CDMA Code-Based Bandwidth Request Mechanism in IEEE 802.16j Mobile Multi-Hop Relay (MMR) Systems

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Abstract—In the IEEE 802.16 system, a Relay Station (RS) is required for the purpose of coverage extension and throughput improvement. However, if we use the RS, original bandwidth request mechanism is not applied to Subscriber Station (SS) which is connected to RS since the bandwidth request mechanism is optimized for single-hop environment. Therefore, we propose an efficient contention based CDMA bandwidth request mechanism for SS located in RS region in the IEEE 802.16 MMR system. In the proposed scheme, an SS can receive the uplink resource very well wherever an SS is located. Through the analysis, we show that the proposed bandwidth request mechanism reduces the signaling cost and delay of system.

I. INTRODUCTION

In the beyond-3G wireless communication, the Relay Station (RS) has been demanded to enhance the throughput and extend the coverage. By introducing the RS, the path loss between the Base Station (BS) and the Subscriber Station (SS) be reduced. This path loss reduction enables the overall throughput to be enhanced. Furthermore, through the RS, the BS can communicate with the SS which is located in non-line-of-sight (NLOS) coverage, that is, the coverage extension is possible. Therefore, for multi-hop relaying of IEEE 802.16/16e standard [1] [2], a new task group what is called 802.16j was created [3]. The goal of the task group is to improve the performance of the IEEE 802.16 system when the RS is introduced. Moreover, the backward compatibility with original IEEE 802.16/16e standard should be satisfied irrespectively of the RS usage.

Owing to the advent of RS, a new function or performance requirement is needed. First, the additional resource is used between BS and RS, the resource allocation in the IEEE 802.16j MMR system will be different from the IEEE 802.16/16e system. Secondly, the SS does not distinguish the RS from the BS. Hence, the BS and the RS operates suitably for resource allocation though a SS which is located in RS region requests the bandwidth. For that reason, the research about the IEEE 802.16j MMR system was started. In [4], a new handover algorithm is proposed to reduce the inter-cell handover in MMR system. In [5], they analyze the performance of bandwidth allocation in 802.16j MMR system. In [6], they propose MAC protocol data unit (MPDU) aggregation and MAC service data unit (MSDU) concatenation on the relay link.

In the 802.16 OFDMA system, several bandwidth request methods are used to transmit the data. However, these methods fit the SS in single-hop system, so some problem may happen if these methods are applied to multi-hop system. Especially, in case of contention-based CDMA bandwidth request, a new concept of bandwidth request mechanism is needed. The reason is as follows. If the contention-based CDMA bandwidth request method is used in the MMR system without any modification, the SS which is located in the BS region can request the uplink resource very well but the SS which in located in RS region requests the resource through the RS. If the RS receives the CDMA code successfully from SS and transmits the the code to BS like the SS does, that is, the RS transmits CDMA code through ranging channel, the BS does not know whether the node that transmits CDMA code is located in BS region or not since the code does not have any information of SS.

Therefore, we propose an efficient contention based CDMA bandwidth request mechanism for SS located in RS region in the IEEE 802.16 MMR system. In the proposed mechanism, the RS relays the information related to the CDMA code through the CQICH or a new message called MR_Code-REP. As a result, the proposed mechanism enables the BS to know where the SS that transmitted the code is in BS region or RS region. The rest of the paper is composed as follows: Section 2 introduces the bandwidth request mechanisms in the IEEE 802.16 OFDMA system. We explains the proposed mechanism in detail in section 3 and we analyze numerically the performance of the proposed mechanism in section 4. In section 5, we evaluate the proposed scheme through the simulation. Finally, we conclude the paper in section 6.

II. BACKGROUND

In the IEEE 802.16 OFDMA system, a SS may have the bandwidth through the following method: request (contention-based) and polling (contention-free). Through two methods, the SS requests the bandwidth and some resource is allocated to SS. The detail process of bandwidth request is as follows.

A. Bandwidth request and allocation in the IEEE 802.16

1) Request
In the IEEE 802.16 OFDMA system, there are three methods which the SS (Subscriber Station) can use to request the uplink resource. The first method is to use the bandwidth request header, the second method is to use the piggyback request and the last method is to use the contention-based CDMA Bandwidth request.

- **Bandwidth request header**

  The SS can request the uplink resource by sending the bandwidth request header to take advantage of remaining resource when the SS receives the uplink resource and the SS still has the remaining resource after the data or control message transmission. This request is originated by not SS but SS’s contention identifier (CID). In other word, the SS requests the uplink resource classified by each service.

- **Piggyback request**

  The piggyback request method is that the SS requests the uplink resource using piggyback request field of the grant management subheader which is optional method in the IEEE 802.16 standard.

- **CDMA code based bandwidth request**

  In the contention-based CDMA bandwidth request, the ranging channel is assigned to SS. When the SS sends the uplink resource, the SS selects a CDMA code randomly from the code subset allocated for bandwidth request. Then, this code is modulated onto the ranging subchannel and is transmitted during the appropriate uplink allocation. After receiving the CDMA code successfully, the BS allocates the uplink resource to SS which transmitted the code using the CDMA_Allocation-IE. However, the CDMA code does not have any information about SS, so the BS broadcasts a CDMA_Allocation-IE which advertises the received CDMA code as well as the ranging slot where the CDMA code has been identified. This information is used by the SS that sent the CDMA code to identify the CDMA_Allocation-IE that corresponds to its bandwidth request. If the SS sends the CDMA code but it does not receive the resource, then the SS thinks that the code is collided with others and it retransmits the code after binary exponential backoff procedure. The procedure is shown as Fig. 1.

2) **Polling**

Polling is the process that a BS periodically allocates same bandwidth to the SSs for the purpose of making the bandwidth requests. In order to make bandwidth requests, the BS allocates some resource to special SS on a periodic basis. The volume of allocated resource is the size that the SS needs to transmit the bandwidth request header (6 bytes). The allocation may be intended to one SS or many SSs. This polling is usually used for SS to support the real-time polling service (rtPS) such as video traffic.

### III. Proposed CDMA code based Bandwidth Request Mechanism in MMR System

In the IEEE 802.16 MMR system, as we mentioned above, it is desirable that wherever an SS is located, the BS should allocate the resource to the SS which wants the uplink resource. Therefore, we propose the efficient bandwidth request mechanism in MMR system. To explain the proposed mechanism, we assume that the BS only controls the SS though the SS is in the RS region, so the RS just relays the packet from the BS to SS. Moreover, we assume that the SS can not distinguish the BS from the RS, so the SS regards the RS as the BS though the SS is connected to the RS. We also assume that the RS operates like the SS when the RS communicates the BS. To explain the our mechanism, we define the link and zone as follows:

- **Access link**
  An 802.16 radio link that originates or terminates at an SS. The access link is either an uplink or downlink as defined in IEEE 802.16 standard.

- **Relay link**
  An IEEE Std. 802.16j radio link between a BS and a RS. This can be a relay uplink or downlink.

- **DL(UL) access zone**
  A portion of the DL(UL) sub-frame in the BS/RS frame used for BS/RS(SS) to SS(BS/RS) transmission

- **DL(UL) relay zone**
  A portion of the DL(UL) sub-frame in the BS/RS frame used for BS(RS) to RS(BS) transmission

#### A. Proposed bandwidth request mechanism

To operate CDMA code based bandwidth request mechanism in IEEE 802.16j MMR system, we propose two methods. One method is that the RS uses a new MR_Code-REP message. Another method is that the RS uses the CQICH of relay link instead of MR_Code-REP message. In the second method, the BS can allocate the CQICH of relay link to an RS in its cell for reporting the information related with BW request CDMA code. The allocation of CQICH for RSs is performed in relay zone.

In the proposed method, if a RS receives BW request CDMA codes from SSs, then the RS counts the number of SS which transmits BW request CDMA code. Then, using MR_Code-REP message or the CQICH of relay link, the RS reports the number of SS to BS. When the BS receives the number of SS that have transmitted the CDMA code from MR_Code-REP message or the CQICH of relay link, the BS provides SS with bandwidth allocation for BW request header or data packet by using CDMA_Allocation_IE. The detailed operation procedure is as follows.

Firstly, SSs select the BW request CDMA code from code set for bandwidth request. Then, the codes are modulated onto Ranging Subchannel and transmitted to RS. On receiving the CDMA codes, the RS stores the CDMA code information such as Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging Subchannel in the buffer. The stored information is thereafter used when the RS transmits the
CDMA_Allocation_IE to the SS. After checking all BW request CDMA codes, the RS counts the number of SSs which have transmitted the CDMA code for bandwidth request, then, transmits the MR_Code-REP message or 6-bits payload on the CQICH of relay link to notify BS the number of SSs which have transmitted CDMA codes for bandwidth request. In MR_Code-REP message, the information related with CDMA code such as Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging Subchannel is not included in the field of message. The MR_Code-REP message has the number of SSs which have transmitted CDMA codes for bandwidth request. On the other hand, when CQICH of relay link is used, to distinguish SS’s number reporting from general CQI reporting on CQICH, using reserved bits in original standard, the BS transmits the CQICH.Enhanced.Allocation_IE in which Feedback Type is newly set as 0b110 and CQICH Type is newly set as 0b000. By using above method, the RS properly can use CQICH of relay link for the purpose of reporting the number of SSs that have transmitted the CDMA code.

After receiving the CDMA code information which means the number of SSs that have transmitted CDMA code for bandwidth request, BS provides uplink bandwidth allocation for the SSs by sending CDMA_Allocation_IE. However, BS does not know the information related with CDMA code such as Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging subchannel because BS receives only the number of SSs who have transmitted CDMA code through MR_Code-REP message or the CQICH of relay link, not the entire CDMA codes of SSs. Therefore, when BS transmits CDMA_Allocation_IE to RS, the CDMA_Allocation_IE does not contain the fields of Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging Subchannel. On receiving the CDMA_Allocation_IE from BS, the RS inserts the fields of Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging subchannel using the stored information in the buffer. Then, RS transmits the CDMA_Allocation_IE for each SS. The proposed bandwidth request mechanism is shown in Fig. 2 and Fig.3. In the proposed method, the procedure of bandwidth request is done only one time though many SSs request bandwidth.

IV. PERFORMANCE ANALYSIS

Three methods are analyzed: conventional message based method, bandwidth request method using MR_Code-REP messages (proposed I scheme) and the CQICH of relay link (proposed II scheme). The conventional message based mechanism means that the RS sends the message that contains the CDMA code information such as Repetition Coding Indication, CDMA Code, Ranging Symbol and Ranging subchannel to BS for each BW request CDMA code. Therefore, if k SSs transmit the CDMA code to RS for bandwidth request, the RS will transmit the MR_Code-REP k times. However, in case of two proposed methods, the procedure of bandwidth request is done only one time though many SSs request bandwidth. In performance analysis, we assume that the number of SSs who have transmitted CDMA code for bandwidth request is k. Also, we assume that the RS relays the data to BS or SS at next frame when it receive the data at current frame. We also assume that there are no errors in all the links. The network architecture is shown as Fig. 4 To evaluate the performance of proposed bandwidth request mechanism, we analyze the signaling cost and delay.

A. Signaling Cost

1) Signaling cost in case of conventional message method

When the SS sends a BW request CDMA code to RS, the RS sends an appropriate RS CDMA code toward BS indicating that one of its SSs is requesting to forward a BW request header to the BS. Therefore, the resource (C_{con}^{RS}) used for the RS to request the bandwidth for one SS is calculated as

\[ C_{con}^{RS} = C_{code}(144\text{bits}) + C_{message}(40\text{bits}) = 184\text{bits} \]  

where \( C_{code} \) means the size of RS CDMA code and \( C_{message} \) means the size of conventional message [2].

Also, the resource (C_{con}^{BS}) used for BS to allocate bandwidth for one SS is calculated as

\[ C_{con}^{BS} = C_{UL\_MAP}(56\text{bits}) + C_{UL\_MAP\_IE}(20\text{bits}) + C_{BW\_REQ\_header}(16\text{bits}) + C_{UL\_MAP}(56\text{bits}) + C_{UL\_MAP\_IE}(20\text{bits}) + C_{CDMA\_Allocation\_IE}(32\text{bits}) = 200\text{bits} \]  

(2)
where \( C_{BW\_REQ\_header} \) means the resource that the BS allocates for RS to transmit the bandwidth request header. \( C_{UL\_MAP\_IE} \) and \( C_{CDMA\_Allocation\_IE} \) are needed for each SS.

Hence, the total resource \( C_{con}^{\text{total}} \) used in bandwidth request scheme through conventional message for \( k \) SSs is given by

\[
C_{con}^{\text{total}} = k \times (C_{RS}^{con} + C_{BS}^{con}) = k \times (184 + 200) = 384 \cdot k \text{ bits}
\]

(3)

2) Signaling cost in case of MR_Code-REP method
When the SSs send BW request CDMA codes to RS, the RS sends an appropriate RS CDMA code toward BS indicating that SSs are requesting to forward a BW request header to the BS. Therefore, the resource \( C_{RS}^{total} \) used for the RS to request the bandwidth for \( k \) SSs is calculated as

\[
C_{RS}^{total} = C_{code}(144\text{bits}) + C_{message}^{total}(16\text{bits}) = 160\text{bits}
\]

(4)

where \( C_{code} \) means the size of RS CDMA code and \( C_{message} \) means the size of MR_Code-REP message.

Also, the resource \( C_{BS}^{total} \) used for BS to allocate bandwidth is calculated as

\[
C_{BS}^{total} = C_{UL\_MAP}(56\text{bits}) + C_{UL\_MAP\_IE}(20\text{bits}) + C_{BW\_REQ\_header}(16\text{bits}) + C_{UL\_MAP}(56\text{bits}) + k \cdot C_{UL\_MAP\_IE}(20\text{bits}) + k \cdot C_{CDMA\_Allocation\_IE}(32\text{bits}) = 148 + 52k \text{ bits}
\]

(5)

where \( C_{BW\_REQ\_header} \) means the resource that the BS allocates for RS to transmit the bandwidth request header. \( C_{UL\_MAP\_IE} \) and \( C_{CDMA\_Allocation\_IE} \) are needed for each SS.

Therefore, the total resource \( C_{total}^{\text{con}} \) used in bandwidth request scheme through MR_Code-REP message for \( k \) SSs is calculated as

\[
C_{total}^{\text{con}} = C_{RS}^{total} + C_{BS}^{total} = 160 + 148 + 52k = 308 + 52k \text{ bits}
\]

(6)

3) Signaling cost in case of CQICH method
We calculate the resource used for proposed bandwidth request method. The resource \( C_{RS}^{H} \) which RS uses to relay the bandwidth request of \( k \) SSs is formulated as

\[
C_{RS}^{H} = C_{CQICH}(6\text{bits}) + \frac{6}{2^p}\text{bits}
\]

(7)

where \( C_{CQICH} \) means the 6-bits payload that is transmitted by the CQICH of relay link and \( 2^p \) means the period of CQICH allocation. \( \frac{6}{2^p} \) means the size of wasted resource when the RS does not use the CQICH of relay link.

After the BS receives the message from the RS through the CQICH of relay link, the resource \( C_{BS}^{H} \) which the BS uses to allocate the bandwidth for \( k \) SSs is derived as

\[
C_{BS}^{H} = C_{UL\_MAP}(56\text{bits}) + k \cdot C_{UL\_MAP\_IE}(20\text{bits}) + k \cdot C_{CDMA\_Allocation\_IE}(32\text{bits}) = 56 + 52k \text{ bits}
\]

(8)

where \( C_{UL\_MAP\_IE} \) and \( C_{CDMA\_Allocation\_IE} \) are needed for each SS.

Therefore, the total resource \( C_{total}^{H} \) used in bandwidth request scheme through CQICH of relay link for \( k \) SSs is calculated as

\[
C_{total}^{H} = C_{RS}^{H} + C_{BS}^{H} = 62 + 52 \cdot k + \frac{6}{2^p} \text{bits}
\]

(9)

B. Delay

To analyze the delay performance, we assume as follows

- \( T_1 \) : Transmission time from SS to RS
- \( T_2 \) : Transmission time from RS to BS
- \( T_3 \) : Transmission time from BS to RS
- \( T_4 \) : Transmission time from BS to SS
- \( T_{CQI} \) : Delay generated due to CQICH reporting (0 < \( T_{CQI} < 27 \text{ frames} \))

1) Delay in case of conventional message based method
The expected minimum delay for bandwidth request about one SS is described as

\[
D_{con}^{\text{one}} = T_1(\text{CDMA code transmission from SS to RS}) + T_2(\text{RS CDMA code transmission from RS to BS}) + T_3(\text{UL_MAP from BS to RS}) + T_2(\text{conventional message from RS to BS}) + T_3(\text{UL_MAP transmission from BS to RS}) + T_4(\text{UL_MAP transmission from RS to SS}) = T_1 + 2 \times (T_2 + T_3) + T_4
\]

(10)

Therefore, the delay needed for bandwidth request about \( k \) SS is calculated as

\[
D_{con}^{\text{total}} = k \cdot (T_1 + 2 \times (T_2 + T_3) + T_4)
\]

(11)

2) Delay in case of MR_Code-REP method
The expected minimum delay \( D_I \) for bandwidth request about \( k \) SS is described as
Delay ($k$ SS, 1 RS, 1 BS)

<table>
<thead>
<tr>
<th>Signaling Cost</th>
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</thead>
<tbody>
<tr>
<td>Conventional message based method</td>
</tr>
<tr>
<td>$k(T_1 + 2 \times (T_2 + T_3) + T_4)$</td>
</tr>
<tr>
<td>MR_Code-REP method</td>
</tr>
<tr>
<td>$T_1 + 2 \times (T_2 + T_3) + T_4$</td>
</tr>
<tr>
<td>CQICH method</td>
</tr>
<tr>
<td>$\frac{T_{CQI}}{2} + T_1 + T_2 + T_3 + T_4$</td>
</tr>
</tbody>
</table>

$$D_I = T_1 (\text{CDMA code transmission from SS to RS})$$
$$+ T_2 (\text{RS CDMA code transmission from RS to BS})$$
$$+ T_3 (\text{UL_MAP from BS to RS})$$
$$+ T_2 (\text{MR_Code-REP message from RS to BS})$$
$$+ T_3 (\text{UL_MAP transmission from BS to RS})$$
$$+ T_4 (\text{UL_MAP transmission from RS to SS})$$
$$= T_1 + 2 \times (T_2 + T_3) + T_4$$  \hspace{1cm} (12)

3) Delay in case of CQICH method

The expected minimum delay ($D_{II}$) for bandwidth request about $k$ SS is described as

$$D_{II} = T_1 + \frac{T_{CQI}}{2} + T_2 + T_3 + T_4$$  \hspace{1cm} (13)

where $T_1$ means the time that it takes to transmit the CDMA code from SS to RS, $\frac{T_{CQI}}{2}$ means average waiting time before CDMA code information is transmitted from RS to BS through CQICH, $T_3$ means the time that it takes to transmit the UL_MAP from BS to RS and $T_4$ means the time that it takes to transmit the UL_MAP from RS to SS.

Each result of signaling cost and delay is shown as Table I, II.

V. NUMERICAL RESULTS

We evaluated the performances of the proposed mechanisms using C++ programming. In case of CQICH based method, the value of $p$ and $T_{CQI}$ is 1, which means that the CQICH is allocated every frame. The number of node is varied from 10 to 20 and the frame size of IEEE 802.16 system we applied is 5 ms.

Fig. 5 shows the numerical result of the signaling cost versus number of nodes for conventional scheme and the proposed scheme, respectively. We observe that when the number of node increases, signaling cost of system in both schemes is larger. Moreover, we can also identify that as the number of nodes increases, the proposed mechanism reduces the signaling cost compared to conventional message based method by merging the bandwidth request of many SSs. Fig. 6 shows numerical result of delay according to user. As shown in figure, delay time of two proposed methods is much less than that of conventional message based scheme. Especially, the delay is reduced by more than 80% with the CQICH based method compared to conventional message method since the CQICH is always connected between BS and RS.

VI. CONCLUSIONS

In this paper, we proposed an efficient contention based CDMA bandwidth request mechanism for SS located in RS region in the IEEE 802.16 MMR system. In the proposed mechanism, an SS can receive the uplink resource very well wherever an SS is located. Furthermore, the proposed mechanism has a better performance in view of the signaling cost and delay than the conventional message based method since the procedure of bandwidth request is done only one time though many SSs request bandwidth.

REFERENCES