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# 메인과 다이버시티 신호사이 위상차를 이용한 공간 다이버시티 결합방법

## Space Diversity Combining Scheme Using Phase Difference between Main and Diversity Signals

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## 요 약

모바일 데이터의 급속한 성장으로 인해 대용량의 백홀 구축 요구가 대두되었으며, 비용 효율 관점에서 쉽게 적은 비용을 가지고 백홀을 신속하게 구축할 수 있는 기술은 점대점 마이크로웨이브이다. 점대점 마이크로웨이브 링크에서의 공간 다이버시티 방법은, 두 개의 수신 안테나에서 오는 신호를 결합시킴으로 페이딩효과를 상쇄시켜 성능을 향상시키는 것이다. 기존의 신호 결합방법으로는 최대 전력 방법과 최소 왜곡 방법이 제안되었다. 하지만, 선택적 페이딩 채널에서 두 기법 모두가 알고리즘의 강건성 관점에서 성능저하가 보고되었다. 그래서, 본 논문에서 현실적 관점에서 효율적이며 더 성능이 향상된 신호결합 기법을 제안하고, 시뮬레이션을 통해 제안된 방법이 신호의 스펙트럼 관점에서 상당한 성능의 향상이 있음을 보인다.

핵심어 : 공간 다이버시티 결합, 점대점 마이크로 웨이브 링크, 무선 백홀, 선택적 페이딩, 신호 스펙트럼

## ABSTRACT

The deployment of high capacity backhaul is required due to explosive growth in mobile data services. For rapid backhaul deployment, point to point microwave is a much easier and cheaper technology. The space diversity scheme is used in point to point microwave links. The purpose of space diversity is to overcome fading by combining signals from two separate receiver antennas. For signal combining algorithm, maximum power and minimum distortion methods were used and these algorithms were reported not to be good enough for robustness in selective fading. In this paper, a more practically efficient signal combining scheme from the main and diversity branch is proposed and evaluated in selective fading channel. The proposed algorithm has shown significant performance improvement in terms of signal spectrum.

**Key words :** Space Diversity Combining, Point to Point Microwave Links, Wireless Backhaul, Selective Fading, Signal Spectrum

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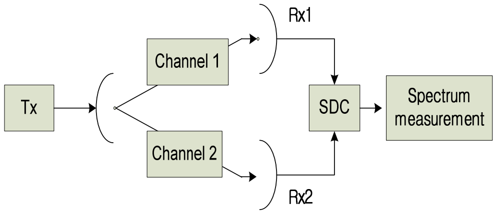
# Ⅰ. Introduction

Today's mobile services are rapidly increasing as a result of a growing demand for new applications [1]. These mobile data services require a deployment of high capacity backhaul [2]. The point to point microwave radio (MWR) can be used for the backhaul solution, because it is designed to provide a highly flexible and cost-effective technology [3-4]. The MWR links have different diversity techniques such as frequency diversity, space diversity, angle diversity, and a combination of these diversities. Frequency diversity and space diversity are the most common forms of diversity in MWR links [5]. Frequency diversity uses two different frequencies for the same MWR link. However, the disadvantage of frequency diversity is more expensive because of two frequency allocations. On the other hand, space diversity uses two separate receiver antennas. The multipath fading does not occur simultaneously at both receiving antennas. Thus space diversity combining (SDC) scheme is used to combat the fading and improve the reliability of signals by combing the signal from different antennas [6]. For SDC algorithms, maximum power and minimum distortion algorithms have been used [7]. However it is reported that neither maximum power nor minimum distortion algorithms performed well in selective fading channel [8]. Thus, a better solution for SDC is needed. In this paper a combining algorithm which incorporates the properties of a maximum power and a minimum distortion criterion is proposed. The organization of this paper is described as follows. Section 2 presents the system model for the SDC analysis and section 3 proposes algorithm for SDC. Section 4 provides the simulation results. Finally, concluding remarks are given in Section 5.

# Ⅱ. System model for SDC analysis

Fig. 1 presents the system model for the SDC analysis. A signal is transmitted via a Tx single antenna and is received via two antennas. Each antenna has an independent fading because the receiver antenna separation between the main branch (Rx1) and diversity branch (Rx2) is more than 100 wavelengths in practical implementation [9]. The received signal from each antenna is combined to mitigate the fading effects.



〈그림 1〉 SDC 분석을 위한 시스템 모델
〈Fig. 1〉 System model for the SDC analysis

## 1. Channel model

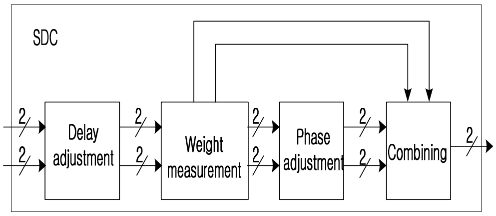
Rummler has developed a multipath fading model for terrestrial communication links between fixed antenna towers [10]. The Rummler channel model is effectively a two-path model for terrestrial microwave links. The transfer function H(f) of Rummler channel model can be written as follows [11].

$$H(f) = a\left[1 - be^{(-j2\pi(f-f_N)\tau)}\right] \tag{1}$$

where f: the frequency,
$f_N$: the notch frequency,
a: the parameter associated with the attenuation of the direct signal path,
b: the parameter associated with the attenuation of the reflected signal path,
τ: the time delay associated with the interpath time delay difference of the two paths (direct and reflected) in the model.

The transfer function is called as minimum phase when a > b and non-minimum phase when a ≤ b.

## 2. Functional block



〈그림 2〉 SDC 기능 블럭도
〈Fig. 2〉 SDC functional block diagram

Fig. 2 presents the SDC functional block diagram. The SDC has two inputs that are received by the main and diversity branch to generate a combined output signal from the two antennas. The SDC is composed of delay adjustment, weight adjustment, phase adjustment, and combining function as shown in Fig. 2. In this figure, the number '2' represents the complex signal, which consists of both real and imaginary signal. The signal received from main and diversity antenna is assumed to be aligned perfectly by the delay adjustment function while the weight adjustment is assumed to be performed properly. For phase adjustment, the maximum power and minimum distortion have been used [8] and they are briefly described for the purpose of reader's convenience in this section.

For the maximum power criterion, the phase is updated as follows.

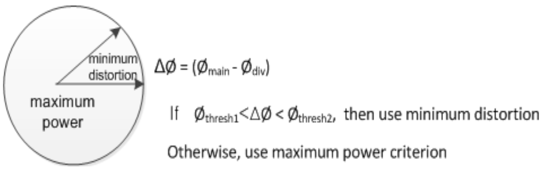
$$\phi[n+1]=\phi[n]+\alpha\times sign\,(Im(cmain\_d[n]\times conj(cdiv\_p[n]))) \tag{2}$$

where ф is an updated phase value, and α is a step size for updated phase. 'Im' means imaginary part of complex number. The cmain_d is the complex main signal and cdiv_p is the complex diversity signal with phase shifter. For the minimum criterion phase adjustment can be expressed as

$$\phi[n+1]=\phi[n]+inv\times\alpha\times sign\,(Re(cmain\_d[n]\times conj(cdiv\_p[n-1])+Re(cdiv\_p[n]\times conj(cmain\_d[n-1])))\times sign(Dist) \tag{3}$$

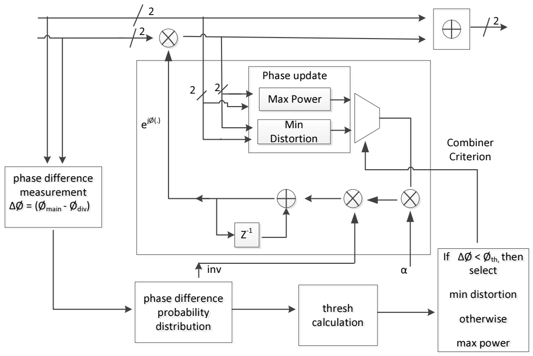
where ф indicates updated phase value, 'inv' means sign inversion (+/-1), and 'Re' represents real part of complex number, Dist = Re(cmain_d[n] × conj(cdiv_p[n-1]).

# Ⅲ. Proposed algorithm for SDC



〈그림 3〉 임계값을 이용한 최대 전력과 최소 왜곡 알고리즘 사용을 결정하는 방법.
〈Fig. 3〉 How to select either maximum power or minimum distortion using thresh value

It is known that neither maximum power nor minimum distortion is a good solution by itself [8]. Thus a better criterion for combining method is needed. In this section, a new algorithm is proposed, which incorporates the properties of maximum power and minimum distortion. Figure 3 presents how proposed algorithm operates to choose maximum power or minimum distortion based on its phase difference, which is calculated between the main channel and diversity signals. If the measured phase difference is between $\varnothing_{thresh1}$ and $\varnothing_{thresh2}$, then minimum distortion criterion is used. Otherwise, maximum power criterion is used. In other words, if phase difference is small and is in the range, then minimum distortion criterion is used. Otherwise, maximum power algorithm is chosen. More detail descriptions are given as follows.



〈그림 4〉 main 과 diversity 수신 안테나에서 신호 위상 차이를 이용한 신호 결합 동작 구성도
〈Fig. 4〉 main and diversity signals combining operation

Figure 4 presents how to calculate and update the phase adjustment based on mixed, i.e., weighted maximum power and minimum distortion criterion.

First, phase difference is measured using each sample of the main and diverse channel complex signal as shown below.

$$\Delta Ø = (Ø_{main} - Ø_{div}) \qquad (4)$$

Second, the probability density function (pdf) of the phase difference samples is calculated. Range of phase differences is defined from －π to +π with resolution of π/8. The length of the probability density vector is equal to 17 values. The phase adjustment direction ‘inv’ can be decided from the pdf as follows. Peak value of pdf is defined along with its index. This index is considered to be the ‘reference’ point for the next calculations. Pdf vector is then divided by two generally non-equal parts. ‘Negative’ part starts from pdf vector index 1, up to peak value index, while the ‘positive’ part starts from the peak value index up to the end index (17-th). All values of ‘negative’ part and ‘positive’ part are summarized. Then the difference between them is calculated. If the difference is negative, i.e, ‘negative’ sum is bigger than ‘positive’ sum, then ‘inv’ is equal to -1. Otherwise, it is positive. In other words, if ‘positive’ sum is bigger than ‘negative’, then ‘inv’ is set as +1.

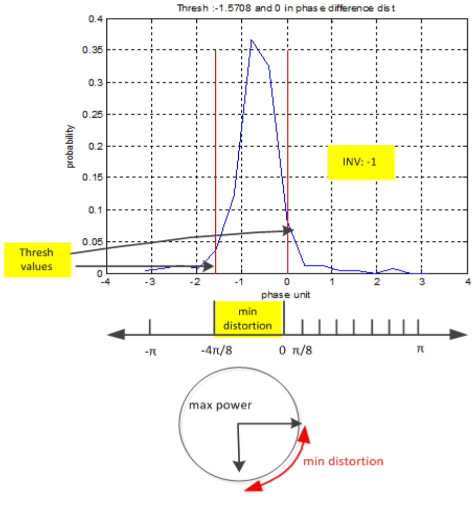
Thresholds values are estimated from phase difference pdf and are decided as follows.

$$P_r[a \le \phi \le b] = \int_a^b f(\theta)d\theta = 0.75 \qquad (5)$$

where a and b represent the negative and positive thresh value for 75% corresponding cumulative density function, where 75% is estimated based on performance simulation. For the thresh value resolution, π/8 unit is used.

Finally, if the phase difference is between thresh values ($Ø_{thresh1} < Ø < Ø_{threh2}$), then minimum distortion criterion should be used. If not, use maximum power criterion.

Fig. 5 shows how to choose maximum power or minimum distortion from two algorithms as an



〈그림 5〉 위상 차이를 이용한 신호 결합의 예시
〈Fig. 5〉 Example for combing operation using phase difference

illustrative purpose. For the thresh value resolution, π/8 unit is used. The thresholds values $\phi_{thresh1}$ and $\phi_{thresh2}$ are -π/2 (-1.5708) and 0 in Fig. 5. When calculated phase difference is between -π/2 (-1.5708) and 0, then minimum distortion is used. Otherwise, select maximum power algorithm.

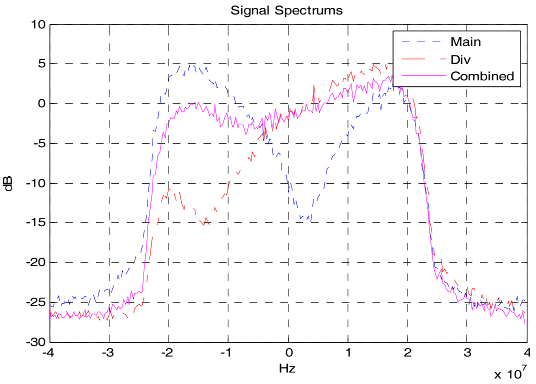
## IV. Simulation results

For the investigation of proposed SDC algorithm robustness, dual path propagation is used for both Rx1 and Rx2 as presented in Fig. 1. Each path is characterized by its gain, phase shift, and delay as shown in equation (1). In these simulations, the gain parameter (a) for direct path is set as 1. The reflected path gain (b) and the notch location ($f_N$) are provided in Table 1, where subscripts M and D stand for main and diversity branch. For diversity receiver sensitivity, performance simulations are evaluated under the minimum phase and non-minimum phase conditions [12-13]. If the reflected path gain (b) is closer to unity, the notch becomes deeper [14].

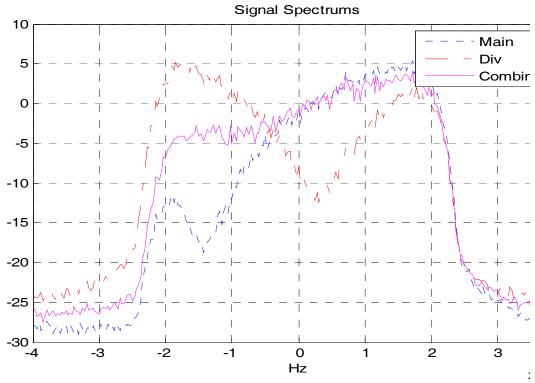
〈표 1〉 시뮬레이션 파라메터
〈Table 1〉 Simulation parameters

| Main Branch | | Diversity Branch | | Fig. Number |
|---|---|---|---|---|
| $b_M$ | $f_N$(M)(MHz) | $b_D$ | $f_N$(D)(MHz) | |
| 1.08 | 3 | 0.9 | -14 | Fig. 6 |
| 1.08 | -14 | 0.9 | 3 | Fig. 7 |
| 0.9 | 3 | 1.08 | -14 | Fig. 8 |
| 0.9 | -14 | 1.08 | 3 | Fig. 9 |
| 1.08 | 7 | 0.9 | 2 | Fig. 10 |
| 1.08 | 7 | 0.9 | 11 | Fig. 11 |

Figure 6 through 11 presents the spectrum of main, diversity, and combined signals. In figure 6-7 and figure 10-11, the main branch has a non-minimum phase while the diversity branch corresponds to the minimum phase. On the other hand, figure 8-9 corresponds to case where main / diversity branch has minimum phase / non-minimum phase. In all figures main / diversity / combined signal spectrum corresponds to the colors blue / red / magenta. In these simulations, different notch locations were swept in order to investigate the algorithm robustness. In figure 6-9, notches are located at 3 and 14MHz while in figure 10-11 notch locations are in 2, 7, and 11MHz. It is observed that the combined signal by space diversity has a much better performance in terms of signal spectrum in figure 6-11. If the combined signal has no distortion at all, it has a flat spectrum. In other words, the less combined signal is distorted, the more flat is the signal spectrum. Some cases are noticed to have a tilted spectrum after combining signal. The residual distortion due to a tilted spectrum can be corrected by equalizer, which will be considered for the further study. One of the main advantages of proposed algorithm is a simple equalizer implementation because of algorithm's robustness, while equalizer complexity is increased for the minimum distortion and maximum power criterions.

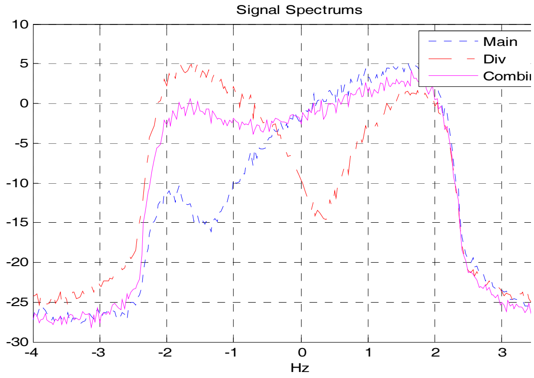


〈그림 6〉 $b_M$=1.08, $f_N$(M)=3MHz, $b_D$=0.9, $f_N$(D)=-14MHz 인 경우 main, diversity, combined 신호의 스펙트럼
〈Fig. 6〉 Spectrum of main, diversity, combined signal in case of $b_M$=1.08, $f_N$(M)=3MHz, $b_D$=0.9, $f_N$(D)=-14MHz



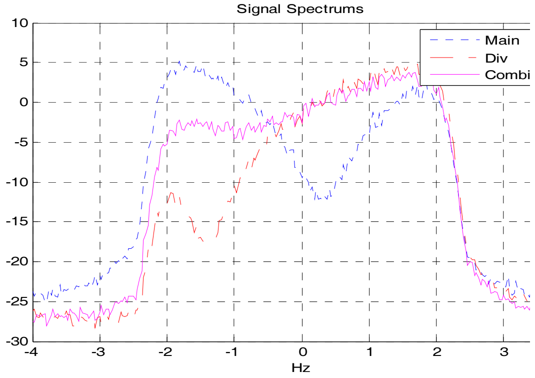
〈그림 7〉 $b_M$=1.08, $f_N(M)$=-14MHz, $b_D$=0.9, $f_N(D)$=3MHz 인 경우 main, diversity, combined 신호의 스펙트럼

〈Fig. 7〉 Spectrum of main, diversity, combined signal in case of $b_M$=1.08, $f_N(M)$=-14MHz, $b_D$=0.9, $f_N(D)$=3MHz



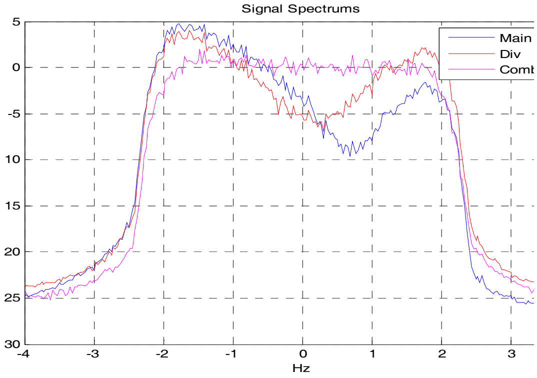
〈그림 9〉 $b_M$=0.9, $f_N(M)$=-14MHz, $b_D$=1.08, $f_N(D)$=3MHz 인 경우 main, diversity, combined 신호의 스펙트럼

〈Fig. 9〉 Spectrum of main, diversity, combined signal in case of $b_M$=0.9, $f_N(M)$=-14MHz, $b_D$=1.08, $f_N(D)$=3MHz



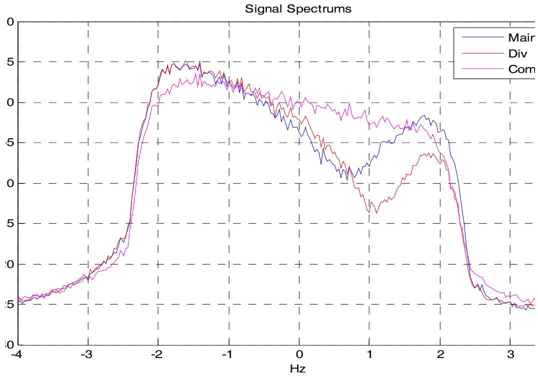
〈그림 8〉 $b_M$=0.9, $f_N(M)$=3MHz, $b_D$=1.08, $f_N(D)$=-14MHz 인 경우 main, diversity, combined 신호의 스펙트럼

〈Fig. 8〉 Spectrum of main, diversity, combined signal in case of $b_M$=0.9, $f_N(M)$=3MHz, $b_D$=1.08, $f_N(D)$=-14MHz



〈그림 10〉 $b_M$=1.08, $f_N(M)$=7MHz, $b_D$=0.9, $f_N(D)$=2MHz 인 경우 main, diversity, combined 신호의 스펙트럼

〈Fig. 10〉 Spectrum of main, diversity, combined signal in case of $b_M$=1.08, $f_N(M)$=7MHz, $b_D$=0.9, $f_N(D)$=2MHz



〈그림 11〉 $b_M$=1.08, $f_N(M)$=7MHz, $b_D$=0.9, $f_N(D)$=11MHz 인 경우 main, diversity, combined 신호의 스펙트럼

〈Fig. 11〉 Spectrum of main, diversity, combined signal in case of $b_M$=1.08, $f_N(M)$=7MHz, $b_D$=0.9, $f_N(D)$=11MHz

## Ⅴ. Conclusion

Space diversity uses two separate receiver antennas to mitigate the fading effects. For SDC, a new proposed algorithm which incorporates the properties of a maximum power and a minimum distortion criterion is presented. This proposed algorithm is based on the phase difference calculation between main and diversity signals. The simulations are performed to observe the algorithm robustness in selective fading channel, when the main and diversity signals have different notch locations. The SDC by proposed algorithm is observed to have performance improvement from the perspective of signal spectrum.

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