On Diversity Combining Techniques in Non-cooperative Communications

Tao Lu   Suli Wu

The 54th Research Institute of CETC, Shijiazhuang Hebei 050081, China E-mail:lutao272@163.com

Abstract

Diversity combining technique is an effective method to combat the multipath fading in wireless channels. However, the traditional diversity combining methods, such as maximal-ratio combining (MRC) and equal-gain combining (EGC) are not suitable for non-cooperative communications. In this paper, selection combining (SC) is introduced into the non-cooperative communication systems, which is very easy to implement. Simulation results validate the effectiveness of this SC method.

1. Introduction

In wireless communication systems, multipath fading caused by troposcatter, ground and water influences the communication between users seriously, which leads to the disruption or distortion of communication and serious errors of digital signals [1-2]. Diversity is an effective and well-known technique to mitigate the effect of multipath fading [3-4]. By skillfully coming two or more copies of the same information bearing signal, different diversity techniques not only can increase the overall signal-to-noise ratio (SNR), but also can reduce the time during which the wireless channel suffers a deep fade.

There are many ways to obtain diversity. Time diversity, frequency diversity and space diversity are well used in modern communication systems, among which space diversity has attracted much interest because of its ability to obtain diversity gain at no additional power or bandwidth expense [3-4]. Since the channel state information (CSI), such as fading amplitude, phase and delay, are often available at the receiver in regular communication systems, maximal-ratio combining (MRC) and equal-gain combining (EGC) are widely used, in which the coherent sum of the individual diversity branch signals is required. However, in non-cooperative communication systems [5-6], most of the CSI are not known by the receiver. Therefore, MRC and EGC cannot be used in such systems to reap diversity gain.

In this paper, selection combining (SC) together with space diversity is introduced into the non-cooperative communication systems to obtain the diversity gain. The basic idea of this scheme is that the receiver selects a particular diversity branch until its SNR falls below a predetermined threshold. Since only one of the branches is selected at any instantaneous instant, the complexity of this scheme is relatively low. Simulation results verify the effectiveness of this combining method for non-cooperative systems.

2. System Models of Different Diversity Combining Methods

In this section, the system models of MRC, EGC and SC methods are carefully analyzed and compared.

2.1 Maximal-ratio Combining (MRC)

The structure of MRC method is shown in Fig. 1.

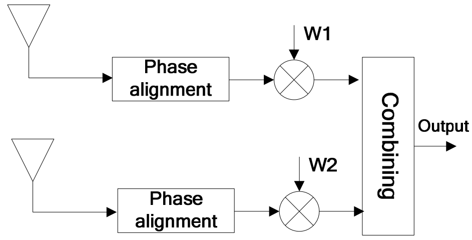

Fig.1 Maximal-Ratio Combining

MRC is the optimum method of diversity combining, since the maximal output SNR can be obtained. However, the implementation complexity of MRC is much higher than that of the other two methods, because all the signals of the diversity branches should be used, and the weighted values of the branches should be adjusted in real time based on the estimated full CSI (fading amplitude, phase and delay), to ensure a maximal SNR of combining output. The maximal output SNR that can be obtained by MRC is the sum of the SNRs of all the branches. MRC can be conducted at

978-1-4673-5225-3/14/$31.00 ©2014 IEEE

intermediate frequency (IF) or baseband, while in the former case, phase correction through a phase locked loop is necessary to realize the phase consistency of the IF signals of all the branches.

2.2 Equal-gain Combining (EGC)

EGC is a widely used combining method in current communication systems, because its ability of anti-fading is close to that of MRC, while its implementation is easier. In this method, the signals of all the branches are combined with an equal gain. It is very similar to MRC except that the weight coefficients are set as one. In some cases, it is not convenient to implement the maximal-ratio combining of the signals of all the branches, so setting all the weight coefficients as one not only simplifies the equipment, but also ensures the possibility of generating an acceptable output signal from a group of unacceptable inputs.

The performance of EGC is not as good as that of MRC, while the fading amplitude is not needed to be estimated by the receiver in EGC, which brings a lower complexity. However, the phase and delay of each branch are still required, which may not be satisfied in non-cooperative communication systems.

2.3 Selection combining (SC)

The implementation complexity of SC is the simplest of the above three combining methods. Fig.2 shows the system model of SC.

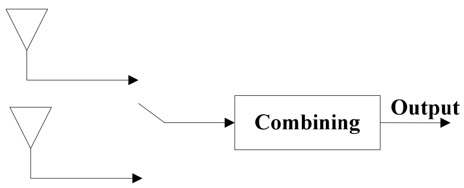

Fig.2 Selective Combining

The SC method compares the SNRs of the signals in two or more branches, and then selects the strongest one to output. This method, in fact, selects only one signal out of several rather than combining them, so the complexity of SC is obviously lower than those of MRC and EGC.

3. Diversity Combining Method for Non-Cooperative Communication Systems

In this section, based on the special characteristics of non-cooperative communications, an SC method for space diversity is introduced to obtain the diversity gain.

3.1 Diversity Method Selection

For non-cooperative signal reception, the diversity method should be designed according to the specific scheme of the object communication system. For example, if frequency diversity is not used in this communication system, then it should not be used in non-cooperative reception, either.

It is shown by practice that space diversity can achieve the best diversity effect. It can resist not only Rayleigh fading effectively, but also the fading caused by the reflection of ground and water surfaces. Moreover, space diversity is not restricted by time or frequency relevance. So, space diversity is chosen for the non-cooperative communication systems, which requires the receiver to equip multiple antennas.

3.2 Signal Combining Point Selection

During the implementation of diversity combining, the selection of signal combining point is critical. At present, two commonly used methods are IF combining and baseband combining. In IF combining, the signals are added up before detection. Because the transmission paths of the signals are different, the times that the signals arrive at the combining point are different, too. So the times must be aligned before combining. In baseband combining, as the frequency is low, there is almost no difference between demodulation output phases, so it is relative simple, and that's why we use baseband combining in our scheme.

3.3 Combining Method Selection

In non-cooperative systems, without the pilot technique, not only the fading amplitude but also the phase and delay of the channels are not available at the receiver. Therefore, both MRC and EGC cannot be used to obtain diversity gain in this situation. From the analysis in Section 2, we know that, after selecting the only one diversity branch in SC method, the operations by the receiver are almost the same with that of the systems without diversity. Moreover, the implementation complexity of SC is very simple. Thus, the SC method is adopted in our scheme.

3.4 Implementation Scheme

The block diagram of a receiver with a second- order space diversity is shown in Fig. 3. Two signals received by the two antennas are demodulated by the diversity receiver, and then the baseband data are obtained. Finally, the SNRs of the two branches of baseband data are compared, and the branch with higher SNR is selected as the demodulation output.

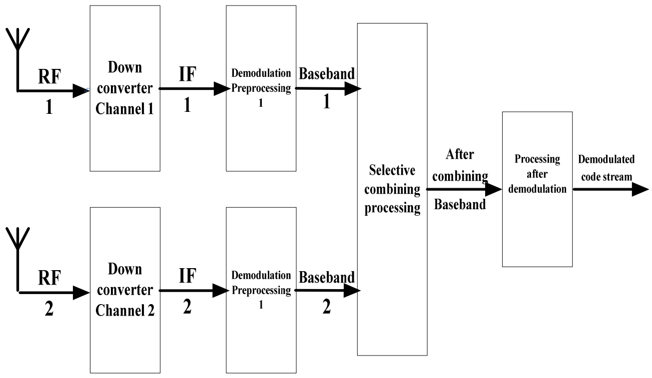

Fig.3 Receiver of Non-cooperative Communication System with SC Method

The statistical results of the second-order diversity combiner are shown in Fig. 4. From top to bottom, the three charts are the statistical results of the signal levels received by Antenna 1, Antenna 2 and the selected one from the two antennas. The abscissa represents the received signal level, and the ordinate represents the probability for the signals to reach this level. After combining the two branches of signals, the probability for the received signal level to be higher than -80dBm is increased by 7% as compared with the results obtained from the first antenna.

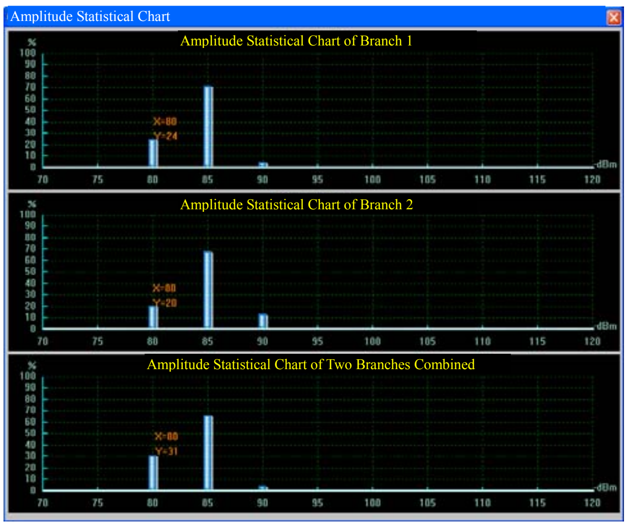

Fig. 4 Statistical Charts of Diversity Combining Effect

The basic implementation processes of the SC method in non-cooperative system are as follows:

a) Select the signal with better quality to output;

b) If the quality of the signal selected for output satisfies the performance requirement, then no other signals would be considered;

c) If the quality of the signal selected for output decreases and could not meet the requirement, a switch should be conducted when another branch of signal is of better quality.

The key for implementing the above processes is the reasonable selection of a threshold for the switch between the two signals. If the threshold is too high, the signal with better quality would be abandoned and the quality of output signal is decreased; whereas if the threshold is too low, the frequent switch between the two branches will also make the system unstable. So, it is necessary to find a switch judgment method and a switch threshold which not only satisfy the system specific requirement but also are easy for engineering implementation.

It is shown in practice that after demodulation but before constellation remapping, the convergence degree of the constellation of baseband data points reflects the SNR of the demodulated data. The higher the degree of convergence, the better the SNR of the demodulated data; whereas the lower, the worse. Therefore, the distance between the baseband data points and the reference points, i.e., the demodulated constellation divergence, can represent the output SNR to a certain degree, which can be used as the criterion for the SC method.

To select a reasonable switch threshold, the relation between the demodulated constellation divergence and BER for different modulation patterns and rates is analyzed and summarized. By analyzing the collected data, it is found that for the same modulation pattern, the difference among the divergences under different rates is little when the BER requirement is met, i.e., the divergence is closely related to the modulation pattern, while it is not much affected by the rate. The demodulated constellation divergences under different modulation patterns with a demodulation BER of $10e^{-5}$ are shown in Table 1. By analyzing the relationship between the measured demodulated constellation divergences and BERs for different modulation patterns, the switch thresholds of the two branches in the SC methods are determined, as shown in Table 2.

Table 1 Demodulated Constellation Divergence for Different Modulation Patterns

Modulation pattern	Demodulated constellation divergence with a demodulation BER of $10e^{-5}$
FSK	250
BPSK	950
QPSK	1300

Table 2 Switch threshold for Different Modulation Patterns

Modulation pattern	Switch threshold
FSK	50
BPSK	70
QPSK	50

Through the above SC method for space diversity, the diversity combining of non-cooperative signals can be implemented, which can increases the output SNR dramatically and obtain the diversity gain. Simulation results show that the correct reception probability of the receiver based on the above combining method is increased by 10%.

4. Conclusion

Diversity combining is a useful technique to increase the overall received SNR at the receiver. The rationale of this technique is to exploit the low probability of concurrence of experiencing deep fades in all the branches to lower the probability of error. Since there is relatively less information can be used in the case of non-cooperative communications, combining is a challenge in the diversity reception of non-cooperative signals. The SC method together with space diversity introduced in this paper is very suitable for the diversity combining of non-cooperative signals since it needs little CSI and is easy to implement. Simulation results verify the effectiveness of this scheme.

5. References

[1] J. G. Proakis, *Digital Communications*, 4th edition. McGraw-Hill, 2001.

[2] A. Goldsmith, *Wireless Communications*. Cambridge University Press, 2005

[3] D. Brennan, “Linear diversity combining techniques”, *Proc.* IRE, vol. 47, pp. 1075-1102, June 1959.

[4] M. K. Simon and M. -S. Alouini, *Digital Communication over Fading Channels*, 2nd edition. John Wiley & Sons, 2005.

[5] E. Waltz, I*nformation Warfare Principles and Operations*, MA: Artech House, 1998.

[6] D. C. Schlecher, *Electronic Warfare in the Information Age*, Artech House, 1999.