무선네트워크에서 적응형 협력통신의 성능 분석에 관한 연구

Ho Van Khuong[†] · 공형윤[††] · 정휘재[†††]

요 약

단일 안테나를 사용하는 사용자들 사이의 협력통신은 무선 매체의 전송 특성이나 경로 손실을 이용하여 안테나의 숫자를 증가하지 않고도 다중 안테나 시스템의 강력한 장점을 얻을 수 있다. 본 논문에서는 ML(Maximum Likelihood) 검파기의 구조를 간단하게 할 뿐만 아니라 에러 확률을 최소화 할 수 있는 전송신호 증폭인자의 최적화를 통해 전파환경의 변화에 순응하는 협력통신의 방법에 대해 제안한다. 제안하는 협력통신에 대해 수학적인 해석에 의한 BER(Bit Error Ratio) 표현을 유도할 뿐만 아니라 모의 실험 결과를 통해 그 성능을 비교한다. 다양한 수학적 계산의 결과를 통해 주파수 비선택적 Rayleigh 페이딩 채널에 AWGN(Additive White Gaussian Noise)이 합쳐진 채널 환경에서 실험한 결과 협력통신이 비 협력통신 보다 현저히 성능이 좋음을 알 수 있다.

키워드 : 협력통신, 최적화, Rayleigh 페이딩, AWGN, 최대우도

Performance Analysis of Adaptive Collaborative Communications in Wireless Networks

Ho Van Khuong[†] · Hyung-Yun Kong[††] · Jeong Hwi Jae[†††]

ABSTRACT

Broadcast nature of wireless medium and path-loss reduction create a favourable condition for collaborative communications (CC) among single-antenna users to gain the powerful benefits of multi-antenna system without the demand for physical arrays. This paper proposes a CC strategy adapting to the propagation environment changes by optimizing the transmit signal amplification factors to simplify the structure of maximum likelihood (ML) detector and to obtain the minimum error probability as well. The closed-form BER expression was also derived and compared to the simulation results to evaluate the performance of the suggested solution. A variety of numerical results revealed the cooperation significantly outperforms non-cooperative counterpart under flat Rayleigh fading channel plus AWGN (Additive White Gaussian Noise).

Key Words : Collaborative Communications, Optimization, Rayleigh Fading, AWGN, ML

1. Introduction

The transmit diversity has received a great deal of attention in recent years as an efficient solution to combat the detrimental effects of channels such as shadowing and deep fading by deploying multiple antennas at transmitter[1, 2]. However, it is impossible to apply this technique in some scenarios where wireless mobiles may not be able to support multiple antennas due to size or other constraints[3]. To overcome this problem, a new concept called collaborative communications was born which allows single-antenna mobiles to gain some benefits of transmit diversity[3-21]. The main idea is that in a multi-user network, two or more users share their information and transmit jointly as a virtual antenna array. This enables them to obtain higher diversity than they could have individually. The way the users share information is by tuning into each other's transmitted signals and by processing information that they overhear. Since the inter-user channel is noisy and faded, this overheard information is not perfect. Hence, one has to carefully study the possible signaling strategies that can exploit the benefits of cooperative communications at most. There are three basic cooperative signaling

---

※ This work was supported by the BK 21 Research Fund of Korea.
This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the IITA(Institute of Information Technology Assessment).

† 준 회 원 : 울산대학교 전기 전자정보시스템공학과 박사과정
†† 정 회 원 : 울산대학교 전기전자정보시스템공학부 부교수
††† 준 회 원 : 울산대학교 전기 전자정보시스템공학과 석사과정

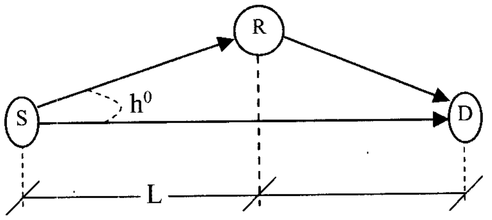
논문접수 : 2005년 9월 22일, 심사완료 : 2006년 7월 31일

methods[3] where *amplify and forward* strategy is the simplest and applicable in many wireless networks such as wireless sensor network, mobile communications network, ad-hoc network, relay network, etc. This is because in every wireless network, there must be a second independent propagation path through an idle user besides the direct link for the signal transmission to the destination. Thus, transmit diversity is obtained to combat shadowing and deep fading. Compared to single transmission, the *amplify and forward*-based cooperation showed a significant performance improvement and channel capacity increase[4-18]. However, a majority of the work on this protocol only concentrates on signal combining at the receiver to minimize the BER. It is well-known that transmit diversity systems can perform better if the knowledge about the channel can be exploited to adapt the weights for each transmit antenna in such a way that the SNR at the receiver is maximized. Similarly, it is possible to apply this principle to the cooperative communications by considering each user's antenna as an element of the physical antenna array and assigning amplification factors adaptively to the channel variation. These amplification factors are practically acquired through training sequences and feedback channel from the receiver to the transmitter. This is our motivation to develop an adaptive CC protocol to optimize weights of user signals with the goal of the minimum error probability through ML detection. Since the existence of one relay node in the wireless networks is almost evident in reality, we only investigate this scenario. With optimum factors, the signal detection at the receiver is extremely simple.

The rest of the paper is organized as follows. Part 2 presents an adaptive collaborative communications protocol to optimize the transmit weights for a generic wireless network. Then the numerical and simulation results that compare the performance of the proposed cooperation with non-cooperation (without a relay) are exposed in part 3. Moreover, this part also discusses thoroughly about the achieved results. Finally, the paper is closed in part 4 with a conclusion.

2. Adaptive collaborative communications protocol

Consider a cooperative transmission in a practical and generic wireless network consisting of a source (*S*), a relay (*R*) and a destination (*D*) as depicted in (Fig. 1) where the function of the relay is simply to amplify the received signal subject to a power constraint and forward to the destination. All users are equipped with single-antenna. To prevent the multi-access interference among active users, an orthogonal channel(e.g., a different time slot or a different frequency band or a different spreading code) is also allocated to each mobile unit in the network. Therefore, the destination receives two versions of the original signal, one from the source and the other with a certain processing delay from the relay. Based on these two data sequences, the ML detection is performed and as we will see later, this detector is very simple without the knowledge of channel state.



(Fig 1) Cooperative communication network model

For simplicity of exposition, we use complex baseband-equivalent models to express all the signals. So, at the destination the received signals at the time n after being filtered with a square-root Nyquist filter and sampled at the symbol rate can be written as

$$y_{SD}[n] = \alpha_{SD} w x[n] + n_{SD}[n] \qquad (1)$$

$$y_{RD}[n] = \alpha_{RD} z y_{SR}[n] + n_{RD}[n] \qquad (2)$$

where

- $y_{SR}[n] = \alpha_{SR} w x[n-d] + n_{SR}[n-d]$
- y_{ij} (i=S, R; j=R, D): received signal at node i when the transmitted signal is from node j.
- $x[n]$: modulated symbol generated from *S*.
- $n_{SD}[n]$, $n_{SR}[n]$, $n_{RD}[n]$: noise samples corrupting the *S-D* channel, *S-R* channel and *R-D* channel. They are modeled as independent zero-mean complex Gaussian r.v.'s (ZMCGRVs) with variances $\sigma^2_{SD}, \sigma^2_{SR}, \sigma^2_{RD}$ correspondingly.
- w, z: amplification factors at the source and relay.
- d: delay time due to the signal processing at the relay.
- α_{SR}, α_{SD}, α_{RD}: path gains of the channels between *S-R*, *S-D* and *R-D*. They reflect the fading level from the transmit antenna to the receive antenna. We assume slow and flat Rayleigh fading, hence, they are modeled as independent samples of ZMCGRVs with variances $\lambda^2_{SR}, \lambda^2_{SD}, \lambda^2_{RD}$, respectively

and constant during the one-symbol transmission of any given node, but change over longer intervals. Because of slow fading, accurate channel estimation is possible at the receiver. Thus, we will assume perfect channel-state information at all the respective receivers.

To take the effect of path loss into account, we use the same model as discussed in [9] where

$$\lambda_{ij}^2 = \left(\frac{d_{SD}}{d_{ij}}\right)^{\beta} \tag{3}$$

Here d_{ij} is the distance between transmitter i and receiver j and β is the path loss exponent. For free-space path loss, we have $\beta=2$ and only this case is considered in the sequel.

At the destination the first signal processing step in detecting $x[n]$ is simply to add $y_{RD}[n]$ and the d-delayed version of $y_{SD}[n]$ to generate the following signal

$$\begin{aligned} y[n-d] &= y_{SD}[n-d] + y_{RD}[n] \\ &= \alpha_{SD} w x[n-d] + n_{SD}[n-d] + \alpha_{RD} z y_{SR}[n] + n_{RD}[n] \\ &= (\alpha_{SD} + \alpha_{SR}\alpha_{RD} z) w x[n-d] + \\ &\qquad \alpha_{RD} z n_{SR}[n-d] + n_{SD}[n-d] + n_{RD}[n] \end{aligned} \tag{4}$$

It is noted that the detection technique given in (4) is different from that in[23] where the maximum ratio combining of $y_{RD}[n]$ and the d-delayed version of $y_{SD}[n]$ is performed. Additionally, it is realized that the proposed detection technique is much simpler than that in[23].

For further simplification, we drop the time indices $n-d$ and n in the sequel. Therefore, $y[n-d]$ can be written as

$$y = Ax + N \tag{5}$$

where

$$A = (\alpha_{SD} + \alpha_{SR}\alpha_{RD} z) w \tag{6}$$

$$N = \alpha_{RD} z n_{SR} + n_{SD} + n_{RD} \tag{7}$$

Since ZMCGRVs n_{SR}, n_{SD} and n_{RD} are mutually independent of each other, conditional on the fading realizations, N is also a ZMCGRV with the variance

$$\sigma^2 = |\alpha_{RD}|^2 |z|^2 \sigma_{SR}^2 + \sigma_{SD}^2 + \sigma_{RD}^2 \tag{8}$$

The ML detection of x given y amounts to minimizing the following metric:

$$|y - Ax|^2 = |A|^2 |x - \bar{x}|^2 + B \tag{9}$$

where the constant term B does not depend on x and where the quantity

$$\bar{x} = \frac{A^* y}{|A|^2} \tag{10}$$

which is also a complex Gaussian r.v.'s with mean x and variance $\sigma^2 / |A|^2$ can be interpreted as the output of an AWGN channel with SNR:

$$SNR = \frac{|A|^2}{\sigma^2} E\left[|x|^2\right] = \frac{|\alpha_{SD} + \alpha_{SR}\alpha_{RD} z|^2 |w|^2}{|\alpha_{RD}|^2 |z|^2 \sigma_{SR}^2 + \sigma_{SD}^2 + \sigma_{RD}^2} E\left[|x|^2\right] \tag{11}$$

The BER performance of the ML detectors depends only on the SNR. Thus, given the channel state at S and R, we can optimize w and z so as to maximize the SNR in $\bar{x}$ (or equivalently, minimize the BER). From Eq. (11), it is found that it is impossible to obtain the maximum SNR with arbitrary value of z even though the power of the relay is infinite. Instead, z must be chosen as a function of the channel realizations during each symbol period. Therefore, we assume that the source power is limited to the fixed amount P_S while the relay can change its power P_R adaptively in accordance with the channel variations. Restricting the source power to a fixed amount can be done by using an automatic gain control (AGC) and the power level variation of the relay is controlled by the destination through the feedback channel. Summarily, the problem of SNR optimization is addressed as

$$\max_{w,z} \quad SNR$$

$$\text{subject to } E\left[|wx|^2\right] = P_S \text{ and } E\left[|z y_{SR}|^2\right] = P_R$$

where P_S and P_R are average powers per symbol of the source and relay; P_R can change correspondingly to the environment condition.

Without the loss of generality, let $E\left[|x|^2\right] = 1$. Then, the constraint conditions can be represented as

$$|w|^2 = P_S \text{ and } |z|^2 = \frac{P_R}{|\alpha_{SR}|^2 P_S + \sigma_{SR}^2}. \tag{12}$$

where the expectation operation is only taken on Gaussian random variable.

Based on Eq. (12), we rewrite Eq. (11) in more compact form

$$SNR=\frac{|\alpha_{SD}|^2\left|1+\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}z\right|^2}{|\alpha_{RD}|^2|z|^2\sigma_{SR}^2+\sigma_{SD}^2+\sigma_{RD}^2}P_S \tag{13}$$

Now *SNR* is a function of one variable *z*. By using the knowledge of geometry, we can find the necessary condition for *SNR* to be maximized is that the vector $(\alpha_{SR}\alpha_{RD}z/\alpha_{SD})$ must have zero-phase, that means

$$z=c\left(\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right)^* \tag{14}$$

With the constraint on magnitude in Eq. (12), the constant *c* is given by

$$c=\sqrt{\frac{P_R}{|\alpha_{SR}|^2P_S+\sigma_{SR}^2}}\Bigg/\left|\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right| \tag{15}$$

Substituting *z* into *A* in Eq. (6), we have

$$A=\left(1+\left|\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right|\sqrt{\frac{P_R}{|\alpha_{SR}|^2P_S+\sigma_{SR}^2}}\right)\alpha_{SD}w \tag{16}$$

To prevent the phase distortion caused by fading, the term $\alpha_{SD}w$ must have zero-phase. Therefore, combining with the condition in Eq. (12), the optimal value of *w* is given by

$$w_{opt}=\frac{\alpha_{SD}^*}{|\alpha_{SD}|}\sqrt{P_S} \tag{17}$$

From Eqs. (13)-(15), we obtain

$$SNR=\frac{|\alpha_{SD}|^2\left|1+\left|\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right|\sqrt{\frac{P_R}{|\alpha_{SR}|^2P_S+\sigma_{SR}^2}}\right|^2}{|\alpha_{RD}|^2\frac{P_R}{|\alpha_{SR}|^2P_S+\sigma_{SR}^2}\sigma_{SR}^2+\sigma_{SD}^2+\sigma_{RD}^2}P_S \tag{18}$$

Let

$$v=\sqrt{\frac{P_R}{|\alpha_{SR}|^2P_S+\sigma_{SR}^2}}\qquad F=\left|\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right|$$
$$G=|\alpha_{RD}|^2\sigma_{SR}^2\qquad H=\sigma_{SD}^2+\sigma_{RD}^2 \tag{19}$$

Rewrite Eq. (18) in the form

$$SNR=\frac{|1+Fv|^2}{Gv^2+H}|\alpha_{SD}|^2P_S$$

To maximize *SNR* with respect to *v*, we take the derivative of *SNR* and set the result to zero

$$\frac{d(SNR)}{dv}=0\qquad\Rightarrow v=\frac{FH}{G}$$

Using Eq. (19), we obtain the optimum transmit power of the relay adaptively to the changes of channel as

$$\begin{aligned}P_R&=\left(\frac{FH}{G}\right)^2\left(|\alpha_{SR}|^2P_S+\sigma_{SR}^2\right)\\&=\left(\left|\frac{\alpha_{SR}}{\alpha_{SD}\alpha_{RD}}\right|\frac{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}{\sigma_{SR}^2}\right)^2\left(|\alpha_{SR}|^2P_S+\sigma_{SR}^2\right)\end{aligned} \tag{20}$$

Then from Eqs. (14)-(18), the optimal values of *z* and *SNR* are found as

$$z_{opt}=\frac{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}{\sigma_{SR}^2|\alpha_{RD}|^2}\left(\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right)^* \tag{21}$$

$$\begin{aligned}SNR_{opt}&=\frac{|\alpha_{SD}|^2\left|1+\left|\frac{\alpha_{SR}\alpha_{RD}}{\alpha_{SD}}\right|\left|\frac{\alpha_{SR}}{\alpha_{SD}\alpha_{RD}}\right|\frac{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}{\sigma_{SR}^2}\right|^2}{|\alpha_{RD}|^2\left(\left|\frac{\alpha_{SR}}{\alpha_{SD}\alpha_{RD}}\right|\frac{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}{\sigma_{SR}^2}\right)^2\sigma_{SR}^2+\sigma_{SD}^2+\sigma_{RD}^2}P_S\\&=\frac{\left(|\alpha_{SD}|^2+|\alpha_{SR}|^2\frac{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}{\sigma_{SR}^2}\right)}{\left(\sigma_{SD}^2+\sigma_{RD}^2\right)}P_S\end{aligned} \tag{22}$$

Eq. (22) shows that the proposed cooperative transmission protocol provides exactly performance as the 2-level receive maximum ratio combining. Moreover, it illustrates that SNR_{opt} or *BER* performance does not depend on the quality of the channel *R-D*. Therefore, in order to improve the performance, the source should adopt a partner such that the inter-user channel (channel *S-R*) is negligibly faded.

Since α_{SD} and α_{SR} are ZMCGRVs, $h=|\alpha_{SD}|^2$ and $g=\left(\sigma_{SD}^2+\sigma_{RD}^2\right)|\alpha_{SR}|^2/\sigma_{SR}^2$ have exponential distributions with mean values λ_{SD}^2 and $\left(\sigma_{SD}^2+\sigma_{RD}^2\right)\lambda_{SR}^2/\sigma_{SR}^2$, correspondingly; that is, $f_h(h)=\lambda_he^{-\lambda_hh}$ and $f_g(g)=\lambda_ge^{-\lambda_gg}$ where $\lambda_h=1/\lambda_{SD}^2$ and $\lambda_g=\sigma_{SR}^2/\lambda_{SR}^2/\left(\sigma_{SD}^2+\sigma_{RD}^2\right)$ and *h*, *g* ≥ 0, are pdf's of r.v.'s *h* and *g*, respectively. As a consequence, the pdf of λ=h+g can be computed by using convolution theorem

$$\begin{aligned} f_{\lambda}(\lambda) &= \int_{-\infty}^{\infty} f_h(x_1) f_g(\lambda - x_1) dx_1 \\ &= \int_0^{\lambda} \lambda_h e^{-\lambda_h x_1} \lambda_g e^{-\lambda_g(\lambda - x_1)} dx_1 \\ &= \frac{\lambda_h \lambda_g}{\lambda_h - \lambda_g} \left[e^{-\lambda_g \lambda} - e^{-\lambda_h \lambda} \right] \end{aligned}$$

with $\lambda \geq 0$.

From Eq. (22), it is straightforward to deduce the pdf of SNR_{opt} as

$$f_{SNRopt}(\gamma) = \frac{a\lambda_h \lambda_g}{\lambda_h - \lambda_g} \left[e^{-a\lambda_g \gamma} - e^{-a\lambda_h \gamma} \right]$$

where

$$a = \frac{\sigma_{SD}^2 + \sigma_{RD}^2}{P_S} \tag{23}$$

Assume that the original signal x is BPSK-modulated, the data bit can be recovered easily by

$$\bar{x} = sign(\mathrm{Re}(y)) \tag{24}$$

where *sign(.)*: a signum function; *Re(.)*: real part of a complex number.

Eqs. (4)-(24) demonstrate that the control of amplification factors at transmit sides makes the detection at the receiver extremely simple. Moreover, the probability of error, conditional on SNR_{opt}, is given by

$$P_e = Q\left(\sqrt{2SNR_{opt}}\right) \tag{25}$$

Here *Q(.)* is the Q-function.

Now, the average BER is found by taking the expectation of P_e over SNR_{opt}; that is,

$$\begin{aligned} P_{e\_avg} &= \int_0^{\infty} Q\left(\sqrt{2\gamma}\right) f_{SNRopt}(\gamma) d\gamma \\ &= \int_0^{\infty} Q\left(\sqrt{2\gamma}\right) \frac{a\lambda_h \lambda_g}{\lambda_h - \lambda_g} \left[e^{-a\lambda_g \gamma} - e^{-a\lambda_h \gamma} \right] d\gamma \\ &= \frac{\lambda_h}{2(\lambda_h - \lambda_g)} \left[1 - \sqrt{\frac{1}{1 + a\lambda_g}} \right] - \frac{\lambda_g}{2(\lambda_h - \lambda_g)} \left[1 - \sqrt{\frac{1}{1 + a\lambda_h}} \right] \end{aligned} \tag{26}$$

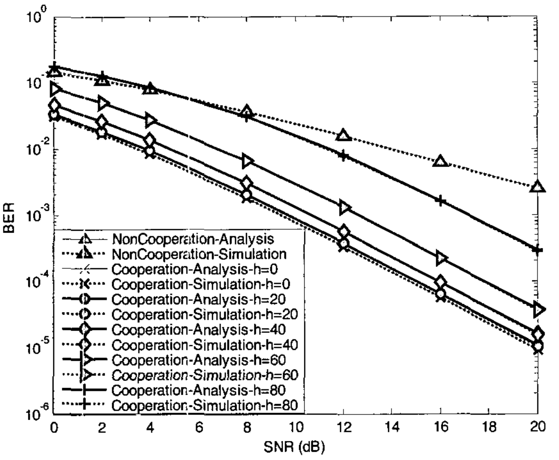
For the case of non-cooperation (without relay), the average *BER* is given by[1]

$$P_{en\_avg} = \frac{1}{2} \left[1 - \sqrt{\frac{P_S \lambda_{SD}^2 / \sigma_{SD}^2}{1 + P_S \lambda_{SD}^2 / \sigma_{SD}^2}} \right] \tag{27}$$

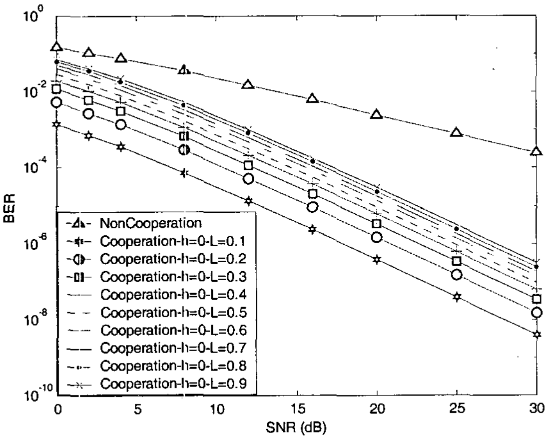
3. Numerical Results

Monte Carlo simulation is performed to verify the accuracy of the closed-form BER expression in Eq. (26). The results are shown in (Fig. 2) where the relay location in the network is depicted in (Fig. 1). The direct path length S-D is normalized to be 1 and the angle between the S-D path and S-R path is denoted as *h*. We also represent the distance between the source and the perpendicular projection of the relay on the S-D line as *L*. In addition, the noise variances at the relay and destination are set to be equal $\sigma_{SD}^2 = \sigma_{SR}^2 = \sigma_{RD}^2 = \sigma_0^2 = 1$. In all relevant figures, the x-axis signifies the global signal-to-noise ratio SNR=P_S/σ_0^2.

(Fig. 2) reveals that the simulation results are consistent with the theoretical ones in Eq. (26). This proves that the analysis is completely exact. Also, (Fig. 2) compares the performance between non-cooperation and the proposed collaboration with respect to different relay positions. We find that the network geometry which is closely related to the path-loss significantly impacts on the quality of the received signal. Scenarios where the relay lies near the direct link S-D($h \leq 60^0$) provide the considerable benefit for the cooperation over the whole SNR range since the cooperation achieves both possible advantages of spatial diversity (diversity order of 2) and propagation loss reduction in comparison to the single transmission. Moreover, because the slope of BER curve of the cooperative scheme is steeper than that of non-cooperation, the BER enhancement keeps dramatically increasing proportionally to the increase in *SNR*. Therefore, the properties of transmit diversity with the CSI priorly known at the transmitter for the physical antenna array also holds for the scenario of the virtual array gained from collection of single antennas of cooperative users. However in other cases where the relay is far away from the source and the destination, the cooperation can be negligibly beneficial or even worse than the direct transmission. As an illustration, the case of(L=0.5 and h=80^0) shows the cooperation's inferiority to



(Fig 2) BER performance of the proposed model with $L=0.5$ and different values of h



(Fig 3) Performance comparison between non-cooperation and proposed model with relays on the direct path

non-cooperation for the low values of SNR.

In general, the relaying cooperation is usually expected to reduce the path loss, corresponding to the situation that the relay is placed closely to the source or the destination, and make use of spatial diversity at most. Therefore, it is better to cooperate with the relay on the direct link S-D. (Fig. 3) investigates the performance degradation of collaborative communications in the signal attenuation due to the path loss when the relay moves apart from the source(L changes). It shows that the closer to the source the relay, the less path loss the transmit signal suffers and the better performance the receiver attains. Moreover, the cooperation always outperforms non-cooperation over the whole range of relay locations on the S-D line. In addition, (Fig. 3) demonstrates that the distance between the relay and the source is a decisive factor for the high performance of the cooperation regardless of R-D link length. For example, the case of $L=d_{SR}=0.1$ achieves a dramatically better performance than that of $d_{SD}=0.1$ ($L=0.9$). On the other words, the symmetry of the relay position on both sides of the S-D line separated by its middle point does not guarantee the same performance. In fact, this result has been foreseen from the analytical expression in Eq. (22) in which a_{SR} (or L) but not a_{RD} is one of the parameters that determines the quality of service of the cooperation.

4. Conclusion

Adaptive collaborative communications protocol to optimize the amplification coefficients at the relay and source with the CSI known in advance at the transmitters to maximize the BER performance was proposed. This protocol is applicable to an arbitrary wireless network with a relay node. Under the Rayleigh fading channel plus Gaussian noise, the numerical results demonstrate that the proposed cooperation considerably improves the performance over the non-cooperation. Moreover, the receiver structure with ML detector can be implemented with negligible hardware complexity. Although the analysis is for the case of one relay node, it is straightforward to extend the results to multiple relays which are expected to further improve the performance because larger diversity gain can be obtained through many independent propagation paths.

References

[1] John G. Proakis, "Digital communications", Fourth Edition, McGraw-Hill, 2001.

[2] V. Tarokh, H. Jafarkhani, A.R. Calderbank, "Space-time block coding for wireless communications: performance results", IEEE Trans on Communications, Vol.17, pp. 451-460, March, 1999.

[3] Aria Nosratinia, Todd E. Hunter, "Cooperative Communication in Wireless Networks", IEEE Communications Magazine, Vol.42, pp.74-80, Oct., 2004.

[4] J. N. Laneman, "Cooperative diversity in wireless networks: Algorithms and architectures," Ph.D. dissertation, MIT, Cambridge, MA, Sep., 2002.

[5] J.N. Laneman, G.W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks", IEEE Trans. Inform. Theory, Vol.49, pp.2415~2525, Oct., 2003.

[6] J.N. Laneman, D.N.C. Tse, G.W. Wornell, "Cooperative diversity in wireless networks: Efficient protocols and outage behavior", IEEE Trans. Inform. Theory, Vol. 50, Issue 12, pp.3062~3080, Dec., 2004.

[7] P.A. Anghel, M. Kaveh, "Exact symbol error probability of a Cooperative network in a Rayleigh-fading environment", IEEE Trans. on Commun., Vol.3, Issue 5, pp. 1416~1421, Sept., 2004.

[8] A. Ribeiro, X. Cai, G.B. Giannakis, "Symbol Error Probabilities for General Cooperative Links", IEEE Trans. Commun., Vol.4, Issue 3, pp.1264-1273, May, 2005.

[9] E. Zimmermann, P. Herhold, G. Fettweis, "The Impact of Cooperation on Diversity-Exploiting Protocols", 59th VTC 2004, Genoa, Italy, May, 2004.

[10] M. S. Pavan Kumar, P. Herhold, R. Bhattacharjee, G. Fettweis, "Cooperative Multi-hop Relaying Over Fading Channels Using a Cascaded 2-hop Technique", IEEE India Annual Conference (INDICON 2004), IIT Kharagpur, India, Dec., 2004.

[11] E. Zimmermann, P. Herhold and G. Fettweis, "On the Performance of Cooperative Relaying in Wireless Networks", European Trans. on Telecommunications, Vol. 16, no. 1, Jan-Feb., 2005.

[12] P. Herhold, E. Zimmermann, G. Fettweis, "A Simple Cooperative Extension to Wireless Relaying", 2004 Int. Zurich Seminar on Communications, Zurich, Switzerland, Feb., 2004.

[13] E. Zimmermann, P. Herhold, G. Fettweis, "A Novel Protocol for Cooperative Diversity in Wireless Networks", European Wireless Conf. 2004, Barcelona, Spain, Feb., 2004.

[14] P. Herhold, E. Zimmermann, G. Fettweis, "On the Performance of Cooperative Amplify-and-Forward Relay Networks", 5th Int. ITG Conf. on Source and Channel Coding(SCC), Erlangen, Germany, Jan., 2004.

[15] E. Zimmermann, P. Herhold, G. Fettweis, "On the Performance of Cooperative Diversity Protocols in Practical Wireless Systems", 58th VTC, Orlando, FL, Oct., 2003.

[16] M. S. Pavan Kumar, R. Bhattacharjee, P. Herhold, G. Fettweis, "Cooperative Multi-hop Relaying Over Fading Channels", Int. Conf. on Signal Processing and Communications (SPCOM 2004), Bangalore, India, Dec., 2004.

[17] H. Ochiai, P. Mitran, V. Tarokh, "Design and analysis of collaborative diversity protocols for wireless sensor networks", VTC2004-Fall, Vol. 7, pp. 4645-4649, 26-29 Sept., 2004.

[18] E.G. Larsson, Yang Cao, "Summary: Not available..... Collaborative transmit diversity with adaptive radio resource and power allocation", Communications Letters, IEEE, Vol.9, Issue 6, pp.511 - 513, June, 2005.

[19] D.J. Love, R.W. Heath, "Necessary and sufficient conditions for full diversity order in correlated Rayleigh fading beamforming and combining systems", IEEE Trans on Wireless Communications, Vol.4, Issue 1, pp.20-23, Jan., 2005.

[20] A. Sendonaris, E. Erkip, B. Aazhang, "User cooperation diversity. Part I-II", IEEE Trans on Communications, Vol. 51, pp.1927-1948, Nov.2003.

[21] R. Pabst, B. Walke, D. Schultz, P. Herhold, H. Yanikomeroglu, S. Mukherjee, H. Visvanathan, M. Lott , W. Zirwas, M. Dohler, H. Aghvami, D. Falconer, G. Fettweis, "Relay-based Deployment Concepts for Wireless and Mobile Broadband Cellular Radio", IEEE Communications Magazine, Sept., 2004.

[22] Athanasios Papoulis, S. Unnikrishna Pillai, "Probability, Random Variables and Stochastic Process", Fourth Edition, McGraw Hill, 2002.

[23] J. Boyer, D.D. Falconer, H. Yanikomeroglu, "Multihop diversity in wireless relaying channels", IEEE Transactions on Communications, Vol. 52, Issue 10, pp.1820-1830, Oct., 2004.

Ho Van Khuong

email : khuongho21@yahoo.com
2001년 베트남 HoChiMinh City
University of Technology
전기전자공학과(학사)
2003년 베트남 HoChiMinh City
University of Technology
전기전자공학과(석사)
2004년~현재 울산대학교 전기 전자정보시스템공학과 박사과정
관심분야 : OFDM, MC-CDMA, 협력 통신, 채널 추정

공 형 윤

email : hkong@mail.ulsan.ac.kr
1989년 미국 New York Institute of Technology 전자공학과(학사)
1991년 미국 Polytechnic Unive-rsity 전자공학과(석사)
1996년 미국 Polytechnic Unive-rsity 전자공학과(박사)
1996년~1996년 LG전자 PCS 팀장
1996년~1998년 LG전자 회장실 전략사업단
1998년~현재 울산대학교 전기전자정보시스템공학부 부교수
관심분야 : 코딩(LDPC, Turbo) 및 모듈레이션 (OFDM, QAM), 멀티코드, Wireless Sensor Network 등

정 휘 재

email : hwijae78@mail.ulsan.ac.kr
2005년 울산대학교 전기전자정보시스템공학부(학사)
2005년~현재 울산대학교 전기전자정보시스템공학과 석사 과정
관심분야 : Turbo Code, QAM, CDMA, 협력 통신