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Comparison of the Combining Methods Used In Space Diversity

Ashwaq A. ALjanaby

Electronic and Communications Dept.

Baghdad University/Engineering Collage

ashwaq.aljanaby @yahoo.com

ABSTRACT

The basic concept of diversity; where two or more inputs at the receiver are used to get uncorrelated signals. The aim of this paper is an attempt to compare some possible combinations of diversity reception and MLSE detection techniques. Various diversity combining techniques can be distinguished: **Equal Gain Combining (EGC), Maximal Ratio Combining (MRC), Selection Combining and Selection Switching Combining (SS).**The simulation results shows that the **MRC** give better performance than the other types of combining (about 1 dB compare with **EGC** and 2.5~3 dB compare with **selection and selection switching combining**).

مقارنة لطرق الجمع المستخدمة مع نظام هوائي لمستقبل متنوع

اشواق عباس الجنابي

مدرس مساعد

كلية الهندسة / جامعة بغداد /قسم الالكترونيك والاتصالات

الخلاصة:

مبدأ الهوائي المتنوع هو إدخال إشارتين او اكثر الى المستقبل لتحصيل اشارات غير مرتبطة. الهدف من هذا البحث هو محاولة لمقارنة بعض طرق التجميع للاستقبال المتنوع مع تقنيات الكشف (MLSE) . انواع مختلفة من طرق التجميع ممكن ان تميز منها : الجمع المتساوي الربح، الجمع للنسبة الاعلى، الجمع الاختياري وجمع تحويل الاختيار. نتائج المحاكاة بينت بان طريقة الجمع للنسبة الاعلى تعطي اداءا افضل من باقي الانواع (حوالي 1dB مقارنة مع الجمع المتساوي الربح و 2.5~3 dB مقارنة مع الجمع الاختياري وجمع تحويل الاختيار).

1-INTRODUCTION:

IN a typical mobile radio environment, the communication between the cell site and mobile is established via many paths, very often without the direct one. This is because the direct path is obstructed by buildings and other obstacles. The resultant signal at the receiving antenna is characterized by deep frequency-selective fades with fading rates dependent on vehicle speed. An intersymbol interference resulting from the multipath propagation conditions arises, which for a global system for mobile communication (GSM)-like system, spans a few signaling intervals. In modern time division multiple-access (TDMA) digital mobile radio systems, data signals are transmitted in bursts of length equal to a few hundred bits, which include training sequence. In this case, a maximum-likelihood sequence-estimation (MLSE) receiver is preferred, but when exposed to deep fades (up to 40-dB notch depth), it can fail as well. Space diversity can improve its performance considerably. In this technique, several antennas, which are separated in space, are used in order to process a few versions of the received signal. When the antennas are spaced appropriately, the received signals can be considered as statistically independent. Therefore, there is a good chance that not all of them will fade at the same time.

Most of the papers devoted to diversity reception with equalization of signals transmitted on fading channels deal with linear or decision-feedback equalizers (P. Balaban and J. Salz, 1992 ,N. W. K. Lo, D. D. Falconer, and A. U. H. Sheikh, , 1991). Recently, MLSE diversity reception has been considered for digital mobile radio independently by a few authors (W.-H. Sheen and G. L. St¨uber, 1991, P. Jung, B. Steiner, and Y. Ma, 1994, Q. Liu and Y. Wan, 1992, R. Krenz and K. Wesolowski, 1994). Sheen and St¨uber derived the metrics and analyzed the performance of a receiver using a combined MLSE equalizer/decoder and diversity reception for multipath Rayleigh fading channels.They also derived a new upper bound on the bit error probability for such cases. In Jung and Steiner analyzed similar receivers deriving the metrics for the Viterbi algorithm (VA) realizing the optimum maximum-ratio combining of the diversity branch signals and its suboptimum combining versions such as equal-gain and selection combining. In the optimum case, the normalized metrics on the channel state trellis resulting from different diversity paths are weighted by the energy-per-bit to noise power density ratio characterizing the selected diversity path. In a similar receiver aimed particularly to GSM applications was considered. In [(Jung and Nasshan,1994) presented potential gains resulting from two-antenna diversity and coherent receiver for DCS 1800.In (Jung, 1995) demonstrated that the suboptimum detector applied jointly with diversity in a GSM-like mobile radio system performs similarly to the ML detector. Finally, one has to admit the original work of (Mogensen,1993) in which, due to the GSM system limitations, he proposed application of post detection soft-decision combining in the base station for an uplink and transmitter diversity, resulting in an intentional time spread used in the base station for a downlink. However, relatively less attention has been paid to the comparison of the optimum -diversity receivers employing the ML detector with other much simpler methods of combining the diversity branch signals when the ML detector is used.

2- DIVERSITY TECHNIQUES:

Diversity techniques can be used in wireless communications systems to improve the performance over a fading radio channel. Here receiver is provided with multiple copies of the same information signal which are transmitted over two or more real or virtual communication channels. Thus the basic idea of diversity is repetition or redundancy of information. In virtually all the applications, the diversity decisions are made by the receiver and are unknown to the transmitter (Vaughan, R. G., 1990, Neelam Srivastava, 2010).

Typically, the diversity receiver is used in the base station instead of the mobile station, because the cost of the diversity combiner can be high, especially if multiple receivers are necessary. Also, the power output of the mobile station is limited by the battery. Handset transmitters usually lower power than mobile mounted transmitters to preserve battery life and reduce radiation into the human body. The base station, however, can increase its power output or antenna height to improve the coverage to a mobile station.

There are several different kinds of diversity techniques which are commonly employed in wireless communication systems :(Neelam Srivastava, 2010, Vijay K. Garg, 2007)

2.1 Space diversity

In Space diversity, there are multiple receiving antennas placed at different spatial locations, resulting in different (possibly independent) received signals.

2.2Frequency diversity

The same information signal is transmitted on different carriers, the frequency separation between them being at least the coherence bandwidth.

2.3Time diversity

The information signal is transmitted repeatedly in time at regularly intervals. The separation between the transmit times should be greater than the coherence time. The time interval depends on the fading rate, and increases with the decrease in the rate of fading.

2.4 Polarization diversity

Here, the electric and magnetic fields of the signal carrying the information are modified and many such signals are used to send the same information Thus orthogonal type of polarization is obtained. It enables detection of smaller radar cross-section (RCS) targets, and avoids the physical, mathematical, and engineering challenges of time of- arrival coherent combining.

2.5 Angle diversity

The scattering of signals from transmitter to receiver generates received signals from different directions that are uncorrelated with each other. Thus, two or more directional antennas can be pointed in different directions at the receiving site and provide signals for a combiner. This scheme may be applied at the base station or at the Mobile unit.

2.6 Path diversity

In code division multiple access (CDMA) systems, the use of direct sequence spread spectrum modulation allows the desired signal to be transmitted over a frequency bandwidth much larger than the channel coherence bandwidth. The spread spectrum signal can resolve in multipath signal components provided the path delays are separated by at least one chip period. A Rake receiver can separate the received signal components from different propagation paths by using code correlation and can then combine them constructively.

3- COMBINING METHODS FOR SPACE DIVERSITY:

The idea of diversity is to combine several copies of the transmitted signal, which undergo independent fading, to increase the overall received power. Different types of diversity call for different combining methods. The goal of a combiner is to improve the noise performance of the system. Here, we review several common diversity combining methods :(Mahrotra, A. ,1994,Neelam Srivastava, 2010,Vijay K. Garg, 2007)..

3.1 Selection Combiner

In this case, the diversity combiner selects the branch that instantaneously has the highest SNR (see Figure 1). We assume that the signal received by each diversity branch is statistically independent of the signals in other branches and is Rayleigh distributed with equal mean signal power P_o. The probability density function of the signal envelope, on branch i, is given as

$$P(r_i) = \frac{r_i}{P_o} e^{-r_i^2/(2P_o)} \quad (1)$$

Where $2P_o$ = mean-square signal power per branch : $\langle r_i \rangle$ and r_i^2 = instantaneous power in the ith branch.Assuming that the signal in each branch has the same mean, the probability that the SNR on any branch is less than or equal to any given value ζ_g is

$$P[\zeta_i \le \zeta_g] = \int_0^{\zeta_g} P(\zeta_i)\,d\zeta_i = 1 - e^{-(\zeta_g/\zeta_o)} \qquad (2)$$

Therefore, the probability that the SNRs in all branches are simultaneously less than or equal to ζ_g is given by:

$$P_{M(\zeta_g)} = P[\zeta_1,\zeta_2,\dots,\zeta_M \le \zeta_g] = \left[1 - e^{-(\zeta_g/\zeta_o)}\right]^M \qquad (3)$$

The probability that at least one branch will exceed the given SNR value of ζ_g is given by:

$$P(\text{at least one branch} \ge \zeta_g) = 1 - P_{M(\zeta_g)} \qquad (4)$$

The percentage of time the instantaneous output SNR ζ_M is below or equal to the given value, ζ_g is equal to P ($\zeta_M \le \zeta_g$).

3.2 Switched Combiner

The disadvantage with selection combining is that the combiner must be able to monitor all M branches simultaneously. This requires M independent receivers which are expensive and complicated; an alternative is to use switched combining. In this case only one receiver is needed, and it is only switched between branches when the SNR on the current branch is lower than some predefined threshold value ζ_g(see Figure 2). This is called a switch and stay combiner.

The performance of a switch combiner is less than that in selection combining, since unused branches may have SNRs higher than the current branch if the current SNR exceeds the threshold. The threshold therefore has to be carefully selected in relation to the mean power on each branch, which must also be estimated with sufficient accuracy.

3.3 Maximal Ratio Combiner

In maximal ratio combining, M signals are weighted proportionally to their signal- to-noise ratios and then summed (see Figure 3).

$$r_M = \sum_{i=1}^{M} a_i\, r_{i(t)} \qquad (5)$$

Where; a_i = weight of ith branch, M = number of branches. Since noise in each branch is weighted according to noise power,

$$\overline{n_i^2(t)} = \sum_{j=1}^{M}\sum_{i=1}^{M} a_i a_j\, \overline{n_{i(t)} n_{j(t)}} \qquad (6)$$

$$N_T = \sum_{i=1}^{M} a_i^2\, \overline{n_i^2(t)} = \sum_{i=1}^{M} a_i^2 N_i \qquad (7)$$

Where: N_T = average noise power $\overline{n_i^2(t)} = 2N_i$, the SNR at the Output is given as:

$$\zeta_M = \frac{1}{2}\cdot\frac{\left|\sum_{i=1}^{M} a_i\, r_{i(t)}\right|^2}{\sum_{i=1}^{M} a_i^2 N_i} \qquad (8)$$

We want to maximizeζ_M. This can be done using the Schwartz inequality.

$$\zeta_{Mmax} = \frac{1}{2}\cdot\sum_{i=1}^{M}\frac{r_i^2}{N_i}$$

$$= \sum_{i=1}^{M} \zeta_i \qquad (9)$$

Thus, the SNR at the combined output is

$$\overline{\zeta_{Mmax}} = \sum_{i=1}^{M}\overline{\zeta_i} = \sum_{i=1}^{M}\zeta_o = M\zeta_o \qquad (10)$$

3.4 Equal Gain Combiner

It is a co-phase combining that brings all phases to a common point and combines them. The combined signal is the sum of the instantaneous fading envelopes of the individual branches. **EGC** is similar to **MRC**, but there is no attempt to weight the signal before addition .Thus a_i = 1. The envelope of the output signal is given as:

$$r = \sum_{i=1}^{M} r_i(t) \qquad (11)$$

and mean output SNR is given as:

$$\overline{\zeta_M} = \frac{1}{2} \cdot \frac{\overline{|\sum_{i=1}^{M} r_i|^2}}{\sum_{i=1}^{M} \overline{N_i}} \qquad (12)$$

Assuming that mean noise in each branch is the same (i.e., N); and the resulting SNR is

$$\overline{\zeta_M} = \frac{1}{2NM} \cdot \overline{\left|\sum_{i=1}^{M} r_i\right|^2} = \frac{1}{2NM} \sum_{i,j=1}^{M} \overline{r_i r_j} \qquad (13)$$

4-COMPUTER SIMULATION AND RERSULTS:

Computer simulation test is carried out to compare the four combining methods for space diversity. The channel used in the test is the Rayleigh fading channel with 3 paths and Doppler frequency of 50 Hz.QPSK signal is transmitted through the channel and three branches (M=3) are used in the receiver. The received signals through these branches and the combining signal is obtained using the four combining methods.Figures 4,5,6 and 7 shows the received signals through three branches and the combining signals using EGC, MRC, Selection combining and Selection Switching combining respectively. It can be seen from figures 4 & 5 that the combined signal using EGC method has less fade than the combined signal using MRC.On other hand, the selection method and selection switching method give less performance then the EGC and MRC.

MLSE detection is used in the receiver; Figure (8) shows the performance of the four combining methods with three branches. It can be observed that the selection and the selection switching diversity combiner have the poorest performance and the maximal ratio the best. The performance of the equal gain diversity combiner is slightly lower than that of the maximal ratio combiner.

On other hand, the single branch (M=1) performance is compared with the three branches and it's clear that the performance of the three branches is better than the single braches. Table (1) shows the SNR required to have a BER of 10^{-4}.

5- CONCLUSION:

One can conclude from results that the space diversity enhance the performance of the detector (SNR improvement about 5 dB minimum). The other conclusion is that the use of the detector with maximal ratio combiner gives better performance than the other combining methods, while the detector with selection switching combiner give the worst performance compared with the other method but it still better than the non combined signal (receiver without diversity).

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Table (1) SNR in dB required to achieve probability of error 10^{-4}

Combining Method	Without diversity (M=1)	EGC (M=3)	MRC (M=3)	Selection (M=3)	SS (M=3)
SNR in dB	25	17.5	16.5	19	20

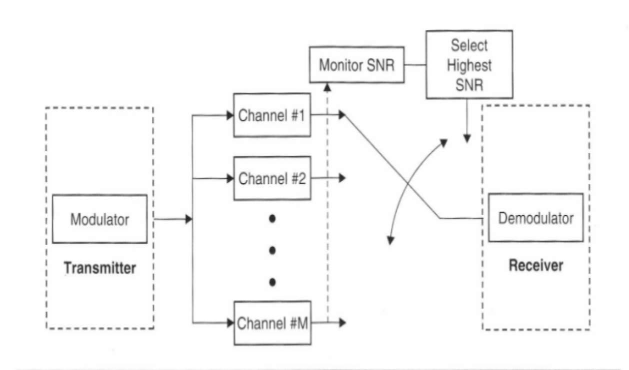

Figure (1) Diversity selection combiner

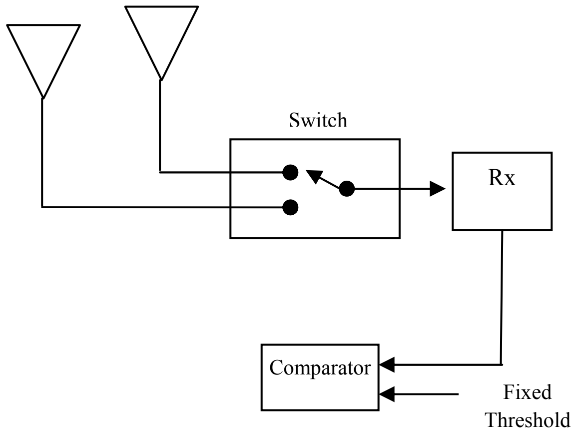

Figure (2) Diversity selection switching combiner

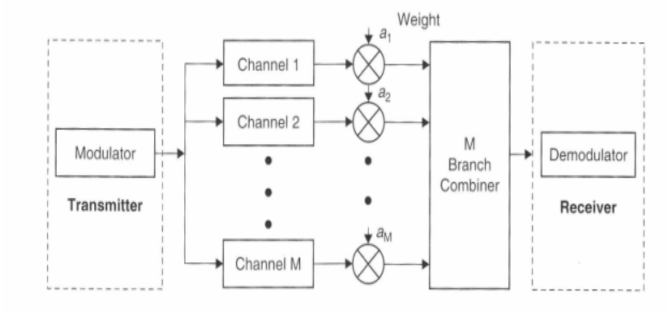

Figure (3) Maximal ratio combining

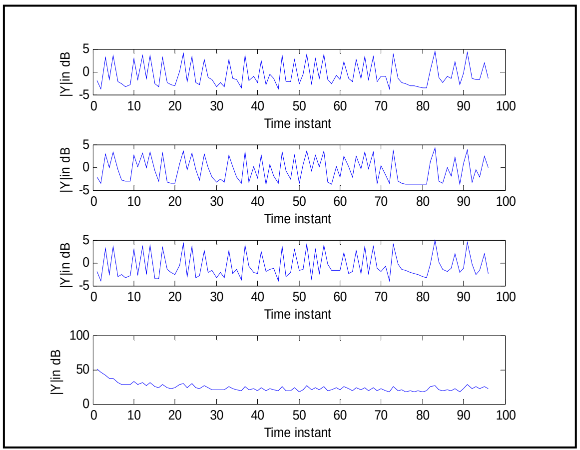

Figure (4) Combining signals with EGC

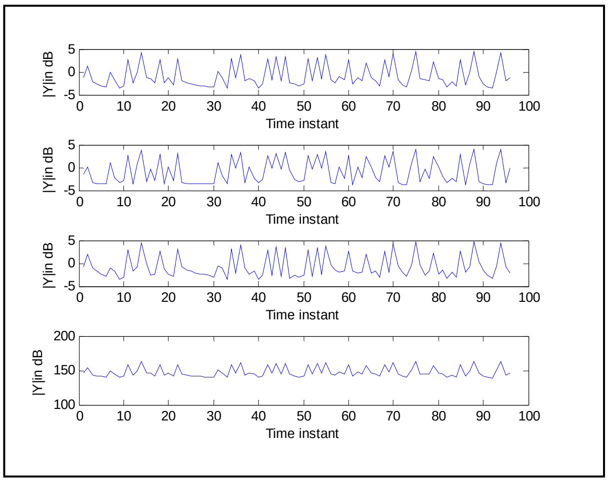

Figure (5) Combining signals with MRC

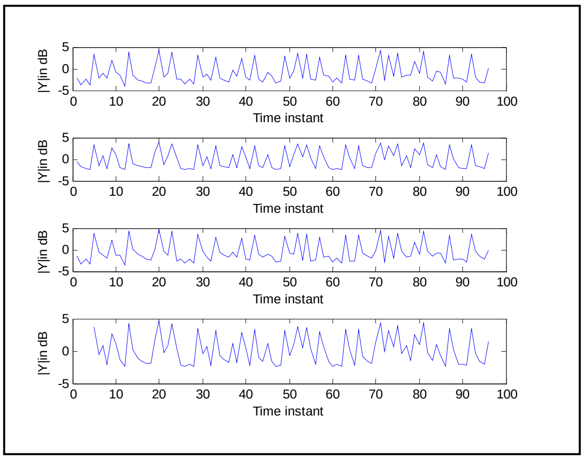

Figure (6) Combining signals with Selection Method

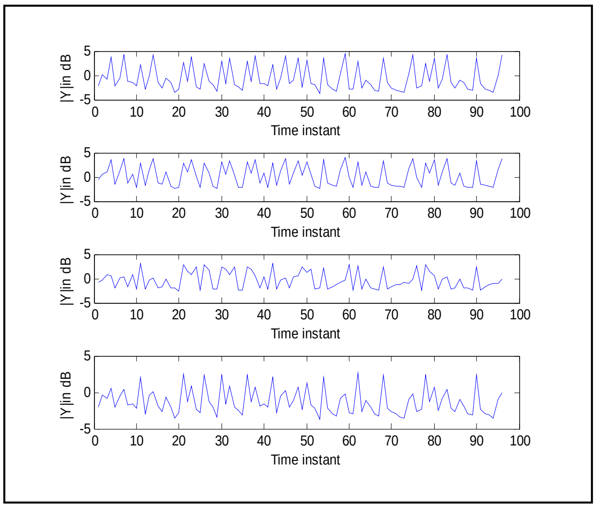

Figure (7) Combining signals with Selection Switching method

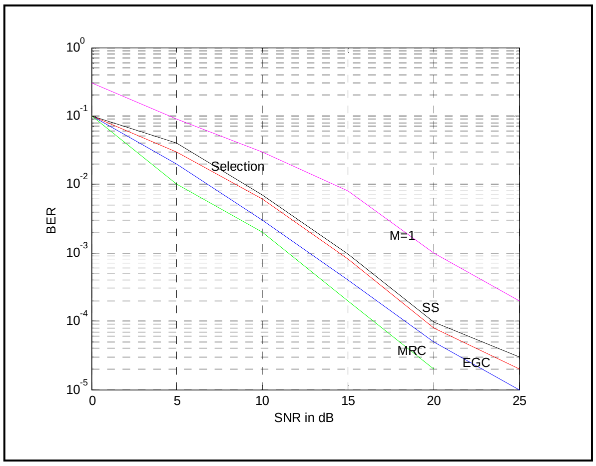

Figure (8) Performance of the four combining schemes with M=3