REED SOLOMON CODED COOPERATION SCHEME IN MOBILE COMMUNICATION NETWORKS AND APPLICATION

by

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To

The spirit of my father, Hussein Almawgani

My mother, Tagwa Bint Ahmed Nosari

My wife, Fadlia Bint Gasem Nosari

My sons, Azzam and Mohammed

My daughter, Shamms

All my brothers and sisters

DECLARATION

I hereby declare that this thesis embodies my own research work and that it was composed by me, at the Department of Electrical and Electronic Engineering at the University Sains Malaysia. Where appropriate, I have made acknowledgement to the work of others.

Abdulkarem Hussein Mohammed Almawgani

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LIST OF ABBREVIATIONS

AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BPSK	Binary Phase-Shift Keying
CDMA	Code-Division-Multiple-Access
CDMA	Code Division Multiplexing Access
CRC	Cyclic Redundancy Check
CWT	Continuous Wavelet Transform
dB	Decibel
DWT	Wavelet Transform
ECC	Error Correction Capability
EEP	Equal Error Protection
EGC	Equal Gain Combining
ELS	Elementary Lifting Steps
Eq.	Equation
FDMA	Frequency Division Multiple Access
IDWT	Inverse Discrete Wavelet Transform
ILWT	Inverse Lifting Wavelet Transform
LDPC	Low density parity check
LWT	Lifting Wavelet Transform
MDS	Maximum Distance Separable
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output

MRC	Maximum-Ratio Combining
MSE	Mean Square Error
OFDM	Orthogonal Frequency Division Multiplexing
pdf	probability density function
PR	Perfect Reconstruction
QoS	Quality of Service
QPSK	Quadrature Phase-Shift Keying
RCPC	Rate Compatible Punctured Convolution Codes
ROI	Region Of Interest
RS	Reed Solomon
RSC	Recursive Systematic Convolutional
SNR	Signal-to-Noise Ratio
TDMA	Time-Division Multiple Access
UEP	Unequal Error Protection

LIST OF SYMBOLS

φ_k	Outage probability at case *k*
γ	The mean value of SNR over the fading channel
Γ	Exponential of pdf with parameter $\frac{1}{\gamma}$
ß	Bandwidth gain
P_{out_1}	Outage probability of User 1
c	Possible cooperative cases
C	Channel capacity
i	Wavelet decomposition levels
k	Cooperation case
K	Original message length
L	Cooperation level
$LH_1, HL_1, HH_1, \ldots,$ LH_i, HL_i, HH_i	high frequencies sub-bands
LL_i	Low frequency sub-band
M	Number of user in cell
M_U	Maximum number of user in cooperation group
N	Codewords length
n	Number of users in cooperation group
N_1	First frames
N_2	Second frame

N_3	Third frame
P	Parity check data
P_1	First part of parity check data
P_2	Second part of parity check data
P-partner	Potential partners
r	Code rate
R	Information rate
R_1	Information rate for second frame R / L
R_2	Information rate for first frame $R / (1-L)$

SKEMA KERJASAMA REED SOLOMON KOD DALAM JARINGAN KOMUNIKASI BERGERAK DAN APLIKASI

ABSTRAK

Teknik komunikasi kerjasama berkod menggunakan antena tunggal mudah alih dalam satu persekitaran multipengguna yang berkongsi antena dan menggabungkan pengekodan saluran untuk mencapai kepelbagaian penghantaran. Tesis ini mengemukakan satu skema kerjasama berkod baru berasaskan kod-kod Reed Solomon (RS). Kod-kod RS sangat berkesan dalam membetulkan kesilapan simbol rawak dan kesilapan letusan rawak melalui saluran pemudaran tanpa wayar. Sistem kerjasama berkod baru itu membahagikan data ke dalam dua kerangka dengan menggunakan topeng operasi aritmetik vektor. Skema baru ini menghasilkan peningkatan ketara gandaan kepelbagaian berbanding skema kerjasama berkod yang terkenal, yang menggunakan kod Perlingkaran Berliang Kadar-Serasi (RCPC). Kajian ini juga menghasilkan ungkapan-ungkapan kebarangkalian keluaran matematik untuk skema kerjasama berkod RS baru ini, untuk membuktikan keupayaannya mencapai gandaan kepelbagaian penuh. Tertib kepelbagaiannya sama dengan dua untuk dua skema kerjasama berkod RS. Analisis kebarangkalian keluaran berasaskan pelbagai antara-pengguna dan keadaan saluran laluan menaik mendedahkan kebaikan-kebaikan skema kerjasama berkod RS dwipengguna berbanding teknik sebelum ini dan skema-skema bukan kerjasama. Skema kerjasama berkod tiga-pengguna ialah peluasan daripada skema dua-pengguna. Tesis ini juga mengemukakan terbitan matematik ungkapan-ungkapan kebarangkalian keluaran untuk skema kerjasama berkod RS tiga-pengguna ini. Ungkapan-ungkapan kebarangkalian keluaran yang diterbitkan itu membuktikan bahawa

kepelbagaian penuh juga dicapai oleh skema kerjasama berkod RS tiga-pengguna ini. Ungkapan-ungkapan kebarangkalian keluaran yang diperoleh dalam kajian ini mendedahkan beberapa ciri prestasi tiga skema kerjasama berkod RS pada pelbagai kadar. Pembandingan berangka BER menunjukkan bahawa skema kerjasama berkod RS tiga-pengguna yang dicadangkan ini menunjukkan prestasi lebih baik berbanding skema dua-pengguna, di bawah pelbagai antara-pengguna dan keadaan saluran laluan menaik. Kajian ini juga membangunkan algoritma gandingan yang menawarkan penyelesaian hampir optimum dalam pemilihan satu pekongsi. Algoritma menawarkan pengurangan masa mencari yang sangat besar berbanding gelintaran habisan. Tesis ini juga mengemukakan satu sistem baru penghantaran imej Perlindungan Ralat Tak Sama (UEP) yang menggabungkan Jelmaan Riak Angkat (LWT), dan skema kerjasama berkod RS digunakan untuk meningkatkan kepelbagaian penghantaran imej, serta mengurangkan lebar jalur penghantaran. Subjalur gelombang rendah ini dibahagikan kepada dua set data dan ia dihantar dengan menggunakan skema kerjasama berkod RS. Data subjalur gelombang tinggi dihantar terus ke stesen pangkal. Keputusan menunjukkan bahawa sistem baru penghantaran imej UEP yang menggunakan skema kerjasama berkod RS berasaskan LWT mencapai gandaan kepelbagaian serta mengurangkan lebar jalur penghantaran berbanding sistem penghantaran imej dengan sistem bukan kerjasama di bawah saluran pemudaran lambat Rayleigh.

REED SOLOMON CODED COOPERATION SCHEME IN MOBILE COMMUNICATION NETWORKS AND APPLICATION

ABSTRACT

Coded cooperative communication technique utilizes single antenna mobiles in a multi-user environment that share their antennas and incorporates channel coding in order to achieve transmit diversity. This thesis presents a new coded cooperation scheme based on Reed Solomon (RS) codes. The RS codes are very effective in correcting random symbol errors and random burst errors over wireless fading channels. The new coded cooperation system splits the data into two frames, using a mask vector arithmetic operation. The new scheme offers significant diversity gain improvement as compared to the renowned coded cooperation scheme that utilizes the Rate-Compatible Punctured Convolutional Code (RCPC). This work also derives the mathematical outage probability expressions for new RS coded cooperation scheme that proves its capacity to achieve full diversity gain. The diversity order is equal to two for two RS coded cooperation scheme. The analytical outage probability under various inter-user and uplink channel conditions shed light on the relative virtues of the two-user RS coded cooperation scheme as compared to previous technique and the non cooperation schemes. The three-user coded cooperation scheme is an extension of the two-user cooperation scheme. This thesis also presents the mathematical derivations of the outage probability expressions for this new three-user RS coded cooperation scheme. The derived outage probability expressions prove that full diversity is also achieved by the three-user RS coded cooperation scheme. The outage probability expressions derived in this work reveal several performance characteristics of the three RS coded cooperation scheme at various rates. Numerical BER comparisons show that the proposed three-user RS coded cooperation scheme performs better than two-user one, under various inter-user and uplink channel conditions. This thesis also develops a coupling algorithm that offers near optimal solution in selecting a partner. The algorithm offers huge reduction in searching time as compared to the exhaustive search. This thesis also proposes a new Unequal Error Protection (UEP) image transmission system that incorporates Lifting Wavelet Transform (LWT) and RS coded cooperation scheme is used to increase image transmission diversity, as well as saving transmission bandwidth. The low frequency sub-bands are partitioned into two sets of data and they are transmitted using the RS coded cooperation scheme. The high frequency sub-bands data are transmitted directly to the base station. Results show that the new UEP image transmission system using LWT based RS coded cooperation scheme achieves diversity gains as well as saving transmission bandwidth as compared to the image transmission system with non cooperative system under slow Rayleigh fading channel.

CHAPTER 1

INTRODUCTION

1.1 Preface

A mobile wireless channel suffers from a multi-path fading, which causes signal attenuation to vary significantly over the course of given transmission period [1]. Multiple input multiple output (MIMO) technique reduces the harmful effects of fading through diversity. In particular, transmit diversity is generated by transmitting different versions of the signal from different locations using multiple antennas. These multiple transmissions significantly improved the received signal quality after they are combined at the base station.

The MIMO technique increases the transmit diversity and also the bit rate for a communication system [2, 3]. However, any wireless device design requires the size and weight to be small and portable. Since the MIMO system requires more than one antenna, the real implementation is less feasible. In order to solve this problem, many researchers have put much of their efforts in the cooperation techniques as a mean to provide transmit diversity as the alternative to the MIMO technique [4].

Many cooperative communication systems proposed by many distinguish researchers [4] consist of two mobile users communicating with a destination. Each user has only one antenna and thus cannot individually generate transmit diversity. The new technique is used to implement virtual MIMO by using single-antenna mobiles in a multi-user environment sharing their antennas to imitate the multiple antenna concepts.

The new cooperative techniques and smart interactions among the network nodes have been proposed in order to enhance the Quality of Service (QoS) in terms of connections and the performance of the whole network.

The cooperation technique is certainly useful in the communication between mobile user and the base stations. In literatures, user cooperation is classified into three major criteria *i.e.* the amplify and forward based cooperative communication method [5], the decode and forward based cooperative communication method [6], and the coded cooperation based cooperative communication method [7].

This thesis presents a new coded cooperation scheme that incorporates the Reed Solomon (RS) channel coding as a mean for user cooperation. In this work, two-user and three-user RS coded cooperation are studied and their performances are analyzed. This thesis also describes in detail the derivation of outage probability analysis for the proposed RS coded cooperation for two-user and three-user. Besides, the performance of the proposed schemes is also evaluated in terms of Bit Error Rate (BER).

1.2 Problem Statement

The most critical parameters affecting the MIMO design are the mutual coupling and correlation due to spacing between the elements and spatial diversity. Analytical studies have shown that for minimal or no mutual coupling, the distance between typical antenna elements needs to be at least half wavelength [8]. Virtual MIMO that uses virtual antenna in the cooperative communication system provides a vital solution for mutual coupling and correlation problem.

In the coded cooperation, the relay will have to decode and re-encode the data. This process need to be done very fast. Therefore, a simple channel coding scheme is required which requires low computational loads. RS codes are the simple forward error correction codes with low decoding computational loads. In addition, the RS codes are robust to the burst errors in wireless channels, thus offer significant advantage to the communication system.

In order to improve the quality of communication, one of the best option is to improve the transmit diversity. The number of cooperation users will increase the diversity order. The increase in diversity order implies the increase in diversity gain. Thus, this provides more stable and efficient communication that can be measured in terms of BER and outage probability.

The usage of redundancy for protection of the transmitted data uses the transmission bandwidth. Since the amount of bandwidth resource is very limited, there is the need to design communication system for data transmission that save the transmission bandwidth and at the same time delivering a good quality of the received data.

As the solution to the above problems, this thesis proposes a new RS coded cooperation communication scheme that integrates cooperative communication with RS codes. Moreover, in order to increase the diversity order, the three-user RS coded cooperation scheme is introduced. Furthermore, Lifting Wavelet Transform (LWT) based RS coded cooperation is introduced to enhance the transmission bandwidth usage. The partner coupling algorithm is introduced to assign the right partner for each user within a certain network cell that has several users.

1.3 Thesis Objectives

The present research focuses on the coded cooperation scheme, which has many advantages for wireless communication systems. The key objectives of this thesis include:

1. To develop an extendable RS coded cooperation scheme.
2. To develop the deriving mathematical expressions of outage probability for evaluating the performance of the proposed schemes.
3. To develop an algorithm that determines the best user to cooperate as partner within a mobile network cell.
4. To develop an image transmission system based on the proposed RS coded cooperation scheme that can significantly save the transmission bandwidth.

1.4 Thesis Contributions

The contributions of this thesis can generally be classified into 4 different parts. These contributions are summarized as follows:

1. Two-user RS coded cooperation scheme
    - A new coded cooperation method is introduced based on the RS codes channel coding. The RS codes are very effective in correcting random burst errors and random symbol errors over wireless fading channels. The channel encoded data fare punctured into two frames using a mask vector that divides the parity check (*P*) into two parts. This technique differs from the rate compatible punctured convolutional (RCPC) method presented elsewhere [7] and performs better.

- The derivation of the outage probability for analyzing the performance of the two-user RS coded cooperation scheme is presented. The performance are then compared with the previous studies.

2. Three-user RS coded cooperation scheme
    - The design of the above two-user RS coded cooperation scheme is extended to three users to increase the transmission quality. The transmission quality increases with the increase in diversity order which is equal to the number of users in the cooperation group. In this work, the diversity order increases from 2 to 3.
    - The derivation of the outage probability for analyzing the performance of the three-user RS coded cooperation scheme is presented. Performance are analyzed and compared with the proposed two-user RS coded cooperation scheme and other well known techniques.

3. Proposes the LWT (Lifting Wavelet Transform) based RS coded cooperation for an image transmission scheme. The data transmission system utilizes the RS coded cooperation scheme developed previously as the main building block. The proposed LWT based RS coded cooperation image transmission system offers significant savings in bandwidth usage as well as delivers good quality of data at the receiver.

4. Develop the partner coupling algorithm in choosing the best partner for cooperation within a multi-users network cell. The proposed algorithm helps to improve the coded cooperation scheme performance.

The outcome of this research will further advance the knowledge towards coded cooperation for user cooperation in mobile networks.

1.5 Scope of Work

This research focuses on the theoretical aspect of the proposed coded cooperation scheme. The proposed new RS coded cooperation scheme is analyzed using the mathematically derived outage probability equations. These equations are analytically used to measure the proposed two-user and three-user RS coded cooperation performance in terms of outage probability. Verification is done whenever the proposed systems are simulated using computer programs. The simulation results of the proposed RS coded cooperation schemes are obtained under slow fading channel. This verifies the correctness of the derived mathematical equations for the outage probability. Also the performance of the proposed data systems is evaluated in terms of BER for various channels Signal to Noise Ratio (SNR).

1.6 Outline of the Thesis

This thesis is organized into six chapters. The remaining chapters of this thesis are organized as follows;

Chapter 2 consists of two main parts; the first part provides background of the study and the second part reviews of previous research works in coded cooperation communication. The first part contains the diversity technique, Maximal Ratio Combining (MRC), cooperation communication, LWT, BER and outage probability and RS codes.

Chapter 3 introduces two-user RS coded cooperation and describes in detail its operation and associated practical details of implementation. Furthermore, mathematical derivation of the outage probability expressions is explained in this chapter. The outage probability expression is confirmed through simulations. Numerical results in terms of BER and outage probability demonstrate the performance of RS coded cooperation under a variety of channel conditions and provide significant performance compared with literature of coded cooperation work.

Chapter 4 discusses the extension of the two-user RS coded cooperation by increasing the diversity order to three-user RS coded cooperation. This extension involved implementing three-user RS coded cooperation and derived the outage probability using a mathematical expression. Furthermore, this chapter highlights the limitation of the possible number of users in proposed RS coded cooperation. The performance evaluation presented numerical BER and outage probability results which demonstrated the better gains of three-user RS coded cooperation over two-user RS coded cooperation scheme.

Chapter 5 presents a discussion on developing a partner coupling algorithm that determines the RS coded cooperation partner in a multi-user environment wireless network. The proposed algorithm was evaluated in terms of outage probability, and a comparison is made to the exhaustive search results and demonstrates the significance in terms of time.

Chapter 6 presents a novel method that incorporates LWT and RS coded cooperation scheme to increase image transmit diversity, as well as saving transmission bandwidth. Results show that the new LWT based RS coded cooperation scheme achieves diversity gains as compared to the non-cooperative system under slow Rayleigh fading channel for all levels of LWT decomposition. In addition, the LWT based RS coded cooperation system with one level wavelet decomposition offers around 37.5% bandwidth gain (ß) as compared to the system without LWT.

Chapter 7 concludes the thesis by summarizing the major findings of the research. It also provides several suggestions to further extend the research in coded cooperation.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

2.1 Background

In this section, the fundamental concept of this thesis work is presented. Then, the concept of diversity technique is presented followed by the concept of cooperation technique. The fundamental concept of RS codes is introduced, where the codes are used to assist the coded cooperation scheme that produces a better scheme compared to other cooperation techniques. This section also covers the details of LWT. Finally, the BER and outage probability measurements in the communication system are explained briefly.

2.1.1 Diversity Techniques

The principle of diversity techniques is that the copies of a transmitted signal are sent through different mediums like different time slots, different frequencies, different polarizations or different antennas for combating the fading effect. If these faded copies are independent, the possibility that all transmitted signals are simultaneously in deep fades is minimized. Therefore, by using appropriate combining methods, the receiver can reliably decode the transmitted signal and the probability of error will be lower.

2.1.1.1 Time Diversity

Time diversity uses different time slots for the diversity transmission. Copies of the transmitted signal are transmitted at different time instants [9]. In the time diversity, the delay for some of the transmitted copies suffers at the receiver before initiating the combination of the received copies of signal and decoding processes.

2.1.1.2 Frequency Diversity

Frequency diversity uses several carrier frequencies to perform the diversity transmission [9]. Some examples of frequency diversity are Orthogonal Frequency Division Multiplexing (OFDM) and spread spectrum i.e. frequency hopping or Direct Sequence-Code Division Multiplexing Access (DS-CDMA).

2.1.1.3 Spatial Diversity

Spatial diversity uses multiple antennas at the transmitter or the receiver to achieve diversity gain for a MIMO system in wireless channels. If the antennas are separated enough more than half of carrier wavelengths and signals from different antennas are affected by independent channel fades.

- Receive diversity uses multiple antennas at the receiver side that is called SIMO system. The signals from different antennas are combined at the receiver to exploit the diversity gain. Receive diversity is characterized by a number of independent fading channels, and its diversity gain is almost equal to the number of receiving antennas.

- Transmit diversity uses multiple antennas at the transmit side that is called the MIMO system. Information is processed at the transmitter and then spread across the multiple antennas for simultaneous transmission. Transmit diversity is first introduced by [10] and it has now become an active research area of space time coding techniques.

2.1.1.4 Cooperative Diversity

In cooperative diversity, several nodes each having one antenna form a kind of combination to cooperatively act as a large transmit or receive array. During cooperation as a transmit array, the terminals first exchange messages which are cooperatively transmitted as a multi-antenna broadcast transmitter; similarly for receive cooperation. The channel therefore shares characteristics such as diversity with the MIMO channel. In a cooperative diversity network, users cooperate to transmit each others' data; to some extent nodes collectively act as an antenna array to create a virtual or distributed MIMO system. Contrary to the MIMO systems, cooperative diversity depends on data transmission by several nodes. Each node acts as a virtual antenna and cooperatively transmits data to a specific destination. Since each node tends to be at different places, cooperative diversity benefits from the ability to find multiple antennas with independent fading. The diversity achieved in coded cooperation system is according to the diversity order that defines the number of users in the network [4, 11].

2.1.2 Cooperative Communication Scheme

Cooperative wireless communication is used with wireless mobile networks or ad-hoc networks to increase their effective quality service. There are many ways to measure the performance of cooperation technique at the physical layer by BER, block error rates or outage probability. In a cooperative communication system, each user transmits own data as well as act as a cooperative partner for another user.

There are several main cooperative signaling methods such as the followings;

2.1.2.1 Amplify and Forward

One of the simplest ways of cooperative communication scheme is amplify and forward [5, 11]. As the name suggests, it is a simple cooperative signaling where each user overhears the noisy version of signal transmitted by its partner and then retransmits after amplification. The sender will transmit its own data to the relay and the base station. The relay node just amplifies and then retransmits this noisy version to the base station. Redundancy is created as two sets of data are sent via two independent paths to create diversity. It is assumed that the path from the cooperating partner to the base station and the path from the source to the base station are statistically independent and at high SNR between the relay and the source and hence full diversity gain can be achieved. When the SNR for both paths are good, the two copies of data are without errors, and hence produces highest diversity. Decision about the transmitted bit is made at the base station from the combined information and for optimal decoding the channel coefficients in the two paths as shown in Fig. 2.1. To avail the channel coefficients at the base station, some feedback line is required for estimating and updating coefficient.

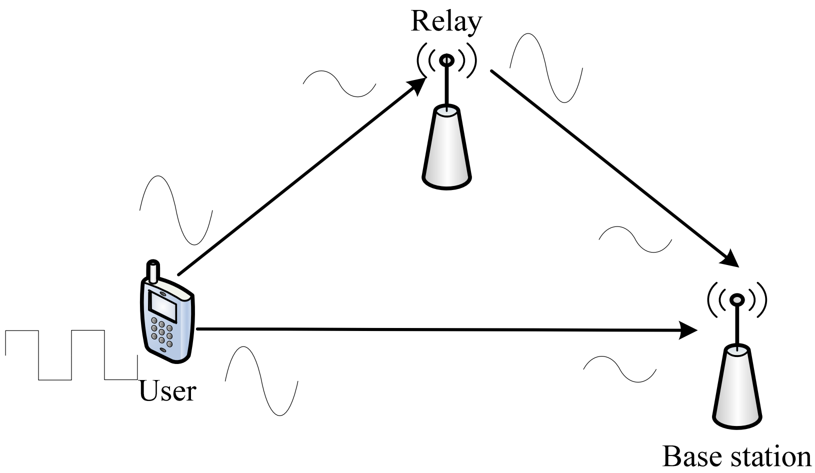

Fig. 2.1 Amplify and forward scheme

2.1.2.2 Decode and Forward

In decode and forward method, the relay detects partner's bits and then retransmits the detected bits. The base station will have the ability to assign any relay node based on the best possible outcome. The main advantage of this method is simplicity and adaptability to channel conditions. However, this method will fail in case of unsuccessful partner detection. Fig. 2.2 shows the decode and forward scheme. An example of decode and forward relaying scheme can be found in [5, 6, 11]. This method is perhaps closest to the idea of an information relay.

In the decode and forward technique, instead of just amplifying the analog received signal, the relay node rely attempts to detect the received signal bits and then retransmits the detected bits to the destination node as shown Fig. 2.2.

By using this decode and forward technique, relay node can eliminate the noise amplification drawback of amplify and forward technique. If the signal at the relay node is decoded perfectly, the total performance at the destination node is improved. However, if the detection at the relay node is not reliable, it will affect the performance of the MRC combination at the destination node (base station). The final performance is limited by the error occurred in the source-relay channel and will be less than amplify and forward technique [6, 12].

The choice between these two relay techniques depends on the quality of source-relay channel. In general, if the relay node is near to the source node, decode and forward technique is selected, and if the relay node is far from the source node, the amplify and forward technique is considered better.

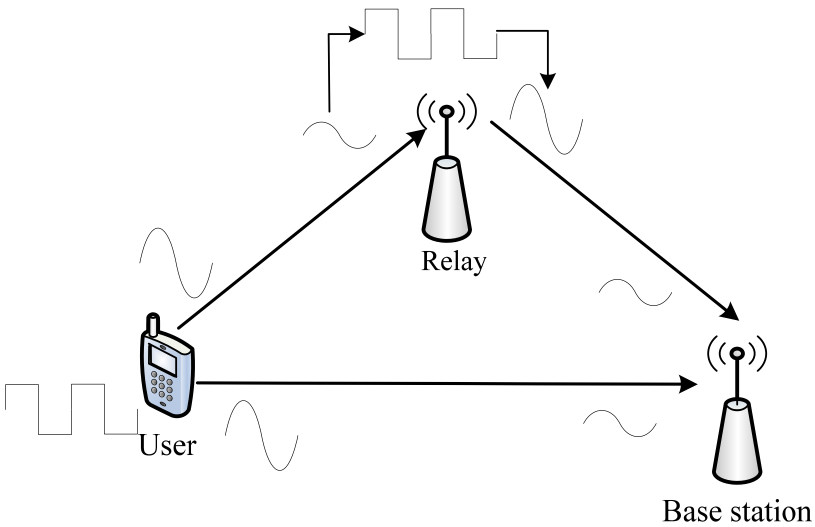

Fig. 2.2 Decode and forward scheme

2.1.2.3 Coded Cooperation

Coded Cooperation is rather an advanced method than the two other methods that were mentioned earlier. In coded cooperation, it will integrate cooperation into channel coding. In coded cooperation, different portions of each user's (partners) code word are sent via an independent fading path similar to the other cooperative schemes. Then each user tries to transmit incremental redundancy to its partner. Whenever that is impossible, the users automatically revert to a non cooperative mode. The key to the efficiency of coded cooperation is that all this is managed automatically through code design, with no feedback between users. Further related reading material on the related research works are available in Section 2.2.1 to Section 2.2.4.

2.1.3 Maximal Ratio Combining (MRC)

The receiver of the cooperative system receives more than one copy of the signal. There are many techniques for combining the copies of receiving signals. In this thesis MRC is chosen among several techniques like equal gain combining and minimum mean square error combining. MRC technique is chosen for the following reasons. First, MRC relies on the knowledge of the complex channel gains [13]. Secondly, MRC acquires the best BER performance among the other combining schemes [14, 15].

For more explanation on MRC, let us consider a system that receives m copies of the transmitted signal S_t through m independent fading paths. It is to be noted that r_k, k = 1, 2, ... m, as the k^{th} path received signal

$$r_k = h_k S_t + n_k \tag{2.1}$$

where s_t is the transmitted signal from the user, h_k are the complex Rayleigh distributed channel fading coefficients of the k_{th} copy of the signal and n_k are uncorrelated and identically distributed samples of a zero-mean additive white Gaussian noise (AWGN) with variance $N_0/2$ per dimension where N_0 denotes the double-sided power spectral density of AWGN.

A maximum likelihood decoder combines the *m* received signals to find the most likely transmitted signal. The receiver needs to find the optimal transmitted signal s_r that minimizes $\sum_{k=1}^{m} \left| r_k - h_k S_t \right|$.

Considering that the receiver knows rightly the channel path gains h_k, the estimated value of transmitted signal can be combined as follows [16];

$$s_k = \sum_{k=1}^{m} r_k h_k^* \tag{2.2}$$

where h^* is the conjugate transpose of channel fading coefficients (h). MRC combines all *m* received signals with weighting factor h_k^*.

Substitute Eq. (2.1) in Eq. (2.2) that give follow Eq.;

$$\begin{aligned} s_k &= \sum_{k=1}^{m} (h_k S_t + n_k) h_k^* \\ &= \sum_{k=1}^{m} \left\| h_k \right\|^2 S_t + \sum_{k=1}^{m} n_k h_k^* \end{aligned} \tag{2.3}$$

For a spatial case in two-user RS coded cooperation, the base station receives two frames that contain two copies of the original message. The base station combines the signals from the two transmission hops using MRC scheme given as follows;

$$
\begin{aligned}
s_r &= \sum_{k=1}^{2} \|h_k\|^2 s_t + \sum_{k=1}^{2} n_k h_k^* \\
&= \left(h_{1,BS}^2 + h_{2,BS}^2\right) s_t + h_{1,BS}^* n_{1,BS} + h_{2,BS}^* n_{2,BS}
\end{aligned} \tag{2.4}
$$

2.1.4 Outage Probability

The spectral efficiency or effective communication in a radio link is often defined as the information rate (*R*) per a given bandwidth (W) ($R = R_s/W$), which results in the unit as b/s/Hz. However, in literature [17] this unit is also used for information rate. Thus, the information (*R*) is defined as the number of bits per second transmitted within a given bandwidth *W*. For example, if a system transmits data (information rate) at a rate 9,600 b/s in a 4,800 Hz-wide system, then information rate is $R = 2$ b/s/Hz [18].

The outage probability, P_{out}, is one of the typical performance criteria of diversity systems operating over fading channels [19, 20]. As a reference, a non-cooperative direct transmission between source and destination with quasi-static fading channel is considered. The capacity of that system is characterized by the instantaneous SNR (γ) and can be expressed using the Shannon formula as $C(\gamma_{u,BS}) = \log_2(1+\gamma_{u,BS})$. The channel is in outage if the conditional capacity falls below a selected threshold rate *R*. In other words, the channel will be in an outage condition whenever the $[C(\gamma_{u,BS}) < R]$ b/s/Hz, or equivalent $[\gamma_{u,BS} < 2^R - 1]$ [21]. In other words, the outage happens in channel if the channel capacity (*C*) falls below the information rate (*R).* The outage probability is found by integrating the probability density function (pdf) of $\gamma_{u,BS}$ over the outage event region [21];

$$P_{out} = Pr[\gamma_{u,BS} < 2^R - 1] = \int_0^{2^R-1} \mathrm{P}_\gamma(\gamma_{u,BS}) d\gamma_{u,BS} \tag{2.5}$$

where $\mathrm{P}_\gamma(\gamma_{u,BS})$ denotes the pdf of random variable Γ. For the case of Rayleigh fading, Γ has an exponential pdf with parameter $\frac{1}{\gamma}$, where γ denotes the mean value of SNR over the fading and accounts for the combination of transmit power and shadowing effects and large-scale path loss [17].

The outage probability for Rayleigh fading can thus be evaluated as in [21];

$$P_{out} = \int_0^{2^R-1} \frac{1}{\overline{\gamma}_{u,BS}} e^{-\frac{\gamma_{u,BS}}{\overline{\gamma}_{u,BS}}} d\gamma_{u,BS} = 1 - e^{\left(-\frac{2^R-1}{\overline{\gamma}_{u,BS}}\right)} \tag{2.6}$$

2.1.5 Reed Solomon (RS) Codes

Reed-Solomon codes are the block-based error correcting codes with a wide range of applications in digital communications and storage. The codes were found by Reed and Solomon in 1960 [22]. The codes are extremely powerful set of non-binary cyclic codes, which are known as the RS codes, for error detection and correction. In 1964, Singleton showed that RS codes have the best possible error-correction capability for any code of the same length and dimension or having the Maximum Distance Separable (MDS) [23]. In this state, the codes achieve “optimal” error correction capability. Through the work of Gorenstein and Zierler [24], it was later discovered that the Reed-Solomon codes can be described as non-binary Bose-Chaudhuri-Hockenghem (BCH) codes. In fact, the RS codes are the extension of the BCH codes, as in the same way the BCH codes are the extension of the Hamming codes [25]. The RS and BCH codes are both designed using the BCH bound [26] applied to the generator polynomial.

This constraint allows these codes to be designed within a specific minimum distance and hence with a certain level of error correcting ability.

The RS codes are $q^m - ary\ (N, K)$ linear cyclic codes of length $q^m - 1$. Hence, according to definition they are non-binary. The RS codes have minimum distance separable (MDS) and the minimum distance is equal to $(N - K + 1)$, where N is the code length and K is the code dimension (the length of the data word). This is the highest minimum distance possible that gives effective error correcting capability.

The sender sends the encoded data blocks, and the number of symbols in each encoded block is $N = 2^m - 1$. The error-correcting ability of the RS code is determined by taking the MDS, or equivalently, by taking as the $N - K$, which serves as the redundancy in the block. If the location of the error symbols are not known in advance, then the RS code is able correct up to $(N - K / 2)$ erroneous symbols. In order words, it can correct errors as half of the redundant symbols added (parity) to the block. For example, suppose the RS code with $m = 3$, $N = 2^3 - 1 = 7$, and $K = 5$. This RS code is used to encode a message with a vector length of 5, where its entries are integers between 0 and 7. A corresponding RS encoded data or codeword is a vector of length 7 whose entries are integers between 0 and 7. Fig. 2.3 illustrates this example with input and output signals with codeword length N of 7, a message length K of 5, and using the default primitive and generator polynomials in the RS code.

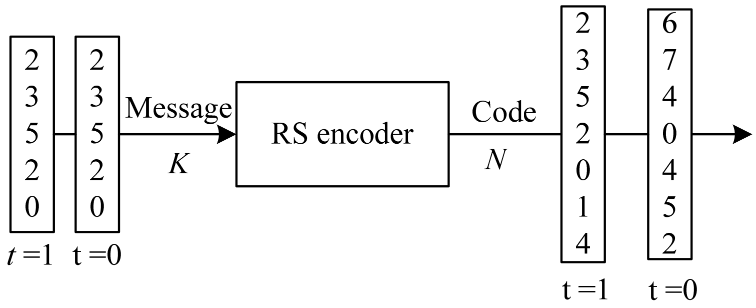

Fig. 2.3 Block diagram of possible input and output for RS code

The RS codes can also be shortened by just taking a subgroup of the codeword where all the words have zero in a certain position and then deleting that co-ordinate. The resulting codes are no longer cyclic but still have the MDS property, i.e. the minimum distance is equal to $(N - K + 1)$. RS codes have good burst error-correcting capabilities and hence are desirable for various applications such as mobile communications, satellite communications and digital data storage systems. Further details on channel coding and RS codes can be found in [25-27]. RS codes as a scheme of block coding, during transmission a block of data is missing or completely erased, as long as enough of the remaining blocks are received, there is still hope to recover the data.

RS codes have been proven to be very effective in correcting burst errors, whereas conventional decoding algorithms often assume that the occurrence of a symbol error is dependent of others, and burst errors are treated as the same as random errors in the decoding procedure [28, 29]. The maximum length of burst errors that can be corrected by RS code is $(N - K)/2$.

RS coding a kind of channel coding techniques good for burst error in the fading channel and suitable for data block transmission. For this reason, RS codes used in this thesis were in the new coded cooperation proposed scheme because the high volume data used could block the data transmission over burst error channel.

2.2 Literature Review on Cooperative Communication

The idea of cooperative relay networks is first introduced in 1971 [30]. In 1979, the ideal of cooperative communication for degraded relay channel is presented in [31]. Some isolated works on cooperation communication are reported in the 80's and 90's, while in the last five years, cooperative communication networks have become an important field with increased number of studies being undertaken in this area.

Future real-time wireless multimedia services require higher data transmission rate as well as improved radio resource management while keeping satisfactory QoS. MIMO antenna technology offers significant multiplexing and diversity gain over single antenna system without increasing the usage of power or bandwidth [16]. However, MIMO system faces practical limitations in mobile network to pack several antennas in small-size portable device. Thus, many researchers have turned their attention on cooperative communication techniques, whereby multiple single-antenna terminals in a network cooperate, hence exploiting the MIMO objective [5, 32, 33].

In wireless networks, signal fading from the multipath propagation impairs the channel and can be mitigated via the use of diversity techniques [20]. Transmit diversity such as MIMO is an attractive technique to be used. Unfortunately, this powerful technique imposes limitation in mobile units due to the device size constraints. Instead of using MIMO technique, the same spatial diversity gain can be achieved through cooperative diversity [5, 34, 35]. In this technique, the base station receives multiple versions of the original message from a single source via one or more partners. Then, it combines these multiple versions data in order to obtain a more reliable estimate of the transmitted message.

Amplify and forward cooperation technique is proposed first as a cooperative signaling scheme [36]. According to the authors, the BER computed for amplify and forward is technique affected due to the noise propagation from the partner. The amplify and forward method results provide significantly better performance than non-cooperative transmission. This technique has been further extended in [5, 11, 37] by deriving the outage probability for quasi-static Rayleigh fading channel. They have demonstrated that amplify and forward signaling achieves diversity order two for two cooperating users.

One of the study in [38] has concentrated on the relay selection in dual-hop amplify and forward systems with perfect information source relay channels and quantized information of relay destination (base station) channel. The author used the BER and outage probability to evaluate the system. Another study [39] focused on the amplify and forward protocol for applications. This work investigated the potential of wireless amplify and forward relaying and introduced three distributed network scenarios that differed in the amount of cooperation between nodes. The amplify and forward cooperative method had been recently studied by several authors from different view of the cooperative system [6, 38, 40, 41].

The first time proposed decode and forward technique for user cooperation in [34] and the details in [35, 42]. This is in fact the pioneer work in the field of cooperative communication. The decode and forward method is the solution to the weakness of amplify and forward, where the amplify and forward technique amplifies both signal and noise.

In the literature [19], the author derive a closed-form analytical solution of outage capacity using fixed decode and forward relaying technique and amplify and forward relaying technique in independent but non identically distributed of Rayleigh fading channels. According to the results, the comparison between the two techniques showed that decode and forward relaying outage capacity outperformed to amplify and forward relaying for a large number of relays.

Another research [43] provides a closed form expression for calculating the BER of the decode and forward relay protocol that used Equal Gain Combining (EGC) at the destination. The results confirmed the theoretical analysis.

Recently, new techniques of coded cooperative diversity communication have been studied, which exploits the benefits of MIMO system and gives superiority diversity over other cooperative techniques [4]. The latest technique is called coded cooperation that has a significant advantage over other techniques. One of such advantages is that the coded cooperation integrates user cooperation with channel coding [44].

There have been only a few studies in coded cooperation area in the recent years. The related coded cooperation works could be classified according to a kind of channel coding integrated with coded cooperation scheme. The coded cooperation method has been published in 2004. It has been proven its significance when compared with other methods. Therefore, this thesis focuses on the work related to coded cooperation.

Specifically the work integrates the RS codes channel coding in the implementation of the RS coded cooperation scheme for the first time.

In this thesis, the RS codes have been chosen to assist the coded cooperation scheme. There are other powerful codes available in literatures such as Turbo codes and Low Density Parity Check (LDPC) codes [45]. These codes involve rather huge amount of decoding computations [46, 47]. Thus, in this work the simple RS codes are chosen since the proposed scheme requires fast encode and decode method at the partner. The RS codes also combat burst errors effectively in fading channels which make them suitable for mobile applications.

In conventional technique of cooperative communication, a cooperating user forwards the received data from its partner via either forwarding or hard detection to destination as presented in [11]. Different methods for cooperation that utilize channel coding scheme have been proposed, and they are generally known as coded cooperation as presented in [4, 20, 48]. In coded cooperation, the codeword of each user is partitioned into two sub-frames. One of the sub-frames is transmitted via the user, and the other via the partner. Hunter and Nosratinia in [5-6] propose a coded cooperation scheme using convolutional codes. In their work, the RCPC are employed to split the encoded message into two codeword parts. Whenever cooperation is not possible, the users automatically revert to the non-cooperative mode.

2.2.1 Coded Cooperation using RCPC Codes

The first publication of coded cooperation method has been reported in [4]. In this work, the cooperation scheme integrate with channel coding, and used RCPC with 1/4 mother code. Coded cooperation works by sending two portions of each user's code