Implementation of SISO and filter part in MIMO relays system based on D-OFDM

Xushen Han
School of Electronic, Information and Electrical Engineering
Shanghai Jiao Tong University
Email: hanxushen1105@sina.com

***Abstract*—Improving channel utilization and capacity is well-known issues in the Cognitive Radio (CR) networks. In this paper, we study the implementation of multiple-input multiple-output (MIMO) relay system to offers significant increases in data throughput[1] and we will build a test bed to implement it based on OFDM system. OFDM mechanism can improve the channel utilization. As we want to transmit the data on transmitter and relays at the same time, we distribute all the information in different sub-channels in discontinuous OFDM (D-OFDM) system. We also design a filter at the receiver to gain the data respectively and combine all the data together. Up to now, we have implement a Single-input single-output and filter part in the D-OFDM system with NI-USPR. This test bed can show the improvement of the throughput of the whole system by combining the D-OFDM and MIMO techniques.**

I. Introduction

With the rapid development of wireless communication technology, The frequency spectrum has become a more and more variable resources, for the number of the users increase as time goes by. On the other hand, the demand for the transmission speed also become an important problem. People demand the higher speed for the real-time video transmission. So we must make fully use of the communication resources to meet the needs of the data throughput and achieve high spectrum utilization at the same time.

In a cognitive radio (CR) network, many researchers have considered the above problem. In [2], the author has proposed a methods to allocate resources by utilizing cooperative relay. The author also implement a test bed consisting of USRP and GNURadio. In [3], the author deploy MIMO nodes as relays to assist weak links in wireless networks. He also provided a polynomial-time approximation scheme (PTAS) algorithm to formulate the MIMO relay deployment problem.

In our work, We establish a MIMO relay system to solve the recourse allocation problem based on D-OFDM theory. In the CR networks showed in fig 1, The access point (AP) wants to transmit data to user S1. We assume the transmitter can send 1 package in one time slot, so this method will only take up the channel 1 and the receiver can get 2 packages in 2 time slots.

But if we have other channels can transmit the data, for example in the fig 2, the AP can transmit some data to S2 at time slot 1, and at time slot 2, S2 can transmit the same data to S1, and AP transmit another package to S1, So in 2 time slots, S1 receive totally 3 packages from AP and through S2.

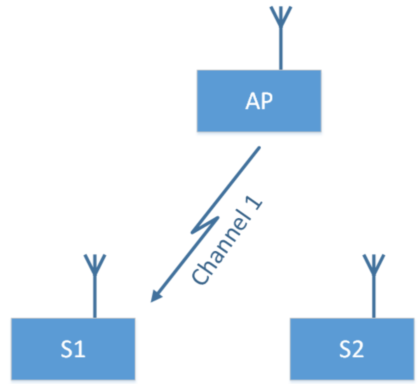


Fig. 1. CP networks without relay

It will use channel 1,2,3 but the package throughput has been improved.

This SISO relay system will make better use of the wasted frequency resources in the channel and have a higher data throughput. The user S2 serve as the relay and transmit an another package to user S1. So in real transmission system, we can treat the idle user as the transmission relay to improve the data throughput in the system. Additionally, If the channel characteristic between the AP and S1 is not so good, while the channel between AP and S2, S1 and S2 are all work smoothly. The secondary user S2 can also serve as the relay and S1 can still communicate with the AP.

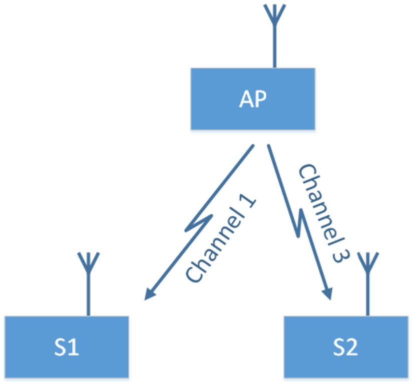
In the following parts we will describe our system firstly. Then we talk about how we build our system and the simulation results. The final part is our conclusion and future work.

II. System description

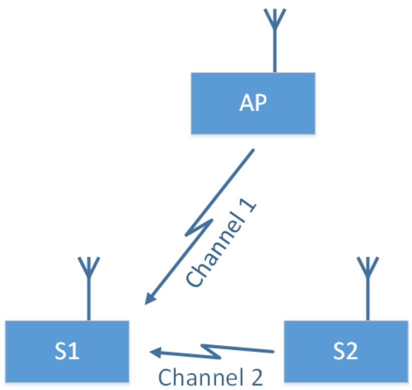
For this part we will firstly discuss a simple case in our system model. Then we will calculate our system's improvement in frequency utilization and data throughput.

A. A Simple case in our system

Think about there are many idle users in the different relay systems, i.e. there are some antennas not be used by any users. For example in fig 3(a), in left relay system S2 is idle while on the right hand S3 is idle. In this situation the whole system will take up 6 channels S1 and S4 can get higher data throughput. But we want to reduce more frequency resources, we combine S2 and S3 as an MIMO AP to sever as a MIMO relay, just

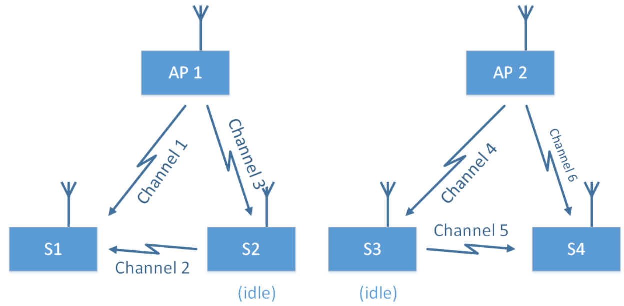


(a) Time Slot 1

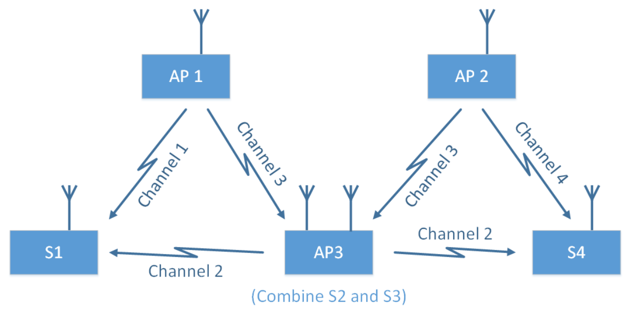


(b) Time Slot 2

Fig. 2. CP networks with relays



(a) Different relay systems



(b) MIMO relay system

Fig. 3. Two Subfigures

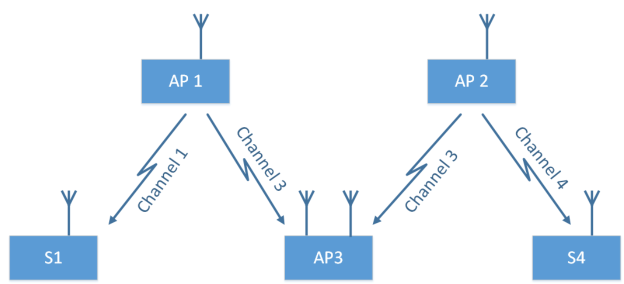
as fig 3(b), we can see that in this network, we only need 4 channels in our system.

In our system, in 2 time slots it will transmit packages than that without MIMO relays. In time slot 1, AP1 send packages to S1 and AP2 send packages to S4 respectively. At the same time, AP1 and AP2 sent packages to AP3 in the same channel, the AP3 distinguish data from two APs with MIMO technology. This step is shown in fig 4(a).

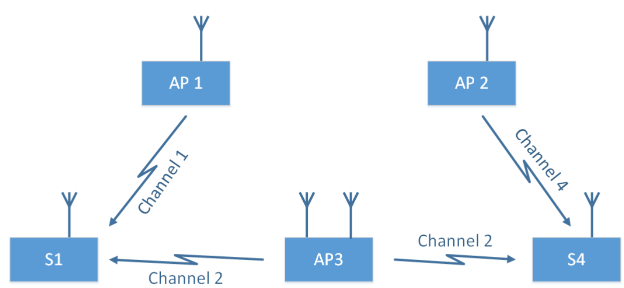
Next step is shown in fig 4(b). In time slot 2, the AP3 send data to S1 and S4 with MIMO technology, At the same time, AP1 and AP2 still transmit data to S1 and S4 respectively. But in users' receivers, they must have ability to tell the data from AP1 and AP2 or MIMO relays. For example, in fig 4(b), AP1 and AP3 transmit data to S1 at the same time. So we design a filter in S1 to fetch the data form APs and MIMO relays, because the data are transmitted in different channels (channel 1 and channel 2). If S1 wants to get data from AP1, the filter must filter out data from AP3, while if the receiver wants the data from AP3, the channel 1 's data must be removed.

So in order to implement our MIMO relay system, we have the following challenges:

- Firstly we must build the SISO system so that the APs can communicate with secondary users. Additionally, preparing for D-OFDM system we should establish the system in different channels.



(a) MIMO relays time slot 1



(b) MIMO relays time slot 2

Fig. 4. Two Subfigures

- Design the digital filter in the receivers so that the receivers can tell the data from APs and MIMO relays.
- Build the MIMO relays in our system. This is our main contribution in previous relay systems.
- Synchronization in receivers. the data from APs and MIMO relays should be synchronized so that the receiver can get all the data from APs.

B. Channel utilization on MIMO D-OFDM

This part is Yument Zhu's work and she must talk about her calculation in her final report for some mathematical proof.

III. System Implementation

Up to now, we have implement the SISO transmission and filter in the receiver part. We will explain our system separately.

A. SISO D-OFDM transmission

To establish the MIMO relay system, a SISO system based on D-OFDM transmission is necessity. Many researchers have been done a lot work on this topic. In [4], the author proposed a transmitter and receiver system for non-continuous OFDM system.

OFDM is a frequency-division multiplexing (FDM) scheme used as a digital multi-carrier modulation method. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions and low symbol rate makes the use of a guard interval between symbols affordable, making it possible to eliminate intersymbol interference (ISI). The orthogonality allows for efficient modulator and demodulator implementation using the FFT algorithm on the receiver side, and inverse FFT on the sender side.

Based on the OFDM system, we establish our SISO D-OFDM system. The fig 5 shows the data flow in transmitters in our D-OFDM system.

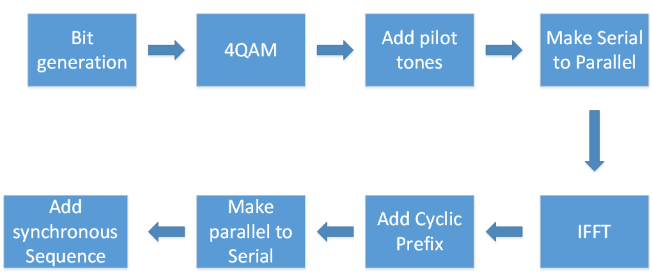


Fig. 5. transmitter data flow

There are some challenges for our system:

- OFDM requires very accurate frequency synchronization between the receiver and the transmitter, So we define a cyclic prefix for every packages.
- For different channels in MIMO D-OFDM system, we must establish sub-channels based on sub-carriers in OFDM system.
- Synchronization in receivers. The data must be specified in each package in receiver

In follow part we will introduce our SISO D-OFDM system in detail.

1) Frequency domain: sub-channel design: In the D-OFDM system, we combine some sub-carriers in frequency domain to establish the sub-channels. We define the 128-points FFT in the transmitter. So we have 128 sub-carriers. According to non-continuous OFDM system implementation of [5], there are 4 channels in our MIMO relay system (see in figure 3(b)), So we should define 4 sub-channels. What's more , we define some non-tones to to separate the sub-channels. These non-tones are some sub-carriers without any data and information. Based on the analysis of the above, we design the following frequency sub-channel shown in table I.

TABLE I
Sub-channel Allocation

sub-carriers No.	categories	band of sub-channels or non-tones
1-5	non-tones	5
6-25	sub-channel 1	20
26-37	non-tones	11
38-57	sub-channel 2	20
58-69	non-tones	11
70-89	sub-channel 3	20
90-102	non-tones	11
103-122	sub-channel 4	20
123-128	non-tones	5

Because of the non-tones between sub-channels, we can use a filter before the receiver to get the data from the APs we wanted and filter out the data no use. So in our MIMO relay system, the channel and spectrum pooling scenario can be seen the fig 6.

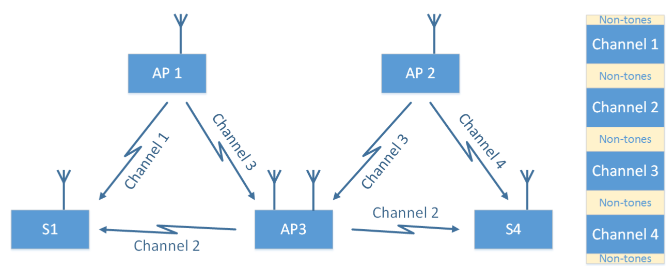


Fig. 6. MIMO relay system Channel Design

2) Time domain: package design: In the time domain, a big problem for the OFDM system is the multipath interference between the symbols because OFDM system request an accurate synchronization in time domain. In order to dismiss the multipath delay and interference, a cyclic prefix (CP) is needed. In [6], the author adopt a CP of 25% of the original symbol duration and get a ideal result. From the OFDM theory we also can see that if the multipath delay is less that 25% length of the symbol, the system can work smoothly and get exact results. If CP is too long, the overhead is large. So our system also adopt CP of 25% of the original symbol.

Except for the multipath problem, There still exist package synchronization problem. So we add synchronise training sequence before the package, to distinguish each package of the data. The training sequence is a Hadamard matrices and we can get the package start using correlation operation.

So our package can be expressed in fig 7.

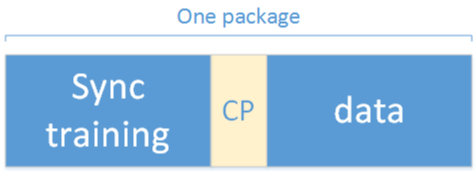


Fig. 7. Package Design

3) Channel estimation: pilot: In the wireless transmission system, the channel characteristics have a significant impact on the signal before the receivers. We assume that the signal after the transmitter is P^R and the signal before the receiver is P^T. Channel characteristic is matrix H, So we have the following cooperation:

$$P^R = P^T * H$$

where $*$ is convolution operation. So if we want to get the channel characteristic matrix H, we can use the following methods:

$$\begin{pmatrix} h_{0,0} & \cdots & h_{0,m} \\ \vdots & \ddots & \vdots \\ h_{n,0} & \cdots & h_{n,m} \end{pmatrix} = \begin{pmatrix} {P^R}_{0,0} & \cdots & {P^R}_{0,m} \\ \vdots & \ddots & \vdots \\ {P^R}_{n,0} & \cdots & {P^R}_{n,m} \end{pmatrix} \begin{pmatrix} {P^T}_{0,0} & \cdots & {P^T}_{0,m} \\ \vdots & \ddots & \vdots \\ {P^T}_{n,0} & \cdots & {P^T}_{n,m} \end{pmatrix}^{-1}$$

So we need ta add some pilot in our frequency tones, These pilot are known both in transmitter but in receiver. The receiver can calculate the channel characteristic with the pilot and recover the data before the channel.

In our system, the location of the pilot in the sub-carriers is shown in 8.

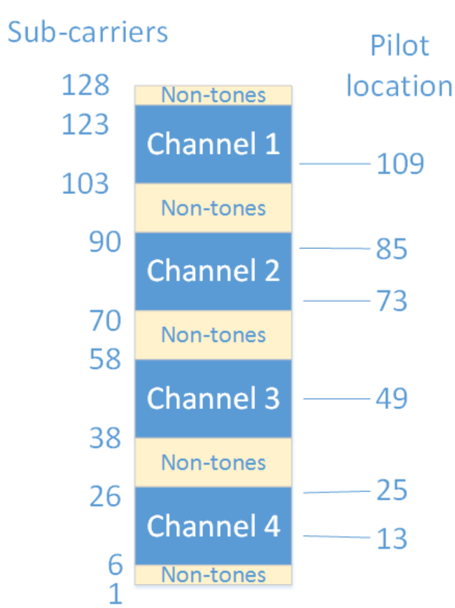


Fig. 8. Pilot Design

These pilot are not be used for data, but it can calculate the channel characteristics of the channel. And we use the difference value of the 6 data to estimate all the value for every frequency points.

B. Filter in receiver

The filter before receiver is used for fetching data from APs or MIMO relays in the different channels. For the data is in different sub-channels in our D-OFDM system, The filter must have a excellent pass band characteristic and filter out the data we don't need. As you can see the passband of each sub-channel is 20 points, So the filter passband must larger than 20 points and stop band must less than 40 points. Because if the stop band length larger than the 40 points, the data in other channels will have an inference on data in receiving channel.

Our filter before the receiver is a digital low-pass filter. As we need a no phase change filter and package length is limited, We design an FIR filter using the Kaiser window.The filter design requirements are in table II

TABLE II
ADD CAPTION

Item	Value
Passband gain	1
Passband cut-off frequency	$> 0.156\pi$
Stopband gain	0
Stopband cut-off frequency	$< 0.313\pi$

We define the passband cut-off frequency is 0.2π and stop band cut-off frequency is 0.25π and we use algorithm 1 to design our filter.

Algorithm 1 Filter Design Algorithm

Input:

The filter passband cut-off frequency, f_p;
The filter passband cut-off frequency, f_s;
The filter passband gain, $mags$;
Package data, S;

Output:

f_p and f_s are available values.

1: Calculate filter amplitude characteristics in frequency domain, $K = kaiserord([f_p, f_s], mags)$;
2: Get the data's frequency amplitude characteristics, $S_f = fft(S)$
3: Calculate output data's frequency amplitude characteristics, $Out_f = S_f \cdot K$
4: Get the output data, $Out = ifft(Out_f)$
5: **return** Out;

When we get the packages after the channel, We get the data we want via the following steps:

- firstly we do a frequency shift to move the data from required channel to low frequency with central frequency 0.
- Then we pass through the filter. At this time unwanted frequency component will be remove with nothing left.

- At last we do a frequency shift again to move the data to the channel frequency.

After this step we can get the information in specific channel and remove other data.

IV. Simulation results

A. Filter simulation

We use labview2013 to design our filter and simulate the results. We define all the data in our 128 points ifft is 1. Before the filter, the amplitude characteristics of data is shown in fig 9

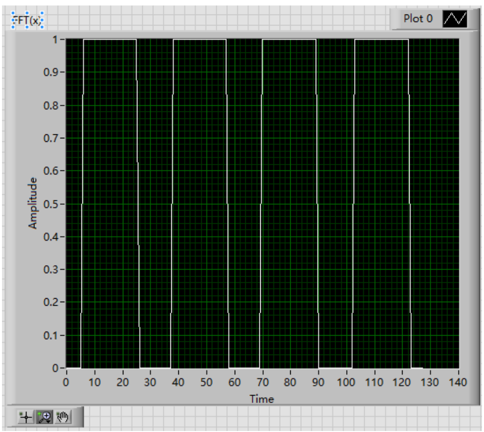


Fig. 9. Pilot Design

You can see that all the data is 1. Now I want to filter the data from point 38-58. So I define the frequency shift is 16 points and we get the result in fig 10

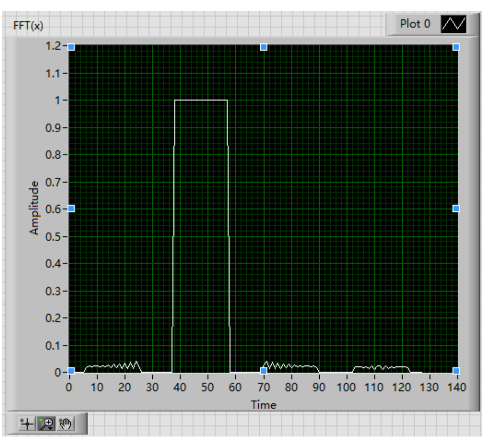


Fig. 10. Pilot Design

You can see the value is left, but other data are all be removed.

B. SISO transmission simulation

We use labview 2013 to establish the SISO D-OFDM system and When we transmit the data, the parameters we defined is shown in fig 11 and the result constellation is shown is shown in fig 12. You can see that the points in constellation can be all made a correct judgement, So our BER based on statistical calculation is 0.

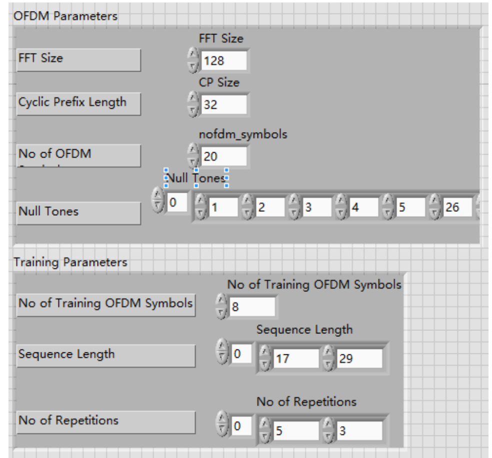


Fig. 11. Pilot Design

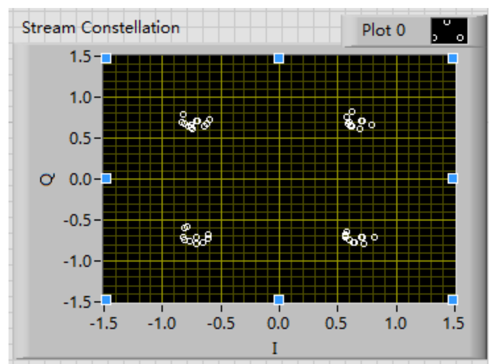


Fig. 12. Pilot Design

V. Conclusion and Future work

Through the above analysis, we can draw our conclusion: Firstly the SISO system based on D-OFDM is feasible. We build this SISO system successfully and transmit the data based on USRP and labview 2013 and get a satisfied result. Then we design our filter based on the Kaiser window, the filter can gain data in one channel and filter out the information in other channels. The performance of filter can meet the needs of receivers.

Although we have finished some parts in our work, our system has not been accomplished. For next steps, we want to finish our MIMO relay parts. Meanwhile, the synchronization in receiver is also important work for us in the future.

References

[1] B. Wang, J. Zhang, and A. Host-Madsen, "On the capacity of mimo relay channels," *Information Theory, IEEE Transactions on*, vol. 51, no. 1, pp. 29–43, 2005.

[2] J. Jia, J. Zhang, and Q. Zhang, "Cooperative relay for cognitive radio networks," in *INFOCOM 2009, IEEE*. IEEE, 2009, pp. 2304–2312.

[3] S. Chu, X. Wang, and M. Li, "Enforcing high-performance operation of multi-hop wireless networks with mimo relays," in *Distributed Computing Systems (ICDCS), 2012 IEEE 32nd International Conference on*. IEEE, 2012, pp. 376–385.

[4] R. Rajbanshi, A. M. Wyglinski, and G. J. Minden, "An efficient implementation of nc-ofdm transceivers for cognitive radios," in *Cognitive Radio Oriented Wireless Networks and Communications, 2006. 1st International Conference on*. IEEE, 2006, pp. 1–5.

[5] J.-m. LI and G.-h. KANG, "Application of nc-ofdm in cognitive radio," *Computer Simulation*, vol. 9, p. 034, 2009.

[6] T. A. Weiss and F. K. Jondral, "Spectrum pooling: an innovative strategy for the enhancement of spectrum efficiency," *Communications Magazine, IEEE*, vol. 42, no. 3, pp. S8–14, 2004.