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Re:	Call for Technical Proposals regarding IEEE Project P802.16j (IEEE 802.16j-076/007r234)
Abstract	IE and TLVs that needs to be added to enable improved network entry support for relay stations.
Purpose	Adoption of the proposed text into P802.16j

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Routing Announcements for Network Entry Support

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1 Introduction

This contribution proposes a method ~~of~~ for optionally transmitting routing related parameters in order to facilitate the network entry of Relay Stations (RSs) in a multihop relay (MR) network. Exemplary mechanisms to compute RS end-to-end metric and convey it across multiple RS hops is provided. Furthermore, the contribution suggests a method of combining this metric with the physical air interface measurement of the access link for computing an MS end-to-end metric between an MR-BS and its subordinate MS.

In order to facilitate the incorporation of this proposal in to IEEE 802.16j standard, specific changes to the baseline working document IEEE 802.16j-06/026r2 are listed in Section 3.

2 General Description

In a multihop IEEE 802.16 network that employs relay stations (RS) for the purpose of coverage extension or capacity improvement, it is important for the RSs entering the network, to consider the routing characteristics of the access station and the path from the access station to its MR-BS, before associating with the access station.

2.1 Elements of Routing Announcements

There are several parameters that are of interest and should be considered.

2.1.1 Path Metric to the MR-BS

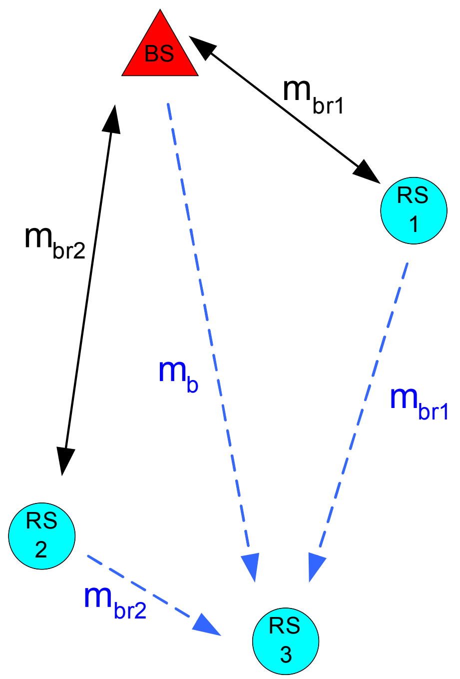

Figure 1 – Path metric announcement

Consider the exemplary network shown in Figure 1. BS is a MR-BS. RS1 and RS2 are already in the network and are associated to BS as per the topology shown. The end-to-end (ETE) path metric between RS1 and BS is m_{br1} and between RS2 and BS is m_{br2}.

When RS3 enters the MR network, it should be made aware of the ETE path metric from each access station to BS, so that RS3 may include this information in its network entry decisions. Each MR-BS and RS should transmit this information on the downlink using the mechanism described in Section 2.2. The MR-BS should also transmit a metric value (m_b, in this example).

2.1.2 Number of Hops to the BS

Each RS should transmit on the downlink, its number of hops to the MR-BS that they are associated to. The mechanism used to transmit this information is described in Section 2.2.

2.1.3 BSID

Each RS should transmit on the downlink, the BSID of the MR-BS it is associated to. The mechanism used to transmit this information is described in Section 2.2.

2.1.4 Next Hop towards the BS

Each RS should transmit on the downlink, the node ID of the device that is their next hop towards the MR-BS. The mechanism used to transmit this information is described in Section 2.2.

2.2 Data Encapsulation

The above information may be encapsulated ~~in to a structure (Routing_Advertisement_IE), and may be carried in the DL-MAP transmitted by the MR-BS and the RSs, as an extended IE.~~

~~Additionally, the above information may be encapsulated~~ as TLV~~s~~ encodings to be carried in the DCD message.

2.3 Modified Network Entry Procedure

Figure 55a has been modified and shown below to depict the changes anticipated to the network entry procedure as a result of the incorporation of path selection.

2.4 MS End-to-End Metric

A typical MS routing scenario in an MR network is illustrated in Figure 2. In this example, an MS comes in range of two relay stations, RS1 and RS2. The MS follows legacy 802.16e access link procedures and attaches to the RS that provides the strongest receive power of the access link preamble. However, this attachment decision could be suboptimum with respect to the MS ETE routing metric to the BS. In this section a procedure for performing optimized routing decisions is proposed.

It is assumed that RS1 and RS2 have established a route with their super ordinate BS and have obtained an estimate of the RS ETE routing metric to the BS using exchange of Routing_Advertisement_IE messages as proposed above. The BS commands RS1 and RS2 to perform access link measurements according to the signaling procedures proposed in [14]. Upon completion of these measurements, RS1 and RS2 obtain estimates of the access link metrics m_{rm1} and m_{rm2}, respectively. These metrics are combined with the corresponding RS ETE metrics m_{br1} and m_{br2} to obtain the MS ETE routing metrics that characterize the performance of the two possible MS-BS paths shown in Figure 2. Upon receiving the two MS ETE routing metrics, which could be relayed to the BS in the MAC management messages, the BS selects an appropriate route for the MS and informs of its routing decision the access RS of interest, in this case RS1 and RS2, via a reply MAC management message. To enact the routing decision, the access RS may rely on the legacy 802.16e handover signaling to switch the attachment point of the MS.

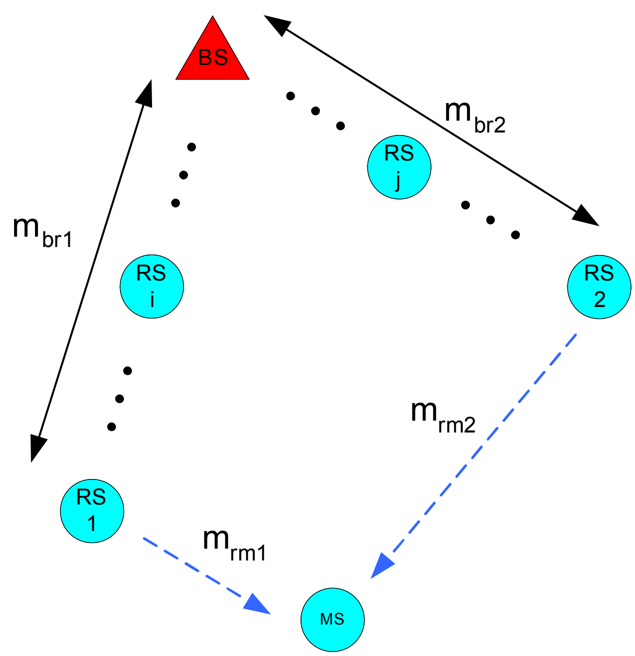

Figure 2 – MS route determination

2.5 Derivation of the end-to-end path metrics

The following PHY abstraction relationship is the key formula for quantifying the end-to-end quality of an N-hop routing path in terms of throughput in an MR network:

$$End\_to\_End\_Throughput = \left(\sum_{n=1}^{N} \frac{1}{Per\_Link\_Throughput\_over\_Hop\_n} \right)^{-1}.$$

In other words, based on this PHY abstraction, MR BS obtains an estimate of the end-to-end throughput by computing the harmonic mean of the per-link throughputs over the individual hops. This equation provides one incarnation of the end-to-end metric, referred to as m_{br1} and m_{br2} in the example figure above.

To motivate the quantification of end-to-end throughput as the harmonic mean of the throughputs over the individual wireless links, consider an N-hop routing path with time-division relaying such that the transmission rate at hop n is R_n bits/second/Hertz and all hops operate over the common bandwidth W but orthogonally time-share the channel. If the transmitted packet contains B bits of information, then the required transmission time at hop n is $t_n = B/WR_n$ seconds (ignoring retransmissions and channel overheads for now). Thus, the end-to-end latency T (i.e., the total time required to transmit this packet in multiple hops over the routing path), and the resulting end-to-end throughput (in bits/second/Hertz) can be calculated as

$$T = \sum_{n=1}^{N} t_n = \sum_{n=1}^{N} \frac{B}{WR_n} \qquad Throughput = \frac{B}{WT} = \left(\sum_{n=1}^{N} \frac{1}{R_n} \right)^{-1},$$

which validates the harmonic mean relationship. Alternatively, we can consider an N-hop routing path with frequency-division relaying such that the transmission rate at hop n is R_n bits/second/Hertz, all transmissions simultaneously occur over the time duration of T seconds and the bandwidth is allocated orthogonally among hops. Hence the channel over hop n should be allocated $W_n = B/TR_n$ Hertz of bandwidth, and accordingly the total required bandwidth W and the resulting end-to-end throughput can be calculated as

$$W = \sum_{n=1}^{N} W_n = \sum_{n=1}^{N} \frac{B}{TR_n} \qquad Throughput = \frac{B}{WT} = \left(\sum_{n=1}^{N} \frac{1}{R_n} \right)^{-1},$$

yielding the identical harmonic mean relationship, which therefore holds for any orthogonal sharing of resources (in time or frequency) among hops over a given routing path.

The harmonic mean formula assumes that optimizing time/frequency allocations among different hops over a given routing path in a channel-dependent manner is possible such that different rates can be transmitted over different hops; i.e., separate rate-adaptations can be performed across multiple hops so that each link can be operated at its best supportable rate chosen with respect to the instantaneous physical layer channel conditions. If the time duration and bandwidth of transmissions have to be fixed across multiple hops regardless of the channel qualities, fixed-rate transmissions over multiple hops will be necessary and therefore the rate supportable over the worst link will be a limitation on the rates chosen over the remaining links, which leads to the end-to-end throughput given by the scaled minimum relationship (applicable to both time-division and frequency-division relaying)

$$Throughput = \frac{1}{N} \min_{n=1,\ldots N} R_n .$$

The discussion in the remaining part of the contribution will focus on the end-to-end PHY abstraction methodology based on the harmonic mean metric, while it should be understood that these techniques can be easily applied to address the scaled minimum metric in the special case of fixed time slot and bandwidth allocation.

In the following, we shall provide two approaches for designing per-link metrics to allow the MR BS estimate the end-to-end throughput over a multi-hop link. It must be emphasized that **other per-link metrics for quantifying throughput over the individual hops can be designed as well; and one can still estimate end-to-end throughput in terms of per-link throughputs through the harmonic mean and scaled minimum formulas**.

Capacity-based Approach:

The capacity-based approach computes the harmonic mean of the capacities (only depends on the signal-to-interference-and-noise ratio (SINR)) over individual wireless links and obtains an end-to-end PHY abstraction given as follows:

$$SINR_{eff} = 2^C - 1, \quad where \quad C = \frac{1}{\sum_{n=1}^{N} \frac{1}{C_n}} = \frac{1}{\sum_{n=1}^{N} \frac{1}{\log_2(1+SINR_{eff,n})}}$$

Where:

$SINR_{eff}$: Effective SINR for the multi-hop route

C : Effective end-to-end capacity for the multi-hop route

C_n : Effective capacity over hop n, $n = 1,\ldots,N$

$SINR_{eff,n}$: Effective SINR over hop n

N : Number of hops over the established route between MR BS and MS

Further analysis on this capacity-based end-to-end PHY abstraction metric can be found in [1]-[4]. The effective SINR parameter, $SINR_{eff,n}$, is determined on a per-hop basis over each individual OFDMA PHY link, using any PHY abstraction methodology. In this respect, for an OFDMA system with K subcarriers, denoting the SINR over the k-th subcarrier and n-th hop by $SINR_{n,k}$, $n = 1,\ldots,N$, $k = 1,\ldots,K$, example PHY abstraction metrics could be

the mean-capacity metric proposed by [5]-[7], where

$$\log_2(1+SINR_{eff,n}) = \frac{1}{K}\sum_{k=1}^{K}\log_2(1+SINR_{n,k}) \Rightarrow SINR_{eff,n} = 2^{\frac{1}{K}\sum_{k=1}^{K}\log_2(1+SINR_{n,k})} - 1,$$

or the exponential effective SNR mapping (EESM) metric proposed by [8]-[11], where, for a given choice of parameter β,

$$SINR_{eff,n} = -\beta \log\left(\frac{1}{K}\sum_{k=1}^{K}\exp\left(-\frac{SINR_{n,k}}{\beta}\right)\right).$$

B. Throughput-based Approach:

This PHY abstraction approach involves more computation but is also more accurate than the capacity-based approach in terms of quantifying the end-to-end throughput performance. Unlike the capacity-based approach, the per-link throughput estimation accounts for losses in data rate due to link errors, finite modulation and coding schemes (MCSs) and overheads associated with channel access and protocols. In this setting, the end-to-end throughput estimation is based on computing the harmonic mean of achievable throughputs over individual wireless links.

We denote the expected transmission time (ETT) (first proposed by [12] for 802.11s mesh standard) over hop n as ETT_n, which represents the overall airtime cost in terms of the amount of channel resources consumed by transmitting the packet over the particular link and includes the cost of data transmission as well as cost of necessary retransmissions to recover from packet decoding errors and cost of overhead. Accordingly, the end-to-end throughput for a given multi-hop route of length N can be expressed as

$$Throughput = \frac{B}{T} = \frac{B}{\sum_{n=1}^{N} ETT_n} \quad where \quad ETT_n = \left(T_{overhead} + \frac{B}{R_n}\right) ETX_n.$$

Where:

ETX_n: Expected number of packet transmissions until successful reception over hop n subject to instantaneous channel conditions

R_n : Aggregate data rate per packet over hop n based on the MCS chosen by the link adaptation algorithm while satisfying a certain target packet error rate (PER) subject to instantaneous channel conditions
B : Number of bits per packet
$T_{overhead}$: Latency cost per link due to fixed channel access and protocol overheads

Note that the total sum of ETTs has a physical meaning as well; it is an estimate of the total end-to-end latency $T = \sum_{n=1}^{N} ETT_n$ experienced by a packet traveling along that path.

In the ETT formula, R_n and ETX_n both depend on the instantaneous channel realizations over hop n; in particular they depend on the vector of received SINRs over the K OFDMA subcarriers given by $\{SINR_{n,k}\}_{k=1}^{K}$, or effectively they depend on a single measure $SINR_{eff,n}$ computed using the per-link PHY abstractions.

To compute ETX_n more explicitly, we consider a hybrid automatic repeat request (HARQ) mechanism over each link, which requires packet retransmissions upon decoding failure, continued until successful reception of each packet. Thus, the definition of ETT also incorporates the impact of retransmissions upon erroneous reception of transmitted frames/packets and hence takes into account the additional transmission time necessary until successful delivery to the destination. Now,

If the HARQ protocol discards erroneous packets completely, we have

$$ETX_n = \frac{1}{1 - PER_n},$$

where PER_n denotes the packet error rate over hop n determined based on the chosen MCS and channel conditions over the physical layer given by the vector of SINRs in the set $\{SINR_{n,k}\}_{k=1}^{K}$.

If the HARQ protocol stores previously received erroneous packets and uses them during later decoding attempts (e.g. as in chase combining), the PER will improve upon retransmissions, which leads to

$$ETX_n = 1 + \sum_{m=1}^{M} \prod_{j=1}^{m} PER_{n,j},$$

where $PER_{n,j}$ denotes the conditional PER over hop n during transmission j provided that the transmissions for the first $j-1$ trials were unsuccessful, and M is the maximum number of allowed transmissions ($M-1$ retransmissions allowed).

Due to the stationarity of the terminals over the wireless backhaul (i.e. MR BS and RSs), we expect that the channels experienced over the hops will be slow-fading (except for the last hop involving the MS) and each node will be able to track its transmit/receive channels to perform link adaptation and estimate supportable throughput.

Considering the cost of each link to be equal to ETT_n, the throughput-maximizing path (i.e., the path that maximizes end-to-end throughput or minimizes end-to-end latency T) is the path that minimizes total end-to-end routing cost given by $T = \sum_{n=1}^{N} ETT_n$ for a path of length of N hops. The use of such end-to-end link QoS metrics toward designing centralized scheduling algorithms for MR systems have been studied in [13].

1

2.6 Computation of End-to-End Metrics Based on UL/DL Control Information

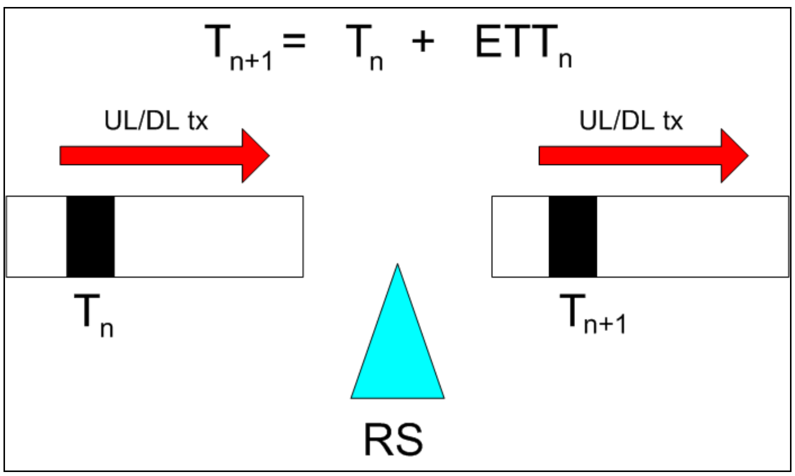

Figure 3 – Computation of ETE metrics

In general, the computation of the end-to-end path cost metric $\sum_{n=1}^{N} \frac{1}{C_n}$ in the capacity-based approach or $\sum_{n=1}^{N} ETT_n$ in the throughput-based approach requires a field in the uplink (UL) and/or downlink (DL) control messages to carry the end-to-end accumulated route costs, i.e. the summation of the reciprocal capacities or ETTs over various hops. This cost metric is to be propagated and updated based on the uplink (UL) and/or downlink (DL) control information transmissions, as depicted below for the throughput-based approach.

Specifically in this contribution, it is proposed to carry the ETE routing information in the Routing_Advertisement_IE transmitted as part of the DL MAP. As the Routing_Advertisement_IEs are received and processed at an RS, the RS will generate its own Routing_Advertisement_IE with the ETE field specifying the end-to-end path cost from itself to its associated MR-BS, taking into account the throughput/latency of transmissions over the current hop.

2

3 Proposed Text Changes

[Insert text in section 4]

OUI – Organizationally Unique Identifier

6.3.2.3.1 Downlink Channel Descriptor (DCD) message

Insert the following text at the end of the 6.3.2.3.1:

The following parameters, which are coded as TLV tuples as defined in 11.4, ~~shall~~ may be included in the DCD message.

Number of hops

The number of hops ~~to RS which transmits the DCD from BS~~from the RS that transmits the DCD to the BS it is attached to.

ETE Metric

The ETE metric of the path between the RS transmitting the DCD and the BS it is associated to.

Metric Type

The type of ETE metric being used.

BSID

The ID of the BS that the RS is associated to.

Next Hop Node ID

The ID of the next hop station towards the BS.

The RS entering the MR network shall decode the DCD and may use its contents to select the access station to enter the MR network through it. The RS shall then proceed to complete the rest of the network entry procedure with the selected access station.

6.3.9 Network entry and initialization

Insert the following text at the end of the 6.3.9:

The RS initial network entry procedure can be divided into the following phases:

a) Scan for downlink channel and obtain path selection parameters
b) Obtain transmit parameters (from UCD message)
c) Decide a desired path and establish synchronization with the superordinate node (BS or RS)
d) Perform ranging
e) Negotiate basic capabilities
f) Authorization RS and perform key exchange
g) Perform registration
h) Set up connections

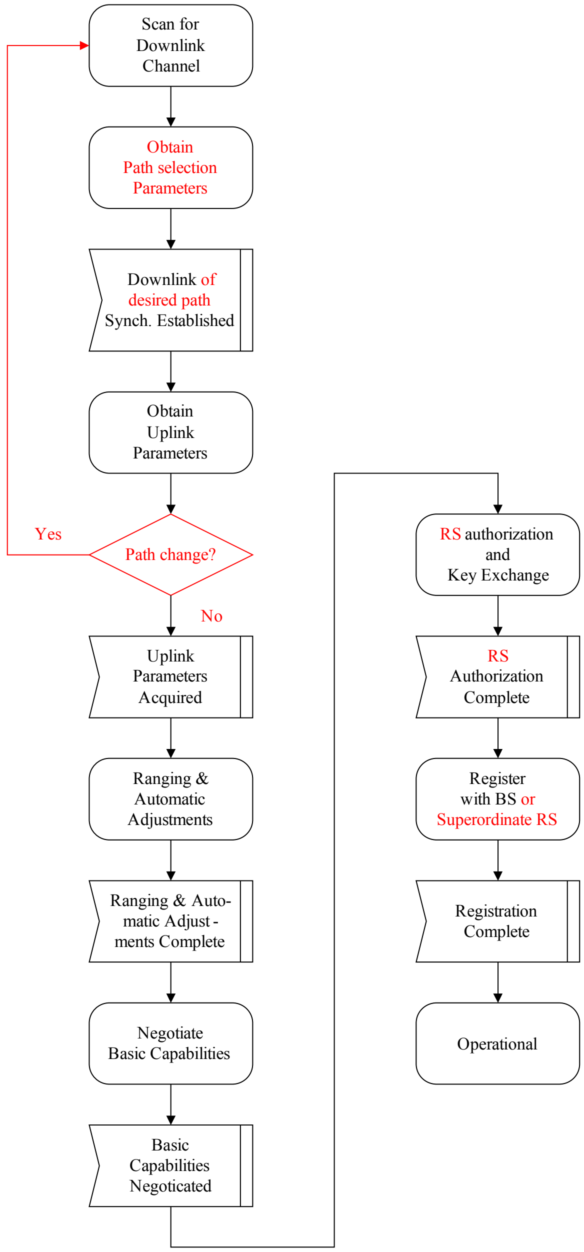

Figure 55a – RS Initialization overview

[Insert text in sub clause 6.3.9.16]

[Insert a new sub clause 6.3.9.16.31]

6.3.9.16.31 Network Entry Procedure for RS

This section describes the network entry procedure for relay stations entering an MR network.

[Insert a new sub clause 6.3.9.16.31.11]

6.3.9.16.31.1 Routing Announcements for network Entry Support

The MR-BS and the RS mayshall transmit the Routing_Advertisement_IE in the form of a DL-MAP extended IE TLV encoded parameters Number of Hops, ETE Metric, Metric Type, BSID, Next Hop Node in the DCD message to support RS network entry in the MR networkin the DL-MAP message transmitted in the MMR-BS-to-MS and RS-to-MS control zones. [These zones are defined in C80216j-06_155].

Routing_Advertisement_IE is The use of these TLV encodings is defined in section 8.4.5.3.2811.4 in Table 385.

The RS entering the MR network shallmay decode use the Routing_Advertisement_IEDCD TLV encodings and use its contents to select the access station to enter the MR network through it. The RS shall then proceed to complete the rest of the network entry procedure with the selected access station.

[Change section 8.4.5.3.2.1]

[Insert new row in Table 277a]

Extended DIUC (hexadecimal)	Usage
0A	Routing_Advertisement _IE

[Insert a new sub clause 8.4.5.3.28]

8.4.5.3.28 Routing Advertisement IE

[Insert the following text in section 8.4.5.3.28]

In the DL-MAP the MR-BS and the RS may transmit DIUC = 15 with the Routing_Advertisement _IE() to facilitate RS network entering.

Syntax	**Size**	**Notes**
Routing_Advertisement_IE(){	-	-
Extended DIUC	4 bits	RANN = 0x0A
Length	4 bits	Length = 0x06 or 0x13
ETE Metric	variable	The metric of the path from the access station to its MR-BS
Metric Identifier	32 bits	Identifies the ETE metric being used. Most significant 3 octets represent the OUI. Least significant 1 octet represents specific metric. See table (below) for metric identifier encoding.
BSID	48 bits	The BSID of the MR-BS to which the access station is associated
Next Hop Node ID	48 bits	The ID of the node next hop towards the MR-BS.
Number of Hops	8 bits	Number of hops from the access station to its MR-BS
}	-	-

The "Length" field of the Routing_Advertisement_IE() could take either of the two values, 0x06 and 0x13. This enables MR-BSs to transmit a shorter version of the Routing_Advertisement_IE().

The following table lists values for the Metric Identifier field and the method to generate vendor specific metric identifiers.

Metric Identifier		**Value**
OUI	**Metric #**	
00-0F-AC	01	TBD (Simple Standardized Metric)
Vendor OUI	Vendor Metric #	Vendor Specific Metric

11.4 DCD management message encodings

Insert the following entries into Table 385:

Table 385 – DCD channel encoding (continued)

Name	Type (1 byte)	Length	Value
Number of hops	61	2	Number of hops from the access station to its MR-BS
ETE Metric	62	2	ETE metric value
Metric Type	63	4	Identifies the ETE metric being used. Most significant 3 octets represent the OUI. Least significant 1 octet represents specific metric. See table (below) for metric identifier encoding.
BSID	64	6	The BSID of the MR-BS to which the access station is associated
Next Hop Node ID	65	6	The ID of the node next hop towards the MR-BS.

The following table lists values for the Metric Identifier field and the method to generate vendor specific metric identifiers.

The IEEE Registration Authority issued Organizationally Unique Identifier (OUI) is used in conjunction with a vendor specific 8-bit metric number to generate the Metric Identifier.

Metric Identifier		**Value**
OUI	**Metric #**	
00-0F-AC	01	TBD (Simple Standardized Metric)
Vendor OUI	Vendor Metric #	Vendor Specific Metric

4 References

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