Brick-Tessellated Frame Structures for 802.16m OFDMA Systems

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IEEE 802.16m-07/047 - This contribution describes a proposed 802.16m frame element called a brick and brick-tessellated frame structures.

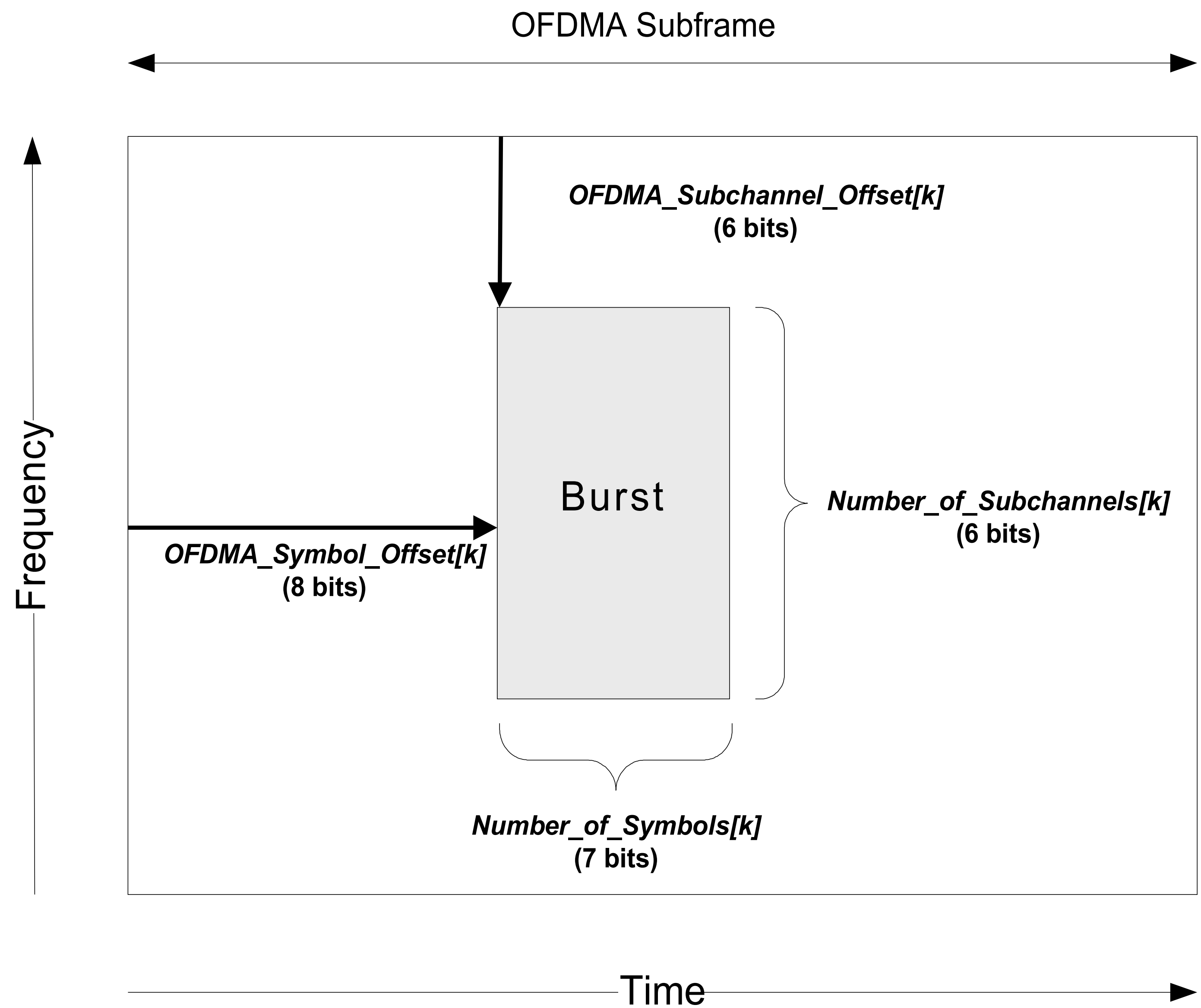
Base Contribution: IEEE C802.16m-08/069

Purpose: To summarize the contents of the base contribution.

Problem Statement

- Legacy 802.16 OFDMA frames require a significant amount of overhead in order to dynamically schedule or allocate downlink (DL) and uplink (UL) bursts to system users.
- Majority of the overhead is due to sequences of Information Elements (IEs) within a frames's DL/UL MAPs. IEs are required to carry DL/UL burst information such as burst location, size, coding, and modulation. One IE is typically required for each burst within a DL/UL subframe.
- Four fundamental IE fields are required to specify the location and size of each DL/UL burst within a DL/UL subframe:
  - Burst locations are specified by an OFDMA Symbol Offset field and an OFDMA Subchannel/Subcarrier Offset field.
  - Burst sizes are specified by a Number of OFDMA Symbols field and a Number of OFDMA Subchannels/Subcarriers field.
- The four fields that specify the location/size of each DL/UL burst can consume a significant amount of frame overhead. Repetition coding will further increase the number of overhead bits consumed by these four fields.

Fundamental IE Fields for Burst Location/Sizing



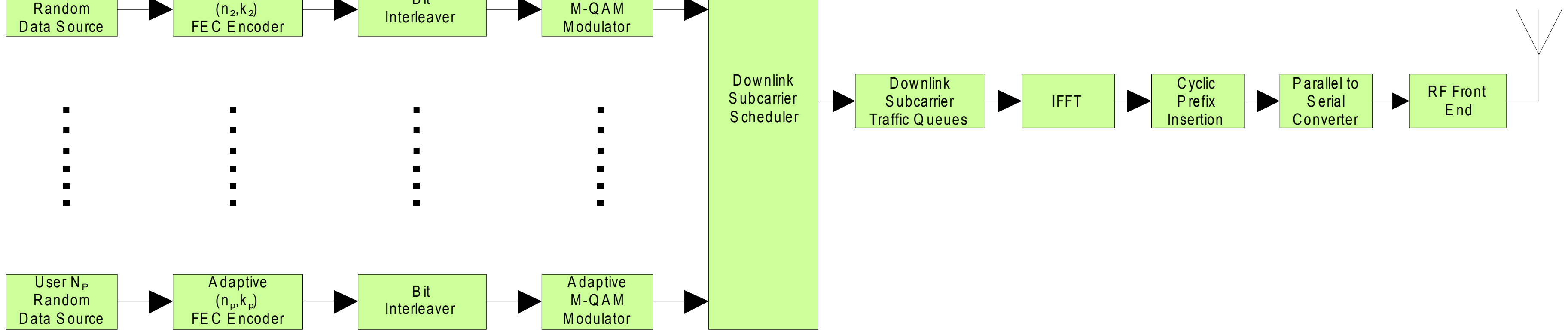
Proposed Solution

- The 802.16m SRD states that an IEEE 802.16m system shall provide improved techniques for reducing overhead; system overhead shall be reduced to a minimum without compromising overall system performance.
- This contribution describes a new frame element called a brick and brick-tessellated frame structures.
- Using brick-tessellated frame structures overhead reduction is gained by decreasing the lengths of the four fundamental IE frame fields needed to specify burst locations/sizes.
- Brick-tessellated frame structures will not compromise overall system performance and can be easily integrated into a harmonized 802.16m frame/superframe structure.

Conceptual System for Burst Generation

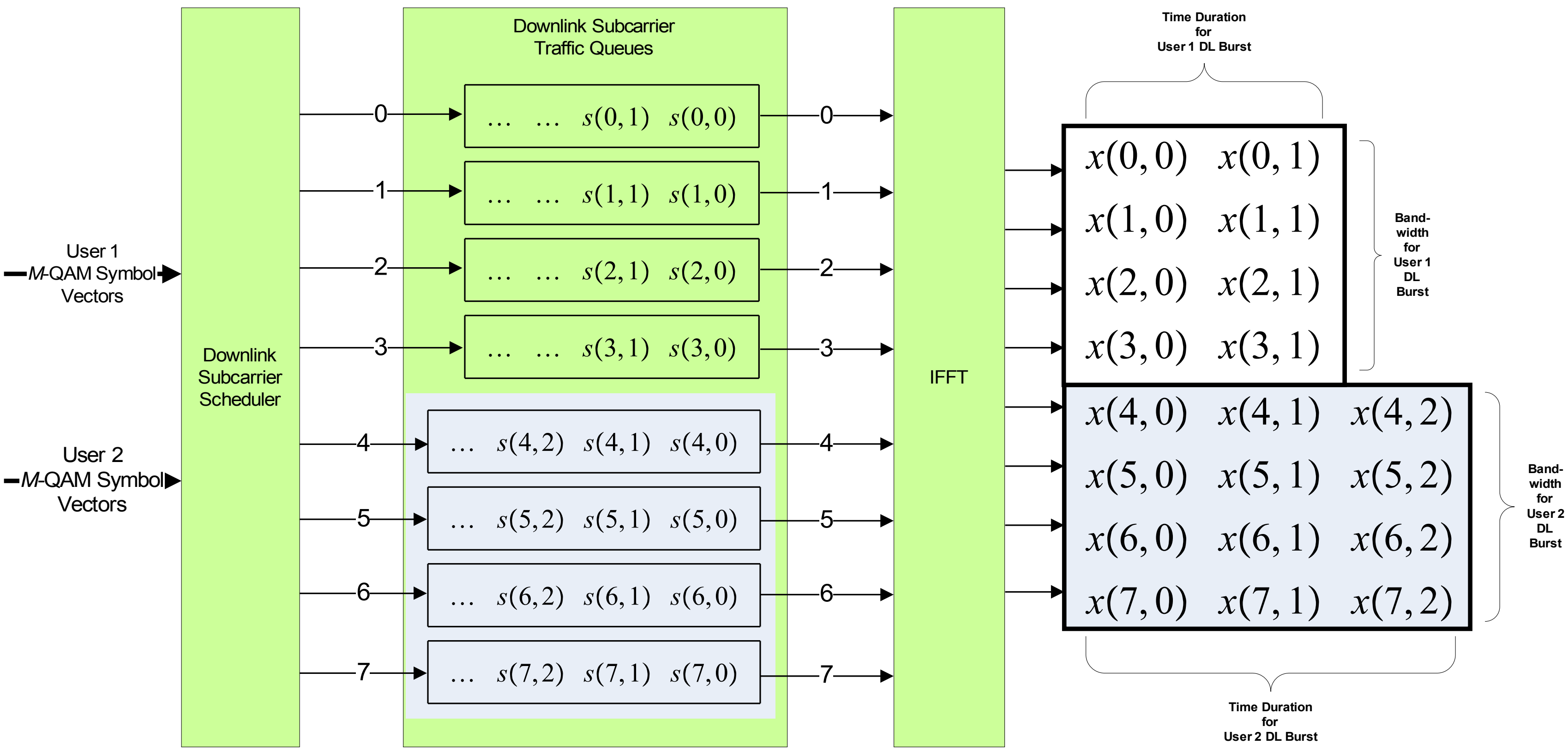
Guard Bands, Preamble, Pilots not shown

Each M-QAM modulator outputs a length βk modulation symbol vector



Example Subsystem for DL Subcarrier Scheduler, DL Subcarrier Traffic Queues, and IFFT

(For example, 2 users, and 2 M-QAM vectors as input)



Bursts for Brick-Tessellated Subframes (1)

- From table below it can be seen that the length βk of a modulation symbol vector output by an M-QAM block above is dependent on the triple:

$$(\eta_k, \kappa_k, m_k),\ k = 0, \ldots, N_P - 1$$

- In legacy 802.16 systems κk, ηk and mk are specified so that βk is always a divisor of two. It is assumed that this is also true for 802.16m systems. Note: Any other selected symbol vector length may be used but length must be a factor of two in order to optimally implement the proposed method.

Code Rate κ_k/η_k	Data Block Size κ_k in Bits	Encoded Data Block Size η_k in Bits	Number of Bits m_k per M-QAM Symbol	Number of M-QAM Symbols β_k per M-QAM Symbol Vector
1/2	320	640	2	320
2/3	640	960	4	240
3/4	960	1280	4	320
5/6	1280	1536	6	256

Bursts for Brick-Tessellated Subframes (2)

- For brick-tessellated subframes a burst is a rectangular or square area within the usable part of subframe comprised of a specified number of OFDMA subcarriers and a specified number of OFDMA symbols.

- Constraining bursts to be rectangles or squares is similar to the approach used by WINNER and LTE which use rectangular *chunks* and *resource blocks*.
- A set of n_B rectangular bursts allocated for a subframe may be parametrized by their heights and their widths:

$$\beta_{H,k},\ k = 0, \ldots, n_B - 1$$

$$\beta_{W,k},\ k = 0, \ldots, n_B - 1$$

- For brick-tessellated subframes burst heights are in units of OFDMA subcarriers and burst widths in units of OFDMA symbols.
- The area of the kth burst within a subframe's time-frequency plane equals a modulation symbol vector's length, it is a divisor of 2 and defined as

$$\beta_k = \beta_{H,k} \times \beta_{W,k}$$

Bursts for Brick-Tessellated Subframes (3)

- Scheduler can be viewed as an operator that reshapes each length-β_k modulation symbol vector into a $\beta_{H,k}$-by-$\beta_{W,k}$ burst matrix or rectangle that lies within a subframe's time- frequency plane.
- For example, given a modulation symbol vector of length 240 acceptable pairs for rectangular burst heights and widths are (12,20), (24,10), (6,40) and (30,8), others are also acceptable but not listed.
- Chosen pair used may be based on channel, interference, network conditions, etc; it is a task of the Downlink Subcarrier Scheduler to chose the optimal pair.
- Within a subframe's time-frequency plane burst allocations for each user may be contiguous, non-contiguous or pseudo-random. Allocation adapts to time-varying channel, interference and network conditions

Bricks and Brick-Tessellated Subframes

- A brick is a rectangular area of a subframe's time-frequency plane that is treated as single logical unit. A brick is constructed from a set of $r > 1$ contiguous OFDMA subcarriers (brick frequency dimension) and a set of $c > 1$ contiguous OFDMA symbols (brick time dimension).
- Brick dimensions r and c are variable and are dependent on burst locations/sizes within DL/UL subframes. Burst locations/sizes are dependent on time-varying channel, interference and network conditions so brick dimensions adapt to subframe burst allocations.
- A brick-tessellated subframe is a rectangular OFDMA subframe that is tessellated by a number of maximal-sized r-by-c bricks that fills the usable part subframe with no overlaps or gaps. It is a logical partitioning of a subframe using bricks.
- Bursts within a brick-tessellated subframe can be located and sized using scaled brick-based fields in which a burst's location and size are specified in units of bricks.
- This allows the four frame fields that specify burst locations and sizes to be reduced in length. The reduction can be significant and is dependent on brick dimensions r and c that serve as scaling factors, the larger the brick dimensions the greater the overhead reduction.

Brick Structure

BRICK STRUCTURE

Contiguous Sequence of OFDMA Symbols (columns); Contiguous Sequence of OFDMA Subcarriers (rows)

$$\boxed{\mathbf{B}(p_0 : p_{r-1}, q_0 : q_{c-1})} = \begin{bmatrix} x(p_0,q_0) & x(p_0,q_1) & x(p_0,q_2) & \dots & x(p_0,q_{c-1}) \\ x(p_1,q_0) & x(p_1,q_1) & x(p_1,q_2) & \dots & x(p_1,q_{c-1}) \\ \vdots & \vdots & \vdots & & \vdots \\ x(p_{r-1},q_0) & x(p_{r-1},q_1) & x(p_{r-1},q_2) & \dots & x(p_{r-1},q_{c-1}) \end{bmatrix}$$

BRICK ELEMENT DEFINITION

$$x(p_a,q_b) = \frac{1}{\sqrt{N_{FFT}}} \sum_{n=0}^{N_{FFT}-1} s(n,q_b) e^{j2\pi p_a n/N_{FFT}}$$

$$a = 0,1,\dots,r-1$$

$$b = 0,1,\dots,c-1$$

BRICK ELEMENT FREQUENCY INDICES

$p_0, p_1, \dots, p_{r-1}$ is a contiguous sequence of r subcarriers indices such that $0 \le p_0 < p_1 < p_2 < \cdots < p_{r-1} \le N_{FFT} - 1$

BRICK ELEMENT TIME INDICES

$q_0, q_1, \dots, q_{c-1}$ is a contiguous sequence of c OFDMA symbol indices such that $0 \le q_0 < q_1 < q_3 < \cdots < q_{c-1}$

Example 1 of a Brick-Tessellated DL Subframe

OFDMA Downlink (DL) Subframe

OFDMA Subcarrier Number

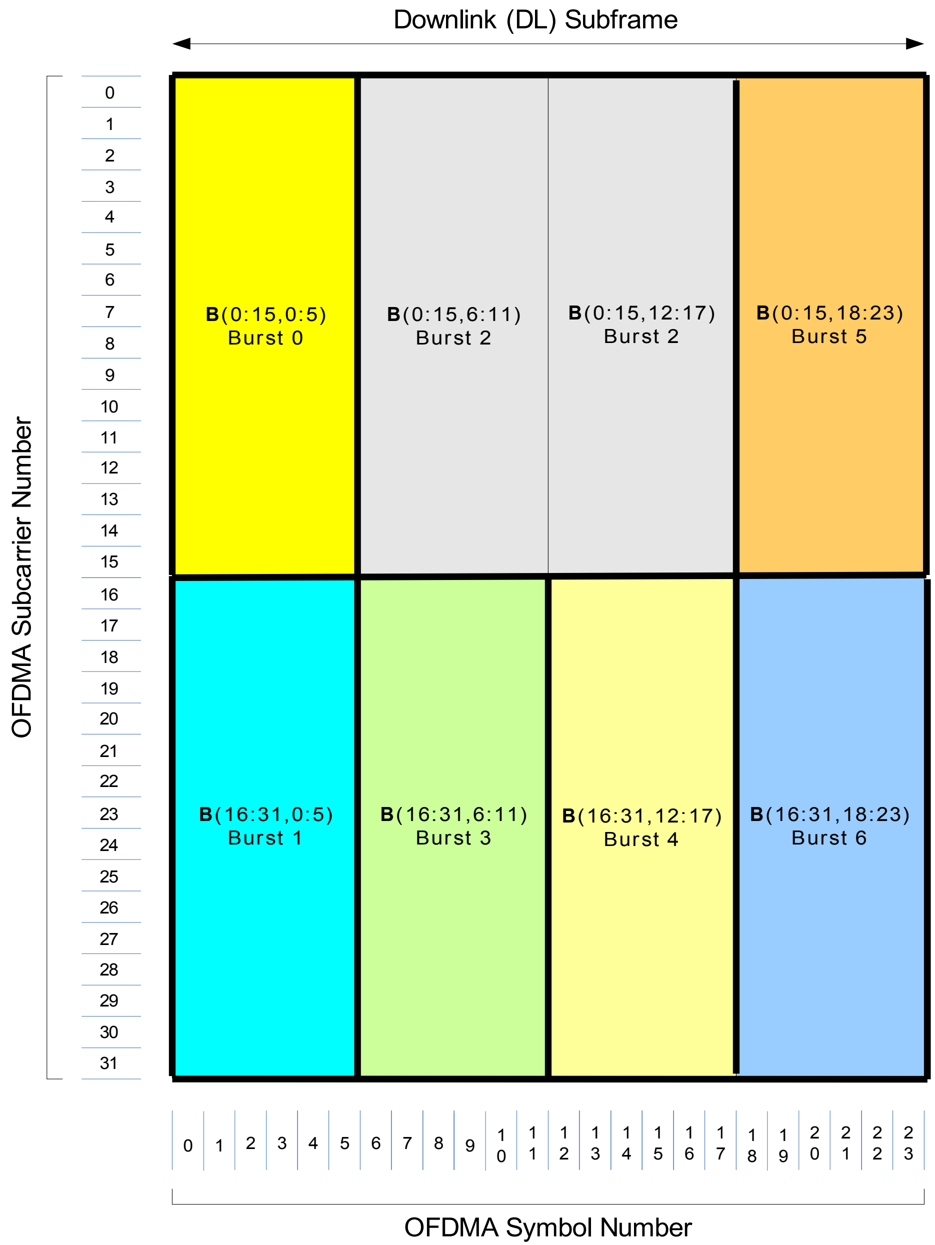
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

B(0:1,0:5) Burst 0	**B**(0:1,6:11) Burst 0	**B**(0:1,12:17) Burst 3	**B**(0:1,18:23) Burst 3	**B**(0:1,24:29) Burst 3
B(2:3,0:5) Burst 0	**B**(2:3,6:11) Burst 0	**B**(2:3,12:17) Burst 3	**B**(2:3,18:23) Burst 3	**B**(2:3,24:29) Burst 3
B(4:5,0:5) Burst 0	**B**(4:5,6:11) Burst 0	**B**(4:5,12:17) Burst 3	**B**(4:5,18:23) Burst 3	**B**(4:5,24:29) Burst 3
B(6:7,0:5) Burst 0	**B**(6:7,6:11) Burst 0	**B**(6:7,12:17) Burst 3	**B**(6:7,18:23) Burst 3	**B**(6:7,24:29) Burst 3
B(8:9,0:5) Burst 0	**B**(8:9,6:11) Burst 0	**B**(8:9,12:17) Burst 3	**B**(8:9,18:23) Burst 3	**B**(8:9,24:29) Burst 3
B(10:11,0:5) Burst 0	**B**(10:11,6:11) Burst 0	**B**(10:11,12:17) Burst 3	**B**(10:11,18:23) Burst 3	**B**(10:11,24:29) Burst 3
B(12:13,0:5) Burst 0	**B**(12:13,6:11) Burst 0	**B**(12:13,12:17) Burst 3	**B**(12:13,18:23) Burst 3	**B**(12:13,24:29) Burst 3
B(14:15,0:5) Burst 1	**B**(14:15,6:11) Burst 1	**B**(14:15,12:17) Burst 1	**B**(14:15,18:23) Burst 4	**B**(14:15,24:29) Burst 4
B(16:17,0:5) Burst 1	**B**(16:17,6:11) Burst 1	**B**(16:17,12:17) Burst 1	**B**(16:17,18:23) Burst 4	**B**(16:17,24:29) Burst 4
B(18:19,0:5) Burst 1	**B**(18:19,6:11) Burst 1	**B**(18:19,12:17) Burst 1	**B**(18:19,18:23) Burst 4	**B**(18:19,24:29) Burst 4
B(20:21,0:5) Burst 1	**B**(20:21,6:11) Burst 1	**B**(20:21,12:17) Burst 1	**B**(20:21,18:23) Burst 4	**B**(20:21,24:29) Burst 4
B(22:23,0:5) Burst 2	**B**(22:23,6:11) Burst 2	**B**(22:23,12:17) Burst 2	**B**(22:23,18:23) Burst 2	**B**(22:23,24:29) Burst 5
B(24:25,0:5) Burst 2	**B**(24:25,6:11) Burst 2	**B**(24:25,12:17) Burst 2	**B**(24:25,18:23) Burst 2	**B**(24:25,24:29) Burst 5
B(26:27,0:5) Burst 2	**B**(26:27,6:11) Burst 2	**B**(26:27,12:17) Burst 2	**B**(26:27,18:23) Burst 2	**B**(26:27,24:29) Burst 5
B(28:29,0:5) Burst 2	**B**(28:29,6:11) Burst 2	**B**(28:29,12:17) Burst 2	**B**(28:29,18:23) Burst 2	**B**(28:29,24:29) Burst 5
B(30:31,0:5) Burst 2	**B**(30:31,6:11) Burst 2	**B**(30:31,12:17) Burst 2	**B**(30:31,18:23) Burst 2	**B**(30:31,24:29) Burst 5

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

OFDMA Symbol Number

Example 2 of a Brick-Tessellated DL Subframe



Example 3 of a Brick-Tessellated DL Subframe

OFDMA Downlink (DL) Subframe

OFDMA Subcarrier Number				
0, 1	**B**(0:1,0:5) Burst 0	**B**(0:1,6:11) Burst 16	**B**(0:1,12:17) Burst 32	**B**(0:1,18:23) Burst 48
2, 3	**B**(2:3,0:5) Burst 1	**B**(2:3,6:11) Burst 17	**B**(2:3,12:17) Burst 33	**B**(2:3,18:23) Burst 49
4, 5	**B**(4:5,0:5) Burst 2	**B**(4:5,6:11) Burst 18	**B**(4:5,12:17) Burst 34	**B**(4:5,18:23) Burst 50
6, 7	**B**(6:7,0:5) Burst 3	**B**(6:7,6:11) Burst 19	**B**(6:7,12:17) Burst 35	**B**(6:7,18:23) Burst 51
8, 9	**B**(8:9,0:5) Burst 4	**B**(8:9,6:11) Burst 20	**B**(8:9,12:17) Burst 36	**B**(8:9,18:23) Burst 52
10, 11	**B**(10:11,0:5) Burst 5	**B**(10:11,6:11) Burst 21	**B**(10:11,12:17) Burst 37	**B**(10:11,18:23) Burst 53
12, 13	**B**(12:13,0:5) Burst 6	**B**(12:13,6:11) Burst 22	**B**(12:13,12:17) Burst 38	**B**(12:13,18:23) Burst 54
14, 15	**B**(14:15,0:5) Burst 7	**B**(14:15,6:11) Burst 23	**B**(14:15,12:17) Burst 39	**B**(14:15,18:23) Burst 55
16, 17	**B**(16:17,0:5) Burst 8	**B**(16:17,6:11) Burst 24	**B**(16:17,12:17) Burst 40	**B**(16:17,18:23) Burst 56
18, 19	**B**(18:19,0:5) Burst 9	**B**(18:19,6:11) Burst 25	**B**(18:19,12:17) Burst 41	**B**(18:19,18:23) Burst 57
20, 21	**B**(20:21,0:5) Burst 10	**B**(20:21,6:11) Burst 26	**B**(20:21,12:17) Burst 42	**B**(20:21,18:23) Burst 58
22, 23	**B**(22:23,0:5) Burst 11	**B**(22:23,6:11) Burst 27	**B**(22:23,12:17) Burst 43	**B**(22:23,18:23) Burst 59
24, 25	**B**(24:25,0:5) Burst 12	**B**(24:25,6:11) Burst 28	**B**(24:25,12:17) Burst 44	**B**(24:25,18:23) Burst 60
26, 27	**B**(26:27,0:5) Burst 13	**B**(26:27,6:11) Burst 29	**B**(26:27,12:17) Burst 45	**B**(26:27,18:23) Burst 61
28, 29	**B**(28:29,0:5) Burst 14	**B**(28:29,6:11) Burst 30	**B**(28:29,12:17) Burst 46	**B**(28:29,18:23) Burst 62
30, 31	**B**(30:31,0:5) Burst 15	**B**(30:31,6:11) Burst 31	**B**(30:31,12:17) Burst 47	**B**(30:31,18:23) Burst 63
OFDMA Symbol Number	0 1 2 3 4 5	6 7 8 9 10 11	12 13 14 15 16 17	18 19 20 21 22 23

Computing Maximal-Sized Brick Dimensions

- Given burst heights in units of OFDMA subcarriers:

$$\beta_{H,k},\ k = 0, \ldots, n_B - 1$$

- Given burst widths in units of OFDMA symbols:

$$\beta_{W,k},\ k = 0, \ldots, n_B - 1$$

- For each subframe brick row/column dimensions are computed using a greatest common divisor algorithm:

$$r = \mathrm{GCD}(\beta_{H,0}, \beta_{H,1}, \ldots, \beta_{H,n_B-1})$$

$$c = \mathrm{GCD}(\beta_{W,0}, \beta_{W,1}, \ldots, \beta_{W,n_B-1})$$

Brick-scaled Fields for Burst Location/Sizing (1)

- Following equations are scaled versions of the legacy location/size fields:

$$Burst\_Time\_Offset[k] = \frac{OFDMA\_Symbol\_Offset[k]}{c}$$

$$Burst\_Time\_Durationt[k] = \frac{Number\_of\_Symbols[k]}{c}$$

$$Burst\_Frequency\_Offset[k] = \frac{OFDMA\_Subchannel\_Offset[k]}{r}$$

$$Burst\_Bandwidth[k] = \frac{Number\_of\_Subchannels[k]}{r}$$

- Note that compared to legacy fields a reduced number of bits is needed for the binary representation. Scaling depends on brick dimensions r and c.
- Using brick-scaled fields a burst's location/size may specified in units of bricks.
- As defined brick dimensions r and c are variable and dependent on burst heights and widths so scaling varies with subframe burst allocations. Brick-scaled fields results in reduced frame overhead and better supports the dynamic allocation of bursts within a subframe.

Brick-scaled Fields for Burst Location/Sizing (2)

- If brick dimensions *r* and *c* are known at the transmit and receive ends of a link, the brick-scaled fields may be transmitted rather than the non-scaled legacy fields.
- Using a GCD algorithm brick dimensions *r* and *c* may be computed at the transmit end and then transmitted to a receiver in subframe header field.
- Brick dimensions *r* and *c* only need to be computed and transmitted once per subframe brick tessellation, not per subframe burst. Hence the increase in additional overhead required for *r* and *c* is small.
- A receiver can locate its received bursts using the received brick-scaled fields and knowledge of *r* and *c*.

Overhead Reduction for Burst 4 in the Example Brick-Tessellated DL Subframe

$$OFDMA\_Symbol\_Offset[k] = 18 \text{ (8 bits)}$$

$$Number\_of\_Symbols[k] = 12 \text{ (7 bits)}$$

$$OFDMA\_Subchannel\_Offset[k] = 14 \text{ (6 bits)}$$

$$Number\_of\_Subchannels[k] = 8 \text{ (6 bits)}$$

$$Burst\_Time\_Offset[k] = \frac{OFDMA\_Symbol\_Offset[k]}{c} = 3 \text{ (2 bits)}$$

$$Burst\_Time\_Durationt[k] = \frac{Number\_of\_Symbols[k]}{c} = 2 \text{ (2 bits)}$$

$$Burst\_Frequency\_Offset[k] = \frac{OFDMA\_Subchannel\_Offset[k]}{r} = 7 \text{ (3 bits)}$$

$$Burst\_Bandwidth[k] = \frac{Number\_of\_Subchannels[k]}{r} = 4 \text{ (3 bits)}$$

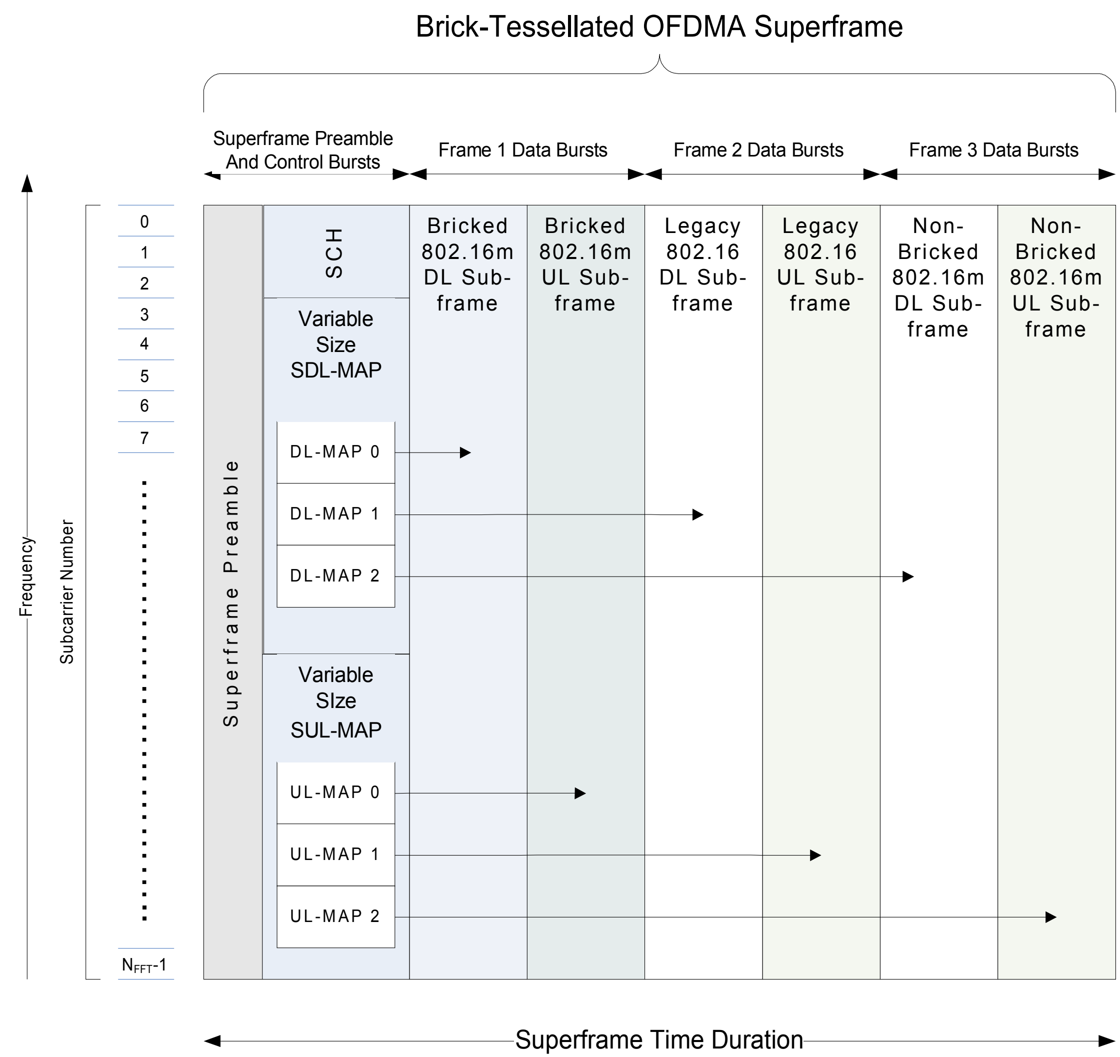
Table of Overhead Reduction for the Example 1 Brick-Tessellated DL Subframe

	Burst Number *k*					
	0	1	2	3	4	5
Burst_Time_Offset[k]	(0,1)	(0,1)	(0,1)	(2,2)	(3,2)	(4,3)
Burst_Time_Duration[k]	(2,2)	(3,2)	(4,3)	(3,2)	(2,2)	(1,1)
Burst_Frequency_Offset[k]	(0,1)	(7,3)	(11,4)	(0,1)	(7,3)	(11,4)
Burst_Bandwidth[k]	(7,3)	(3,2)	(5,3)	(7,3)	(4,3)	(5,3)
Total # of bits using brick-scaled fields	7	8	11	8	10	11
Total # of bits using non-scaled 802.16 fields	27	27	27	27	27	27
% decrease in overhead bits	74	70	59	70	63	59
Overall decrease in overhead bits using brick-scaled fields is 66 %						

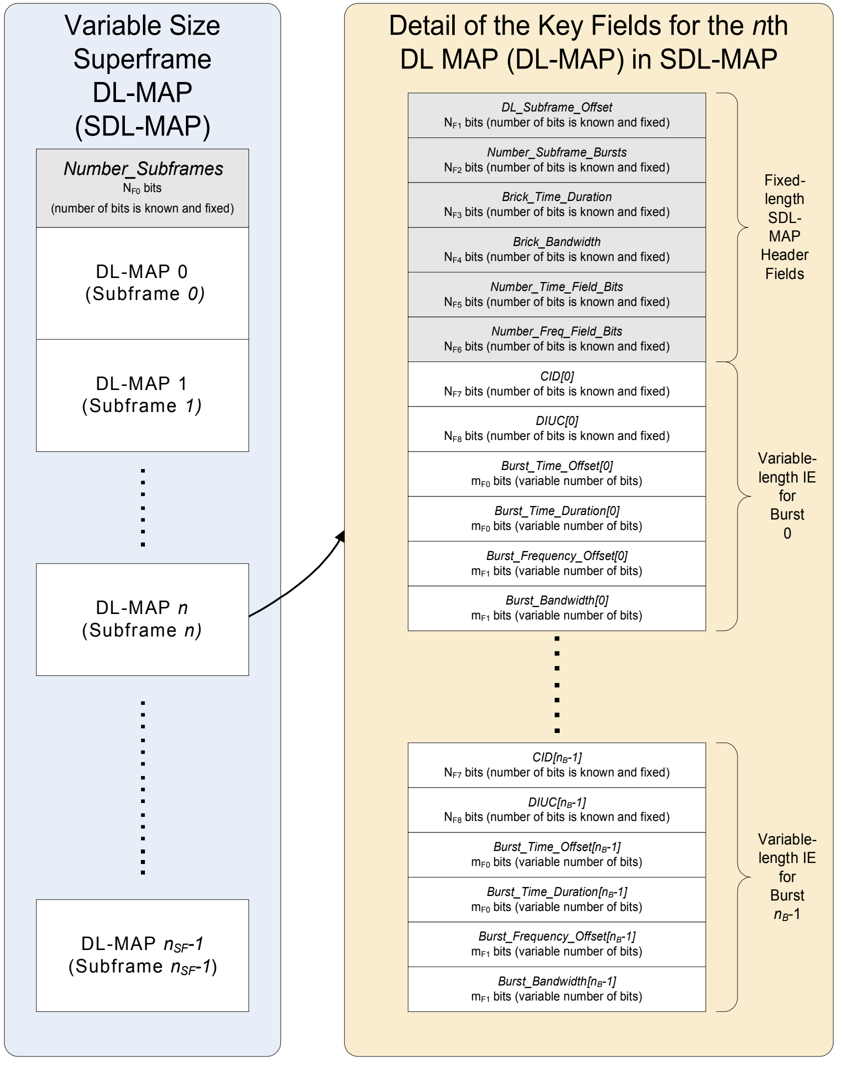
Table of Overhead Reduction for the Example 2 Brick-Tessellated DL Subframe

	Burst Number *k*						
	0	1	2	3	4	5	6
Burst_Time_Offset[k]	(0,1)	(0,1)	(1,1)	(1,1)	(2,2)	(3,2)	(3,2)
Burst_Time_Duration[k]	(1,1)	(1,1)	(2,2)	(1,1)	(1,1)	(1,1)	(1,1)
Burst_Frequency_Offset[k]	(0,1)	(1,1)	(0,1)	(1,1)	(1,1)	(0,1)	(1,1)
Burst_Bandwidth[k]	(1,1)	(1,1)	(0,1)	(1,1)	(1,1)	(1,1)	(1,1)
Total # of bits using brick-scaled fields	4	4	5	4	5	5	5
Total # of bits using non-scaled 802.16 fields	27	27	27	27	27	27	27
% decrease in overhead bits	85	85	81	85	82	82	82
Overall decrease in overhead bits using brick-scaled fields is 83 %							

Brick-Tessellated OFDMA Superframes



Key Overhead Fields for Brick-Tessellated OFDMA Superframes



Conclusions

- The proposed method may be easily integrated with any harmonized superframe/frame structure.
- The proposed method may also be used an alternative subframe structure when reduced overhead is required.
- Currently the main purpose and advantage of tessellating subframes with *r*-by-*c* bricks is to reduce the overhead associated with the four IE fields needed to specify a burst's location and size.
- Bricks may also be used as fundamental frame elements in techniques for scheduling, channel estimation, brick-based MIMO, logical channels, and other MAC and PHY layer functions.
- These techniques will require further investigation and subsequent modifications and/or extensions to the technique described within this contribution.

References

- IEEE 802.16m System Requirements Document, IEEE 802.16m-07/002r4
- Brick-Tessellated Frame Structures for 802.16m OFDMA Systems, C80216m-08_069.pdf

Proposed Text
(see contribution C80216m-08_069.pdf)

3. Definitions, Symbols, and Abbreviations

3.1 Definitions

For the purposes of the System Description Document, the following definitions shall apply:

3.1.1 Burst: A OFDMA burst is a rectangular or square area within a subframe comprised of a specified number of OFDMA subcarriers and a specified number of OFDMA symbols. A set of n_B DL or UL subframe bursts may be parametrized by their heights ($\beta_{H,k}$, $k = 0, \ldots, n_B - 1$) and their widths ($\beta_{W,k}$, $k = 0, \ldots, n_B - 1$) where burst heights $\beta_{H,k}$ are in units of OFDMA subcarriers and burst widths $\beta_{W,k}$ in units of OFDMA symbols. Bursts contain OFDMA user's FEC encoded and modulated MAC packet or protocol data units. OFDMA supports adaptive burst profiling meaning coding and modulation may be changed for each burst within a DL or UL subframe.

3.1.2 Brick: A brick is a rectangular area of a subframe's time-frequency plane that is treated as single logical unit. A brick is constructed from a set of $r > 1$ contiguous OFDMA subcarriers (brick frequency dimension) and a set of $c > 1$ contiguous OFDMA symbols (brick time dimension). Brick dimensions r and c are variable and are dependent on burst locations and sizes within DL/UL subframes, burst locations and sizes within DL/UL subframes are dependent on time-varying channel, interference and network conditions.

3.1.3 Brick-Tessellatted Subframe: A tessellation of a two-dimensional plane is a collection of plane structures that fills the plane with no overlaps and no gaps. A brick-tessellated subframe is a rectangular OFDMA subframe that is tessellated by collection of maximal-sized r-by-c bricks that fills the subframe with no overlaps or gaps. It is a logical partitioning of a subframe using bricks. The location and size of a burst within a subframe is specified using four fields. Bursts within a brick-tessellated subframe can be located and sized using scaled brick-based fields in which a burst's location and size are specified in units of bricks. This allows the four frame fields that specify burst locations and sizes to be reduced in length. The reduction in frame overhead bits can be significant and is dependent on brick dimensions r and c that serve as scaling factors, the larger the brick dimensions the greater the overhead reduction.

3.1.4 Brick-Tessellatted Superframe: A brick-tessellated superframe is comprised of a Superframe Preamble, a Superframe Control Header (SCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tessellated downlink and uplink subframes. The superframe structure allows legacy 802.16 frames to be interlaced or multiplexed with brick-based 802.16m frames.

11. Physical Layer

11.1 Legacy OFDMA Subframes

Text for this section to be provided by other harmonized contributions

11.2 OFDMA Subframes

Text for this section to be provided by other harmonized contributions

11.3 OFDMA Superframes

Text for this section to be provided by other harmonized contributions

11.4 Brick-Tessellated OFDMA Subframes

OFDMA frames require a significant amount of overhead in order to dynamically schedule or allocate downlink and uplink bursts to system users. The majority of the overhead is due to sequences of Information Elements (IEs) within a frames's DL/UL MAPs. The IEs are required to carry downlink (DL) and uplink (UL) burst information such as burst locations and sizes, burst FEC coding, and burst modulation. One IE is required for each burst allocated or scheduled for subsequent DL and UL subframes.

Four IE fields are required to specify the location and size of each DL/UL burst within a subframe's time-frequency plane. Burst locations are specified by an OFDMA Symbol Offset field and an OFDMA Subchannel/Subcarrier Offset field, burst sizes are specified by a Number of OFDMA Symbols field and a Number of OFDMA Subchannels/Subcarriers field. These four fields can consume a significant amount of frame overhead for a set of scheduled DL/UL bursts. Repetition coding of these four fields will further increase the number of overhead bits consumed by these four fields.

In addition to the OFDMA subframe structures defined in Sections 11.1 and 11.2 the IEEE 802.16m system will provide a alternative brick-tessellated subframe structure that may be used to reduce frame overhead.

A brick is a rectangular area of a subframe's time-frequency plane that is treated as single logical unit. Bricks are constructed from a set of r contiguous OFDMA subcarriers (brick frequency dimension) and a set of c contiguous OFDMA symbols (brick time dimension). Mathematically a brick is defined as an r-by-c matrix $\mathbf{B}(p_0 : p_{r-1}, q_0 : q_{c-1})$ where integers r and c denote brick row and column dimensions. Brick matrix elements $x(p_a, q_b)$ are produced by length-N_{FFT} IFFT operations on M-QAM modulation symbol vectors. Integers p_a ($a = 0, ..., r-1$) and q_b ($b = 0, ..., c-1$) denote OFDMA subcarriers and OFDMA symbol numbers, they are contiguous and ordered as follows:

$$
\begin{aligned}
0 &\leq p_0 < p_1 < p_2 < \cdots < p_{r-1} \leq N_{FFT} - 1 \\
0 &\leq q_0 < q_1 < q_2 < \cdots < q_{c-1}
\end{aligned}
$$

A tessellation of a two-dimensional plane is a collection of plane structures that fills the plane with no overlaps and no gaps. A brick tessellation of a rectangular OFDMA subframe is defined as a collection of maximal-sized r-by-c bricks that fills the subframe with no overlaps or gaps. It is a logical partitioning of a subframe using bricks. Figure 9 illustrates a simple brick-tessellated DL subframe. Given a set of burst heights ($\beta_{H,k}$, $k = 0, \ldots, n_B - 1$) in units of OFDMA subcarriers and a set of burst widths ($\beta_{W,k}$, $k = 0, \ldots, n_B - 1$) in units of OFDMA symbols, brick row and column dimensions used for a subframe brick tessellation are defined as

$$
\begin{aligned}
r &= \mathrm{GCD}(\beta_{H,0}, \beta_{H,1}, \ldots, \beta_{H,n_B-1}) > 1 \\
c &= \mathrm{GCD}(\beta_{W,0}, \beta_{W,1}, \ldots, \beta_{W,n_B-1}) > 1
\end{aligned}
$$

where GCD denotes a greatest common divisor algorithm.

Bursts within a brick-tessellated subframes can be located and sized using scaled brick-based fields in which a burst's location and size are specified in units of bricks. This allows the four fields that specify burst locations and sizes to be reduced in length. The reduction in overhead bits can be significant and is dependent on brick dimensions r and c that serve as scaling factors, the larger the brick dimensions the

Figure 9: Example brick tessellation of a OFDMA DL subframe with brick dimensions $r = 2$ and $c = 6$. Note that each subframe burst is tessellatted with an integer number of r-by-c bricks. Hence to reduce frame overhead the location and size of each burst may be specified in units of bricks rather then OFDMA subcarriers/subchannels and OFDMA symbols. Each burst has a unique OFDMA user address. To adapt to channel conditions burst allocations for each user may be contiguous, non-contiguous or pseudo-random. A schedular determines the optimal subframe burst allocation and addressing for each subframe.

greater the overhead reduction. Further, burst locations and sizes within DL and UL subframes are dependent on time-varying channel, interference and network conditions. Using brick-tessellated subframes the scaled brick-based fields can be varied in their lengths for each transmitted subframe. This results reduced frame overhead and better supports the dynamic allocation of bursts within a subframe.

11.5 Brick-Tessellated OFDMA Superframes

In addition to the OFDMA superframe structure defined in Section 11.3 the IEEE 802.16m system provides a alternative brick-tessellated superframe structure that may be used to reduce frame overhead without compromising overall system performance. Figure 10 shows an brick-based 802.16m superframe structure that may be used for an 802.16m system that operates in a Time Division Duplexing (TDD) mode. The superframe is comprised of a Superframe Preamble, a Superframe Control Header (SCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tesellatted downlink and uplink subframes. The superframe structure allows legacy 802.16 frames to be interlaced or multiplexed with brick-tessellated 802.16m frames. Figures 9 shows an example of brick-tessellated DL subframe that may comprise the 802.16m DL subframes shown in Figure 7. As shown in Figure 9, the superframe structure also allows non-bricked 802.16m frames to inserted into the superframe.

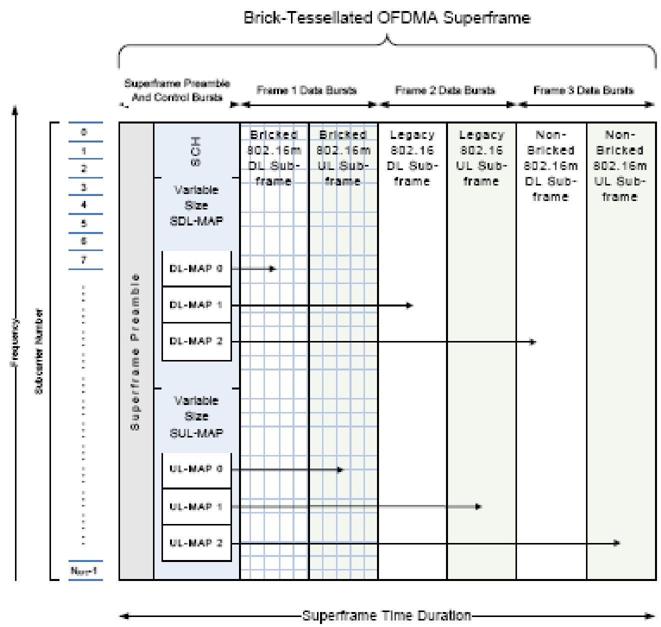


Figure 10: Example brick-based superframe structure for TDD modes of operation. The superframe contains a Superframe Preamble, a Superframe Control Header (SCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tessellated downlink and uplink subframes that support OFDMA user data. For simplicity transmit and receive time gaps are not shown. Figure 9 shows example of brick-based DL subframes that may comprise the superframe. Information Elements within the SDL-MAP and the SUL-MAP provide the necessary control data needed for superframe configuration and changes. Information Elements within the SDL-MAP and the SUL-MAP also specify the brick tessellations to be used for each DL and UL subframe.