (2n, n) invertible code which is designed for error correction.

When the truncated protocol is used, the throughput is given by

$$\eta_{truncated} = \frac{k}{n} \frac{1}{[P_c + 2(1-P_c-P_e)P_t]} \quad \cdots\cdots (8)$$

Where k/n is the code rate, P_c is the probability that the received cell contains no error, P_e is the undetected error probability for the code C_0, and P_t is the probability that can be corrected to the original cell.

Each probability in (8) is defined as

$$P_c = (1-P_{FEC})^n \quad \cdots\cdots (9)$$

$$P_e \le [1-(1-P_{FEC})^k]\, 2^{-(n-k)} \quad \cdots\cdots (10)$$

$$P_t = P_c + (1-P_c-P_e)\frac{q_0 - y}{1-y} \quad \cdots\cdots (11)$$

where, $q_0 = \sum_{j=0}^{t} \binom{2n}{j} P_{FEC}^{\,j} (1-P_{FEC})^{2n-j}$,

$y = (1-P_{FEC})^n$

$\cdot [2\sum_{l=0}^{t} \binom{n}{l} P_{FEC}^{\,l} (1-P_{FEC})^{n-l} - (1-P_{FEC})^n]$

Figure 10 shows the throughput characteristic of ARQ techniques according to BER.

From the Fig. 10, it is found that the truncated Type-Ⅱ hybrid ARQ technique gives better performance in throughput than the Type-Ⅰ hybrid SR-ARQ technique.

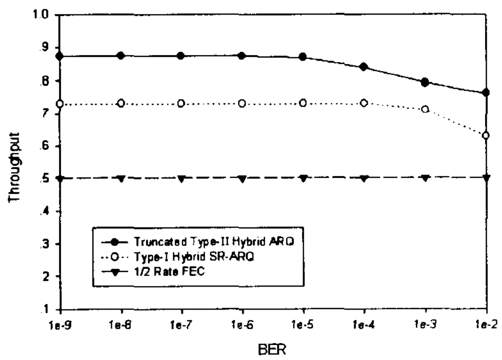

Fig. 10. Throughput characteristic of ARQ techniques according to BER.

V. Performance Analysis

The parameters used in the computer simulation are shown in Table 1.

Figure 11 shows the simulation results of WATM cells' BER obtained by introducing the fading compensation technique with pilot symbols in each of various modulation techniques in Rician fading channel.

Table 1. Parameters used in simulation.

Error correcting capability of RS code	t=8
Code rate of convolutional code	R=1/2
Constraint length of convolutional code	k=7
Number of outer interleaver branchs	B=38
Number of inner interleaver blocks	N=96
Interval of pilot symbols	ND=32
Modulation	QPSK, QAM

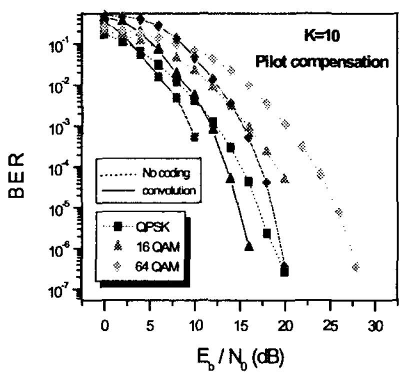

Fig. 11. Simulation results of WATM cells' BER obtained by various modulation techniques in Rician fading channel.

From the Fig. 11, it is confirmed that the BER performance of 64 QAM becomes better than each of the BER performance of other modulation techniques by adopting the convolutional coding technique at BER=10^{-5} of WATM.

Figs. 12 and 13 show the simulation results of WATM cells' BER obtained by various coding techniques at each case of K=6, K=10 in Rician fading channel. It is obvious that each performance of BER is improved considerably by introducing the fading compensation technique of inserting pilot symbols into the concatenated FEC.

VI. Conclusions

In this paper, we have provided the optimum error control technique for improving overall performance of WATM using the concatenated FEC, interleaving, pilot symbol-added fading compensation, and truncated Type-II hybrid ARQ. Also, the performance of WATM system in indoor environment has been analyzed by means of BER and throughput characteristics, so the results are as follows.

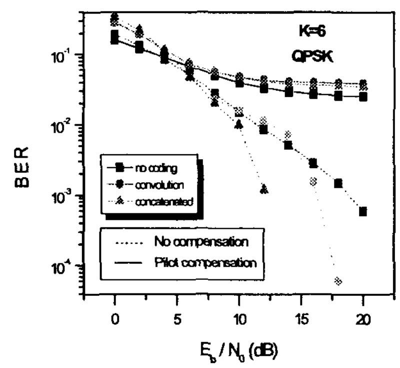

Fig. 12. Simulation results of WATM cells' BER obtained by various coding techniques in Rician fading channel (K=6).

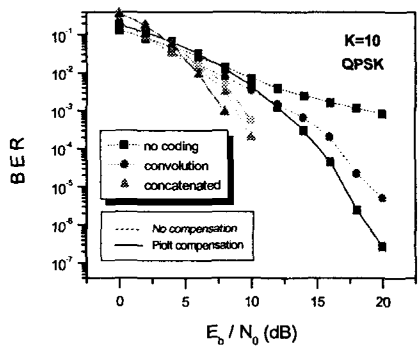

Fig. 13. Simulation results of WATM cells' BER obtained by various coding techniques in Rician fading channel (K=10).

Note the even with only an eight error- correcting RS code a 10^{-10} BER can be achieved with only $E_b/N_o \approx 2.5$ dB which is about 4.5 dB less than required with R=1/2, k=7 code alone in AWGN. However, the BER performance of WATM can't be improved any more as E_b/N_o increases (see Fig. 12), so the pilot symbol-added fading compensation is required to optimize th WATM error control in indoor environment. Therefore, it has known that the BER performance of WATM with the concatenated FEC is improved considerably by introducing the fading compensation technique as shown is Fig. 12 and Fig. 13.

We have found that the truncated Type-II hybrid ARQ technique gives better performance in throughput than the Type-I hybrid SR-ARQ technique as shown in Fig. 10.

In conclusion, for optimizing the performance of WATM in indoor environment, it is desirable to select various parameters like as error-correcting size of RS code, branch number of outer interleaver, code rate of convolutional code, block size of inner interleaver, and symbol interval of fading compensator. Also, it is required to introduce the pilot symbol-added fading compensation with the concatenated FEC for time-critical traffic, and the truncated Type-II hybrid ARQ method for quality-critical traffic.

References

[1] J. Immonen, J. M. Romann and A. Hashimoto, "Requirement and protocol architecture for MBS access to ATM network," in *Proc. RACE MTS 95*, pp. 324-333, Nov. 1995.

[2] K. Y. Eng et al, "BAHAMA : A broadband ad-hoc wireless ATM local area network," in *Proc. ICC'95*, pp. 1216-1223, June 1995.

[3] J. Durkin et al, "Error control for wireless links," *ATM Forum*/98-0203, April 1998.

[4] 滑川敏彦, 奥井重彦, *通信方式*, 日本 東京, 森北出版株式會社, 1989年 9月.

[5] R. Bultitude, "Measurement, characterization and modeling of indoor 800/900 MHz radio channels for digital communications," *IEEE Commun. Mag.*, vol. 25, pp. 5-12, June 1987.

[6] B. Sklar, *Digital Communications*, Prentice-Hall, 1988.

[7] G. C. Clark, and J. B. Cain, *Error Correction Coding for Digital Communication*, Plenum Press, 1981.

[8] S. Sampei and T. Sunaga, "Rayleigh fading compensation for QAM in land mobile radio communications," *IEEE Trans. Commun. Technol.*, vol. COM-42, pp. 137-147, May 1993.

[9] Y. M. Wang and S. Lin, "A modified selective repeat type-II hybrid ARQ system and its performance analysis," *IEEE Trans. Commun.*, vol. COM-31, pp. 593-608, May 1983.

강 영 흥 (Young-Heung Kang)
1984년 2월 : 한국항공대 통신공학과 졸업(공학사)
1986년 2월 : 한국항공대 대학원 전자공학과 졸업(공학석사)
1993년 2월 : 한국항공대 대학원 전자공학과 졸업(공학박사)
1988년 2월 ~ 1990년 2월 : 한국항공대 통신정보공학과 조교
1995년 8월 ~ 1996년 8월 : 일본 오사카대학 객원교수
2000년 1월 ~ 현재 : 한국 ITU-R 위원
1990년 4월 ~ 현재 : 군산대 전자정보공학과 부교수
주관심분야 : 위성통신, 이동통신, 표준화

신 송 섭(Song-Sup, Shin)
1994년 2월 군산대학교 정보통신공학과 졸업(공학사)
2000년 2월 군산대학교 대학원 정보통신공학과 졸업(공학석사)
2000년 1월 (주)현정시스템 기술연구소 입사
현재 (주)싸이텍소프트 기술연구소 전임연구원 근무
주관심분야 : 무선 ATM, 에러제어기법, ADSL, VDSL, 마이크로프로세서