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Re:	Call for Technical Proposals regarding IEEE Project P802.16j (IEEE 802.16j-06/027).
Abstract	The document contains technical proposal, i.e. efficient resource utilization scheme on the basis of precoding and cooperative transmission in downlink, for IEEE P802.16j.
Purpose	The document is submitted for discussion and adoption in 802.16j
Notice	
Release	
Patent Policy and Procedures	

Efficient Resource Utilization Scheme on the basis of Precoding and Cooperative Transmission in Downlink

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1. Introduction

In the standard [1], OFDMA subcarrier allocation algorithms are different for the uplink and downlink. In the downlink, the pilots are allocated first. After that, the data subchannels are allocated. There is no mechanism to associate pilots with data subchannels and the pilots can be utilized by all the data subchannels for channel estimation. This subcarrier allocation algorithm forbids simultaneous BS/RSs transmissions in one OFDM symbol, which will cause the pilot collision problem to SSs (Subscriber Station) [2], and thus results in low resource utilization efficiency [3].

In this contribution, a novel scheme is proposed to solve the pilot collision problem and achieve efficient resource utilization on the basis of joint precoding and cooperative transmission by BS/RS in downlink. The merits of the proposed scheme are

- High efficiency of resource utilization
  - Resource reuse
  - Avoid unusable spare resource caused by pilot collision problem
- Good BER performance
  - No pilot collision
  - Spatial diversity
- Simplified RS
  - Scheduling is performed at the BS
- Small overhead

2. Inefficient Resource Utilization Caused by Pilot Collision Problem

The pilot collision problem is referred to the mismatch between channel estimation and true data channel response. It is a special problem after inducing RSs (Relay Station) into the wireless networks. For example, we consider the mobile relay network shown in fig.1. In fig.1, we assume SS1 is served by RS and SS2 is served by BS. SS1 can receive the signals from BS, e.g. in throughput enhancement case. Not losing generality, we assume RS transmits data to SS1 in data subchannel 1 and BS transmits data to SS1 in data subchannel 2. If RS and BS transmit data in the same OFDM symbol simutaneously (concurrent transmissions), SS1 will hear two pilots (one from RS and the other from BS) and estimate a sum of the channel (H1+H2) rather than the true data channel response (H1). This problem is named as pilot collision problem, which will greatly reduce the performance of SS1.

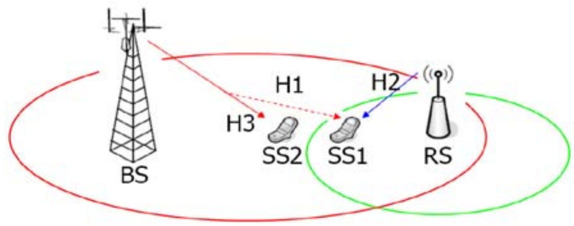

Fig.1 Illustrations of Pilot Collision Problem between BS and RS

The pilot collision problem can also happen when multiple RSs transmit in the same OFDM symbol, as shown in fig.2.

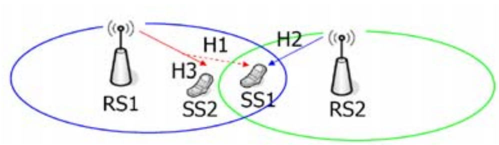

Fig.2 Illustrations of Pilot Collision Problem between multiple RSs

The pilot collision problem not only reduces the performance of the involved SS but also has a serious effect on efficient resource utilization. Because forbidding the simultaneous BS/RSs transmissions in one OFDM symbol, pilot collision problem is a big obstacle to effective resource utilization as indicated in [3]. For example, as shown in fig.3, if BS has the spare resource in the OFDM symbol, RSs can not utilize this spare resource for transmissions. Similarly, if the data of one RS can not occupy the whole OFDM subcarriers in one OFDM symbol, the remained resource can not be used by BS or other adjacent RSs. Besides causing unusable spare resource, pilot collision problem is very harmful to resource reuse for the similar reason.

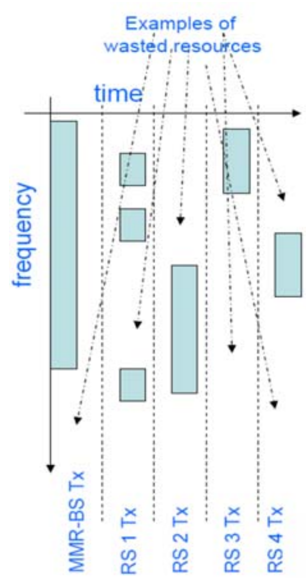

Fig.3 Inefficient resource utilization caused by pilot collision problem (From Ref. [3])

The resource can not be efficiently shared and utilized among BS/RSs until the pilot collision problem can be appropriately solved without changing the SS/MS, which is required by IEEE 802.16j PAR.

3.Proposed Method

In the following, first the key ideas of cooperative transmission and precoding are presented. After that, a proper scheduling scheme is elaborated and examples are given to illustrate the proposed scheme for coverage extension and throughput enhancement. Finally, the process procedure and the merits of the proposed scheme are summarized.

3.1 Cooperative transmission and Precoding

Cooperative transmission can be adopted at BS and RSs to solve the pilot collision problem without changing SS. The concept of cooperative transmission is shown in fig.4. During the concurrent transmissions of BS and RS in one OFDM symbol, BS transmits not only pilots and data of SS2 but also data of SS1. RS transmits pilots and data of SS1. Data of SS2 and data of SS1 are transmitted in different data sub-channels, which are determined by the scheduler at BS. Through BS and RS transmitting pilots and data of SS1 at the same time on the same subcarrier, the pilot collision problem at SS1 can be solved because SS1 receives not only the "collided" pilots but also the "collided" data. Therefore, SS1 can perform the correct detection without any modifications.

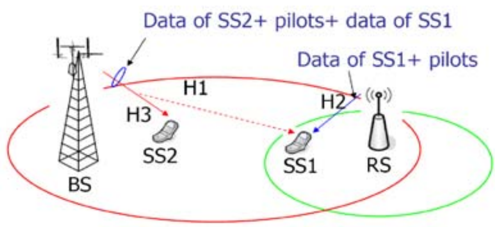

Fig.4 Cooperative transmission

During the cooperative transmission, BS and RS can jointly optimize the transmission power of pilot and data so as to reduce the total transmission power. Precoding using in this contribution refers to the transmission power optimization of pilots and data and does not require the fully channel response at the BS and RS before transmission. Table.1 shows the precoding method.

Table 1 Joint precoding of pilot and data

	Pilot	Data
BS	$W_{BM}^{P}(n)\cdot P$	$W_{BM}^{D}(n)\cdot D_{BM}$
RS	$W_{RM}^{P}(n)\cdot P$	$W_{RM}^{D}(n)\cdot D_{RM}$

Precoding

In table 1, W_{BM}^{P} denotes the precoding coefficient of pilot for BS to MS transmissions. W_{BM}^{D} denotes the precoding coefficient of data for BS to MS transmissions. W_{RM}^{P} denotes the precoding coefficient of pilot for RS to MS transmissions. W_{RM}^{D} denotes the precoding coefficient of data for RS to MS transmissions. P denotes the pilot signal and D_{BM}, D_{RM} denote the data of BS to MS transmission and RS to MS transmission respectively. $W_{BM}^{P}, W_{BM}^{D}, W_{RM}^{P}, W_{RM}^{D}$ can take constant values during the cooperative transmissions.

Generally, the precoding in cooperative transmissions has two purposes. One is for simultaneous transmission and the other is for resource reuse. In the following, examples of precoding for different purposes are shown.

Table 2 and fig.5 show the precoding for simultaneous transmission. For example, table 2(a) means that: 1)BS transmits pilot signal P in pilot location defined in standard [1], transmits D_1 (data of SS1) in the subchannel ϕ_1 and transmits D_2 (data of SS2) in the subchannel ϕ_2. 2) RS transmits pilot signal P in pilot location defined in standard [1], transmits D_1 (data of SS1) in the subchannel ϕ_1 and does not transmit signal in the subchannel ϕ_2. Due to the cooperative transmission of BS and RS in subchannel ϕ_1, BS to SS2 and RS to SS1 transmissions can happen in one OFDM symbol simultaneously without causing SS1 to suffer from pilot collision. Therefore, the unusable spare resource caused by pilot collision problem can be avoided.

Table 2 (b) gives an other precoding example, which shows that by combining with proper scheduling the total transmission power of BS and RS can be reduced. If we schedule a SS2 near BS, the total transmission power of BS and RS can be reduced on the premise of satisfying the performance requirement of SS2.

Table 2 Examples of precoding for simultaneous transmission

(a)

	Pilot	Data ϕ_1	Data ϕ_2
BS	P	D_1	D_2
RS	P	D_1	0

(b)

	Pilot	Data ϕ_1	Data ϕ_2
BS	$P/\sqrt{2}$	$D_1/\sqrt{2}$	$D_2/\sqrt{2}$
RS	$P/\sqrt{2}$	$D_1/\sqrt{2}$	0

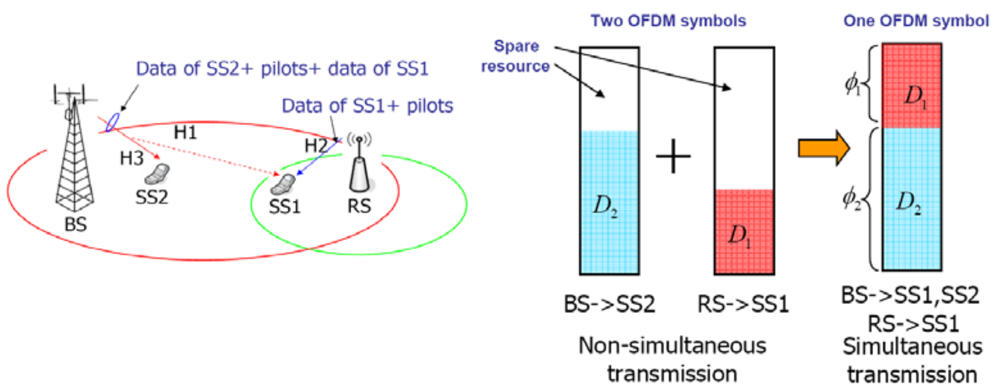

Fig.5 Examples: Precoding for simultaneous transmission

Table 3 and fig.6 show the precoding for resource reuse. Table 3 means that: 1)BS transmits pilot signal P in pilot location defined in standard [1], transmits D_3 (data of SS3) in the subchannel ϕ_1 and transmits D_1 (data of SS1) in the subchannel ϕ_2. 2) RS transmits pilot signal P in pilot location defined in standard [1], transmits D_3 (data of SS3) in the subchannel ϕ_1 and transmits D_2 (data of SS2) in the subchannel ϕ_2. During the transmission of RS to SS2 and SS3, BS to SS1 transmission can be scheduled at the same time if SS1 is out of the RS coverage. Through cooperative transmission by BS and RS to SS3, SS3 will not suffer from the pilot collision problem caused by the simultaneous BS and RS transmission. The transmission power of BS and RS can also be adjusted in cooperative transmission by scheduling proper SSs as in the simultaneous transmission case.

Table 3 Example of precoding for resource reuse

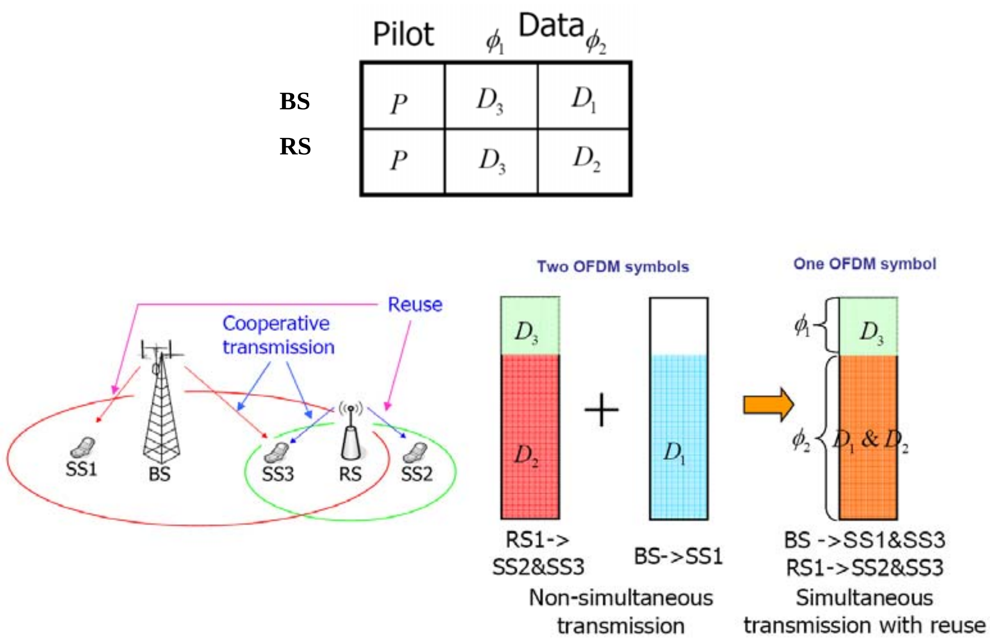

Fig.6 Example: Precoding for resource reuse

Cooperative transmission and joint precoding enable resource reuse and avoid the unusable spare resource caused by pilot collision problem, and therefore can achieve high efficiency of resource utilization by combining with proper scheduling.

3.2 Proper scheduling on the basis of cooperative transmission and precoding

In the following, we first show the key steps of the proposed scheduling scheme. After that, we elaborate the proposed scheduling scheme by using an example of Manhattan model. Finally, we present resource utilization example with both coverage hole for coverage extension purpose and the Manhattan model for throughput enhancement purpose. The frame structure in [4] is used in illustrations. However, the proposed scheme is not limited to frame structure in [4].

The proposed scheduling scheme has four key steps.

Step 1)Classify MS

Divide MSs into different categories according to their SNRs to BS and RSs.

Step 2)Determine the initial reuse groups

Determine the initial reuse groups according to FRF (Frequency reuse factor).

Step 3)Mapping

Substep1: Adjust the MSs in different initial reuse groups according to their data lengths.

Substep2: Multiplex different groups to occupy the whole OFDM subcarriers.

Step 4)Joint Procoding

Joint precoding pilots and data at BS and RS, and perform cooperative transmissions to MSs.

Example of scheduling: Each step of the proposed scheduling scheme is explained in detail in the following by using Manhattan model shown in fig.7.

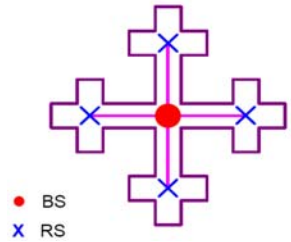

Fig.7 Manhattan model

Step1): Classify MS

Purpose: Preparation for scheduling and resource reuse.

We define “MS_{inner}” as MS which can receive one much stronger signal from one BS/RS than other RSs and/or BS and “MS_{middle}” as MS which can receive multiple comparable strong signals from BS and/or RSs.

In this step, all the MSs will be classified into different categories under different transmission cases.

There are total 2^N-1=31 different transmission cases (where N is the number of BS and RSs in one cell). For simplicity, we use RS_0 to denote BS in the following.

- ✓ 5 RS_i (i=0,1,…,4) transmit simultaneously, 1 case
- ✓ 4 out of the 5 RSs transmit simultaneously, 5 cases
- ✓ 3 out of the 5 RSs transmit simultaneously, 10 cases
- ✓ 2 out of the 5 RSs transmit simultaneously, 10 cases
- ✓ 1 out of the 5 RSs transmits, 5 cases

Determine the MS_{inner} and MS_{middle} of different RS_i in each case respectively.

Step2): Determine the initial reuse groups

Purpose: Find all transmissions which can be reused.

Operations: The initial reuse groups are obtained on the basis of the MS classification from high FRF (Frequency Reuse Factor) to low FRF. If a MS belongs to a reuse group with high FRF, the MS should be removed from all reuse groups with low FRF. There are total 2^N-1 initial reuse groups with FRF ranging from N to 1.

For Manhattan model, there are 31 initial reuse groups in total with FRF ranging from 5 to 1.

- ✓ 1 groups with FRF=5
- ✓ 5 groups with FRF=4
- ✓ 10 groups with FRF=3
- ✓ 10 groups with FRF=2
- ✓ 5 groups with FRF=1

Three initial reuse groups with FRF equal to 5, 4(when RS1, RS2, RS3 and RS4 transmit simultaneously) and 3 (when RS1, RS2 and RS3 transmit simultaneously) are shown in the follows.

FRF=5
$$\begin{cases} MS_{FRF=5}^{RS_0} = \bigcup\limits_{k=1,2,3,4} MS_{inner}^{RS_0-RS_k} \\ MS_{FRF=5}^{RS_1} = \bigcup\limits_{k=0,2,3,4} MS_{inner}^{RS_1-RS_k} \\ MS_{FRF=5}^{RS_2} = \bigcup\limits_{k=0,1,3,4} MS_{inner}^{RS_2-RS_k} \\ MS_{FRF=5}^{RS_3} = \bigcup\limits_{k=0,1,2,4} MS_{inner}^{RS_3-RS_k} \\ MS_{FRF=5}^{RS_4} = \bigcup\limits_{k=0,1,2,3} MS_{inner}^{RS_4-RS_k} \end{cases}$$

FRF=4
$$\begin{cases} MS_{FRF=4}^{RS_1} = \bigcup\limits_{k=2,3,4} MS_{inner}^{RS_1-RS_k} - MS_{FRF=5}^{RS_1} \\ MS_{FRF=4}^{RS_2} = \bigcup\limits_{k=1,3,4} MS_{inner}^{RS_2-RS_k} - MS_{FRF=5}^{RS_2} \\ MS_{FRF=4}^{RS_3} = \bigcup\limits_{k=1,2,4} MS_{inner}^{RS_3-RS_k} - MS_{FRF=5}^{RS_3} \\ MS_{FRF=4}^{RS_4} = \bigcup\limits_{k=1,2,3} MS_{inner}^{RS_4-RS_k} - MS_{FRF=5}^{RS_4} \end{cases}$$

FRF=3
$$\begin{cases} MS_{FRF=3}^{RS_1} = \bigcup\limits_{k=2,3} MS_{inner}^{RS_1-RS_k} - MS_{FRF=5}^{RS_1} - MS_{FRF=4}^{RS_1} \\ MS_{FRF=3}^{RS_2} = \bigcup\limits_{k=1,3} MS_{inner}^{RS_2-RS_k} - MS_{FRF=5}^{RS_2} - MS_{FRF=4}^{RS_2} \\ MS_{FRF=3}^{RS_3} = \bigcup\limits_{k=1,2} MS_{inner}^{RS_3-RS_k} - MS_{FRF=5}^{RS_3} - MS_{FRF=4}^{RS_3} \end{cases}$$

Where $MS_{inner}^{RS_i-RS_k}$ denotes MS_{inner} belongs to RS_i and between RS_i and RS_k.

Step3): Mapping

Purpose: Properly schedule the transmissions of BS and RSs in one frame to achieve frequency reuse and efficient resource utilization.

There are two sub-steps in this step:

Sub-step1: Adjust MSs in initial reuse group according to their data lengths to achieve frequency reuse as much as possible.

Sub-step2: Multiplex different groups to fully utilize the whole OFDM subcarriers.

Examples of processing of sub-step1 and sub-step2 are shown in the follow fig.8~fig.10.

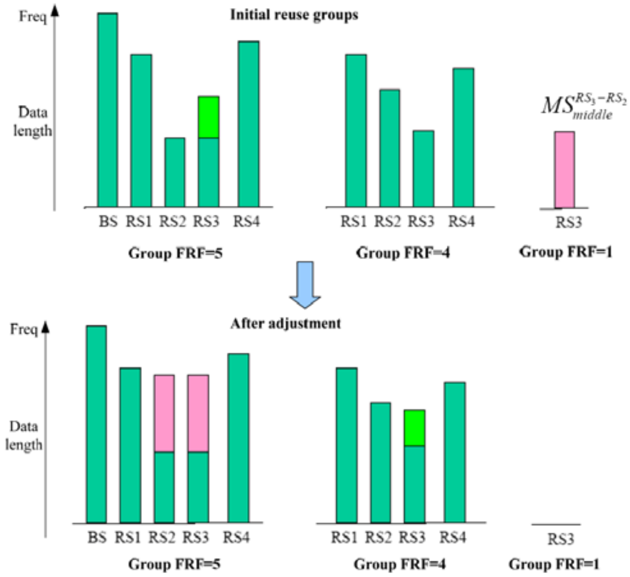

Fig.8 Example of sub-step 1

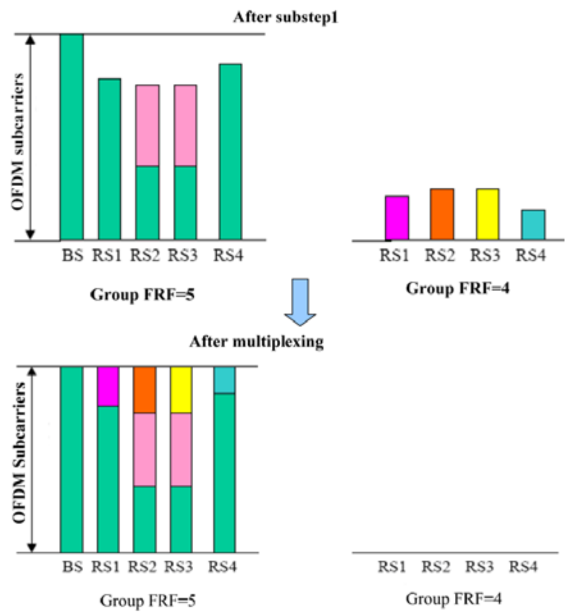

Fig.9 Example1 of sub-step2: Multiplex reuse group FRF=5 (MS_{inner}) and reuse group FRF=4 (MS_{inner})

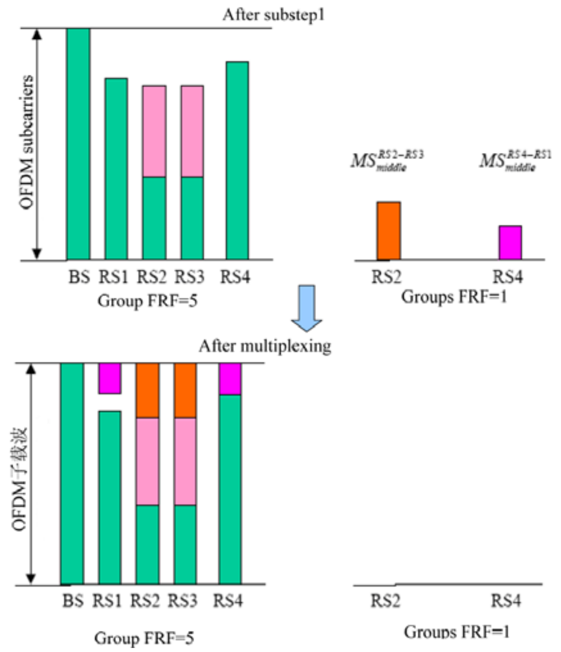

Fig.10 Example2 of sub-step2: Multiplex reuse group FRF=5 (MS_{inner}) and reuse groups FRF=1 (MS_{middle}) with spatial diversity

Step4): Precoding

Purpose: eliminate pilot collision problem caused by reuse and multiplexing.

According to the resource reuse and multiplexing on each OFDM symbols, BS calculates the precoding weight (transmission power) of pilot and data at BS and RSs in the cooperative transmissions and informs the RS the weight. BS and RS perform the cooperative transmissions to MSs.

Fig.11 presents the process procedure of the proposed scheme within a frame.

1) During the UL subframe, BS and RS monitor the ranging signals of all the MSs in their coverage to obtain SNR information of MS.
2) RS reports its obtained SNR information to BS during the RB (RS to BS) transmission in the UL subframe.
3) BS performs the proposed scheduling scheme by utilizing the measured and reported SNR information of MS. BS allocate resource for BS transmissions and RS transmissions in the DL sub-frame, and MS transmissions and RS transmissions in the UL sub-frame.
4) BS transmits data of MSs served by RS to RS and informs RS of the precoding weight.
5) BS and RS perform the cooperative transmissions and non-cooperative transmissions to different SSs.

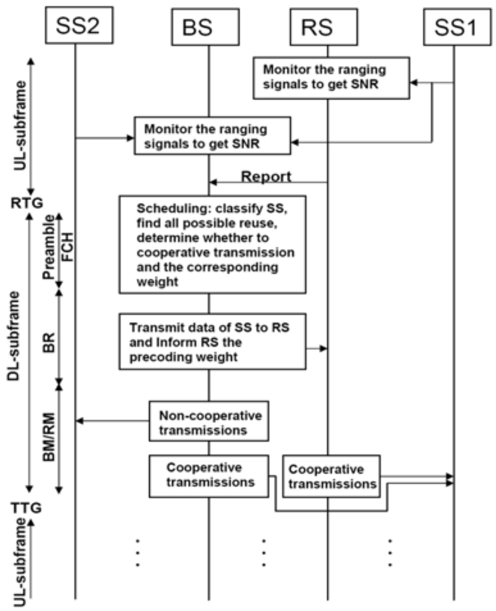

Fig.11 Process procedure of the proposed scheme within a frame

Example 1: Resource utilization example for coverage extension

Fig.12 shows the resource utilization example for coverage hole for coverage extension purpose. The frame structure in [4] is used for illustrations. However, the proposed scheme is not limited to frame structure in [4].

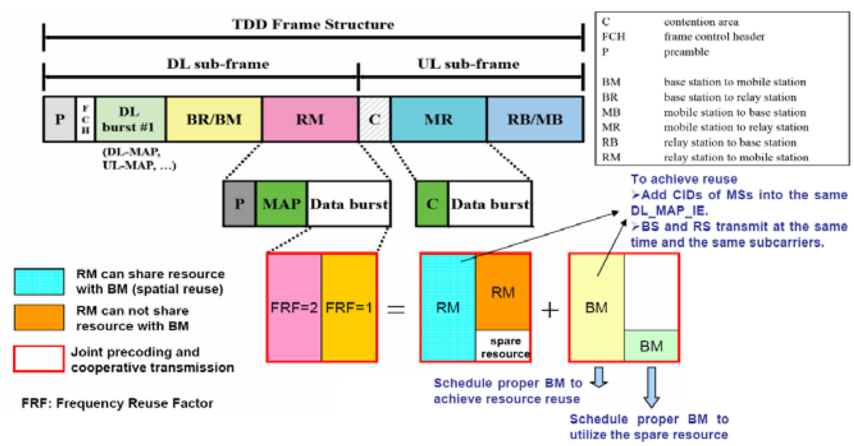

Fig.12 Resource utilization example for coverage hole

Example 2: Resource utilization example for throughput enhancement

Fig.13 shows the resource utilization example for Manhattan model for throughput enhancement purpose. The frame structure in [4] is used for illustrations. However, the proposed scheme is not limited to frame structure in [4].

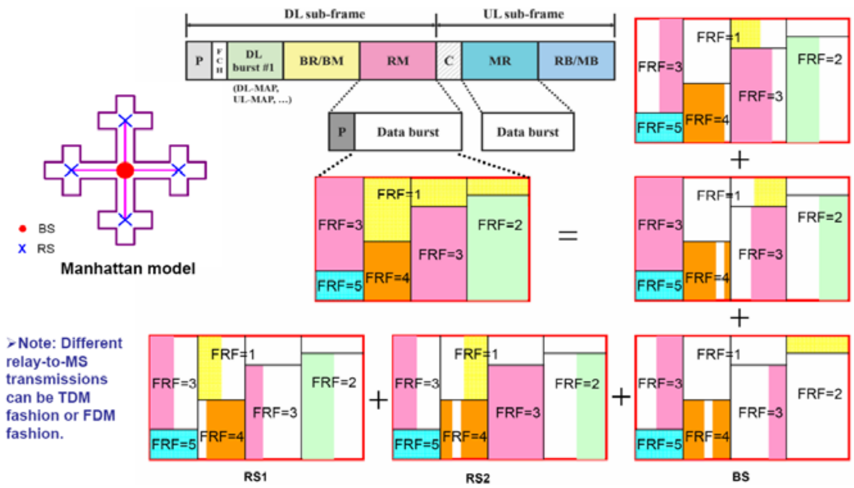

Fig.13 Resource utilization example for Manhattan model

3.3 Merits of the proposed scheme

The proposed cooperative transmission scheme does not require CSI (Channel State Information) and the only needed information is (coarse) SNRs from MS/SS to BS/RS, e.g. in the fig.1, the SNRs from SS1 to BS and RS. The SNR information is used to adjust the transmission power of pilot and data at BS and RS during the cooperative transmission. Through precoding and cooperative transmission, the transmission of BS and RS can be multiplexed in the one OFDM symbol (the unusable spare resource caused by pilot collision problem is avoided) and frequency reuse can be achieved. The merits of the cooperative transmission method are summarized as follows

- High efficiency of resource utilization
  - Resource reuse
  - Avoid unusable spare resource caused by pilot collision problem
- Good BER performance
  - No pilot collision
  - Spatial diversity
- Simplified RS
  - Scheduling is performed at the BS
- Delay
  - Same frame relay
- Small overhead
  - Generally, BS has the SNRs of MSs, e.g for handover, AMC or power control purpose, etc.. If so, no overhead in the uplink
  - In the downlink, the overhead is about KxN, which is much smaller than the reused resource or the unusable spare resource. (where K is the bits number for expressing the precoding weight, e.g K=3~5, and N is the number of MSs, which needs cooperative transmission, and the severing RSs of which need to change the transmission power.)
- No modification at SS/MS
- Can be applied to other frame structures, like [5][6].

4. Summary

Efficient resource utilization scheme among BS and RSs is very essential for mobile multihop relay networks. To achieve this target, pilot collision problem needs to be solved without changing MS/SS. We recommend efficient resource utilization on the basis of joint precoding and cooperative transmission at BS/RS, which can successfully solve the pilot collision problem and enable the efficient and flexible resource ultilization.

5. References

[1] IEEE Standard for Local and Metropolitan area networks, Part 16: Air Interference for Fixed Broadband Wireless Access Systems, IEEE 802.16-2004.

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[6] C802.16j-06/002, Some Considerations on Mobile Multihop Relay Based System, Huawei.