# Performance Analysis of Dual-Hop Cooperative Transmission with Best Relay Selection in a Rayleigh Fading Channel

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요 약

**Key Words :** Bit error Rate(BER), Amplify and Forward (AF), Multiple Input Multiple Output (MIMO), Decode-and-Forward(DF), Probability Density Function(PDF)

## ABSTRACT

Wireless Relaying is a promising solutions to overcome the channel impairments and provides high data rate coverage that appear for beyond 3G mobile communications. In this paper we present end to end BER performance of dual hop wireless communication systems equipped with multiple Decode and Forward relays over Rayleigh fading channel with the best relay selection. We compare the BER performance of the best relay with the BER performance of single relay. We select the best relay based on the end to end channel conditions. We further calculate the outage probability of the best relay. It is shown that the outage probability of the best relay is equivalent to the outage probability when all relays take part in the transmission. We apply Orthogonal Space Time Block coding(OSTBC) at the source terminal. Numerical and simulation results are presented to verify our analysis.

## I. Introduction

Dual hop transmission is a technique by which the channel from source to destination is split into two shorter links using a relay[1]. In this case the key idea is that the source relays a signal to destination via a third terminal that acts as a relay. It is an attractive technique when the direct link between the base station and the original mobile terminal is in deep fade or heavy shadowing or there is no direct link between source and destination.

On the other hand diversity technique is an effective technique to mitigate the severe form of interference that arises due to the multi path propagation of wireless signal gain without increasing the expenditure of transmission time or bandwidth. Although transmission diversity is clearly advantageous on a cellular base station, it might not be practical for other scenarios. Especially due to cost, size or hardware limitations, a wireless device may not be able to support multiple transmission antennas. In order to overcome this limitation a new form of diversity technique, the cooperative diversity(named so as it comes from user cooperation) has been introduced[2]-[5]. It exploits the broadcast nature of the wireless transmission. In cellular, the ad-hoc network when one user is transmitting information to a remote terminal, other users nearby also receive it and transmit the signal to the destination. This process results in multiple copies of same signal from independent fading

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paths at the destination and brings diversity.

Depending on the nature and the complexity of the relays cooperative transmission system can be classified into two main categories; regenerative and non regenerative systems. In regenerative systems, relay fully decodes the signal that went through the first hop and then retransmits the decoded version to the second hop. This is also referred to as decode-and-forward or digital relaying. On the other hand, non regenerative systems use less complex relays that just amplify and forward the incoming signal without performing any sort of decoding. It is called amplify-and-forward [6] or analog [7] relaying. The performance of both systems has been well studied in [1, 8, 9, 10]. In [11] a distributed space time coded(STC) cooperative scheme is proposed, where the relays decode the received symbols from the source and utilize a distributed space time code. The number of distributed antennas(distributed relays) for cooperation is generally unknown and also may be not unique. So coordination among the cooperating nodes is needed prior to the use of a specific space time coding scheme.

Moreover, if many relay stations transmit signal to destination then it also needs synchronization of carrier phases among several transmit receive pairs which will increase the complexity of receiver as well as cost. Choosing the minimum number of relays for reducing cooperation overhead and saving energy without performance loss is an important concern. There are various protocols proposed to choose the best relay among a collection of available relays in literature. In [12], the author proposed to choose the best relay depending on its geographic position, based on the geographic random forwarding protocol proposed in [13] and [14]. In [15], the author proposed opportunistic relay based on the instantaneous channel conditions. This single relay opportunistic selection provides no performance loss from the perspective of diversity-multiplexing gain trade off, compared to schemes that rely on distributed space time coding[15].

In this paper our aim is to analyze the system with multiple relay nodes where source has two transmit antennas and each relay and destination have one antenna. In the second hop, before transmitting signal to destination the best relay is selected based on the instantaneous channel conditions of two hops. This technique can save the transmission power of the network. It also reduces the decoding complexity at receiver side and at the same time achieves diversity gain. However this intermediate relay shall increase the maximum distance between source and destination also increase the spectral efficiency.

The paper is outlined as follows: Section II introduces channel model. Relay selection protocol is described in Section III. Section IV derives the probability density function (PDF) and moment generation function (MGF) of the received SNR per bit and analyzes the BER performance when QPSK constellations are used. Section V shows the outage behavior of the best relay. Simulation results are presented in Section VI and finally Section VII presents conclusion and future work.

## Ⅱ. System and Channel Model

We are considering a wireless dual hop network where a number of relay nodes are placed randomly and independently according to some distribution. The direct link between source and destination may be blocked by some obstacles. The relays can communicate with both end points. In our model the source equipped with two transmit antennas and each relay node has a single antenna which can be used for both transmission and reception. All transmissions are assumed to be half duplex and therefore a relay station can not transmit and receive at the same period. During the first hop source broadcasts symbols, the relays listen and during the second hop, relays forward the decoded version of the received signal to destination.

Fig.1 shows the channel model. We are assuming the channel remains constant during the two hops with Rayleigh fading. We are applying

OSTBC at the source. No channel information is available at source. So no power or bit loading is performed at source. Each transmission antenna of source is assumed to use the same transmission power $\sigma_s^2 = P/t$, where $P$ is the total transmission power of the base station and $t$ is the number of antennae at base station. In this paper we are considering $t$=2. For two transmit antenna, there exists a rate one OSTBC defined by the transmission matrix $X_1$,

$$X_1 = \begin{pmatrix} X_1 & -X_2^* \\ X_2 & X_1^* \end{pmatrix} \quad (1)$$

where $x_1$ and $x_2$ are a pair of complex symbols to be transmitted and * denotes the complex conjugate.

We assume there are $r$ relays and number of transmit antennae at source is 2. So the channel matrix for the first hop is given by

$$H_{SR} = \begin{pmatrix} h_{11} & h_{12} \\ \vdots & \vdots \\ h_{r1} & h_{r2} \end{pmatrix} \quad (2)$$

where the element $h_{ij}$ denotes the channel gain between the $i$th relay and the $j$th transmission antenna of source, $i = 1,2,\cdots r$ and $j = 1,2$. We assume that each element of $H_{SR}$ is independent and identically distributed complex Gaussian random variable with zero mean and $\beta_1$ variance. If we

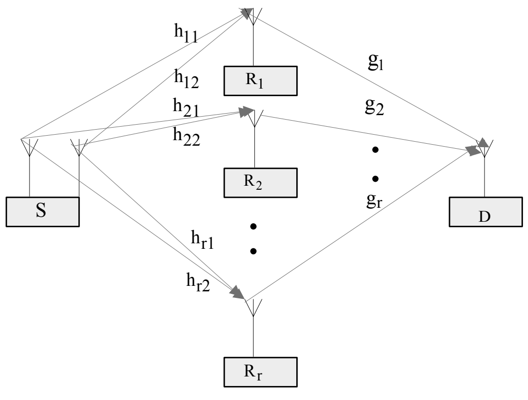


Fig. 1. A half duplex dual hop relay network

notice carefully we observe each row of $H_{SR}$ represents the channel coefficient between source and relay. So the channel matrix for each relay can be represented by

$$\alpha_i = \begin{pmatrix} h_{i1} & h_{i2} \end{pmatrix} \text{ for } i = 1,2,...r \quad (3)$$

And for the second hop $g_i$ is the individual relay to destination fading amplitude.

## Ⅲ. Relaying Protocol

In single relay selection schemes only one opportunistic relay transmits the received signal to destination. In previous work opportunistic relay is defined considering distance toward source or destination [14] or considering the channel condition. The selection of the best relay based on distance is not a good selection since communication link between transmitter and receiver locating in the same distance might have enormous difference in terms of received signal due to fading and shadowing. In [15], authors select the best relay based on the channel condition. In this paper we are assuming all relays can listen to each other. After monitoring the instantaneous channel condition each relay also broadcast the information to each other. If the relays are hidden to each other then they send information to destination and destination decides among them which is the most opportunistic for relaying and broadcasts the decision to relay stations[15].

Let $\alpha_{si}$ and $\alpha_{id}$ denote the total channel power from source to $i$th relay and $i$th relay to destination respectively. Here, $\alpha_{si}$ and $\alpha_{id}$ describe the quality of the wireless path between source to relay and destination to relay. $\alpha_{si}$ is calculated by relay $i$ by the following equation.

$$\alpha_{si} = |h_{i1}|^2 + |h_{i2}|^2 \quad (4)$$

And $\alpha_{id} = |g_i|^2$ is the fading amplitude from relay to destination. Since the two hops are both important for end to end performance, each relay calculates corresponding $h_i$ based on the two decision rules.

Rule1: $h_i = \min\{\alpha_{si}, \alpha_{id}\}$. (5)

Rule 2: $h_i = \dfrac{2}{\dfrac{1}{\alpha_{si}} + \dfrac{1}{\alpha_{id}}} = \dfrac{2\alpha_{si}\alpha_{id}}{\alpha_{si} + \alpha_{id}}$ (6)

The relay $i$ that maximizes function $h_i$ is one with the “best” end to end path between initial source to destination. After being selected as the best relay it relays signal to destination. In this paper it is assumed the destination have perfect channel information available for decoding the received signal.

## Ⅳ. END to-END Ber Analysis

When OSTBC $X_1$ is used at the source the signals received at each relay are given by,

$$Y_i = \alpha_i X_1 + E_i \quad (7)$$

where

$$Y_i^R = \left[ y_i^1 . \quad y_i^l . \ . y_i^L \right] \quad (8)$$

and

$$E_i = \left[ e_i^1 . \ . e_i^l \quad e_i^L \right]. \quad (9)$$

where $y_i^1$ and $e_i^1$ denote the received signal and the additive complex white Gaussian noise with mean zero and variance $\sigma_A^2$ respectively, at the $i$th relay during the $l$th symbol duration where the block length of the OSTBC is denoted by $L$.

After that each relay decodes them with an efficient ML detector and takes decision among them which is more opportunistic for relaying signal to destination and then transmits it to destination according to single opportunistic relay selection protocol[15]. Let $i$th relay is the most appropriate for relaying signal to destination. Then the received signal at destination is

$$Y^D = \mathrm{g_i} X_2 + e^D. \quad (10)$$

where $X_2$ is the transmitted signal matrix from relay to destination and $e^D$ is the complex additive white Gaussian noise with mean zero and variance $\sigma_B^2$. Assume $\sigma_A^2 = \sigma_B^2 = \sigma^2$. From (8) the received SNRs for the first hop can be given as:

$$\gamma^R(\rho) = c\rho\left|\alpha^i\right|^2 = c\rho\sum_{j=1}^{2}\left|h_{ij}\right|^2 \quad (11)$$

where $c = L/(t.K.Log_2 M)$ and $\rho = P/\sigma^2.K$ is the number of complex symbol transmitted by $X_1$. And for the second hop it is like a SISO channel and SNR can be given by,

$$\gamma^D(\rho) = \rho\left|\mathrm{g}_i\right|^2 / \log_2 M \quad (12)$$

where M is the modulation order.

The MGF of the first hop and the second hop for $\gamma^R(\rho)$ and $\gamma^D(\rho)$ are respectively obtained by,

$$M_{\gamma^R}(s) = \left(1 + c\beta_1\rho s\right)^{-2} \quad (13)$$

and

$$M_{\gamma^D}(s) = 1/\left(1 + \gamma^D s\right). \quad (14)$$

By taking the inverse Laplace transform of (13) and (14), the PDF of $\gamma^R(\rho)$ and $\gamma^D(\rho)$ respectively are given by,

$$f_{\gamma^R(\rho)}(\gamma) = (c\beta_1\rho)t\frac{1}{(t-1)!}e^{-\gamma/c\beta_1\rho} \quad (15)$$

and

$$f_{\gamma^D(\rho)}(\gamma) = \frac{1}{\gamma}e^{-\gamma/\gamma^D(\rho)s}. \quad (16)$$

The PDF of phase $\theta$ of the received signal with SNR $\gamma$ is given by in [16]

$$f_\theta(\theta|\gamma) = \frac{1}{2\pi} e^{-\gamma}\log_2 M\left[1+\cos\theta\sqrt{4\pi\log_2 M\gamma}e^{\gamma\log_2 M\cos^2\theta} \times\left(1-\frac{1}{2}erfc\left(\sqrt{\gamma\log_2 M}\cos\theta\right)\right)\right] \quad (17)$$

where $\mathrm{erfc}(x) = \frac{1}{\sqrt{\pi}}\int_x^\infty e^{-y^2}dy$. Then the exact probability that the phase $\theta$ of the received signals lies in a decision region $[\theta_l, \theta_u]$ is given by,

$$\Pr\left\{\theta\in\left[\theta_l,\theta_u\right];\rho\right\} = \int_0^\infty\int_{\theta_l}^{\theta_u} f_\theta(\theta\mid\gamma)f_{\gamma(\rho)}(\gamma)d\theta d\gamma . \quad (18)$$

The BERs of M-ary PSK constellation for the first and the second are respectively obtained by,

$$P_R^{M-PSK}(\rho) = \frac{1}{\log_2 M}\sum_{j=1}^{M} e_j\int_0^\infty\int_{\theta_{lj}}^{\theta_{uj}} f_\theta(\theta\mid\gamma)f_{\gamma^R(\rho)}(\gamma)d\theta d\gamma \quad (19)$$

$$P_D^{M-PSK}(\rho) = \frac{1}{\log_2 M}\sum_{j=1}^{M} e_j\int_0^\infty\int_{\theta_{lj}}^{\theta_{uj}} f_\theta(\theta\mid\gamma)f_{\gamma^D(\rho)}(\gamma)d\theta d\gamma \quad (20)$$

where $\theta_{l_j} = (2j-3)\pi/M$ and $\theta_{u_j} = (2j-3)\pi/M$ for j=1,⋯,M and $e_j$ is the number of bit errors in the decision region ($\theta_{l_j} = (2j-3)\pi/M$, $\theta_{u_j} = (2j-3)\pi/M$).

In regenerative system, the relay decodes the received signal and then re-transmits the decoded one to the destination. The signal received at the destination has undergone two states of decoding in cascade, and the end to end BERs of M-ary PSK constellation are given by,

$$P^{M-PSK}(\rho) = P_R^{M-PSK}(\rho) + P_D^{M-PSK}(\rho) - 2P_R^{M-PSK}(\rho)P_D^{M-PSK}(\rho) \quad (21)$$

Finally we obtained the end to end BER of M-ary PSK constellations by substituting (19) and (20) in Eq. (21).

## V. Outage Probability

The mutual information between the source and relay nodes i= 1,2,⋯,r in the first hop can be given by

$$I_{i1} = \frac{1}{2}\log(1+\Omega_{i1}SNR) \quad (22)$$

with $\Omega_{i1} = \frac{|h_{i1}|^2+|h_{i2}|^2}{2}$. $\Omega_{i1}$ is exponential distribution with parameter $\lambda_1 = \frac{1}{2}$ as shown in Appendix A.
and the mutual information in the second hop of this corresponding relay is given by

$$I_{i2} = \frac{1}{2}\log(1+\Omega_{i2}SNR). \quad (23)$$

The probability density function of $\Omega_{i1}$, $\Omega_{i2}$ are in order as follows.

$$f(\Omega_{i1},\lambda_1) = \lambda_1 e^{\Omega_{i1}\lambda_1} \quad (24)$$

$$f(\Omega_{i2},\lambda_2) = \lambda_2 e^{\Omega_{i2}\lambda_2} \quad (25)$$

So the capacity of the network for relay $i$ is the minimum of the mutual information of these two hops.

$$C(\gamma_i) = \min(I_{i1}, I_{i2}). \quad (26)$$

We are selecting the best relay based on end to end channel condition. So the maximum capacity of the entire network depends on the mutual information of the best relay. The mutual information of the best relay can be given by

$$I = \max_{i\in|1,..,r|}(\min(I_{i1}, I_{i2})). \quad (27)$$

$$I = \max_{i\in|1,..,r|}(\min(\frac{1}{2}\log(1+\Omega_{i1}SNR, \frac{1}{2}\log(1+\Omega_{i2}SNR))). \quad (28)$$

So the network capacity

$$C(\gamma) = I \quad (29)$$

The outage probability $P_{out}$ can be defined as the probability that instantaneous capacity $C(\gamma)$ fall below outage capacity $C_{out}$.

$$P_{out} = \Pr(C(\gamma) < C_{out}) \quad (30)$$

$$P_{out} = \Pr(\max_{i \in |1,..,r|}(C(\gamma_i) < C_{out})) \quad (31)$$

Du0e to the independent channel assumption it given by

$$P_{out} = \prod_{i=1}^{r} P_{out}^{i} \quad (32)$$

with $P_{out}^{i} = \Pr(C(\gamma_i) < C_{out})$.

$$P_{out}^{i} = \Pr(\min(\frac{1}{2}\log(1+\Omega_{i1}SNR), \frac{1}{2}\log(1+\Omega_{i2}SNR)) < C_{out})$$
$$= \Pr(\min((\Omega_{i1}, \Omega_{i2}) < w)), w = \frac{2^{2C_{out}} \text{-} 1}{SNR} \quad (33)$$

Then by using order statistics in [17]

$$\Pr(\min(\Omega_{i1}, \Omega_{i2}) = F(\lambda_1) + F(\lambda_2) - F(\lambda_1)F(\lambda_2)$$
$$= (1-e^{-\lambda_1 w}) + (1-e^{-\lambda_2 w}) - (1-e^{-\lambda_1 w})(1-e^{-\lambda_2 w})$$
$$= 1 - e^{-(\lambda_1+\lambda_2)\frac{2^{2C_{out}}-1}{SNR}} \quad (34)$$

$$P_{out}^{i} = 1 - e^{-(\lambda_1+\lambda_2)\frac{2^{2C_{out}}-1}{SNR}}. \quad (35)$$

And finally by putting this value of $P_{out}^{i}$ into Eq. (29) we get the outage probability $P_{out}$.

## Ⅵ. Simulation Result

In this section we are presenting our simulation results of BER performance and outage behavior. We consider QPSK and 16QAM constellation for 2 transmit antennas equipped at source.

We are assuming that the channels are slow Rayleigh fading channel. Two sorts of simulation are performed, one for decision rule 1 and another for decision rule 2. We can see that the performances are nearly the same for both cases. From Fig. 2 and Fig. 3 we see the BER performance of the best relay among a set of relays is always better than the BER performance of single relay. It is also shown that the better BER performance can be achieved by adopting more relay nodes. Modulation order also affects the difference between

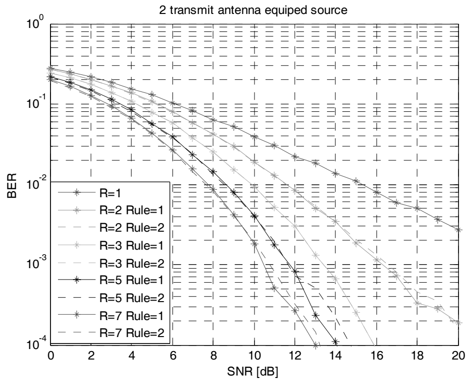


Fig. 2. BER vs. SNR for Relay selection. Tx=2, modulation=QPSK.

the BER performances, as shown in Fig. 3. However, for higher modulation order, the difference becomes negligible. Comparing Fig.2 and Fig. 3, it is easily noticeable.

Fig.4 and Fig.5 illustrate the outage performance of the best relay for outage capacity

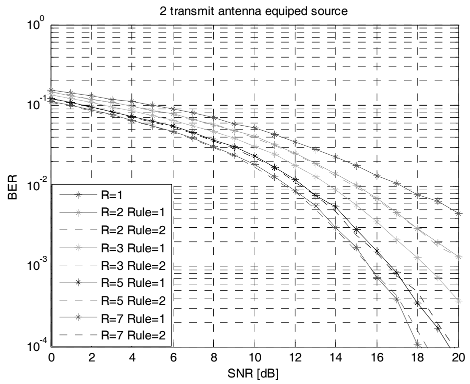


Fig. 3. BER vs. SNR for Relay selection. Tx=2, modulation=16QAM.

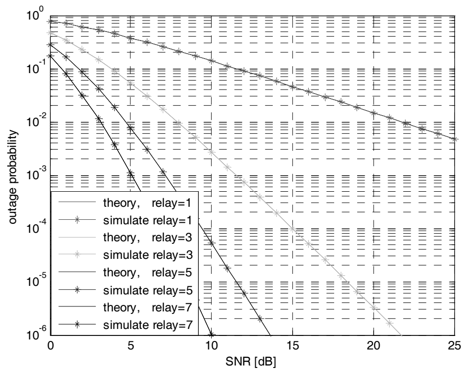


Fig. 4. Outage probability vs. against transmit SNR(db), $C_{out} = .5$bps/Hz, $\lambda_1 = 1/2$, $\lambda_2 = 1$

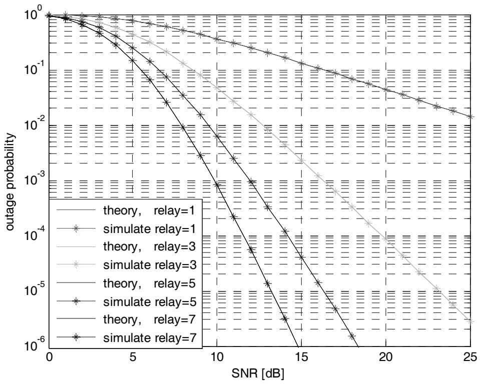


Fig. 5. Outage probability vs. against transmit SNR(db), $C_{out} = 1$bps/Hz, $\lambda_1 = 1/2$, $\lambda_2 = 1$

$C_{out} = .5$bps/Hz and $C_{out} = 1$bps/Hz. It is shown t0hat theoretically result match with simulation result perfectly. Both figure shows that the outage probability decreases with increase in number of relays. By adopting more relays better outage performance can be achieved.

## Ⅶ. Conclusion

In this paper we presented end to end BER performance and outage performance of dual hop wireless transmission by selecting the best relay based on the instantaneous channel condition. Both BER performance and outage performance can be improved by adopting more relays. However the outage performance of the best relay is equivalent to the outage behavior when all relay nodes participate into the second hop. The single relay selection can reduce receiver complexity and at the same time will increase the network coverage. In future we will continue our work in multi-hop transmission for covering long distance environment.

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## Appendix A

Let n=1,2⋯k be normally distributed random variable with mean 0 and variance 1, Then the random variable

$$Q \sim \sum_{i=1}^{k} X_i^2 \tag{36}$$

is distributed according to the chi-square distribution with k degrees of freedom. This pdf of Q is given by

$$f(x;k) = \begin{cases} \frac{1}{2^{k/2}\Gamma(k/2)} x^{(k/2)-1} e^{-x/2} & \text{for} \quad x > 0, \\ 0 & \text{for} \quad x \le 0, \end{cases} \tag{37}$$

when $\Gamma$ is the gamma function defined by

$$\Gamma(\alpha) = \int_0^{\infty} x^{\alpha-1} e^{-x} dx \tag{38}$$

if k=2, then Eq. (37) is an exponential distribution with parameter $\frac{1}{2}$.

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received his B.S. and M.S. degrees both in Electrical and Computer Engineering from the Korea University, Seoul, Korea in 1997 and 1999, respectively. In 1999, he joined the Electronics and Telecommunications Research Institute(ETRI), Deajeon, Korea where he has worked on development and standardization for wireless LAN and wireless PAN as a senior member of engineering staff. Also, he is currently a voter for standardization group of IEEE 802.11 and IEEE 802.15. His research interests include next generation mobile radio communication system and broadband wireless networks, with special emphasis on medium access control layer design and performance analysis. His recent research is focused on the high speed wireless local and personal area networks systems.

**Kyung S. Kwak** Lifelong Member

received the B.S. degree from the Inha University, Inchon, Korea in 1977, and the M.S. degree from the University of Southern California in 1981 and the Ph.D. degree from the University of California at San Diego in 1988, under the Inha University Fellowship and the Korea Electric Association Abroad Scholarship Grants, respectively. From 1988 to 1989 he was a Member of Technical Staff at Hughes Network Systems, San Diego, California. From 1989 to 1990 he was with the IBM Network Analysis Center at Research Triangle Park, North Carolina. Since then he has been with the School of Information and Communication, Inha University, Korea as a professor. He had been the chairman of the School of Electrical and Computer Engineering from 1999 to 2000 and the dean of the Graduate School of IT and Telecommunications from 2001 to 2002 at the

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Since 1994 he had been serving as a member of Board of Directors, and the vice president for Korean Institute of Communication Sciences (KICS) and served for the president of 2006 year term. He is the president of Korea Institute of Intelligent Transportation System for the term of 2009In 1993, he received Engineering College Young Investigator Achievement Award from Inha University, and a distinguished service medal from the Institute of Electronics Engineers of Korea (IEEK). In 1996 and 1999, he received distinguished service medals from the KICS. He received the Inha University Engineering Paper Award and the LG Paper Award in 1998, and Motorola Paper Award in 2000. He received Official Commendations for the research achievements in UWB radio from Ministry of Information & Communication and Prime Ministry of Korea in 2005 and 2006, respectively. Also, in 2007, Headong Paper Award. In 2008, he is elected as Inha Fellow Professor(IFP). He published 60 SCI journal papers, more than 200 conference and domestic papers, obtained 11 registered patents and 35 pending patents, and proposed 9 technical proposals on IEEE 802.15(WPAN) PHY/MAC. His research interests include multiple access communication systems, UWB radio systems and WPAN/WBAN, sensor networks. Mr. Kwak is members of IEEE, IEICE, KICS and KIEE.