Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Interference Measurement and Neighborhood Discovery for IEEE 802.16j Multi-hop Relay Network**
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Re:	IEEE 802.16j-06/034:"Call for Technical Proposals regarding IEEE Project P802.16j"
Abstract	This contribution introduces the fundamental concept of interference measurement and propose the message and mechanism to perform interference measurement and neighborhood discovery for IEEE 802.16j Multi-hop Relay network
Purpose	Propose the mechanism and message to perform interference measurement and neighborhood discovery for IEEE 802.16j Multi-hop Relay network.
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Patent Policy and Procedures	

Interference Measurement and Neighborhood Discovery for IEEE 802.16j Multi-hop Relay Network

This contribution will introduce the fundamental concept of interference measurement behind the relative contributions proposed in Dallas's meeting [1-4], and then proposes a mechanism and its required message to perform interference measurement and neighborhood discovery in IEEE 802.16j Multi-hop Relay network.

The objectives of the interference measurement presented in [1-4] are not only to measure the existing interference but also to predict the potential interference level for different network topologies or resource reuse scenarios. Therefore, the MR network can be configured/re-configured based on this measurement result.

According to the mechanism proposed in this contribution, MR-BS can request all the RSs or a set of the RSs in a MR cell to transmit the reference signals over the designated symbol duration for the measurement and identification by other stations. After the RSs reporting the measurement and identification results to the MR-BS, it has the full knowledge that how each RS may interfere the other RSs. Then various algorithms for segment assignment/reuse, neighborhood discovery, neighbor list establishment and topology configuration can be benefited by this information.

An example is presented in section III presents how we can utilize this information to predict the received interference and SINR level for the relay links under different resource (ex. segment) reuse scenarios and topologies. Therefore, the MR network can be configured or reconfigured by proper algorithms and such prediction results.

Another example presents the resource reuse in access links can also base on the RSS matrix [1], which is translated as an interference matrix in that example. Note that the way to utilize these measurement results can be implementation issue.

I. The necessities of interference measurement

In the multi-hop relay systems, the coverage extension and user throughput enhancement may be achieved at the expense of system capacity [5,6]. It is because the user data in relay links carries the same information as the data in access links, therefore, all the traffic in relay links can be treated as a kind of overhead. If the capacity improvement leaded by better signal quality and higher transmission rate can not compensate the capacity loss due to radio resources consumed by relay links, the overall system capacity will be degraded due to the deployment of the RSs into the network.

In order to increase the system capacity, reusing the radio resources (i.e. sub-channel and symbol time, or segment) in different relay and/or access links has been shown as an efficient solution. Compared with the case without reusing radio resources, the simulation results in Figure 1 shows that the system capacity can be substantially increased [5,6]. Moreover, its capacity is also significantly outperformed with respect to the case without relaying.

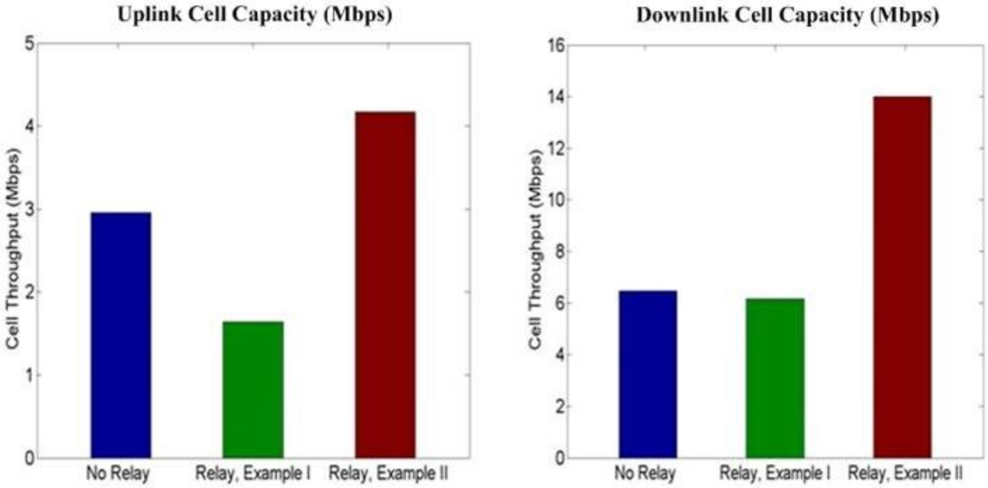

Fig.1 Capacity comparison for different relay scenarios

However, considering an arbitrary MR network as shown in Figure 2, a fundamental problem is: "**Which links can reuse the same radio resources without disturbing each other?**".

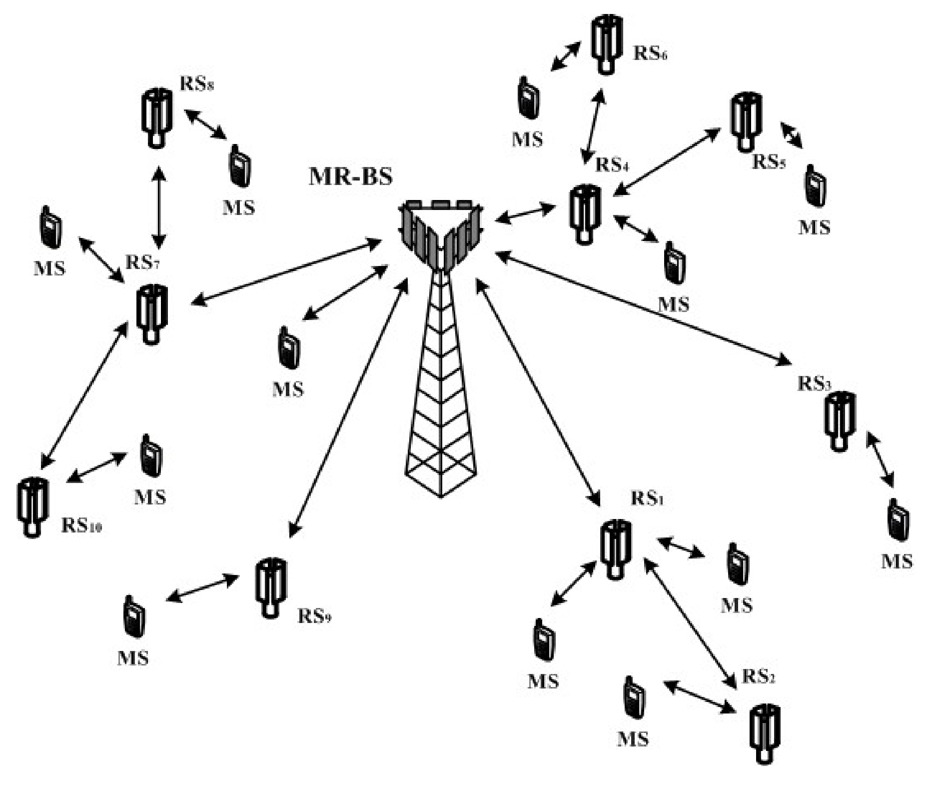

Fig.2 An example of IEEE 802.16j MR network

A traditional method is performing the cell planning when deploying each RS. Therefore, the transmit power, resource assignment and reuse scenario can be manually configured based on the geographical location and the field trial measurement results. However, the geographic location may not be able to reflect the real propagation environment, and the interference measurement can provide better prediction for MR network to explore the propagation enviroments.

An alternative method is to configure the MR network in automatic manner, which means that the RSs can detect and measure the radio signal transmitted from each other, and then report the detection and measurement results to MR-BS (or any other controller) to configure the MR network automatically. Therefore, the MR network can be easily managed in response to time variant traffic distribution or other load unbalance situations. For example, the MR-BS may instruct the permutation scheme of RS_3 to be changed from PUSC to FUSC (or assign more segments), so as to increase the capacity over the specific area.

In order to make MR network able to automatic configure/reconfigure its reuse scenario, an interference measurement and neighbor detection mechanism will be necessary to provide the required information to MR-BS.

Moreover, the results of interference measurement and neighborhood detection can also be applied to compose the neighbor list for each station, and the example presented in this contribution also shows that it can also be utilized to determine the topology for MR network.

II. The concept of interference measurement mechanism

The fundamental concept of the interference measurement mechanism can be illustrated by Figure 3, which includes a MR cell composed by one MR-BS and several RSs. The MR-BS network can designate one or more time-frequency regions for specific stations to transmit the reference signals (e.g. same format as 16e preamble), and other stations can perform the measurement over the same time-frequency region.

As a specific example as shown in Figure 3, RS_{10}, RS_8, RS_2 and RS_5 are requested to transmit the reference signals by MR-BS, and the rest of other stations will perform the measurement of the those reference signals.

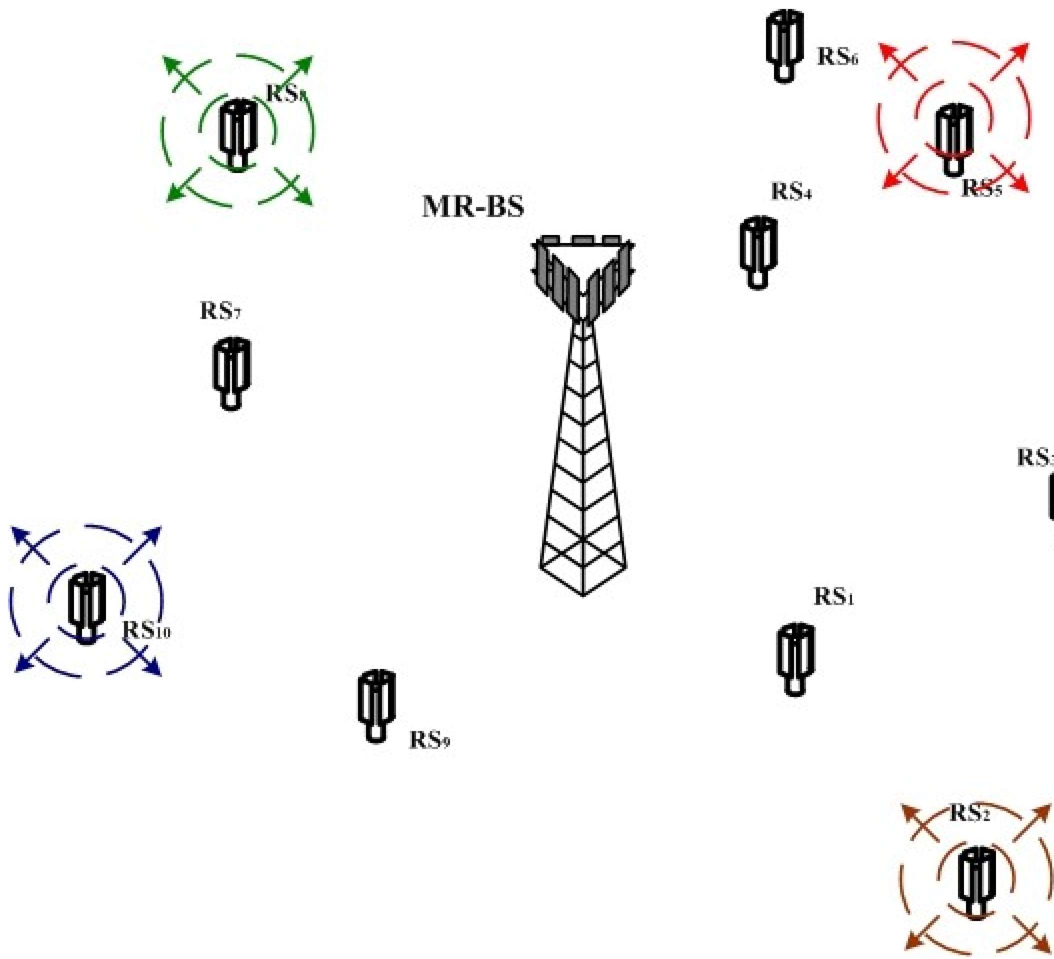

Fig.3 An example the interference measurement mechanism

If the reference signals transmitted by the four RSs are not associated to any identification (ID) of these stations, i.e. receiver side can not identify the transmitter by the received radio signal, the MR network should designated non-overlapped time-frequency regions for each of them to transmit, which is shown in Figure 4. Therefore, the receiver side can identify the transmitter of the reference signal by comparing the station which is authorized to transmit over each region.

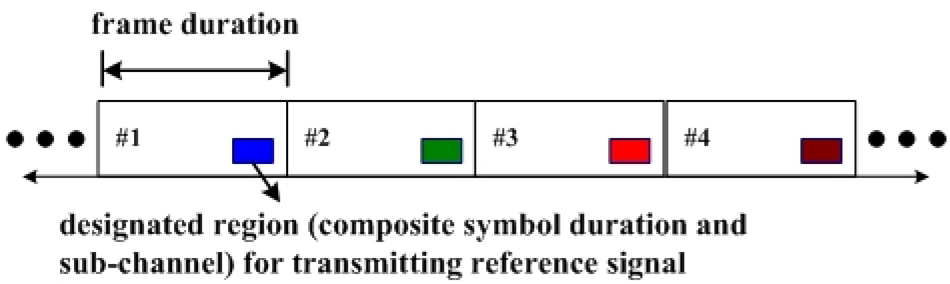

Fig.4 An example of the arrangement on measurement opportunity if each station transmits the same reference signal

If the reference signals transmitted by the four RSs are specific for each station which associated to the ID of these stations (e.g. the same format as 16e preamble), i.e. receiver side can identify the transmitter by the received the reference signal, the MR network can designated the same time-frequency region for each of them to transmit the reference signals, which is shown in Figure 5. Therefore, the receiver can identify the transmitter ID by detecting the reference signals.

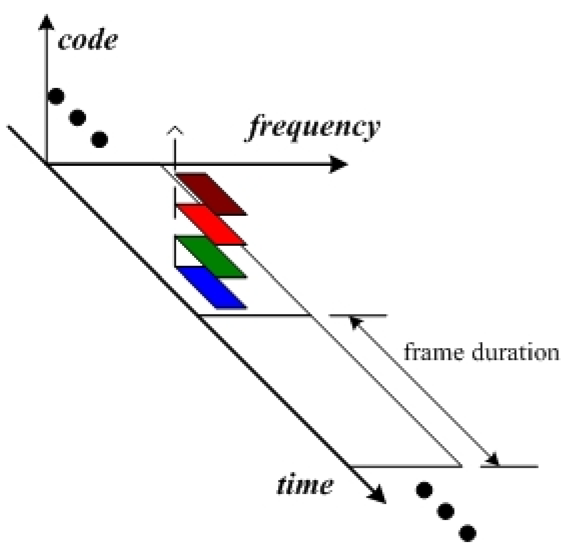

Fig.5 An example of the arrangement on measurement opportunity if each station can transmit different reference signals

After the measurement, each station can report the RSS (received signal strength) and the corresponding transmitter ID to the MR-BS.

III. An example to perform interference and SINR prediction for relay links

In Figure 6, an example with 4 stations (1 MR-BS and 3 RSs) is presented to illustrate how we can predict the interference and SINR level for different resource reuse scenario and topology. According to the aforementioned measurement mechanism, each station can transmit a reference signal for other stations to perform measurement and identification. Therefore, these stations have the knowledge of the RSS (Received Signal Strength) of the reference signal from each other, as shown in Figure 6.

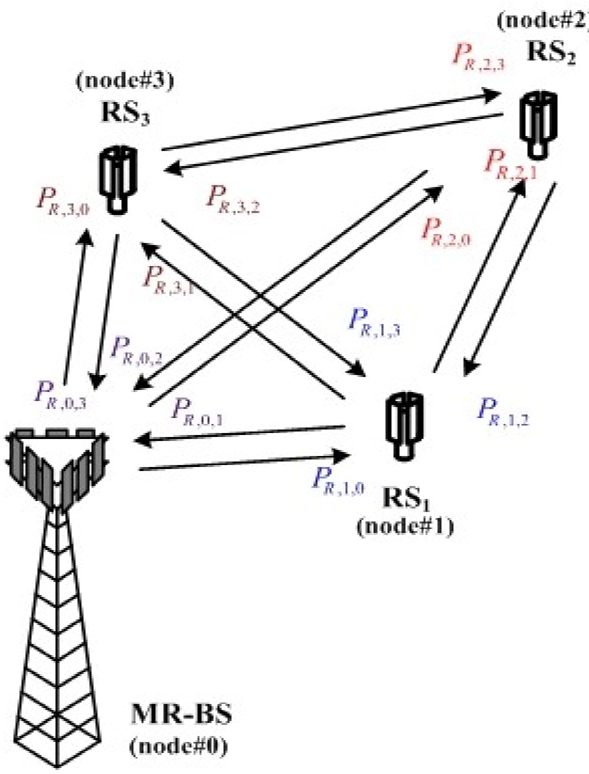

Fig.6 An example to illustrate the interference and SINR prediction

After each station reports its measurement results, the RSS matrix as shown in Figure 7 can be obtained at the MR-BS. Note that the interference generated by the stations which is not involved in this mechanism is considered as the background interference in this example. Therefore, the parameter $P_{R,i,i}$ is defined as the thermal noise power plus background interference power, which is estimated by the node #*i*.

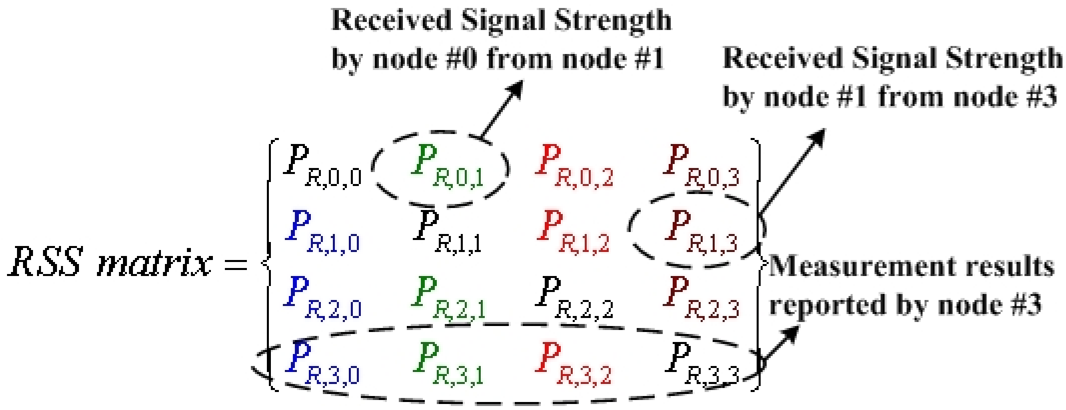

Fig.7 RSS matrix recorded by the MR-BS

According to the RSS matrix presented in Figure 7, the coordinator can predict the interference and SINR for each resource reuse scenario and topology of the MR network. Figure 8 represents the first example for the prediction under the topology #1, and here we define the $L_{i,j}$ to indicate the radio link between node #*i* and node #*j*.

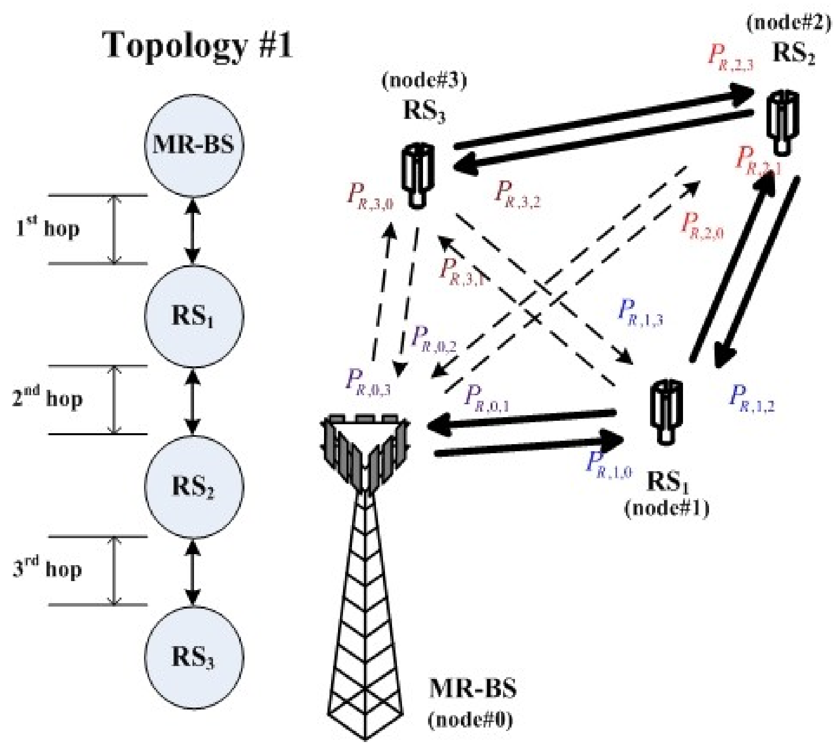

Fig.8 An example for interference and SINR prediction under Topology #1

According to the Topology #1, the interference and SINR prediction of each resource reuse scenario is shown as Table 1. Note that $\{L_{i,j},L_{x,y}\}$ defines that the link $L_{i,j}$ and the link $L_{x,y}$ are reusing the same radio resources but transmitting "different data", and each station is assumed not able to transmit and receive at the same time. The following prediction results are represented in linear values (not in dB).

Tab.1 Predicted Received Interference and SINR Level based on the RSS Matrix and Topology #1

Reuse Scenario		Predicted Received Interference Level			
		Node #0	**Node #1**	**Node #2**	**Node #3**
DL	$\{L_{0,1}\},\{L_{1,2}\},\{L_{2,3}\}$	*Null*	$P_{R,1,1}$	$P_{R,2,2}$	$P_{R,3,3}$
	$\{L_{0,1},L_{2,3}\},\{L_{1,2}\}$	*Null*	$P_{R,1,2}+P_{R,1,1}$	$P_{R,2,2}$	$P_{R,3,0}+P_{R,3,3}$
UL	$\{L_{3,2}\},\{L_{2,1}\},\{L_{1,0}\}$	$P_{R,0,0}$	$P_{R,1,1}$	$P_{R,2,2}$	*Null*
	$\{L_{1,0},L_{3,2}\},\{L_{2,1}\}$	$P_{R,3,0}+P_{R,0,0}$	$P_{R,1,1}$	$P_{R,1,2}+P_{R,2,2}$	*Null*

Reuse Scenario		Predicted Received SINR Level			
		Node #0	**Node #1**	**Node #2**	**Node #3**
DL	$\{L_{0,1}\},\{L_{1,2}\},\{L_{2,3}\}$	*Null*	$\frac{P_{R,1,0}}{P_{R,1,1}}$	$\frac{P_{R,2,1}}{P_{R,2,2}}$	$\frac{P_{R,3,2}}{P_{R,3,3}}$
	$\{L_{0,1},L_{2,3}\},\{L_{1,2}\}$	*Null*	$\frac{P_{R,1,0}}{P_{R,1,2}+P_{R,1,1}}$	$\frac{P_{R,2,1}}{P_{R,2,2}}$	$\frac{P_{R,3,2}}{P_{R,3,0}+P_{R,3,3}}$
UL	$\{L_{3,2}\},\{L_{2,1}\},\{L_{1,0}\}$	$\frac{P_{R,0,1}}{P_{R,0,0}}$	$\frac{P_{R,1,2}}{P_{R,1,1}}$	$\frac{P_{R,2,3}}{P_{R,2,2}}$	*Null*
	$\{L_{1,0},L_{3,2}\},\{L_{2,1}\}$	$\frac{P_{R,0,1}}{P_{R,0,3}+P_{R,0,0}}$	$\frac{P_{R,1,2}}{P_{R,1,1}}$	$\frac{P_{R,2,3}}{P_{R,2,0}+P_{R,2,2}}$	*Null*

Then, consider the second prediction example under the Topology #2, which is shown in Figure 9. In Topology #2, RS_1 and RS_2 are transmitting the same data over the same resource region so that they act like a single station from the receiver's point of view, and they are defined to be within the same cluster [7] in this example. Therefore, the notation $[L_{i,j},L_{x,y}]$ defines that the links $L_{i,j}$ and $L_{x,y}$ are reusing the same radio resources and transmitting "the same" data over the same resource region, which acts like a virtual station as defined in [8], so that the radio signals of both links are combined over the air from receiver's point of view.

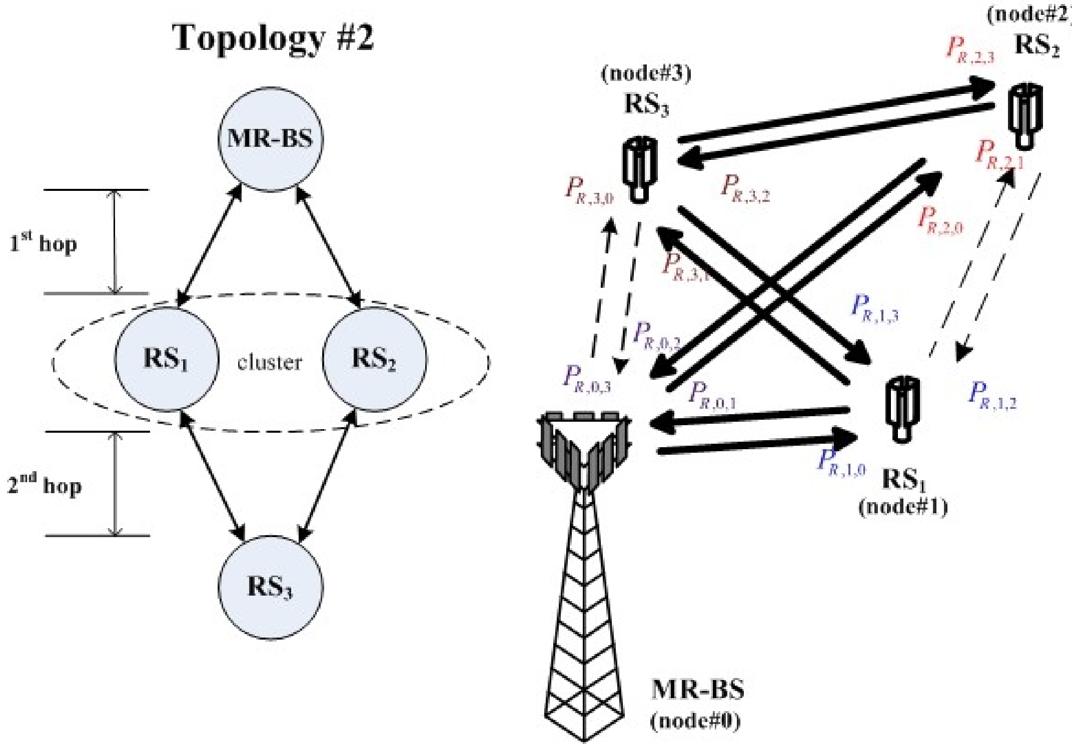

Fig.9 An example for interference and SINR prediction under Topology #2

Therefore, the interference and SINR level for each reuse scenario can be predicted as the results in Table 2. Note that the links with the transmitters which are the stations within the same cluster shall be treated as one logical link.

Tab.2 Predicted Received Interference and SINR Level based on the RSS Matrix and Topology #2

Reuse Scenario		**Predicted Received Interference Level**			
		Node #0	**Node #1**	**Node #2**	**Node #3**
DL	$\{L_{0,1}\},\{L_{0,2}\}$, $[L_{1,3}, L_{2,3}]$	*Null*	$P_{R,1,1}$	$P_{R,2,2}$	$P_{R,3,3}$
UL	$\{L_{1,0}\},\{L_{2,0}\}$, $[L_{3,1}, L_{3,2}]$	$P_{R,0,0}$	$P_{R,1,1}$	$P_{R,2,2}$	*Null*
Reuse Scenario		**Predicted Received SINR Level**			
		Node #0	**Node #1**	**Node #2**	**Node #3**

DL	$\{L_{0,1}\},\{L_{0,2}\}$, $[L_{1,3}, L_{2,3}]$	*Null*	$\frac{P_{R,1,0}}{P_{R,1,1}}$	$\frac{P_{R,2,0}}{P_{R,2,2}}$	$\frac{P_{R,3,1}+P_{R,3,2}}{P_{R,3,3}}$
UL	$\{L_{1,0}\},\{L_{2,0}\}$, $[L_{3,1}, L_{3,2}]$	$\frac{P_{R,0,1}+P_{R,0,2}}{P_{R,0,0}}$	$\frac{P_{R,1,3}}{P_{R,1,1}}$	$\frac{P_{R,2,3}}{P_{R,2,2}}$	*Null*

In summary, when predicting the interference level based on the RSS matrix, the interference of specific receiver node #*i* can be the summation of:

1. The thermal noise power and background interference power.
2. The RSS of the stations which transmit over the same resource region but their target is not node #*i*.

In addition, when predicting the SINR level of specific receiver node #*i* based on the RSS matrix and the aforementioned interference prediction results:

1. Its denominator can be the aforementioned interference prediction result
2. Its nominator can be the RSS which transmit over the same resource region and their target is node #*i*.

IV. Text proposal

---Start of the text---

Insert the new subclause at the end of 6.3.9

During the RS network registration process, a RS acts as a MS/SS and use REG-REQ to inform the MR-BS that it has relay capability to MR-BS.

Insert new subclause (6.3.2.3.62)

6.3.2.3.62 RS neighborhood sounding request (RS_NBR-SOUND-REQ) message

The BS may transmit a RS_NBR-SOUND-REQ message when it wants to initiate an RS neighborhood sounding. An RS receiving this message may transmit or receive the reference signal to perform the RS neighborhood sound. The message shall be transmitted on the basic CID.

Syntax	Size	Notes
RS_NBR-SOUND-REQ_Message_Format() {		
Management Message Type = TBD	8 bits	
NBR_MEAS_MODE	1 bit	0: Receive mode 1: Transmit mode
If (NBR_MEAS_MODE==0){		
N_NBR_LIST	8 bits	Number of neighboring stations in the neighbor list
Begin PHY Specific Section {		
For (i=0, i<N_NBR_LIST, i++){		

Preamble Index	8 bits	Preamble index corresponds to position of the station in MR_NBR-INFO
OFDMA Symbol Offset	8 bits	The location to receive the reference signal
}		
Report Request TLVs	Variable	TLV specific
}		
else {		
OFDMA Symbol Offset	8 bits	The location to transmit the reference signal
}		
}		

The measurement type TLV may include physical CINR and RSSI to allow more flexibility in interference measurement. It shall be determined based on the capability of the RS and the deployed interference management method.

NBR_MEAS_MODE

Instruct the RS to transmit (if NBR_MEAS_MODE=1) or receive (if NBR_MEAS_MODE=0) the reference signal over the designated OFDMA symbol offset

N_NBR_LIST

Number of neighboring stations in the neighbor list

OFDMA Symbol Offset

The location of the reference signal to be transmitted or received. If NBR_MEAS_MODE is set as 0, RS shall scan the reference signals over each segment at the designated OFDMA symbol offset.

The RS_NBR-SOUND-REQ shall contain the Report Request TLV (define in 11.11 REP-REQ management message encodings). On receiving RS_NBR-SOUND-REQ, a RS shall measure the interference from the neighbors using the specified methods in the Report Request TLVs.

Insert new subclause (6.3.2.3.63)

6.3.2.3.63 RS neighborhood sounding report (RS_NBR-SOUND-RPT) message

Syntax	Size	Notes
RS_NBR-SOUND-RPT_Message_Format() {		
Management Message Type = TBD	8 bits	
N_NBR_LIST	8 bits	Number of neighboring stations in the neighbor list
Begin PHY Specific Section {		
For (i=0, i<N_NBR_LIST, i++){		
Preamble Index	8 bits	Preamble index corresponds to position of the station in MR_NBR-INFO
Report Response TLVs	Variable	TLV specific
}		

}		
}		

N_NBR_LIST

Number of neighboring stations in the neighbor list

The RS_NBR-SOUND-RPT shall contain the Report Response TLV (define in 11.11 REP-RSP management message encodings).

Insert a new subclause 6.3.27.1

6.3.27.1 Interference measurement by RS sounding

In order predict the interferences between different RSs, the MR-BS needs to collect the interference measurements from RSs. The protocol of interference measurement between MR-BS and RSs consists of three steps.

Firstly, the MR-BS sends a REP-REQ message to a set of RSs, subject to interference analysis. Besides, the REP-REQ message indicates the TLV of Channel type request is RS sounding (see 11.11). The number of RSs, RSs' CIDs, and the reporting period are also included in the REP-REQ. When an BS receives such an REP-REQ, it expects to hear the RS_NBR-SOUND-REQ (6.3.2.3.62) in the subsequent frames until the time indicated in the TLV of report period in the REP-REQ message.

Secondly, the related MR-BSs that constitute the designated a set of RSs, subject to the interference analysis allocate a RS_NBR-SOUND-REQ (an exclusive transmission period) for each RS involved in RS sounding. In particular, the NBR_MEAS_MODE in the RS_NBR-SOUND-REQ (see 6.3.2.3.62) indicates the RS to transmit or receive ~~a~~ the reference signal, and the OFDMA Symbol Offset indicates the location of the reference signal shall be transmitted or received. This mechanism can also be applied to measure the reference signal transmitted from the RSs within different MR cell, which can be achieved by inter-cell coordination through the network backbone. Depending on the implementation, one or more BSs or one or more RSs could be instructed to perform RS sounding via proper coordination. Therefore the method could be used for RS to/from BS and/or RS to/from RS, within a set of RSs and BSs. In other words, the stations to be involved within this mechanism may not be restricted by the boundary of MR cell. The entire interference detection/measurement and management procedures could be driven by a network management interference entity or under the control of the MR-BS and thus to be limited to only one cell, if chosen (implementation selectable)

The scheduling of RS_NBR-SOUND-REQ by MR-BS is implementation specific. The scheduling of RS Sounding zone shall consider allowances made by an RS-TTG and RS-RTG in between transmit and receive periods to allow the RS to properly switch between transmit and receive mode. The capabilities RS-TTG and RS-RTG will be provided by the RS during RS network entry.

Thirdly, after the number of frame whose value is indicated in the report period TLV of the REP-REQ message has been passed, all RSs have to send back the measurement results to the MR-BS. More than one round of measurements may be allocated by MR-BS. An averaging of all the subsequent measurements may be executed at the MR-BS level or at the network management entity level, being implementation specific. Since the RSs may not communicate with each other, while performing the measurement, the measured signal strength can be treated as an approximation or a prediction of the potential interference between different radio links if they reuse the same radio resources. Therefore, the MR network can be configured or reconfigured based on this measurement results, being implementation specific.

11.11 RS REP-REQ management message encodings

Change fourth row of the second table in 11.11 as indicated:

Name	Type	Length	Value
Channel Type request	1.3	1	0b00 = Normal subchannel, 0b01 = Band AMC Channel, 0b10 = Safety Channel, 0b11 = ~~Reserved~~Sounding 0b100 = RS Sounding

Insert the following table at the end of 11.11:

Name	Type	Length	Value
RS sounding type request	1.9	variable	Compound
RS Sounding number	1.9.1	1	number of RSs, N_{RS}, participating in RS sounding measurement
RS CID	1.9.2	N_{RS}*2	RS(1) … RS(N_{RS}) basic CID where NRS is the number of RSs participating in the RS Sounding measurements
Report period	1.9.3	1	RS sends REP-RSP after the number of frames since receiving the REP-REQ
RS Sounding Zone-specific CINR request	1.10	1	Bits #0-3: in multiples of 1/16 (range is [1/16,16/16]) Bits #4-7: Reserved, shall be set to zero
RS Sounding Zone-specific RSSI request	1.11	1	Bit #0: Type of zone on which RSSI is to be reported 0: RS reports RSSI on all subcarriers 1: RS reports RSSI on the subcarriers allocated in the Sound zone allocation IE Bits #2-5: in multiples of 1/16 (range is [1/16,16/16]) Bits #6-7: Reserved, shall be set to zero

Insert the following text at the end of 11.11:

When the TLV of Channel type request indicates the support of RS sounding, TLV of type 1.9 and 1.10 may be included in REP-REQ. TLV of RS Sounding number indicates the number of RSs participate in the interference management. TLV of RS CID carries the basic CIDs of all participating RSs. TLV of report period indicates the period of measurement in the unit of frame number. After this period, the designated RSs shall report to the MR-BS the measurement results. TLV of RS Sounding Zone-specific CINR requested is needed only when RSs are requested to report CINR measurements (implementation specific); TLV of RS Sounding Zone-specific RSSI requested is needed only when RSs are requested to report RSSI measurements (implementation specific).

11.12 RS REP-RSP management message encodings

Insert the following rows into the third table as indicated:

REP-REQ Channel Type request (binary)	Name	Type	Length	Value
100	RS Sounding CINR Report	2.6	N_{RS}	CINR for each RS
100	RS Sounding RSSI Report	2.7	N_{RS}	RSSI ranging from –40 dBm (encoded 0x53) to –123 dBm (encoded 0x00)

Insert the following text at the end of 11.12:

When an RS received an REP-REQ with the TLV of Channel type request, it shall respond to the MR-BS with an REP-RSP with TLV of Sound reports (type 2.6 or 2.7) after measuring RS sounding signals from other RSs. The reporting time is indicated in REP-REQ. A vector of N_{RS} measurement results of all participating RSs is reported by each RS. Moreover, an RS reports CINR or RSSI or both information dependent on whether the corresponding TLV (type 1.10 or 1.11) appears in REP-REQ.

---End of the text---

V. References

[1] IEEE C802.16j-06/148, "Estimation of Initial Interference Matrix."

[2] IEEE C802.16j-06/169, "Reusing the Radio Resources in IEEE 802.16j Multi-hop Relay System."

[3] IEEE C802.16j-06/216, "Relay-Station Power Control and Channel Reuse."

[4] IEEE C802.16j-06/225, "Directional Distributed Relay with Interference Control and Management."

[5] IEEE C802.16mmr-05/041, "System Performance of Relay-based Cellular Systems in Manhattan-like Scenario."

[6] IEEE C802.16mmr-06/003, "On the Throughput Enhancement of Fixed Relay Concept in Manhattan-like Urban Environment."

[7] IEEE C802.16j-06/168, "A RS Clustering Scheme for IEEE 802.16j."

[8] IEEE C802.16j-06/234, "Relay Grouping and PUSC Segment Selection for FCH/MAP Transmission."