An Implementation of Decode-and-Forward Cooperative Strategy in NS-2 Simulator

Istvan Andras Nador and H. Srikanth Kamath

Abstract—In situations, when energy efficiency is crucial due the limited battery capacity and in noisy environment utilising spacial distribution is proven to be highly beneficial. Cooperative network strategies are based on this assumption.

After introducing the related works in the field this report describes our method of implementing and simulating decode-and-forward cooperative strategy in the presence of additive white Gaussian noise (AWGN) on the transmit channel and also aims to explain the fundamental definitions of signalling theory, that were essential in designing the simulation. It also serves as an introduction to cooperative network strategies, explaining the basic concepts of the field. A mathematical model of decode-and-forward is presented that based on code division multiple access (CDMA) channel access method. The study describes an implementation of a cooperative strategy in NS 2 simulator as a physical layer protocol. The implementation involves fundamental modifications in NS 2 simulator’s base classes.

Keywords—Cooperative Communication, Decode-and-Forward, Signal to Noise Ratio, CDMA, Bit Error Rate, NS 2

I. INTRODUCTION

Cooperative communication is an effective solution for the degrading effects of fading on communication performance. The rapid fluctuation of signal strength is called fading. This spatial phenomenon can occur even at low device velocity due to multi path propagation. The fading may vary with time, geographical position and/or radio frequency and is often modelled as a random process. A communication channel that experiences fading called fading channel. In wireless systems, fading may either be due to multi path propagation, referred to as multi path induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. With the help of cooperative communication network diversity can be increased, what makes possible the use of more effective (combining) techniques at the receiver. The result is a more reliable channel that consumes the same amount of power or we can achieve the same reliability with smaller power consumption.

I. RELATED WORKS

The two-part paper of Andrew Sendonaris, Elza Erkip and Behnaam Aazhang [2] [3] describe methods to gain advantage on spectral diversity and present it in detail from the abstract level of modelling until the implementation issues. The work of Gerhard Kramer, Ivana Mari and Roy D. Yates[8] is a comprehensive summary of all the achievements in cooperative communication.


And finally works [4], [5] and [6] are essential to master NS 2 simulator, one of the most powerful network simulator tool.

II. COOPERATIVE RELAYING STRATEGIES

A. Amplify-and-Forward

In this technique a third node is helping in the communication of two others by after receiving, simply retransmitting exactly the same signal with the only modification in transmit power. This method saves power, but does not benefit any kind of coding, which could improve the security of the channel.

B. Decode-and-Forward

In contrast with amplify-and-forward, when applying decode-and-forward, the relay node performs a complete decoding of the received signal and transmits the re-encoded message. If no decoding error occurred, the relaying node serves as a second source transmitting the same message.

C. Compress-and-forward

The compress-and-forward strategy allows the relay node to compress the received signal before transmitting it to the destination node, where the Wyner-Ziv coding has been known as the optimal compression algorithm.

III. FUNDAMENTALS

Before we present the implementation of this particular cooperation strategy we explain some fundamental definitions:

A. SNR

Signal to noise ratio is a dimensionless ratio of average signal power (at the receiver) to the noise power.

$$SNR = \frac{P_s}{P_n}$$

SNR is often measured in decibels:
\[ SNR_{dB} = 10 \log_{10} \left( \frac{P_s}{P_N} \right) \]

B. White Noise

White noise is a random signal which contains equal power within a fixed bandwidth at any center frequency. \( N_0/2 \) is the spectral height of the white noise and corresponds to the noise power spectrum at all frequencies. White noise power is infinite, so the above defined SNR will be zero, but there is another existing SNR calculation for white noise:

\[ \int s^2(t)dt \]

\[ N_0/2 \]

Where \( s(t) \) corresponds to the signal value at time \( t \).

C. CDMA

Code division multiple access is a channel access method that achieves multiple access of the same channel at the same time by multiple users via orthogonal codes. Each node has its own spreading code (chip code or chipping sequence) that is orthogonal to any other chip code, so the signals of different nodes can be distinguished from each other. The chip codes are sequence of bits. When the hall chipping sequence is transmitted it corresponds to a one bit, if the negate is transmitted of every bits in the chipping sequence it corresponds to a zero bit from the according node. Chip period \( T_c \) is duration required to transmit one bit of the chip code. The use of an N-length spreading code would normally result in an N-time longer transmit time. The original transmit time can be retained by spreading the bandwidth of the data with the same transmitted power. To accomplish this, the bandwidth has to be split to N equal intervals, so the bits of the chip code can be sent simultaneously. Hence N called the CDMA’s spreading gain \( (N_0) \). 

IV. IMPLEMENTING DECODE-AND-FORWARD

The method of decode-and-forward cooperation strategy that we have implemented is based on the method published in [3]. The system framework for this implementation is CDMA, but other systems like TDMA or FDMA may also be suitable. The mathematical model used in [3] includes Rayleigh fading model, but since remarkable performance improvement can be gained even if the channel is not faded (see [1]) the model we used does not imply fading. For the sake of simplicity [3] considers cooperation between only 2 transmitters (users), and one receiver (base station). In this paper we also use that approach. The users can learn phase information from the base station, so they can cancel out these phases respectively, hence a synchronous system can be assumed. The mathematical model can be described with the following equations:

\[ Y_0(t) = X_1(t) + X_2(t) + Z_0(t) \]
\[ Y_1(t) = X_1(t) + Z_1(t) \]
\[ Y_2(t) = X_2(t) + Z_2(t) \]

Where \( Y_0(t), Y_1(t), Y_2(t) \) correspond to the received signals, \( X_1(t), X_2(t) \) to the transmitted signals. \( Z_0(t), Z_1(t), Z_2(t) \) are zero-mean Gaussian noise random processes with spectral height \( N_0/2 \) for \( i = 0,1,2 \).

Figure 1: How Cooperation is Implemented for Conventional CDMA

The transmission period of one bit of data is split into two periods. In the first period both users broadcast their own data bit and listen to the others data bit. Note that this is only possible if both users know the other users’ chipping sequence, what can be a security issue, and coding is necessary in practical applications. In the second period each user transmits a linear combination of its own and the other’s bit, which is considerably easy to accomplish in a CDMA system. The simple addition of the two different chipping sequences coding the data bits composes the signal of the second period. The transmitted signals in the first period expressed by formula:

\[ X_1(t) = a_{11} b_1 c_1(t) \]
\[ X_2(t) = a_{21} b_2 c_2(t) \]

And in the second period:

\[ X_1(t) = a_{12} b_1 c_1(t) + a_{13} \hat{b}_2 c_2(t) \]
\[ X_2(t) = a_{22} b_2 c_2(t) + a_{23} \hat{b}_1 c_1(t) \]

Where \( c_i(t) \) for \( i = 1,2 \) are the users’ spreading code, \( b_i \) for \( i = 1,2 \) are the bits transmitted by the users and \( a \) is the amplitude.

The power allocation can be adjusted via the amplitude, because of \( a^2 = P \). This makes our model adoptable to channel changes. If the inter-user SNR drops, less power can be spent for cooperating (via decreasing the corresponding transmitting amplitudes).

V. SIMULATION OF BIT RECEPTION

In the first period of bit transmission both users can estimate the transmitted bit using the following formula:

\[ \hat{b}_i = sign \left( \frac{1}{N_c} c_i^T Y_{rec} \right) \]

For \( i = 1,2 \).

Where \( Y_{rec} \) is the received signal, \( N_c \) is the CDMA spreading gain, \( n_0 \) is the receiver noise, \( \sigma_0^2 \) is the spectral height of \( Z_{rec}(t) \). Note that the formula above assumes that zero bit is represented by the integer \(-1\) and one bit by the integer \(+1\).
After the base station receives both signals it combines them and makes a decision for the received bit. The signals received from user 1 can be written as

\[ y_{11} = a_{11} b_1 + n_{11} \]
\[ y_{12} = a_{12} b_1 + a_{22} b_1 + n_{12} \]

Where \( \tilde{b}_1 \) is user 2’s estimate of \( b_1 \) using the method that has been given above. \( n_{11} \) and \( n_{12} \) are statistically independent and distributed according to \( \mathcal{N}(0, \sigma^2_i / N_c) \). From \( y_{11} \) and \( y_{12} \) the data bit can be estimated by

\[ \tilde{b}_1 = \text{sign}(\langle a_{11} \lambda (a_{12} + a_{22}) \rangle y) \]

Where \( \lambda \in [0, 1] \) is a measure of the base station’s confidence in the bits estimated by the partner and \( y = \tilde{y}_{11}, y_{12} \sigma_i \sqrt{N_c} / \sigma_c \)

VI. IMPLEMENTATION IN NS 2 SIMULATOR

We have implemented a simulation of the decode-and-forward technique described in this report. Cooperation is a technology of the physical layer, so we have rewritten the phy class of NS 2 simulator and have not made any changes in the mac class. Packages are the atomic units in NS 2, originally it does not simulate the transmission of bits or digital signals. As a result, we had to extend the usage of packages to represent only sole data bits. From this perspective, an error in the channel that alters the transmitted signal is represented with the flip of the corresponding bit of information that is held by an instance of this special kind of package.

The fundamental modification of the NS 2 source code makes necessary to perform other changes as well. In decode-and-forward the users have to resend the data they have received, which involves copying packages. NS 2 reuses the memory it has allocated for packages to gain better performance due the avoidance of repeated new and delete calls. As a result a copy constructor had to be written into the package class to assure, that NS 2 will not write to the memory of the package that was saved in the physical layer.

VII. CONCLUSION

The simulation result on figure 2. shows that decode-and-forward is an effective strategy to decrease BER. The difference is slight –but still evident–, because the simulation did not cover any fading model. The simulation was useful in showing that, without the present of any fading effect, decode-and-forward still stays a powerful technique. A future work is to include fading into the simulation to show the real benefits of this strategy.

Also, this case study was successfully revealed that, with appropriate modifications, NS 2 is capable of simulating physical layer protocols. Future works can exploit these capabilities even more with implementing additional physical protocols and eventually develop built-in support to NS 2 for physical layer protocols.

REFERENCES