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Re:	IEEE 802.16m-07/047 - Call for Contributions on the 802.16m System Description Document (SDD)	
Abstract	This document contains proposed text for the System Description Document. The text defines concurrent relay station frame zones that may significantly increase throughput within 802.16m systems that support multi-hop relaying.	
Purpose	To review and adopt the proposed text in the next revision of the 802.16m System Description Document.	
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Concurrent Relay Station Frame Zones for Multi-hop Relaying

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1 Introduction

The IEEE 802.16m System Requirements Document [1] states that an IEEE 802.16m system should provide techniques to enable multi-hop relaying [2]. The deployment of fixed and mobile relay stations within IEEE 802.16m systems poses many technical challenges. For example protocol data unit (PDU) routing, radio resource management, the use of advanced antenna technologies, network management, network security, cooperative relaying methods, etc. To facilitate the deployment of relay stations new network subsystems and methods are required. These subsystems and methods should not degrade system performance and should be added to existing systems with minimal system changes.

OFDMA frame structures are comprised of a number of frame elements such as bursts, zones, logical subchannels, logical subchannel groups, etc. Frame elements are physical layer or radio resources. Depending on time-varying channel, interference and network conditions a base station must optimally allocate or schedule frame elements to network users within its service area; the chosen allocations should maximize individual link spectral efficiencies and network capacity.

A zone is one complete logical time-frequency part or partition of an OFDMA subframe. There are a number of types of zones. To support multi-hop relaying one or more relay station zones may be serially concatenated within an OFDMA frame (see [3] for an example). Each zone is typically associated with a single relay station within a multi-hop network path. Hence, for multi-hop relaying the serial concatenation of relay station zones may result in a decrease in network capacity/throughput and an increase in latency. For 802.16m systems improved multi-hop frame structures and techniques are needed to better support multi-hop relaying.

Network capacity/throughput can be increased and latency decreased by concurrently transmitting or reusing relay station zones for independent network links. In this contribution we describe a technique for relay station zone reuse and a frame structure for multi-hop relaying that allows relay station zones to be concurrently transmitted. In the proposed technique a base station allocates relay station zones based on the spatial distribution of its subordinate relay and subscriber stations. A base station can concurrently use relay station zones for two or more relay stations whenever the spatial distribution of the stations is such that their co-channel interference is acceptable for their required service qualities.

2 A Network Model for Multi-hop Relaying

Figure 1 illustrates a segment of an example wireless cellular network $\mathcal{N}$ with relay stations added to support multi-hop PDU relaying. It will be used as a reference model to describe our contribution. The example network includes one base station (BS) and three relay stations (RS1, RS2, and RS3). Working together the base station and relay stations provide radio coverage to subscriber stations (SS1 to SS8). The relay and subscriber stations may be fixed in location or mobile. The circles enclose the coverage areas of the base station and relay stations, the relay station coverage areas may be varying if they are mobile.

Within the base station (or relay station) the Figure 1 network may be represented by the network graph shown in Figure 2. The network graph is defined by the triple $\mathcal{N} = (N, L, \mathbf{Q})$. Set N is the network's $M = 12$ element node set comprised of base stations, subscriber stations and relay stations, that is,

$$\begin{aligned} N &= \{n_1, n_2, n_3, n_4, n_5, n_6, \ldots, n_{12}\} \\ &= \{BS, RS1, RS2, RS3, SS1, SS2, \ldots, SS8\} \end{aligned} \tag{1}$$

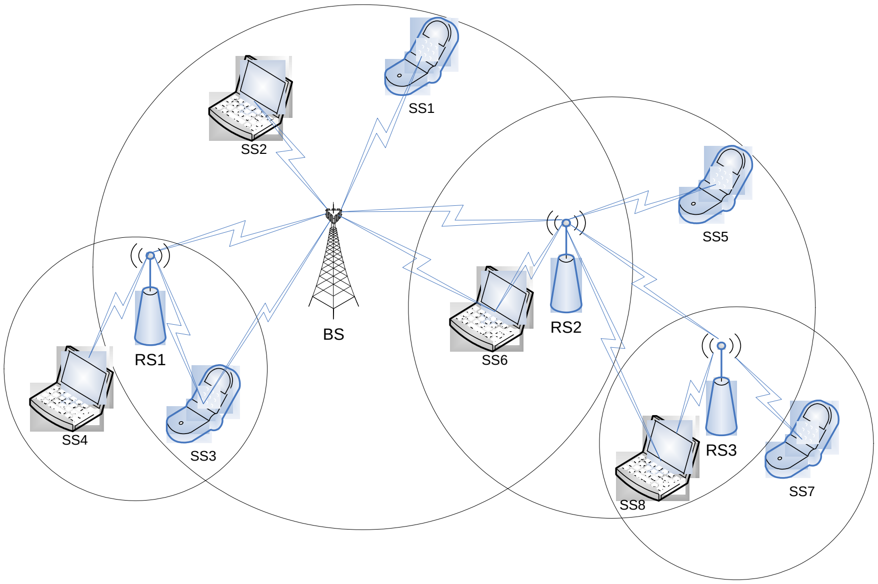

Figure 1: Example multi-hop network model for contibution description. The example network includes one base station (BS) and three relay stations (RS1, RS2, and RS3). Working together the base station and relay stations provide radio coverage to subscriber stations (SS1 to SS8).

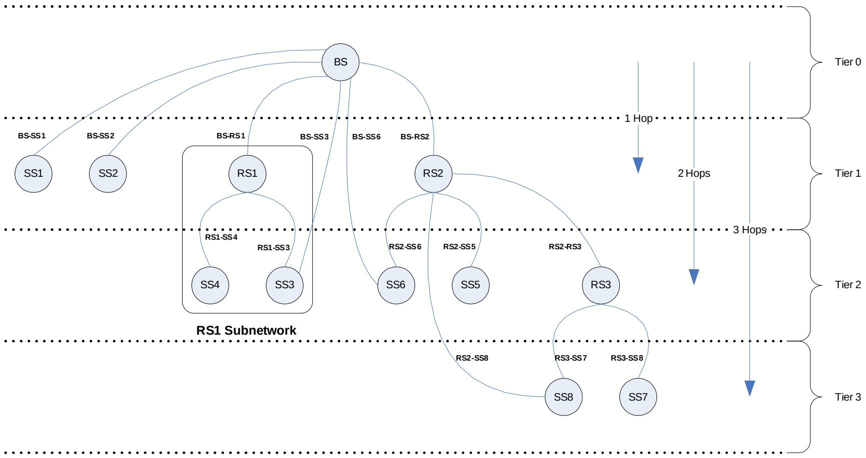

Figure 2: Weighted undirected graph $\mathcal{N} = (N, L, \mathbf{Q})$ for the example network in Figure 1. Using only link quality estimates from its subordinate stations a base/realy station may construct a network graph such as $\mathcal{N}$.

Set L is the network's link set comprised of node pairs; each pair denotes a link connection within the network, that is,

$$L = \{(BS,\, SS1)\,, (BS,\, SS2)\,, (BS,\, RS1)\,, \ldots, (RS3,\, SS7)\,, (RS3,\, SS8)\} \tag{2}$$

The M-by-M matrix $\mathbf{Q}$ contains link quality values; each element q_{ij} within $\mathbf{Q}$ is associated with a link in L. For the network of Figures 1 and 2 the 12-by-12 matrix $\mathbf{Q}$ is shown in Figure 3.

	BS	**RS1**	**RS2**	**RS3**	**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**
BS	0	BS-RS1	BS-RS2	0	BS-SS1	BS-SS2	BS-SS3	0	0	BS-SS6	0	0
RS1	BS-RS1	0	0	0	0	0	RS1-SS3	RS1-SS4	0	0	0	0
RS2	BS-RS2	0	0	RS2-RS3	0	0	0	0	RS2-SS5	RS2-SS6	0	RS2-SS8
RS3	0	0	RS2-RS3	0	0	0	0	0	0	0	RS3-SS7	RS3-SS8
SS1	BS-SS1	0	0	0	0	0	0	0	0	0	0	0
SS2	BS-SS2	0	0	0	0	0	0	0	0	0	0	0
SS3	BS-SS3	RS1-SS3	0	0	0	0	0	0	0	0	0	0
SS4	0	RS1-SS4	0	0	0	0	0	0	0	0	0	0
SS5	0	0	RS2-SS5	0	0	0	0	0	0	0	0	0
SS6	BS-SS6	0	RS2-SS6	0	0	0	0	0	0	0	0	0
SS7	0	0	0	RS3-SS7	0	0	0	0	0	0	0	0
SS8	0	0	RS2-SS8	RS3-SS8	0	0	0	0	0	0	0	0

Figure 3: Link quality matrix $\mathbf{Q}$ for the network shown in Figures 1 and 2. Each matrix element is associated with a link. For example, matrix element q_{31} contains the value BS2-RS2 which indicates the quality of the link connecting the BS and RS2. In a TDD mode of operation we have by channel reciprocity $q_{ij} = q_{ji}$, hence $\mathbf{Q}$ is symmetric so only 14 of the 28 non-zero values need to be determined. Given only link quality estimates from its subordinate stations the matrix $\mathbf{Q}$ may be constructed by a base station. The base station may then use $\mathbf{Q}$ for deriving connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$.

Values of zero within the link quality matrix $\mathbf{Q}$ indicate that no link exists between a network node pair. The non-zero link ranks may be any value or combination of values that can be used to indicate the quality of network link. For example, the value BS-RS1 (the row-1, column-2 element q_{12} in $\mathbf{Q}$) may contain a four bit link-quality value such as

$$\text{BS-RS1} = \begin{cases} 0 & \text{if } 0 < SINR(BS, RS1) \leq \alpha_1 \\ 1 & \text{if } \alpha_1 < SINR(BS, RS1) \leq \alpha_2 \\ 2 & \text{if } \alpha_2 < SINR(BS, RS1) \leq \alpha_3 \\ 3 & \text{if } \alpha_3 < SINR(BS, RS1) \end{cases} \tag{3}$$

Here $SINR(BS, RS1)$ denotes an estimate of the ratio of signal power to interference-plus-noise for the network link $(BS,\, RS1)$ and α_i, $i = 1, 2, 3$, specified SINR decision region bounds.

A network path of hop-length N_P from a source node to sink node is a sequence of N_P links from L. Network paths within $\mathcal{N}$ are elementary meaning all network nodes in a path are traversed only once. Network paths within $\mathcal{N}$ contain no cycles meaning the initial and final nodes in a path are distinct. The rank of a network path is defined as a the summation of its link ranks. From Figures 1 or 2 it is easily seen that some possible BS downlink network paths are as follows:

- BS communicates with SS1 and SS2 over a 1-hop path.
- BS may communicate with SS3 via a 2-hop path or a 1-hop path. For the 2-hop path DL PDUs are first sent from the BS to RS1, RS1 then sends the PDUs to SS3. The path chosen depends on the ranks of the two candidate paths.
- BS communicates with SS5 via a 2-hop path. Downlink PDUs from the BS must first be transmitted to RS2, RS2 then transmits the PDUs to SS5.

- BS may communicate with SS6 via a 2-hop path or a 1-hop path. For the 2-hop path DL PDUs are first sent from the BS to RS2, RS2 then sends the PDUs to SS6. The path chosen depends on the ranks of the two candidate paths.

3 Network Connectivity Matrices

For concurrent relay zone usage a method for multi-hop connectivity identification is required so the base station of Figure 1 can determine the spatial distributions of its subordinate relay and subscriber stations. For this requirement we describe a technique for constructing a network connectivity matrix that only requires link quality estimates from users within a network. The technique is an application of the algorithm described in [4], [5] and [6].

The 1-hop network connectivity matrix $\mathbf{C}^{(1)}$ for an arbitrary M-node network $\mathcal{N} = (N, L, \mathbf{Q})$ is defined as the M-by-M matrix $\mathbf{C}^{(1)} = \{c_{ij}^{(1)}\}_{i,j=1}^{M}$ where

$$c_{ij}^{(1)} = \begin{cases} 1 & \text{if a link from node } n_i \text{ to } n_j \text{ exists} \\ 0 & \text{if a link from node } n_i \text{ to } n_j \text{ does not exist} \\ 0 & \text{if } i = j \end{cases} \tag{4}$$

The 1-hop network connectivity matrix may be easily obtained from a link quality matrix $\mathbf{Q}$ by applying a specified function or decision rule that maps elements q_{ij} to 0 or 1. For example, the following decision rule may be used to map the link quality matrix to a 1-hop connectivity matrix:

$$c_{ij}^{(1)} = \begin{cases} 1 & \text{if } q_{ij} \geq SINR_{\min} \\ 0 & \text{if } q_{ij} < SINR_{\min} \end{cases} \tag{5}$$

Here q_{ij} is the (i,j)th element in the link quality matrix and $SINR_{\min}$ the SINR value that supports the minimum physical layer coding and modulation. Figure 4 shows the 1-hop network connectivity matrix for the network of Figure 2. The ith row lists all the 1-hop connections for the BS, RS or SS denoted by the row header. For example, row 1 contains all 1-hop connections to the base station.

Given $\mathbf{C}^{(1)}$ the m-hop (integer $m > 1$) connectivity matrix for network $\mathcal{N}$ is defined by the M-by-M matrix $\mathbf{C}^{(m)} = \{c_{ij}^{(m)}\}_{i,j=1}^{M}$ where

$$c_{ij}^{(m)} = \begin{cases} \leq m & \text{If node } n_i \text{ is connected to } n_j \text{ by a path of } N_P \leq m \text{ links or hops} \\ 0 & \text{otherwise} \end{cases} \tag{6}$$

The element $c_{ij}^{(m)}$ is computed using the iterative equation

$$c_{ij}^{(m)} = c_{ij}^{(m-1)} + \psi_{ij}^{(m)}, \ m \geq 2 \tag{7}$$

where

$$\psi_{ij}^{(m)} = \begin{cases} 0 & \text{If } i = j \\ 0 & \text{If } c_{ij}^{(m-1)} > 0 \\ m & \text{If } \sum_{k=1}^{M} c_{ik}^{(m-1)} c_{kj}^{(1)} > 0 \text{ when } i \neq j \text{ and } c_{ij}^{(m-1)} = 0 \\ 0 & \text{Otherwise} \end{cases} \tag{8}$$

Figure 5 shows the $m = 3$ hop network connectivity matrix $\mathbf{C}^{(3)}$ for the example network of Figure 1 and 2.

Figure 6 shows a simple MATLAB script for computing the m-hop network connectivity matrix using the above iterative equation. It was used to compute the connectivity matrices shown in Figure 5.

	BS	**RS1**	**RS2**	**RS3**	**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**
BS	0	1	1	0	1	1	1	0	0	1	0	0
RS1	1	0	0	0	0	0	1	1	0	0	0	0
RS2	1	0	0	1	0	0	0	0	1	1	0	1
RS3	0	0	1	0	0	0	0	0	0	0	1	1
SS1	1	0	0	0	0	0	0	0	0	0	0	0
SS2	1	0	0	0	0	0	0	0	0	0	0	0
SS3	1	1	0	0	0	0	0	0	0	0	0	0
SS4	0	1	0	0	0	0	0	0	0	0	0	0
SS5	0	0	1	0	0	0	0	0	0	0	0	0
SS6	1	0	1	0	0	0	0	0	0	0	0	0
SS7	0	0	0	1	0	0	0	0	0	0	0	0
SS8	0	0	1	1	0	0	0	0	0	0	0	0

Figure 4: One-hop symmetric connectivity matrix $\mathbf{C}^{(1)}$ for the network shown in Figures 1 and 2. Given only link quality estimates from its subordinate stations the connectivity matrix may be constructed by a base station. The base station may use the connectivity matrix for specifying concurrent relay station zone allocations within an 802.16m network that supports multi-hop relaying.

	BS	**RS1**	**RS2**	**RS3**	**SS1**	**SS2**	**SS3**	**SS4**	**SS5**	**SS6**	**SS7**	**SS8**
BS	0	1	1	2	1	1	1	2	2	1	3	2
RS1	1	0	2	3	2	2	1	1	3	2	0	3
RS2	1	2	0	1	2	2	2	3	1	1	2	1
RS3	2	3	1	0	3	3	3	0	2	2	1	1
SS1	1	2	2	3	0	2	2	3	3	2	0	3
SS2	1	2	2	3	2	0	2	3	3	2	0	3
SS3	1	1	2	3	2	2	0	2	3	2	0	3
SS4	2	1	3	0	3	3	2	0	0	3	0	0
SS5	2	3	1	2	3	3	3	0	0	2	3	2
SS6	1	2	1	2	2	2	2	3	2	0	3	2
SS7	3	0	2	1	0	0	0	0	3	3	0	2
SS8	2	3	1	1	3	3	3	0	2	2	2	0

Figure 5: Three-hop symmetric connectivity matrix $\mathbf{C}^{(3)}$ for the network shown in Figures 1 and 2. Given only link quality estimates from its subordinate stations the connectivity matrix may be constructed by a base station. The base station may use the connectivity matrix for specifying concurrent relay station zone allocations within an 802.16m network that supports multi-hop relaying.

```
N_HOPS = 3;  % Maximum number of hops
M = 12;      % Connectivity matrix dimension
% A = M-by-M 1-hop connectivity matrix of Figure 4;
B = zeros(M,M);

% Algorithm for computing the m-hop connectivity matrix C
C = A;
for m = 2:N_HOPS
    for i = 1:M
        for j = 1:M
            if ((i ~= j) & (C(i,j) <= 0))
                for k = 1:M
                    if ((C(i,k) > 0) & (A(k,j) > 0))
                        B(i,j) = m;
                        break;
                    end
                end
            end
        end
    end
    C = C + B;
    B = zeros(M,M);
end
```

Figure 6: Non-optimal MATLAB script for computing the m-hop connectivity matrix. Example code is set for $M = 12$ and $m = N\_HOPS = 3$. Code was used to generate $C^{(3)}$ shown in Figure 5.

4 Concurrent Relay Station Frame Zones for Multi-hop Relaying

The technique for concurrent relay zone usage will now be summarized. Referring to Figure 1 the base station will allocate relay zones for all downlink and uplink transmissions. For relay zone reuse the base station will allocate or schedule relay zones based on the spatial distributions of its subordinate relay and subscriber stations. The base station will concurrently use or reuse relay zones whenever the spatial distribution of relay and subscriber stations is such that their co-channel interference is acceptable for a desired service quality. The base station will acquire needed location and spatial distribution information from its network graph $\mathcal{N} = (N, L, \mathbf{Q})$ and one or more link connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$. The specific technique will be described in a future 802.16m contribution.

Figure 7 shows an example frame structure with concurrent relay zone usage. Figure 8 clarifies how the RS1 and RS3 DL/UL Zones are reused by RS1 and RS3 due to the spatial distribution of RS1 and RS3. For comparison Figure 9 shows an example DL subframe structure that does not reuse relay zones. Figure 10 clarifies how the RS1 and RS3 DL/UL Zones are sequentially transmitted by RS1 and RS3 resulting in a throughput decrease when compared to the proposed technique.

To further describe concurrent relay zone usage we now refer to Figures 1 and 7 and give an overview of the DL zones within the frame structure shown in Figure 7. An overview of the UL zones should be clear and is not needed at this time.

The BS DL Zone is comprised of a BS Preamble, FCH, DL-MAP, UL-MAP and DL bursts that are transmitted by the base station to its 1-hop relay stations (RS1, RS2) and its 1-hop subscriber stations (SS1, SS2, SS3, SS6). Burst allocations for the Base Station DL/UL Zones are specified by the BS using Information Elements (IEs) within the DL/UL-MAPs.

The BS Preamble is used by the BS's 1-hop neighbors (RS1, RS2, SS1, SS2, SS3, SS6) for DL synchronization (frame timing acquisition, frequency offset estimation, symbol timing estimation). RS1, RS2, SS1, SS2, SS3, SS6 also use the BS Preamble as a reference signal to obtain link quality estimates BS-RS1, BS-RS2, BS-SS1, BS-SS2, BS-SS3 and BS-SS6. These estimates will be transmitted to the BS in the subsequent BS UL Zone so the BS can update row one of the link quality matrix $\mathbf{Q}$ shown in Figure 3. Using the updated matrix $\mathbf{Q}$ the BS can update its used connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$, using equation 5 and the iterative algorithm described above.

The RS2 DL Zone is comprised of an RS2 Preamble, FCH, DL-MAP, UL-MAP and DL bursts that are transmitted by RS2 to its 1-hop relay station RS3 and its 1-hop subscriber stations (SS5, SS6, SS8). Burst allocations for the RS2 DL/UL Zones are specified using IEs within the DL/UL-MAPs. These MAPs are specified by the BS so RS2 serves as a MAP forwarding node for the BS.

The RS2 Preamble is used by the RS2's 1-hop neighbors (RS3, SS5, SS6, SS8) for DL synchronization. RS3, SS5, SS6, and SS8 also use the RS2 Preamble as a reference signal to obtain link quality estimates RS2-RS3, RS2-SS5, RS2-SS6 and RS2-SS8. These estimates will be transmitted to the BS in the subsequent RS2 UL Zone so the BS can update row three of the link quality matrix $\mathbf{Q}$ shown in Figure 3. Using the updated matrix $\mathbf{Q}$ the BS can update its used connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$.

Because of the spatial distribution of RS1 and RS3 (see Figure 1) the downlink zones for RS1 and RS3 are transmitted concurrently using the same relay zones (see Figure 8 for clarification).

The RS1 DL Zone is comprised of an RS1 Preamble, FCH, DL-MAP, UL-MAP and DL bursts that are transmitted by RS1 to its 1-hop subscriber stations (SS3, SS4). The RS1 Preamble, the FCH, and the DL/UL-MAPs are not shown within Figure 7. If shown they would have a similar structure to that shown for the RS2 DL Zone. Burst allocations for the RS1 DL/UL Zones are specified using IEs within the DL/UL-MAPs. These MAPs are specified by the BS so RS1 serves as a MAP forwarding node for the BS.

The RS1 Preamble is used by the RS1's 1-hop neighbors (SS3, SS4) for DL synchronization. SS3 and SS4 also use the RS1 Preamble as a reference signal to obtain link quality estimates RS1-SS3 and RS1-SS4. These estimates will be transmitted to the BS in the subsequent RS1 UL Zone so the BS can update row two of the link quality matrix $\mathbf{Q}$ shown in Figure 3. Using the updated matrix $\mathbf{Q}$ the BS can update its used connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$.

The RS3 DL Zone is comprised of an RS3 Preamble, FCH, DL-MAP, UL-MAP and DL bursts that are transmitted by RS3 to its 1-hop subscriber stations (SS7, SS8). The RS3 Preamble, the FCH, and the DL/UL-MAPs are not shown within Figure 7. If shown they would have a similar structure to that shown for the RS2 DL Zone. Burst allocations for the RS3 DL/UL Zones are specified using IEs within the DL/UL-MAPs. These MAPs are specified by the BS so RS3 serves as a MAP forwarding node for the BS.

The RS3 Preamble is used by the RS3's 1-hop neighbors (SS7, SS8) for DL synchronization. SS7 and SS7 also use the RS3 Preamble as a reference signal to obtain link quality estimates RS3-SS7 and RS3-SS8. These estimates will be transmitted to the BS in the subsequent RS3 UL Zone so the BS can update row four of the link quality matrix $\mathbf{Q}$ shown in Figure 3. Using the updated matrix $\mathbf{Q}$ the BS can update its used connectivity matrices $\mathbf{C}^{(m)}$, $m \geq 1$.

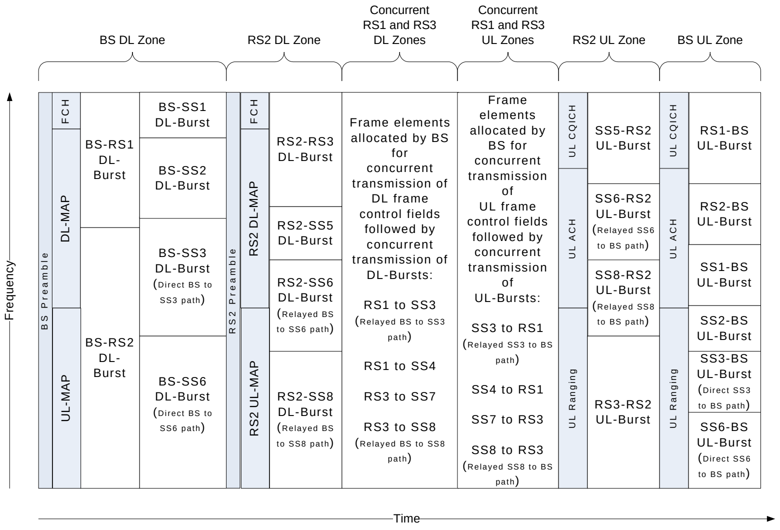

Figure 7: Example OFDMA Frame with concurrent relay station DL and UL zones.

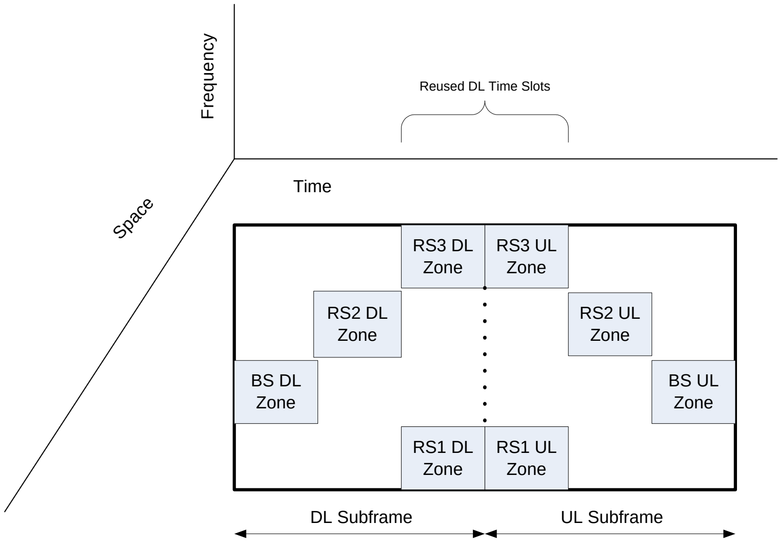

Figure 8: Conceptual example of concurrent DL and UL relay station zones within an OFDMA frame.

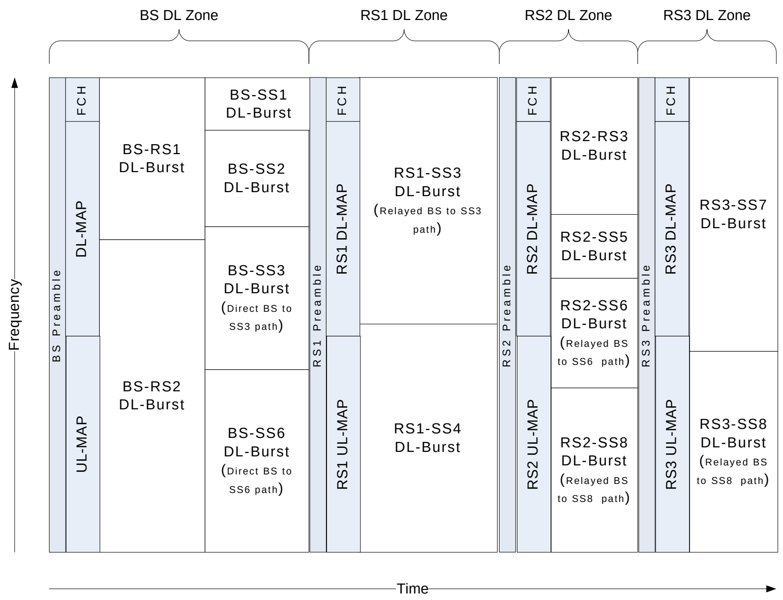

Figure 9: Example of serially concatenated relay station zones within a downlink OFDMA subframe. Similar to the current 802.16j frame structure for relaying.

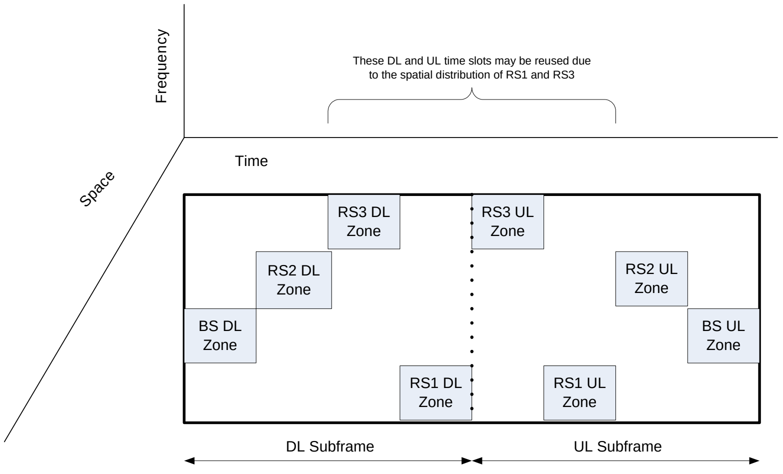

Figure 10: Conceptual example of serially concatenated DL and UL relay station zones within an OFDMA frame.

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7. Draft Table of Content for the IEEE 802.16m System Description Document, IEEE C802.16m-07/320r1

5 Proposed Text for the 802.16m System Description Document

Temporary section numbers for the proposed text below are in accordance with the current version of the Table of Contents for the IEEE 802.16m System Description Document [4]. The proposed text concerns frame structures for multi-hop relaying.

16. Support for Multi-hop Relaying

For legacy IEEE 802.16 networks user capacity and data throughput may be degraded due to network conditions such as the following:

- Unavailable or congested network spectrum. Allocated spectral bands are becoming more and more congested with desired and undesired signals due to the proliferation of both intentional and unintentional electromagnetic emissions. Congested spectrum results in a combination of low and high power signals being simultaneously observed by a receiver's antenna or antenna array. Consequently, desired signals may be obscured and undetectable since they can be buried beneath much stronger clusters of interfering signals.
- Poor signal quality at cell edges due to neighboring cell interference and low DL and UL signal powers. Low power DL and UL signals result in a decrease in throughput since the base and subscriber stations adapt their signals (modulation and coding) to channel and network conditions.
- Service coverage holes due to shadowing from various buildings, structures and trees.
- Subscriber stations out of the radio signal range of any fixed base station.
- Non-uniformly distributed subscriber stations and traffic load due to urban hot spots and rural locations.

One approach to help mitigate these network conditions is to increase the number of base stations and thereby reduce base station cell size. Base stations are complex and consist of transmitting and receiving circuitry, control circuitry, digital signal processors and a single antenna or an antenna array. Optimal base station design and deployment is attained with respect to signal transmit power, antenna height and antenna spatial coverage or beamwidth. Key issues of concern for this approach are the high cost of base station installation and limited access to locations that support their installation. Indeed, the cost for deploying a cellular network is normally dominated by base station sites (e.g. real estate costs, planning, maintenance, distribution network, energy, etc.).

Another approach that is less costly and that can also provide improvements in network capacity, data throughput and service area coverage is to use relay stations that work with base stations. Relay stations are typically smaller in size and simpler in complexity than base stations. Conceptually a relay station can serve as a base station for a subscriber station and as a subscriber station for a base station. Relay stations can be managed by a base station, but they may also have some local control of relay functions within their cell of a cellular network.

Within an 802.16m system one or more relay stations can be deployed to relay or forward signals between subscriber stations and base stations. Subscriber station and base station protocol data units (PDUs) may hop through one or more relay stations before reaching their desired destination. Some specific benefits gained from relay station deployment within an 802.16m system are the following:

- Throughput enhancement via the replacement of low rate, unreliable links with multiple high rate, reliable links.
- Coverage extension to isolated network service areas.

- Reduced power consumption and increased battery life for mobile subscriber stations.
- More efficient radio resource use and reuse due to the spatial distribution of network stations.
- Increased network capacity and improved network load sharing.
- More flexible placement of base station or cell sites due to fewer access limitations.
- Better network fault tolerance and spatial diversity via multi-path redundancy.

802.16m system relay stations may be classified as fixed, nomadic or mobile. A fixed relay station is permanently installed at a location; a nomadic relay station may be moved but is fixed when operating. A mobile relay station may be placed on vehicle such as a bus, train or boat and is intended to operate while the vehicle is fixed or in motion.

802.16m system relay stations can be further classified according to their forwarding strategy:

1. Amplify-and-forward: An amplify-and-forward relay station acts as an analog repeater. The use of an amplify-and-forward relay station may result in a signal noise increase.
2. Decode-and-Forward: A decode-and-forward relay station fully decodes received PDUs, re-encodes and retransmits the received PDUs, possibly propagating decoding errors that may lead to a wrong decision at a destination.
3. Decode-and-Reencode: A decode-and-reencode relay station fully decodes a received PDU, but constructs a codeword differing from the source codeword. Decode-and-reencode relay stations allow smart forwarding and can take advantage of adaptive transmission with different modulation and coding schemes on different network hops. Further they can participate in interference avoidance and mitigation schemes. However, the main problem is the possibility of error propagation through a network path.

802.16m system relay station usage methods can be classified as conventional or cooperative. In a conventional relaying method deployed relay stations help reduce the end-to-end network path loss between a PDU source and its destination. Conventional relaying methods employ relay stations as pure forwarders that operate in a network path within the cellular network. Each relay station in a network path relies solely on PDUs sent to it by its immediate path predecessor. A cooperative relaying methods takes a conventional relaying method one step further. The basic idea in a cooperative relaying method is to achieve spatial diversity by allowing cooperation among spatially distributed relay stations. More specifically, relay station transmissions received at a destination may be combined to achieve spatial diversity. Antenna arrays are attractive for spatial diversity but their use requires the integration of multiple antenna elements at a base, subscriber or relay station. Further, signals received by antenna array elements should be uncorrelated for optimal performance. In scenarios where these conditions cannot be met, cooperative relaying provides an alternative by distributing the antenna array elements among base, subscriber and relay stations, hence a “virtual” antenna array may be implemented.

16.1 Frame Structures for Multi-hop Relaying

Text for this section to be provided by other harmonized contributions or 802.16j [3]

16.1.1 Basic Frame Structure Elements

Text for this section to be provided by other harmonized contributions or 802.16j [3]

16.1.2 Relay Station Frame Zones

Text for this section to be provided by other harmonized contributions or 802.16j [3]

16.1.3 Concurrent Relay Station Frame Zones

In addition to the frame structures for multi-hop relaying defined in Section 16.1.2 the IEEE 802.16m system will provide alternative multi-hop framing techniques that reduce frame overhead without compromising overall system performance. The technique is summarized in this section.

A zone is logical time-frequency partition of an OFDMA subframe. There are a number of types of zones that may be used within an 802.16m system. To support multi-hop relaying one or more relay station zones may be serially concatenated within an OFDMA frame as shown by the example in Figure 11. For multi-hop relaying the serial concatenation of relay station zones may result in a decrease in network capacity and throughput and an increase in latency.

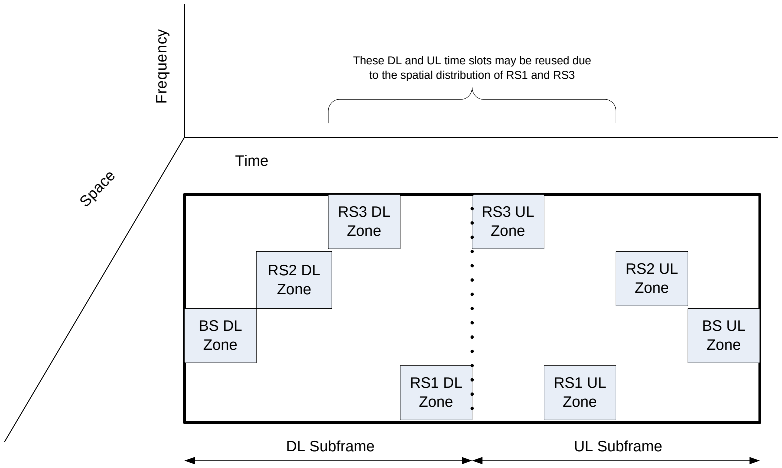

Figure 11: Conceptual example of serially concatenated DL and UL relay station zones within an OFDMA frame.

Figure 12 illustrates a segment of an example 802.16m network with relay stations added to support multi-hop PDU relaying. The example network includes one base station (BS) and three relay stations (RS1, RS2, and RS3). Working together the base station and relay stations provide radio coverage to subscriber stations (SS1 to SS8). The circles enclose the coverage areas of the base station and relay stations.

As shown in Figure 12 the coverage areas of RS1 and RS3 do not overlap. Their spatial distribution allows them to transmit concurrently with minimal co-channel interference. Hence, relay zones for RS1 and RS3 may be used concurrently to increase network capacity and throughput. Specifically, the base station may command RS1 and RS3 to concurrently use the same relay zones for their downlink PDU transmissions to the subscriber stations within their coverage areas. The base station may also command RS1 and RS3 to concurrently use the same relay zones for their uplink PDU transmissions to the BS and RS2. Figure 13 shows a conceptual representation of concurrent relay station zone usage that can be compared with Figure 11.

802.16m systems will provide alternative multi-hop framing techniques that support concurrent relay station frame zones as just described. A base station may schedule or allocate concurrent relay station zones based on the spatial distribution of its subordinate relay and subscriber stations. A base station can concurrently use relay station zones for two or more relay stations whenever their spatial distribution is such that their co-channel interference is acceptable for their required service qualities.

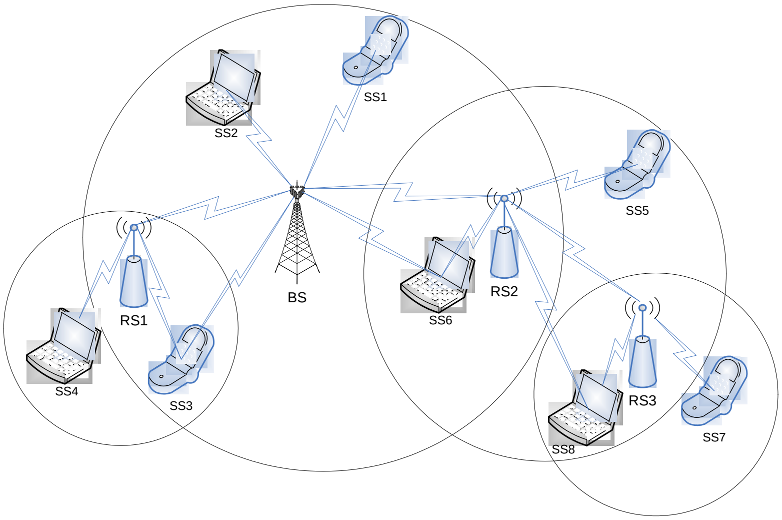

Figure 12: Example multi-hop network model for contibution description. The example network includes one base station (BS) and three relay stations (RS1, RS2, and RS3). Working together the base station and relay stations provide radio coverage to subscriber stations (SS1 to SS8).

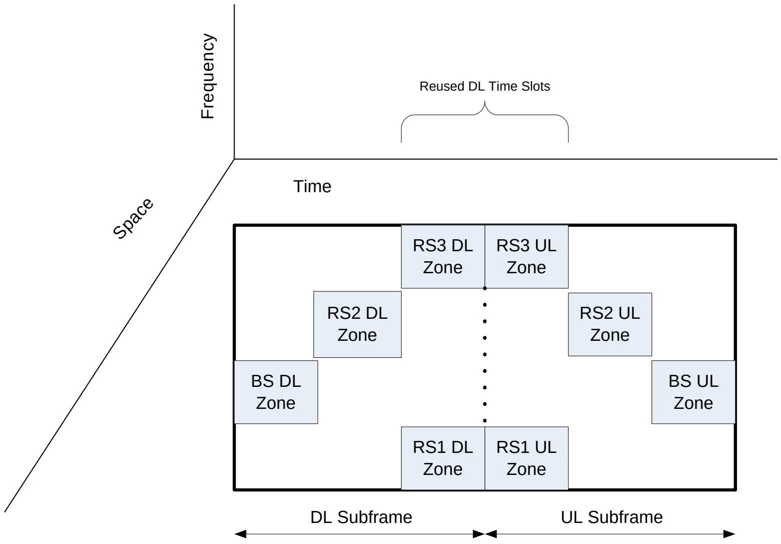

Figure 13: Conceptual example of concurrent DL and UL relay station zones within an OFDMA frame.