Project	***IEEE 802.16j Mobile Multihop Relay Task Group***
Title	***Aggregation in 802.16j ─ Enhanced Concatenation and Packing***
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Source(s)	**Jeffrey Z. Tao, Koon Hoo Teo, Jinyun Zhang** *Mitsubishi Electric Research Lab* *201 Broadway* *Cambridge, MA 02139 USA* *Voice: 617-621-{7557,7527}* *Fax: 617-621-7550* *{tao, teo, jzhang}@merl.com* **Toshiyuki Kuze** *Mitsubishi Electric Corp* *5-1-1 Ofuna Kamakura, Kanagawa* *2478501, Japan* *Voice: +81-467-41-2885* *Fax: +81-467-41-2486* *Kuze.Toshiyuki@ah.MitsubishiElectric.co.jp*
Re:	*Response to the call for proposal of the 802.16j relay TG (i.e., IEEE 802.16j-06/027, “Call for Technical Proposals regarding IEEE Project P802.16j”, October 15, 2006).*
Abstract	*This contribution describes enhancements to the MAC level concatenation and packing mechanisms defined in current IEEE 802.16e.*
Purpose	*To adopt the enhanced concatenation and enhanced packing schemes proposed herein into IEEE 802.16j.*
Notice	
Release	
Patent Policy and Procedures	

Aggregation in 802.16j
— *Enhanced Concatenation and Packing*

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Jeffrey Z. Tao, Koon Hoo Teo, Jinyun Zhang
Mitsubishi Electric Research Lab
201 Broadway
Cambridge, MA 02139 USA

Toshiyuki Kuze
Mitsubishi Electric Corp
5-1-1 Ofuna Kamakura, Kanagawa
2478501, Japan

1. Introduction

As illustrated in **Figure 1**, the new mobile multi-hop relay-based (MMR) network architecture imposes a demanding performance requirement on relay stations. These relays will functionally serve as an aggregating point on behalf of the BS for traffic collection from and distribution to the multiple MSs associated with them, and thus naturally incorporate a notion of "traffic aggregation". However, the packet construction mechanism in IEEE 802.16/16e standard, which was designed for handling traffic solely on a per-connection basis, cannot apply on the relay link directly, as it may render a potential bottleneck and preponderantly limit the overall network capacity.

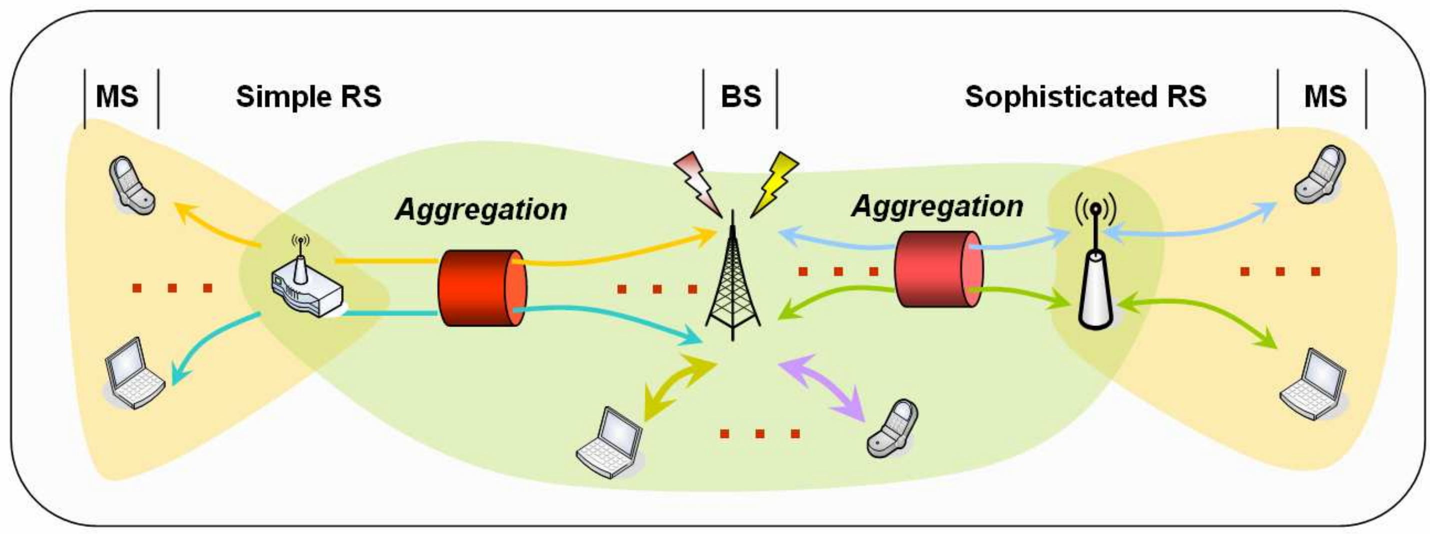

Figure 1: An illustration of an IEEE 802.16j network.

In this contribution, we propose two enhancements related to MAC level concatenation and packing, which incarnate the inherent notion of "aggregation" and alleviate the dismal efficiency degradation on the relay links. As confirmed by the preliminary performance evaluation, the enhanced concatenation and packing schemes can achieve significant overhead reduction, and thus better prepare the 802.16e protocol for its adoption in MMR network.

2. Summary of Proposal

In the current point-to-multipoint (PMP) network topology, resource allocation is performed by BS on a per connection basis, and all the MSs are treated more or less equally. This is a sensible design for a single-hop

PMP network, but by no means the most efficient one. Indeed, it has already been shown in [3][4] that as the number of connections increases, the overhead entailed thereby can cost as much as over 50% MAC efficiency degradation. The primary culprits of the performance deterioration are twofold:

- **Data plane**

Usually, the resource allocated to each individual connection cannot be fully consumed, because the actual data bits do not map exactly to the assigned OFDMA symbols and subchannels. Due to this *mapping inefficiency*, variable number of padding bits will be appended at the end of the data, leading to resources waste as depicted in **Figure 2**.

- **Management plane**

  In the current management plane, one downlink MAP information element (DL MAP IE) normally contains the schedule for one connection only. This design becomes cumbersome and inefficient as the number of connections grows large.

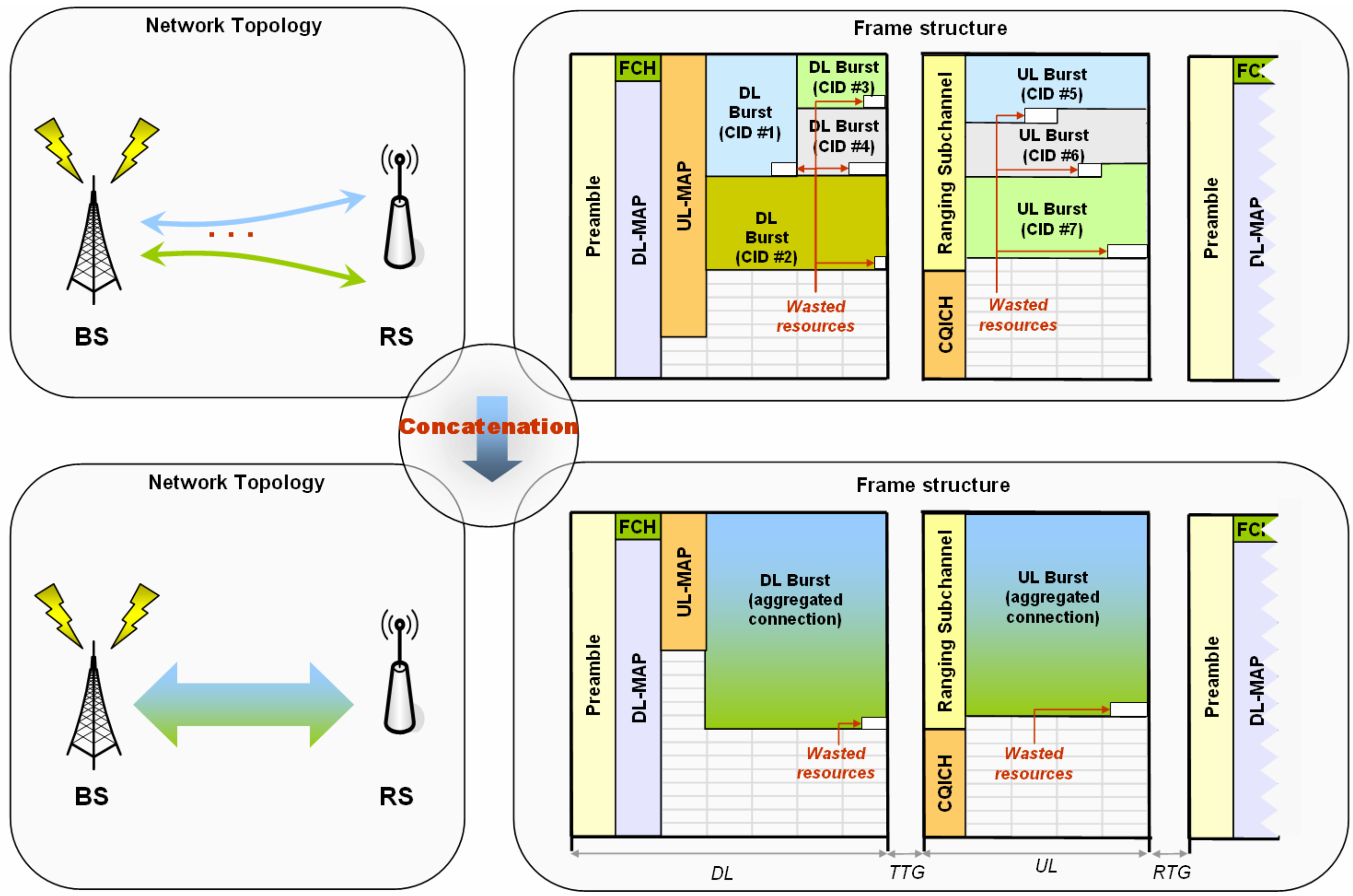

Figure 2: An illustration of efficiency improvement by concatenation.

The aforementioned problem is exacerbated when the current IEEE 802.16e OFDMA protocol is applied on the relay link between a BS and a RS, or between a pair of RSs, as significant number of connections will be logically or physically aggregated therein.

To curb the waste and improve the performance of current IEEE 802.16e protocol on relay links, we propose to enhance the legacy concatenation scheme, which directly addresses the problem in the data and management planes. In addition, we also introduce an extension of the current packing mechanism, intending to complement the highly restrictive original version defined in the current 802.16.

2.1 Enhanced Concatenation

IEEE 802.16 [1] has defined an operation called concatenation, whereby multiple MPDUs can be concatenated into a single transmission burst in either uplink or downlink direction, regardless of whether these MPDUs are belonging to the same connection or not. In essence, IEEE 802.16 concatenation is equivalent to an aggregation at MPDU level.

IEEE 802.16e [2] has further extended the DL MAP IE of legacy IEEE 802.16 [1] in order to carry the identifiers of multiple connections (CIDs) in a single information element (IE). The last missing link to enabling efficient concatenation on relay link is the capability of supporting multiple connections using one uplink information element. In the uplink, allocations for regular data traffic are specified as duration in slots, whereas the starting point for allocation is determined based upon the prior allocation appearing in the UL-MAP.

For those situations where backward compatibility with legacy MSs has to be honored, the UL MAP IE thus shall be modified in such a fashion that these legacy MSs are still able to derive their own assigned schedule based on the new UL MAP IE. Thus, we propose to extend the UL MAP IE for relay link as portrayed in **Figure 3** and **Figure 4**, where the support to multiple connections can be accomplished while backward compatibility is also maintained. For the sake of brevity, all the ensuing discussions apply for communications occurring on relay links only, unless otherwise noted.

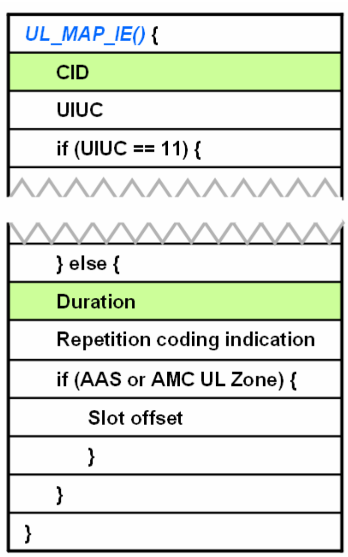

Figure 3: UL_MAP_IE 1.

UL_MAP_IE() {
CID
UIUC (set to 11)
if (UIUC == 11) {
Extended-2 UIUC (set to 0x09)
Length
N_CID (8 bits)
for (n = 0; n < N_CID; n++) {
CID;
}
}
}

Figure 4: UL_MAP_IE 2.

Whenever a relay station deems appropriate and necessary, it can aggregate a set of connections of the same QoS requirement from multiple MSs into a single logical connection. To convey resource allocation information associated with this set of connections, the UL MAP IE shown in **Figure 3** should appear first in the UL-MAP message. Its CID field contains the identifier of the corresponding new logical connection established on the relay link or a CID that the intended destination simply can recognize, while its duration covers the total resources given to all the connections belonging to this logical set. All the MSs that communicate with the BS directly can still understand the UL MAP IE 1, and thus calculate the starting point of the resource given to itself. The UL MAP IE 1 should be followed by UL MAP IE 2 immediately, which indicates the identifier of all the individual connections that the preceding UL MAP IE 1 covers. Since UL MAP IE 2 follows the ULMAP extended-2 IE format specified in IEEE 802.16e, all the legacy MSs simply skip this information element upon reception, and thus the backward compatibility remains intact.

The newly defined UL_MAP_IE, in conjunction with current DL_MAP_IE can provide necessary and sufficient signaling support to accommodate multiple connections. Thus, MPDU concatenation initially introduced in [1] now can be enabled in the data plane to achieve higher efficiency on the relay link. As qualitatively illustrated in

Figure 2, the total management plane overhead (e.g., UL_MAP_IE, etc.) and overhead caused by mapping inefficiency experience an appreciable reduction, thus resulting in MAC protocol efficiency improvement.

2.2 Enhanced packing

The packing mechanism defined in IEEE 802.16/16e essentially is an MSDU aggregation. However, it confines its scope to MSDUs from the same connection only. This poses a highly restrictive constraint particularly on a relay link, as MSDUs of different CIDs or even from different MSs may be transported over a single logical connection between the BS and RS, given the connection aggregation capability described before.

In order to relax the restriction imposed by legacy packing mechanism and extend the applicability of aggregation at MSDU level, we propose an enhanced packing (EP-SH) for communication on relay link. As illustrated in **Figure 5**, the whole packed MPDU is started with a general MAC header (GMH), followed by enhanced-packing subheader, various legacy subheaders (xSH), and the individual MSDU. The enhanced-packing (i.e., EP) subfield, which once was a reserved bit in the generic MAC header, will be used to indicate that the current MPDU contains packed MSDU using enhanced packing.

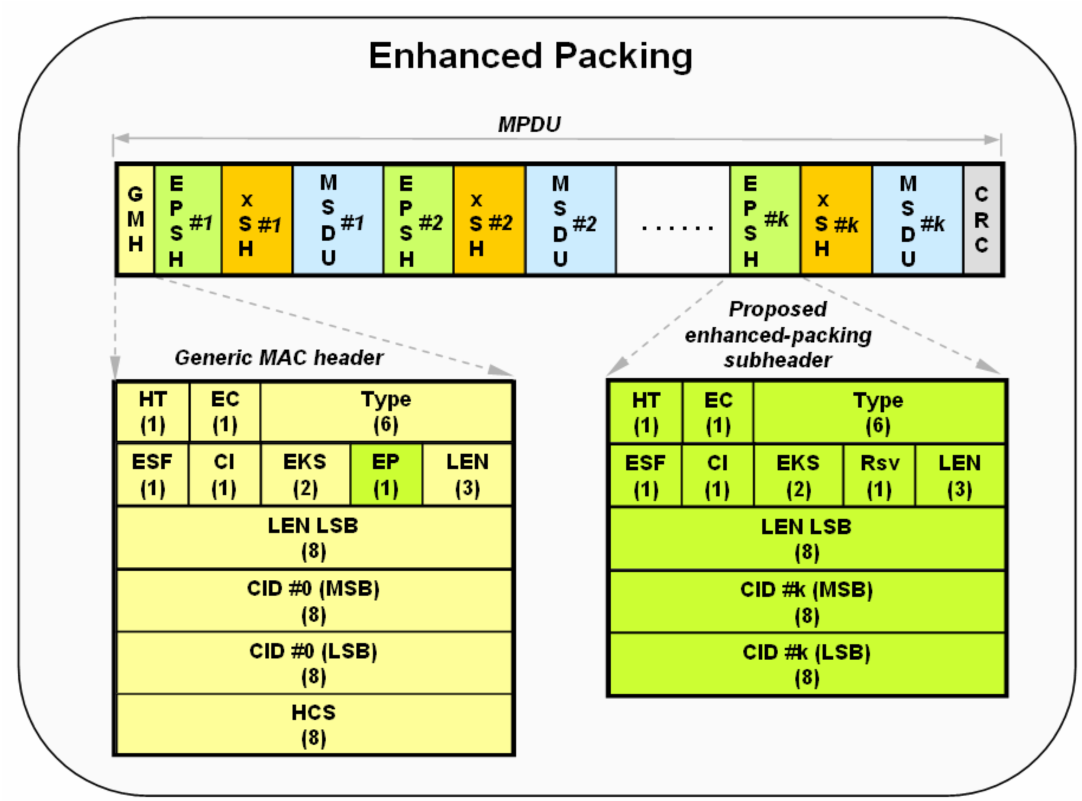

Figure 5: Enhanced packing

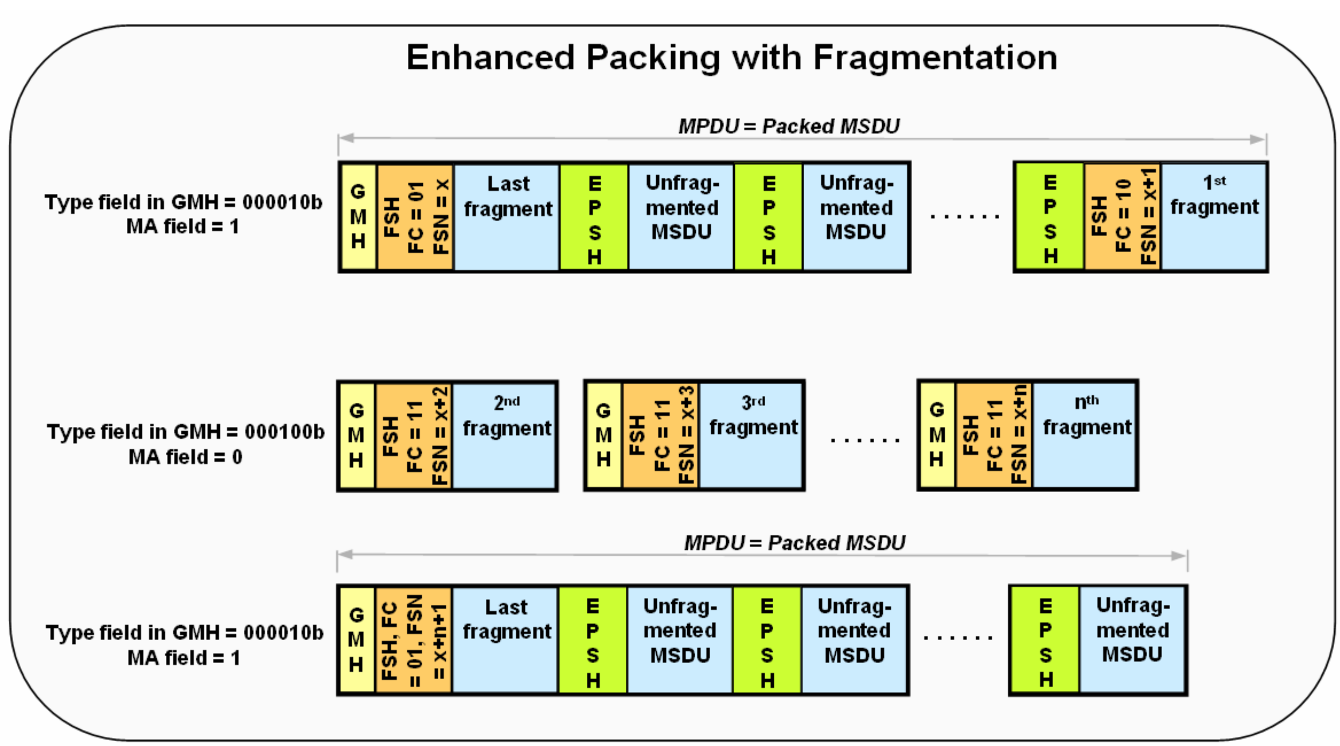

Figure 6: Enhanced packing with fragmentation

It is evident that the proposed EP-SH and the generic MAC header bear appreciable resemblance. Indeed, the only subfields that EP-SH can eliminate from the generic MAC header are header checksum (HCS) and cyclic redundancy check (CRC). All other subfields have to be retained, as many configurations (e.g., security protection, encryption key, MSDU length, and CID, etc.) may vary on a per MSDU basis. It is worthwhile to note that any concern of potential compromise of reliability can be dismissed, as similar overhead reduction approach was pursued in the legacy packing scheme.

The output of a legacy packing process, namely a packed MSDU, can again participate in the enhanced-packing process. In this case, one EP-SH will be placed directly in front of the first packing subheader (PSH) of the packed MSDU. As a result, an MPDU may contain both packing subheaders and enhanced-packing subheader.

Enhanced packing can also co-exist with fragmentation. As shown in Figure 6, EP-SH appears only once for an MSDU to be fragmented, and should be inserted right in front of the fragmentation subheader (FSH) for the first fragment.

The relation between EP-SH and FSH described above also applies for an ARQ-enabled connection, as such connection should be managed as if fragmentation was enabled, regardless of whether fragmentation is actually enabled or not in reality [1].

Since there is only one bit of reserved field left in the IEEE 802.16e generic MAC header, it is certainly a piece of highly scarce resource that many other potential protocol extensions may vie for. Alternatively, we can use the most significant bit (i.e., bit #5) of the type field in generic MAC header to indicate the presence of enhanced-packing subheader. As another option to signal the existence of EP-SH is to use a combination value of the six-bit long type field that is impossible to appear if using IEEE 802.16e standard interpret,

Moreover, as the enhanced-packing subheader contains a comprehensive set of information, it is possible to support a rich set of additional functions, such as attaching CRC on a per MSDU basis, etc.

3. Performance Results

To perform a more quantitative evaluation, we define MAC protocol efficiency Eff and efficiency improvement Eff_+ as:

$$\begin{cases} Eff = \dfrac{B}{T} \times \dfrac{1}{R} \times 100\% \\ Eff_+ = \dfrac{Eff(scheme\ \ 1) - Eff(scheme\ \ 2)}{Eff(scheme\ \ 2)} \times 100\% \end{cases}$$

Equation 1

where B, T, and R denote the total number of MSDU bits, time to transmit these bits, and the actual physical layer transmission rate, respectively. To concentrate on the proposed schemes, an error-free channel condition is assumed. The network under investigation only includes one BS and one RS, and all the connections are established on the relay link. Moreover, suppose each connection has infinite traffic supply, and thus always has packets to transmit during the slots assigned to it. Other key PHY and MAC parameters used in evaluation are summarized in Table 1.

Table 1: Key PHY and MAC parameters

DL/UL permutation	***FFT size***	***Channel bandwidth***	***MCS (data)***	***MCS (MAP and preamble)***	***Cyclic prefix (G)***
PUSC/PUSC	*1024*	*20 MHz*	*64 QAM 3/4*	*QPSK 1/2*	*1/32*
Sampling factor (n)	***Period for UCD/DCD***	***Frame duration***	***Number of UL BW/RNG subchannels***		***RTG/TTG***
28/25	*Every 10 frames*	*20 ms*	*6*		*10 μs*

3.1 Enhanced concatenation

First of all, the size of UL-MAP message is depicted in Figure 7 as a function of number of connections for both the legacy IEEE 802.16e and the proposed extension of UL MAP IE. Evidently, the adoption of new UL MAP IE format always results in smaller management plane overhead, as compared to the legacy scheme. In addition, the overhead reduction becomes more pronounced, as the number of parallel connections grows. For example, the saving achieved can reach as high as 50%, when the relay station has to simultaneously support 55 connections or more.

Figure 8 further illustrates the relation between MAC efficiency and number of connections. It can be observed in Figure 8 that MPDU concatenation in conjunction with the extended UL MAP IE can sustain a stable MAC efficiency, while the legacy protocol yields serious efficiency degradation as the number of connections grows. This highly desirable feature of insensibility is particularly indispensable for 802.16j MMR network, as the relay links will experience magnitude of increase in the number of connections.

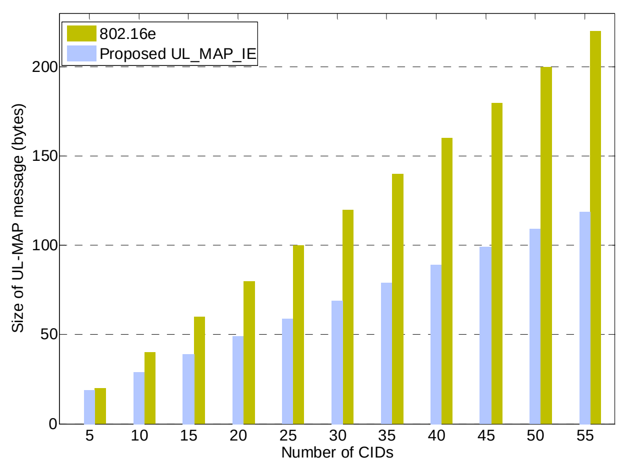

Figure 7: Size of UL_MAP message

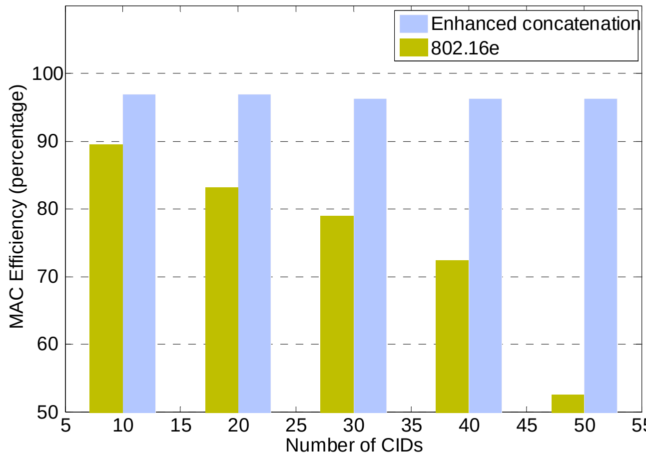

Figure 8: MAC efficiency (MPDU = 1000 bytes)

Figure 9 portrays the same relation as Figure 8, but focus on MPDUs of smaller size (i.e., 500). A simple comparison between these three figures suggests that both the MAC efficiency and the corresponding improvement enabled by the proposed MPDU concatenation heavily rely on the packet size. A closer examination of the performance results reveals that as the MPDU size decreases, it becomes more likely to occupy most of the allocated slots by fitting in small packets, thereby lowering the waste caused by mapping inefficiency to a lesser but still appreciable level.

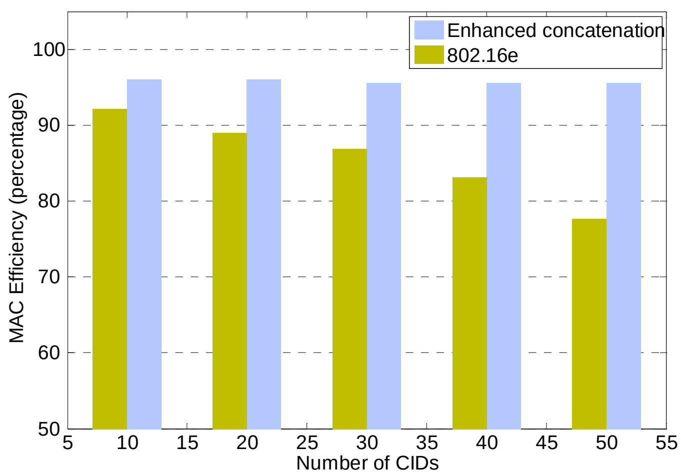

Figure 9: MAC efficiency (MPDU = 500 bytes)

3.2 Enhanced packing

Given the non-negligible impact of packet size, the performance of enhanced packing is evaluated with a wide variety of MSDU length, and results suggest that both packing and the proposed enhanced packing are most effective in the short packet region, which is consistent with the finding made in [4]. An empirical packet size distribution plotted in Figure 10 [6] is used to further evaluate enhanced packing in a more realistic environment. The traffic collected in [6] assumes a bimodal pattern, where packets generated by MAC management/control and TCP handshake (≤ 200 bytes) and by Ethernet data (= 1500 bytes) dominate. Although the distribution is specifically for IEEE 802.11 WLAN traffic, it is reasonable to assume that similar pattern also applies for IEEE 802.16e traffic.

Under the empirical traffic model, the efficiency improvement reaped in by enhanced packing is on average approximately *66%* of that by packing mechanism. On the other hand, the proposed enhanced packing enjoys a much wider applicability than the legacy packing, as it can handle MSDUs of different CIDs. Therefore, the two schemes are recommended to be deployed together on the relay links, thanks to their complementary nature.

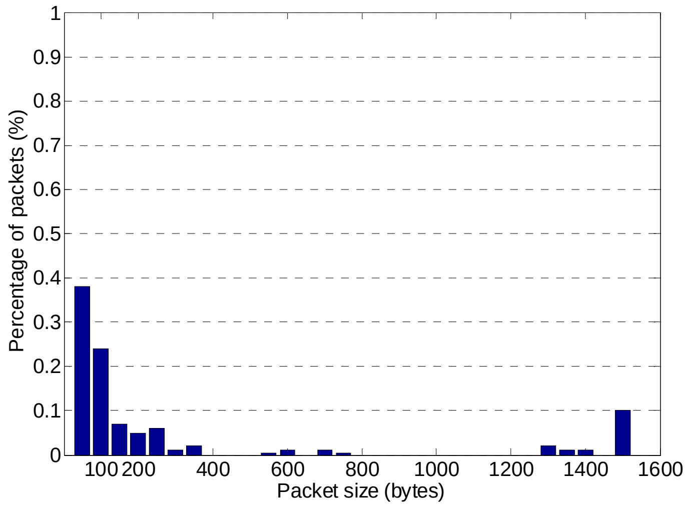

Figure 10: Empirical packet size distribution (IEEE 802.11)

4. Proposed Text Changes

6. MAC common part sublayer

6.3.2 MAC PDU formats

6.3.2.1 MAC header formats

Change Table 4 as indicated:

Table 4 – MAC header format

Syntax	Size	Notes
MAC Header () {		
…		
If (HT == 0) {		
…		
EKS		
EP	*1 bit*	*Indicate the presence of enhanced packing*

		EP = 1: enhanced packing subheader is present *EP = 0: enhanced packing subheader is absent*
LEN		
…		
}		

Replace Figure 19 with the following figure:

HT (1)	*EC (1)*	*Type (6)*		
ESF (1)	*CI (1)*	*EKS (2)*	*EP (1)*	*LEN (3)*
LEN LSB (8)				
CID (MSB) (8)				
CID (LSB) (8)				
HCS (8)				

Figure 19 – Generic MAC header format

Change the following row into Table 5:

Table 5 – Generic MAC header fields

Name	**Length (bits)**	**Description**
EP	*1 bit*	*Indicate the presence of enhanced packing* *EP = 1: enhanced packing subheader is present* *EP = 0: enhanced packing subheader is absent*

Insert the following to the end of 6.3.2.1.1:

The EP bit in the Generic MAC header indicates that the enhanced packing subheader is present.

Insert the following new subclause after 6.3.2.2.7:

6.3.2.2.8 Enhanced packing subheader

When enhanced packing is used, the MAC may pack multiple SDUs with different CID numbers into a single MAC PDU, with an enhanced-packing subheader preceding each individual MSDU. The enhanced packing subheader (EPSH) is shown in Table 13m.

Table 13m – Enhanced packing subheader format

Syntax	***Size (bit)***	***Notes***
MAC Aggregation Subheader () {		
HT	*1*	*Set be set to 0*
EC	*1*	*Encryption control* *0 = payload is not encrypted* *1 = payload is encrypted*

Type	*6*	*Indicate the presence or absence of certain subheaders and other features.* *On the relay link, the most significant bit shall be interpreted as indication of enhanced packing.*
ESF	*1*	*Extended subheader field.* *0 = Extended subheader is absent* *1 = Extended subheader is present*
CI		*CRC indicator* *1 = CRC is included in the MPDU* *0 = CRC is not included*
EKS	*2*	*Encryption key sequence* *The index of*
Rsv	*1*	*Reserved*
LENGTH	*11*	*The length in bytes of the MPDU including the MAC header and the CRC if present*
CID	*16*	*Connection identifier*
}		

6.3.3 Construction and transmission of MAC PDUs

6.3.3.4 Packing

Insert the following to the end of 6.3.3.4:

If enhanced packing is turned on for a connection, the MAC may pack multiple MAC SDUs with different CID numbers into a single MAC PDU. The transmitting side has full discretion as to whether or not to pack a group of MAC SDUs in a single MAC PDU. The capability of unpacking MPDU generated by enhanced packing is mandatory.

Insert the following new subclause after 6.3.3.4.3:

6.3.3.4.4 Enhanced packing

A MAC PDU constructed using enhanced packing is shown in Figure 27a. If more than one MAC SDU is packed into the MAC PDU, the indication of the presence of enhanced-packing subheader will be provided in the generic MAC header (e.g., EP bit, or MSB of the type field, etc.). Note that unfragmented MAC SDU and MAC SDU fragments may both be present in the same MAC PDU (see figure 28b).

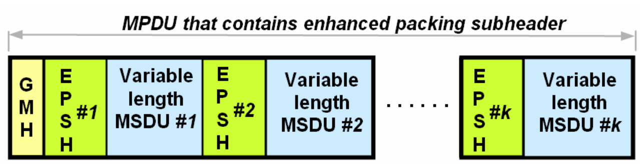

Figure 27a – MPDU generated as an output of enhanced packing

Simultaneous fragmentation and enhanced packing requires guidelines to be followed so it is clear which MAC SDU is currently in a state of fragmentation. To accomplish this, when an enhanced-packing subheader is present, the fragmentation information for individual MAC SDU or MAC SDU fragment is still contained in the corresponding fragmentation subheader.

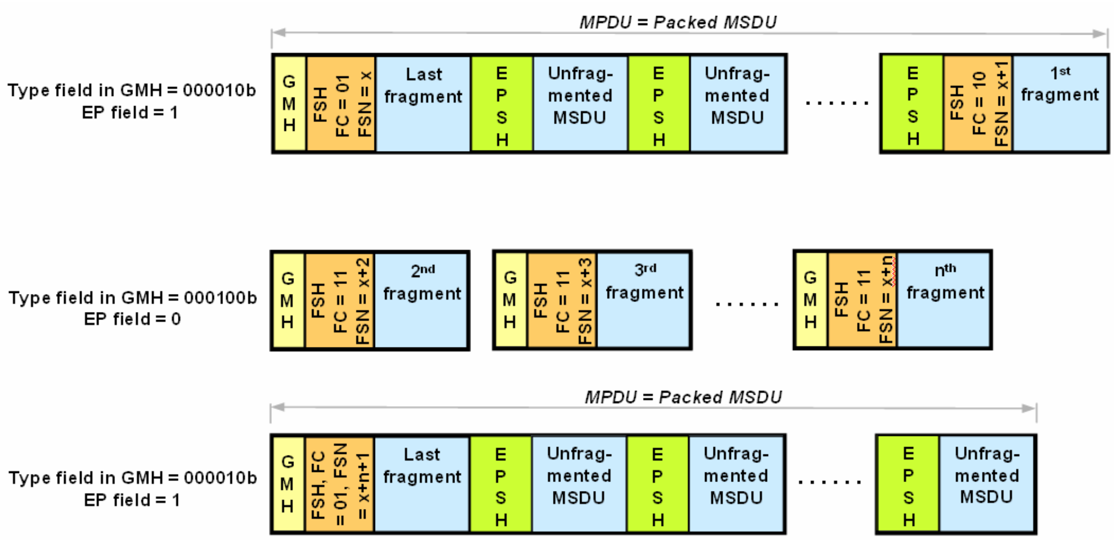

Figure 28a – Enhanced packing with fragmentation

The use of enhanced-packing subheader for ARQ-enabled connections is similar to that for non-ARQ connections, except that ARQ-enabled connections shall set the Extended Type bit in the generic MAC header to 1.

The ARQ-enabled connections, when enhanced-packing subheaders are in use, fragmentation information for each individual MAC SDU or MAC SDU fragment is contained in the associated fragmentation subheader. When the enhanced-packing subheader is not in use, fragmentation information for the MAC PDU's single payload (MAC SDU or MAC SDU fragment) is contained in the fragmentation subheader appearing in the message.

8 PHY

8.4.5 Map message fields and IEs

8.4.5.4 UL_MAP IE format

Insert the following before the beginning of subclause 8.4.5.4.1:

When the in the UL_MAP IE corresponds to a logical aggregate connection established between the RS and BS, the *Duration field* should indicate the duration, in unit of OFDMA slots, of the allocation for all the connections indicated in the immediately succeeding UL_MAP extended-2 IE with extended-2 type code 0x09.

8.4.5.4.4.2 UL_MAP extended-2 IE format

Change Table 290c as follows:

Table 290c – Extended-2 UIUC Code Assignment for UIUC = 11

Extended-2 Type (hex)	*Usage*
…	
09	*UL enhanced concatenation*
…	

Insert new subclause 8.4.5.4.29:

8.4.5.4.29 UL enhanced concatenation IE format

UL enhanced concatenation IE should immediately follow the UL_MAP_IE it is associated with. It shall include all the CIDs, for which the resource indicated in the immediately preceding UL_MAP_IE has been allocated. It is up to the implementation whether all CIDs have to be included in this IE or only a partial list is provided. It is under the discretion of RS as to how to divide the allocated resources among these connections, whose CID is not listed in the corresponding UL enhanced concatenation IE.

Table 302w – UL enhanced concatenation IE format

Syntax	*Size (bit)*	*Notes*
UL enhanced concatenation IE () {		
Extended-2 UIUC	*4*	*UL enhanced concatenation IE () = 0x09*
Length	*8*	*Length in bytes of following fields*
N_CID	*8*	*Number of CIDs included*
For (n=0; n<N_CID;n++) {		
CID;	*16*	*CID of the connection, to which the resource has been allocated to in the immediately preceding UL_MAP_IE*
}		
}		

5. References

[1] "IEEE Standard for Local and Metropolitan Area Networks − Part 16: Air Interface for Fixed Broadband Wireless Access Systems," IEEE Computer Society and the IEEE Microwave Theory and Techniques Society, October 2004.

[2] "IEEE Standard for Local and Metropolitan Area Networks − Part 16: Air Interface for Fixed Broadband Wireless Access Systems, Amendment 2: Physical and Medium Access Control Layers for Combined Fixed

and Mobile Operation in Licensed Bands," IEEE Computer Society and the IEEE Microwave Theory and Techniques Society, February 2006.

[3] S. Redana, M. Lott, and A. Capone, "Performance evaluation of point-to-multi-point (PMP) and mesh air-interface in IEEE standard 802.16a," in Proceedings of IEEE 60th Vehicular Technology Conference (VTC 2004-Fall), (Los Angeles, CA), September 2005.

[4] A. E. Xhafa, S. Kangude, and X. Lu, "MAC performance of IEEE 802.16e," in Proceedings of IEEE 62nd Vehicular Technology Conference (VTC 2005-Fall), (Dallas, Texas), September 2005.

[5] "Harmonized definitions and terminology for 802.16j Mobile Multihop Relay," IEEE 802.16j-06/014r1 http://www.ieee802.org/16/relay/index.html, October 2006.

[6] J. Yeo, M. Youssef, and A. Agrawala, "Characterizing the IEEE 802.11 Traffic: The Wireless Side," Technical report, Department of Computer Science, University of Maryland, March 2004, http://www.cs.umd.edu/˜moustafa/papers/CS-TR-4570.pdf