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Re:	IEEE 802.16m-07/047 - Call for Contributions on the 802.16m System Description Document (SDD)
Abstract	This contribution describes brick-tesellatted frame structures that can used to significantly reduce frame overhead within 802.16 OFDMA systems. Proposed text for the System Description Document is also provided.
Purpose	To discuss and add the proposed text to the current version of IEEE 802.16m System Description Document.
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Brick-Tessellated Frame Structures for 802.16m OFDMA Systems

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1 Problem Description

The IEEE 802.16m System Requirements Document [1] 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. The current IEEE 802.16 frame structure [2] requires 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, FEC coding, and modulation.

Figure 1 shows as example DL burst within a DL subframe's time-frequency plane. The units on the time axis are OFDMA symbols, the units on the frequency axis are logical subchannels. From Figure 1 it can be seen that the following four frame fields are required to specify the location and size of each burst within the subframe: (1) $OFDMA\_Symbol\_Offset$, (2) $Number\_of\_Symbols$, (3) $OFDMA\_Subchannel\_Offset$, and (4) $Number\_of\_Subchannels$. Burst locations are specified by the $OFDMA\_Symbol\_Offset$ and $OFDMA\_Subchannel\_Offset$ fields. Burst sizes are specified by the $Number\_of\_Symbols$ and $Number\_of\_Subchannels$ fields.

For each transmitted DL and UL burst the above four fields for burst location and size specification require 27 bits in overhead (this value may be slightly different in some cases). Repetition coding of 2, 4 or 6 bits will further increase the number of overhead bits consumed by these four fields. Indeed, they are fundamental frame fields that may be targeted in order to reduce frame overhead and thereby increase network data throughput for 802.16m systems.

To better see the effect that the above four fields have on frame overhead we give a simple example. As stated in the current 802.16 standard [2] the maximum number of bursts to decode in one DL subframe is 64. The IE overhead required to specify the locations and sizes of 64 DL bursts using the above four fields is $64 \times 27 = 1728$ bits (assume DL-MAP is transmitted using a rate 1/2 code, QPSK modulation, no repetition coding). If the FFT length is 2048 the 1728 overhead bits required for burst locations and sizes will leave only 320 OFDMA subcarriers available for the frame's FCH, UL-MAP, right and left guard bands, DIUC and other DL fields that may carry information such as base station identification code, MIMO configuration, multi-hop relaying information, power levels, etc. Hence, one or more additional OFDMA symbols may be needed for the total overhead resulting in a decreased system throughput rate.

2 Proposed Solution

This contribution describes a technique for reducing IEEE 802.16m system overhead. System overhead reduction is gained by decreasing the lengths of the four frame fields that are required to specify the location and size of a burst within a DL/UL subframe.

The technique is based on brick-tessellated subframes. 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). A tessellation [3] 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.

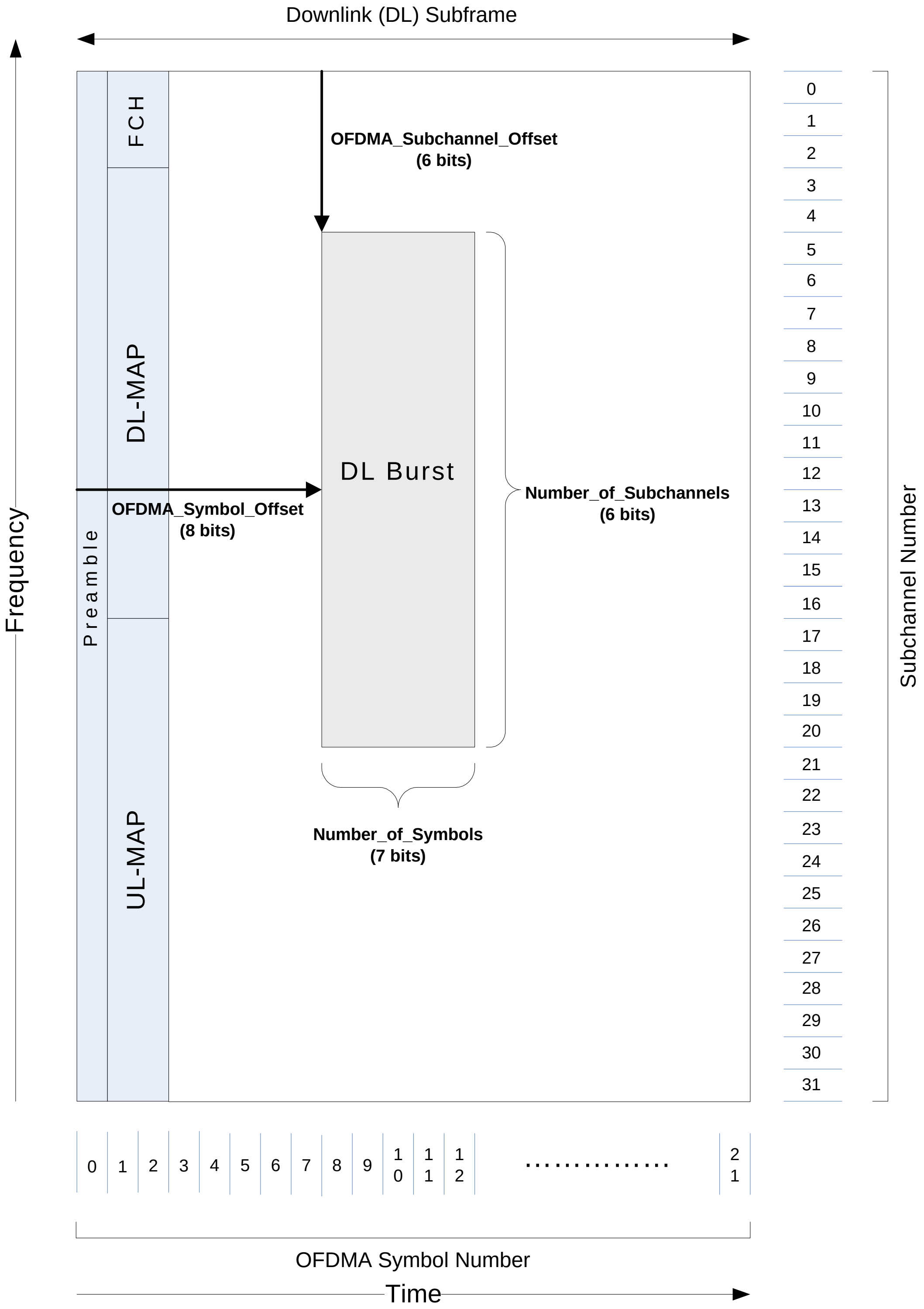


Figure 1: Illustration of an OFDMA DL burst and the four frame fields required to specify its location and size within a DL subframe. Each burst requires 27 bits in overhead just to specify its location and size. Depending on a subframe's burst allocation, these fields may consume a significant amount of frame overhead which will adversely effect system throughput rates.

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 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 that serve as scaling factors, the larger the brick dimensions the 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 contributes to reduced frame overhead and better supports the dynamic allocation of bursts within a subframe.

In this contribution a brick-tessellated superframe structure is also described. Bricked-tessellated superframes are comprised of a Superframe Preamble, a Superframe Control Header (SFCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tessellated DL and UL subframes. The superframe structure subsumes legacy IEEE 802.16 frames and can be easily modified or extended for other proposed IEEE 802.16m frame/superframe ideas.

As stated above the main purpose and advantage of tessellating subframes with r-by-c bricks is to reduce the overhead associated with the four fields needed to specify a burst's location and size. However, it should be mentioned that bricks may also be used as fundamental frame elements in techniques for scheduling, channel estimation, brick diversity combining from multiple antenna streams, 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.

In the following sections of this contribution we first describe a subsystem for generating OFDMA bursts within 802.16m systems. We then describe how subframes populated with bursts may be tessellated using bricks of varying dimension. The basic approach for frame overhead reduction using brick-tessellated subframes is then described. Brick-tessellated superframes are then described as are required key overhead fields. The contribution concludes with proposed text for the SDD document.

3 Burst Generation for Brick-Tessellated Subframes

To describe our proposed technique we first need to describe how user data streams are mapped to data bursts within a subframe's time-frequency plane. Figure 2 shows a conceptual block diagram an OFDMA subsystem for mapping N_P user data streams to data bursts that comprise a downlink (DL) subframe. Adaptive FEC (forward error correction) coding and M-QAM modulation are used to assure variable degrees of service quality for the N_P users.

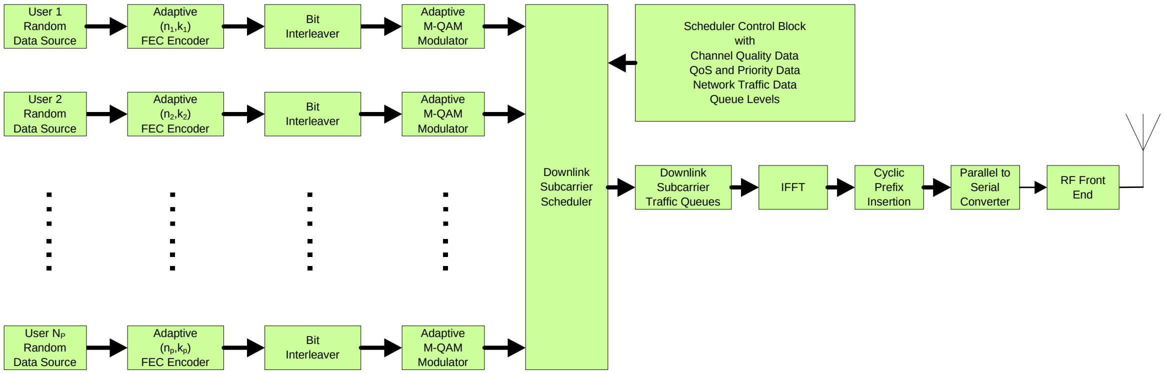


Figure 2: Conceptual block diagram of single-output OFDMA subsystem for mapping N_P user data streams to downlink data bursts. Wide lines represent vectors, narrow lines represent scalars. For simplicity the insertion of pilot symbols and guard bands is not shown.

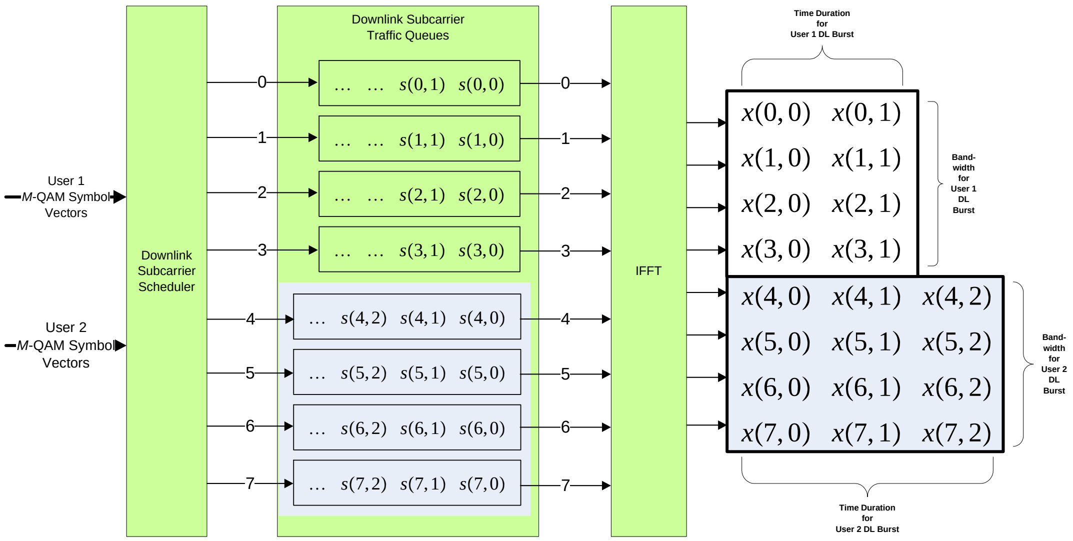


Figure 3: Illustration showing the mapping of user modulation symbol vectors to DL data bursts. The blocks show the details of Figure 2 blocks (DL Subcarrier Scheduler, Traffic Queues and IFFT) for the simple case $N_{FFT} = 8$ and only two users. The traffic queues contain M-QAM modulation symbols. User 1 is mapped to subcarriers 0 to 3, user 2 is mapped to subcarriers 4 to 7. Bursts for User 1 and 2 are boxed by bold lines.

The N_P user data sources produce randomized binary-valued data blocks of various lengths κ_k, $k = 0, \ldots, N_P - 1$. These data blocks are input to adaptive FEC encoders that are parametrized by pairs (η_k, κ_k) where η_k denotes the length of an encoded data block. The code and/or code rate of an FEC encoder may be adapted. Some code options for the FEC encoder are Convolutional Codes, Duo-Binary Turbo-Codes (also called convolutional turbo codes) and Low Density Parity Check codes.

The encoded data blocks are bit interleaved and then input to the adaptive M-QAM modulators. Parameter M may be set to $M = 4$ (QPSK), $M = 16$ (16-QAM) or $M = 64$ (64-QAM). The M-QAM modulators output modulation symbol vectors of length $\beta_k = \eta_k/m_k$, $k = 0, \ldots, N_P - 1$. Each symbol within a modulation symbol vector is generated by mapping $m_k = \log_2(M)$ bits from the bit interleaver output to a complex-valued symbol within the selected M-QAM signal constellation.

Table 1 shows an example set of values for κ_k, η_k, m_k and β_k. From Table 1 it can be seen that the length β_k of a modulation symbol vector is dependent on the triple (η_k, κ_k, m_k), $k = 0, \ldots, N_P - 1$. For example, if $\kappa_k = 320$, $\eta_k = 640$, and $m_k = 2$ the length of the resulting modulation symbol vector is $\beta_k = \eta_k/m_k = 320$. In legacy 802.16 systems κ_k, η_k and m_k are specified so that β_k is always a divisor of two. It is assumed that this is also true for 802.16m systems. It should be mentioned that the proposed method will also work for modulation symbol vectors having desired lengths other than $\beta_k = \eta_k/m_k$. However, any other selected symbol vector length must be a factor of two in order to optimally implement the proposed method.

A downlink 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 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 (see Figure 1).

The DL Subcarrier Scheduler maps each modulation symbol vector of length β_k to a burst within a subframe's time-frequency plane. The DL Subcarrier 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 that lies within a subframe's time-frequency plane. The area of the kth burst within a subframe's time-frequency plane

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

Table 1: Example coding and modulation parameters taken from the IEEE 802.16 standard.

equals a modulation symbol vector's length, that is $\beta_k = \beta_{H,k} \times \beta_{W,k}$.

Figure 3 shows a simple example of subsystem for implementing the DL Subcarrier Scheduler, the DL Subcarrier Traffic Queues and the IFFT subcarrier modulator with $N_{FFT} = 8$. In accordance with values output by the scheduler's control block, the DL Subcarrier Scheduler routes the modulation symbols within its input modulation symbol vectors to the appropriate first-in, first-out DL traffic queues. In the example the DL Subcarrier Scheduler routes User 1 modulation symbols to the queues for OFDMA subcarriers 0 through 3; user 2 modulation symbols are routed to the queues for OFDMA subcarriers 4 through 7. Note that each column in the traffic queues is associated with an OFDMA symbol. The IFFT block subcarrier modulates each traffic queue column it receives as input.

Figure 3 also shows two user DL bursts within an area of a DL subframe. Each burst row is associated with an OFDMA subcarrier and each column within an OFDMA symbol. Burst elements are defined as

$$\begin{aligned} x(p,q) &= \frac{1}{\sqrt{N_{FFT}}} \sum_{n=0}^{N_{FFT}-1} s(n,q) e^{j2\pi pn/N_{FFT}} \\ p &= 0,1,\ldots,7, \; q = 0,1,2 \end{aligned} \tag{1}$$

where p denotes a discrete subcarrier frequency and q the transmit time of an OFDMA symbol or equivalently the OFDMA symbol number. The summation defines an inverse fast Fourier transform operation on a length $N_{FFT} = 8$ vector of M-QAM modulation symbols $\{s(n,q)\}_{n=0}^{N_{FFT}-1}$.The area of the bursts are $\beta_{H,1} \times \beta_{W,1} = 8$ and $\beta_{H,2} \times \beta_{W,2} = 12$ where $\beta_{H,1} = 4$, $\beta_{W,1} = 2$, $\beta_{H,2} = 4$, and $\beta_{W,2} = 3$.

4 Brick-Tessellated Subframes

As defined in the 802.16 standard [2], a *slot* is a rectangular OFDMA frame element that is defined in units of logical subchannels (slot frequency dimension) and OFDMA symbols (slot time dimension). A slot's rectangular size is always one logical subchannel by one, two, three, or six OFDMA symbols. Each DL/UL burst is comprised of a number of slots.

A brick is more general frame element that is not restricted in size, it is comprised contiguous OFDMA subcarriers and contiguous OFDMA time slots that are treated as a single logical unit. Mathematically a brick is defined as an r-by-c matrix

$$\mathbf{B}(p_0 : p_{r-1}, q_0 : q_{c-1}) = \begin{bmatrix} x(p_0,q_0) & \ldots & x(p_0,q_{c-1}) \\ x(p_1,q_0) & \ldots & x(p_1,q_{c-1}) \\ \vdots & & \vdots \\ x(p_{r-1},q_0) & \ldots & x(p_{r-1},q_{c-1}) \end{bmatrix} \tag{2}$$

where integers $r > 1$ and $c > 1$ denote brick row and column dimensions. Brick element

$$\begin{aligned} x(p_a, q_b) &= \frac{1}{\sqrt{N_{FFT}}} \sum_{n=0}^{N_{FFT}-1} s(n, q_b) e^{j2\pi p_a n / N_{FFT}} \\ a &= 0, 1, \ldots, r-1 \\ b &= 0, 1, \ldots, c-1 \end{aligned} \tag{3}$$

is produced via a length-N_{FFT} IFFT operation on an M-QAM modulation symbol sequence $\{s(n, q_b)\}_{n=0}^{N_{FFT}-1}$. Integers p_a and q_b respectively denote subcarrier frequencies and OFDMA symbol numbers, they are contiguous and ordered as follows:

$$0 \le p_0 < p_1 < p_2 < \cdots < p_{r-1} \le N_{FFT} - 1 \tag{4}$$

$$0 \le q_0 < q_1 < q_2 < \cdots < q_{c-1} \tag{5}$$

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. For each brick tessellation the DL Subcarrier Scheduler shown in Figure 2 must provide the heights and widths of all n_B bursts allocated to a subframe. Given burst heights ($\beta_{H,k}$, $k = 0, \ldots, n_B - 1$) in units of OFDMA subcarriers and 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 computed from

$$r = \text{GCD}(\beta_{H,0}, \beta_{H,1}, \ldots, \beta_{H,n_B-1}) \tag{6}$$

and

$$c = \text{GCD}(\beta_{W,0}, \beta_{W,1}, \ldots, \beta_{W,n_B-1}) \tag{7}$$

where GCD denotes the greatest common divisor. The GCD of two or more non-zero integers is the largest positive integer that divides these integers without remainder. For example, the GCD of burst heights $\beta_{H,0} = 24$, $\beta_{H,1} = 16$ and $\beta_{H,2} = 12$ is 4. The GCD has numerous properties that can be used for its computation such as the property $\text{GCD}(\beta_{H,0}, \beta_{H,1}, \beta_{H,2}) = \text{GCD}(\text{GCD}(\beta_{H,0}, \beta_{H,1}), \beta_{H,2})$. This property can be extended to any number of bursts that comprise a subframe. There are many efficient algorithms for computing the GCD. The Euclidean algorithm, extended Euclidean algorithm, and binary GCD algorithm are efficient for GCD computations. The following function shows a simple Euclidean algorithm for computing the GCD of two non-zero integers x_1 and x_2.

```
function GCD($x_1, x_2$)
while $x_1 > 0$ {
    $temp = x_2$
    $x_2 = x_1 \bmod x_2$
    $x_1 = temp$
}
return $GCD = x_1$
```

Given brick dimensions r and c the number n_R of r-by-c bricks that cover the bandwidth of a brick tessellated subframe is

$$n_R = \frac{N_{FFT}}{r} \tag{8}$$

where N_{FFT} denotes the number of OFDMA subcarriers. Similarly, the number n_C of r-by-c bricks that cover the time duration of a tessellated subframe's is

$$n_C = \frac{N_{Symbls}}{c} \tag{9}$$

where N_{Symbls} denotes the number of OFDMA symbols within a subframe.

Figures 4, 5 and 6 show example brick tessellations of OFDMA downlink subframes. For simplicity guard bands are not shown, only the data part of a subframe is shown. In Figure 4 six bursts are shown within the DL subframes's time-frequency plane. Their heights ($\beta_{H,k}$, $k = 0, \dots, 5$) in units of OFDMA symbols are 14, 8, 10, 14, 8, and 10. Their widths ($\beta_{W,k}$ $k = 0, \dots, 5$) in units of OFDMA symbols are 12, 18, 24, 18, 12 and 6. Computing the GCD of the burst heights and widths gives the brick dimensions $r = 2$ and $c = 6$. The number of bricks used to cover the subframe's bandwidth is $n_R = 16$, the number of bricks used to cover the subframe's time duration is $n_C = 5$. In Figure 5 the brick dimensions are $r = 16$ and $c = 6$. The number of bricks used to cover the subframe's bandwidth is $n_R = 2$, the number of bricks used to cover the subframe's time duration is $n_C = 4$. In Figure 6 the brick dimensions are $r = 2$ and $c = 6$. The number of bricks used to cover the subframe's bandwidth is $n_R = 16$, the number of bricks used to cover the subframe's time duration is $n_C = 4$.

5 Overhead Reduction using Brick-Tessellated Subframes

The main purpose and advantage of tessellating subframes with r-by-c bricks is to reduce the overhead associated with the four fields needed to specify a burst's location and size. Using a subframe tessellated with bricks, the locations and sizes of bursts can be specified in units of bricks rather than OFDMA subcarriers/subchannels and OFDMA symbols. The approach can be described by using Figure 4. Referring to Figure 4 it can be seen that the location and size of the kth burst in a subframe may be specified by the following factored frame fields:

$$OFDMA\_Symbol\_Offset[k] = Burst\_Time\_Offset[k] * c \tag{10}$$

$$Number\_of\_Symbols[k] = Burst\_Time\_Duration[k] * c \tag{11}$$

$$OFDMA\_Subchannel\_Offset[k] = Burst\_Frequency\_Offset[k] * r \tag{12}$$

$$Number\_of\_Subchannels[k] = Burst\_Bandwidth[k] * r \tag{13}$$

where

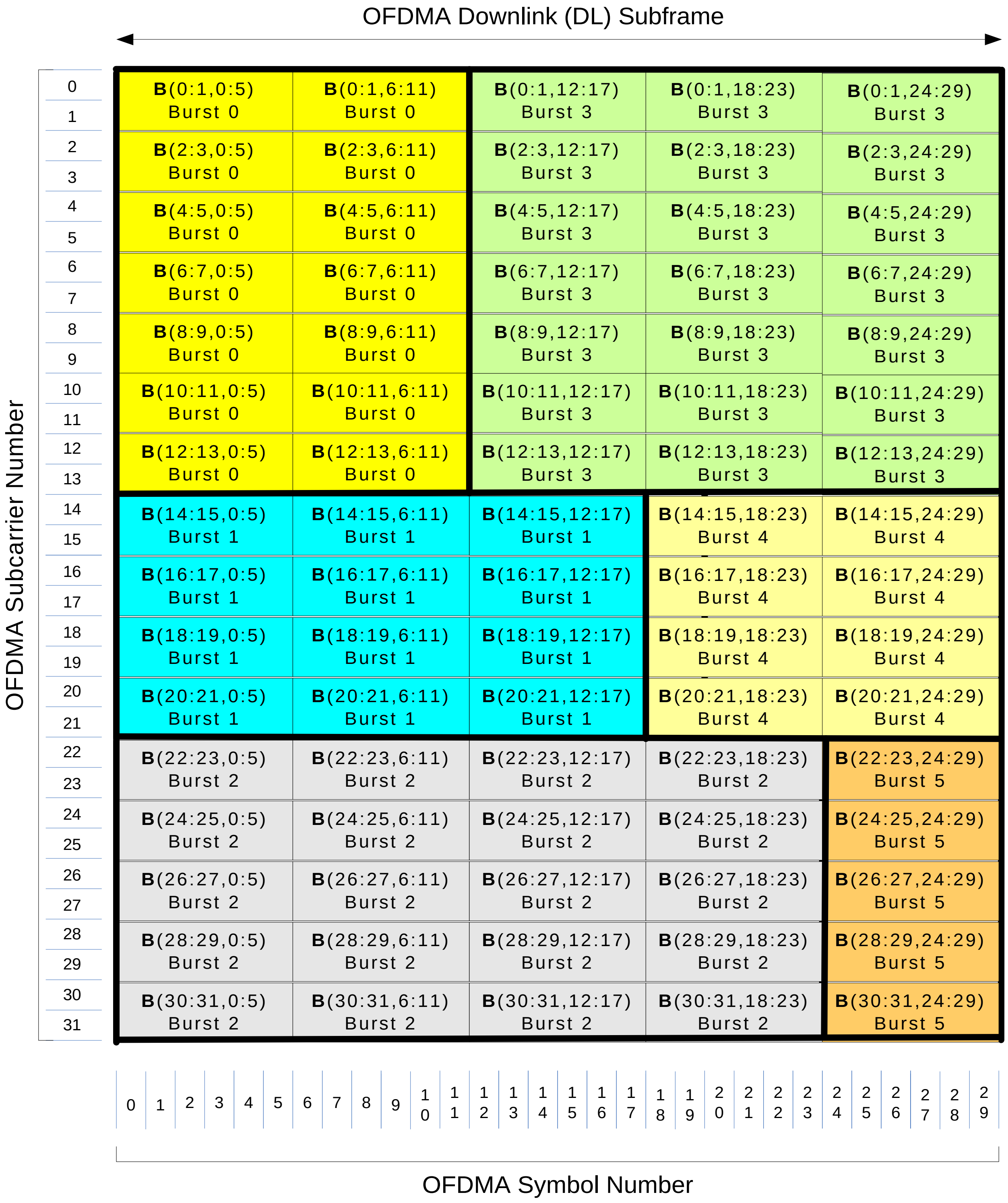
$$Burst\_Time\_Offset[k] = \frac{OFDMA\_Symbol\_Offset[k]}{c} \tag{14}$$

$$Burst\_Time\_Durationt[k] = \frac{Number\_of\_Symbols[k]}{c} \tag{15}$$

$$Burst\_Frequency\_Offset[k] = \frac{OFDMA\_Subchannel\_Offset[k]}{r} \tag{16}$$

$$Burst\_Bandwidth[k] = \frac{Number\_of\_Subchannels[k]}{r} \tag{17}$$

Equations 14 through 17 are *scaled* versions of the fields shown in Figure 1 so a reduced number of bits is needed for their binary representation. From equations 6 and 7 we see that scaling values r and c are dependent on burst heights and widths. If brick dimensions r and c are known at the transmit and receive



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

Figure 4: Example brick tessellation of a OFDMA DL subframe. Bricks are defined using equation 2. Brick dimensions $r = 2$ and $c = 6$ are computed using equations 6 and 7. 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. For example, bursts 0, 4 and 5 may be addressed to one user and bursts 1, 2, 3 and 4 to another user. A schedular determines the optimal subframe burst allocation and addressing for each subframe.

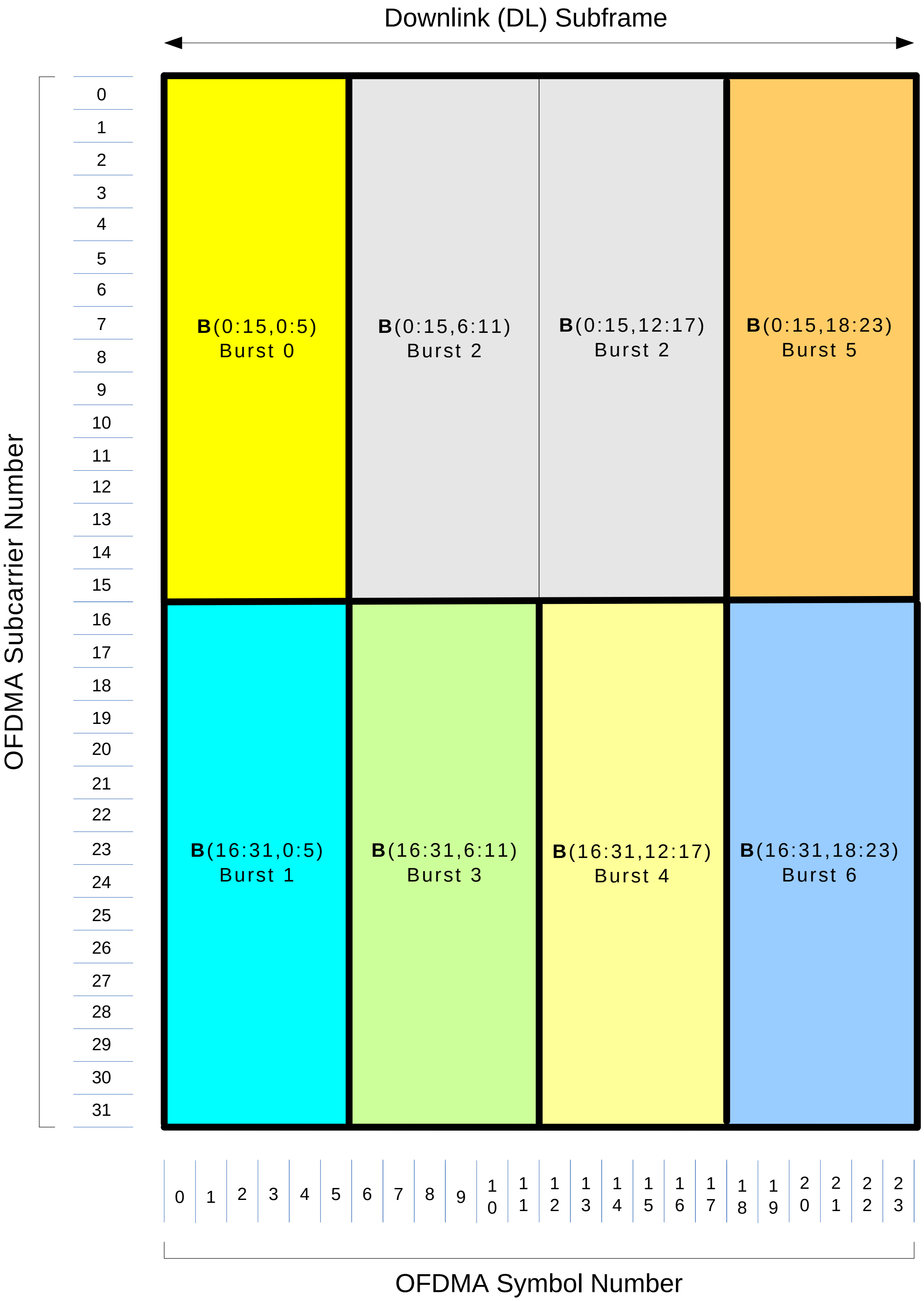
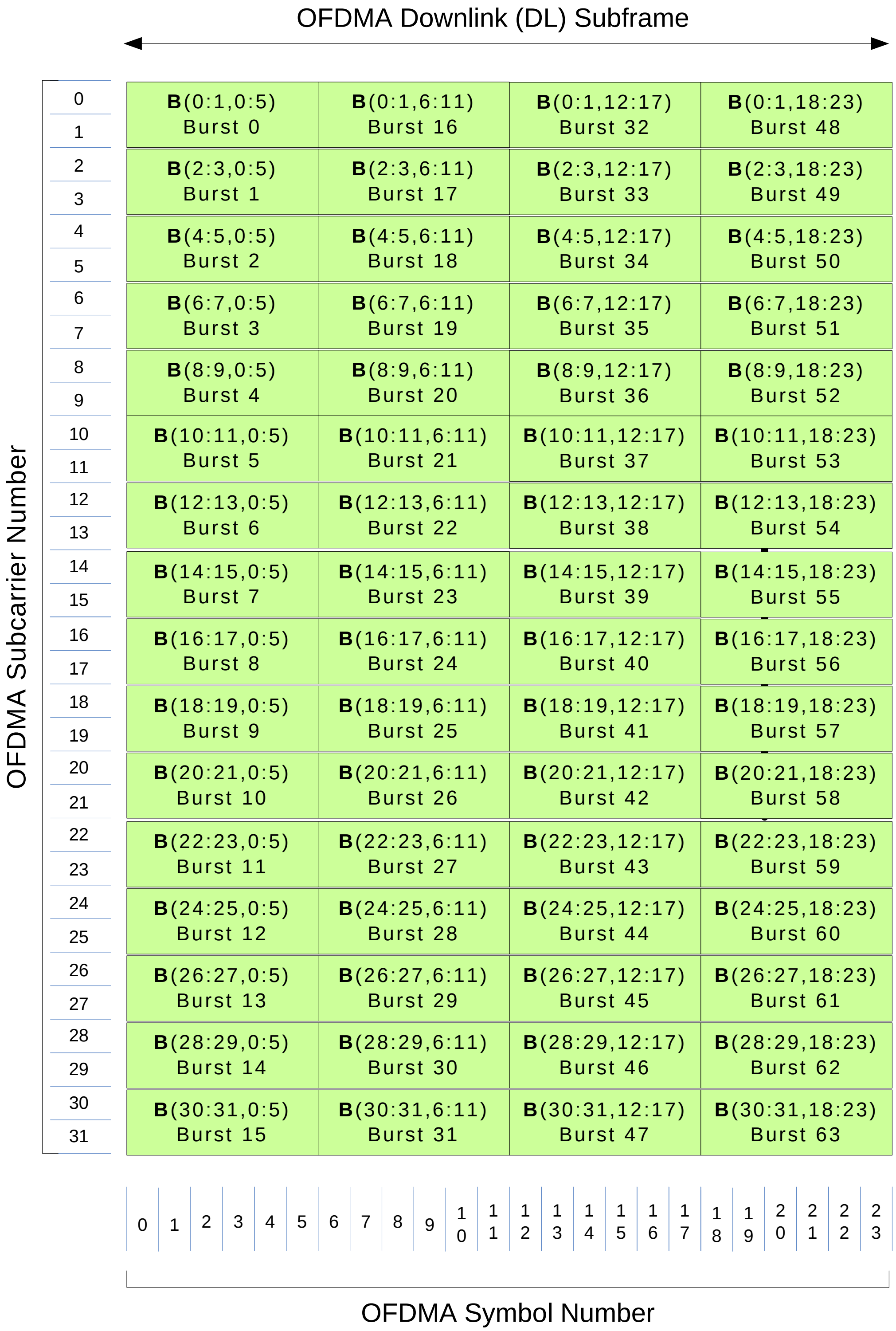


Figure 5: Example brick tessellation of OFDMA DL subframe with brick dimensions $r = 16$ and $c = 6$. Brick dimensions are computed using equations 6 and 7. Note that each subframe burst is tessellatted with an integer number of r-by-c bricks. Hence to reduce frame overhead the location and size of each burst may be specified in units of bricks rather then OFDMA subcarriers/subchannels and OFDMA symbols.



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
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
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
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
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
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
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
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
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
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
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
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
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
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
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
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

Figure 6: Example brick tessellation of OFDMA DL subframe with brick dimensions $r = 2$ and $c = 6$. Brick dimensions are computed using equations 6 and 7. In this example brick dimensions equal burst dimensions $\beta_{H,k}$ and $\beta_{W,k}$, $k = 0, 1, ..., 63$, each subframe burst is tessellatted with a single r-by-c brick. 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. To adapt to channel time-varying channel, interference and network 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.

ends of a link, the scaled fields (14 through 17) may be transmitted rather than the original non-scaled fields shown in Figure 1. For each subframe brick dimensions r and c may be computed at the transmit end of a link using equations 6 and 7, they may then be transmitted to a receiver. A receiver can locate its bursts within a received subframe using equations 10 through 13 given the received scaled fields (14 through 17) and knowledge of r and c. It must be emphasized that r and c only need to be computed and transmitted once per subframe, not per subframe burst. Hence the increase in additional overhead required for r and c is small.

From equations 14 through 17 it is seen that the scaling values r and c should be as large as possible in order to maximize frame overhead reduction, values of r and c equal to one must be avoided. As described in Section 3 data block lengths κ_k, encoded data block lengths η_k, and bits per modulation symbol m_k are divisors of two so modulation symbol vectors of length $\beta_k = \eta_k/m_k$ are constrained to be divisors of two. The area of the kth burst is a subframe's time-frequency plane $\beta_k = \beta_{H,k} \times \beta_{W,k}$. Since β_k is constrained to be a divisor of two, products $\beta_{H,k} \times \beta_{W,k}$ are also divisors of two. Hence, the mapping of bursts to subframes can be implemented in a manner that eliminates GCD values that are equal to one. For example, given a burst of area $\beta_k = \beta_{H,k} \times \beta_{W,k} = 240$ acceptable pairs for $(\beta_{H,k}, \beta_{W,k})$ are $(12, 20)$, $(24, 10)$, $(6, 40)$ and $(30, 8)$, others are also acceptable but not listed. The chosen pair to be used may be based on channel, interference and network conditions; it is a task of the Downlink Subcarrier Scheduler to chose the optimal pair $(\beta_{H,k}, \beta_{W,k})$.

To see the significant overhead reduction gained by using brick-scaled fields (14 through 17), Figure 4, 5 and 6 may again be used. Referring to Figure 4 it can be seen that location and size of Burst 4 ($k = 4$) may be represented by the non-scaled field values

$$\begin{aligned}
OFDMA\_Symbol\_Offset[k] &= 18 \text{ (8 bits)} \\
Number\_of\_Symbols[k] &= 12 \text{ (7 bits)} \\
OFDMA\_Subchannel\_Offset[k] &= 14 \text{ (6 bits)} \\
Number\_of\_Subchannels[k] &= 8 \text{ (6 bits)}
\end{aligned}$$

Using equations 6 and 7 brick dimensions for the DL subframe in Figure 4 are $r = 2$ and $c = 6$. The brick-scaled location and size fields for Burst 4 are defined as

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

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

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

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

Note that the brick-based fields require only 10 bits compared to fields the original non-scaled fields which require 27 bits.

Tables 2 and 3 show the scaled brick-based field values for all six bursts within the DL subframes of Figures 4 and 5. Each table pair contains a field's decimal value (first number) and the number of bits required to represent the decimal value within a transmitted subframe field. The tables also show the total number of overhead bits using brick-scaled fields and non-scaled fields as shown in Figure 1. Percent decreases in overhead bits are also shown. Note that the overall decrease in overhead bits using the scaled brick-based field is 66 % and 83 % which is significant.

	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 2: Table of values for the brick-scaled fields associated with the brick tessellated subframe shown in Figure 4. Each table pair contains a field's decimal value followed by number of bits that are required to represent the decimal value in a binary or base-2 representation.

	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 %							

Table 3: Table of values for the brick-scaled fields associated with the brick tessellated subframe shown in Figure 5. Each table pair contains a field's decimal value followed by number of bits that are required to represent the decimal value in a binary or base-2 representation.

Similarly for the 64 bursts shown in Figure 6 subframe it can shown that the total number of bits for the *Burst_ Time_ Offset[k]*, *Burst_ Time_ Duration[k]*, *Burst_ Frequency_ Offset[k]* and *Burst_ Bandwidth[k]* fields is 96 bits, 64 bits, 200 bits, and 64 bits. The total number of bits using brick-scaled fields is the summation equal to 424 bits. For comparison, the total number of bits using non-scaled fields is 1728 bits. Hence, the overall decrease in overhead bits using brick-scaled fields is 75 %.

6 Brick-Tessellated OFDMA Superframes

Figure 7 shows an example brick-based 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 downlink and uplink subframes. The superframe structure allows legacy 802.16 frames to be interlaced or multiplexed with brick-based 802.16m frames. Figures 4, 5 and 6 show examples of brick-based DL subframes that may comprise the 802.16m DL subframes shown in Figure 7, brick-based UL subframes may also be used. Note that if the superframe contains only one frame it reduces to the current IEEE 802.16 frame structure. Hence the superframe structure subsumes the current IEEE 802.16 frame structure.

The brick-based superframe structure shown in Figure 7 is very general and can be modified or extended in many ways in order to incorporate novel frame structure ideas proposed for 802.16m. For example, (1) different types of logical channels may be mapped to sets of OFDMA subcarriers within the superframe control or data sections, they may be added or used in place of the SCH, SDL-MAP, and SUL-MAP; (2) the superframe structure shown Figure 7 has a DL-to-UL ratio of 1-to-1, this ratio could be varied; (3) the time durations of the 802.16m and legacy 802.16 frames may be changed; (4) additional control fields may be added to the SCH, SDL-MAP and SDL-MAP, (5) novel preamble and pilot signals may be added if required to improve 802.16m system performance.

7 Key Overhead Fields for Brick-Tessellated OFDMA Superframes

To better understand how brick-tessellated superframes or subframes may be used within 802.16m systems we define the key fields needed for an implementation of the proposed technique. Figure 8 shows a set of key fields for the superframe SDL-MAP shown in Figure 7. The SUL-MAP will have similar fields. Referring to left side of Figure 8 it is seen that the SDL-MAP is comprised of a *Number_ Subframes* field and a total of n_{SF} DL-MAPs (DL-MAPs 0 to $n_{SF} - 1$). Each DL-MAP is associated with a DL subframe within the Figure 7 superframe, each DL subframe shall be configured using a single DL-MAP. The *Number_ Subframes* field and DL-MAP fields are transmitted from top to bottom in sequential order. Hence the fields can be sequentially loaded into in a RAM buffer at the transmit end and sequentially read from a RAM buffer at the receive end. If the superframe structure has one or more legacy 802.16 frames (e.g. Frame 2 in Figure 7) the corresponding superframe DL/UL-MAPs can be pointers to the locations of the legacy 802.16 frames within the superframe. For example, the *DL_ Subframe_ Offset* field described below may be used.

The right side of Figure 8 shows the detail of the nth DL-MAP within the sequence of n_{SF} DL-MAPs. The detail for each of the n_{SF} DL-MAPs is the same unless it is associated with a legacy 802.16 frame. In this case it may be a simple pointer as mentioned above. The first six fields within the nth DL-MAP are SDL-MAP header fields that are fixed in length. Following the six SDL-MAP header fields is a variable-length sequence of n_B IEs that provide the information needed to specify subframe burst allocations. Only key IE fields required for burst location/sizing, burst coding/modulation, and burst addressing are shown in Figure 8. Other fields may be easily added to the SDL-MAP and IEs in order to support other 802.16m requirements such as MIMO.

Referring to Figure 8, key fields for the nth DL-MAP are defined as follows:

1. The length-N_{F0} *Number_ Subframes* field contains the binary representation of a positive integer $n_{SF} \geq 1$ that specifies the total number of DL subframes within a DL superframe. Note that if $n_{SF} = 1$ the superframe contains only one frame and the superframe structure reduces to the legacy IEEE 802.16 frame structure. The field's length N_{F0} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum number of DL subframes allowed for an 802.16m implementation. For example, if the maximum number of DL subframes allowed is 64, N_{F0} must equal 6 bits in order to support up to 64 DL subframes per superframe. The number of DL subframes n_{SF} could then be any positive integer ranging from 0 to 63. The starting address of the *DL_ Subframe_ Offset* field in decimal is

$$Address\_Number\_Subframes = 0 \tag{18}$$

   Note that for simplicity we have used an address of 0. In an actual implementation this value would have to be offset by the summation of lengths of the SCH and any other preceding fields.

2. The length-N_{F1} *DL_ Subframe_ Offset* field contains the binary representation of a positive integer that specifies the offset of the nth DL subframe within a superframe. The nth DL subframe shall start at the value given in the *DL_ Subframe_ Offset* field. The field's length N_{F1} is fixed and known

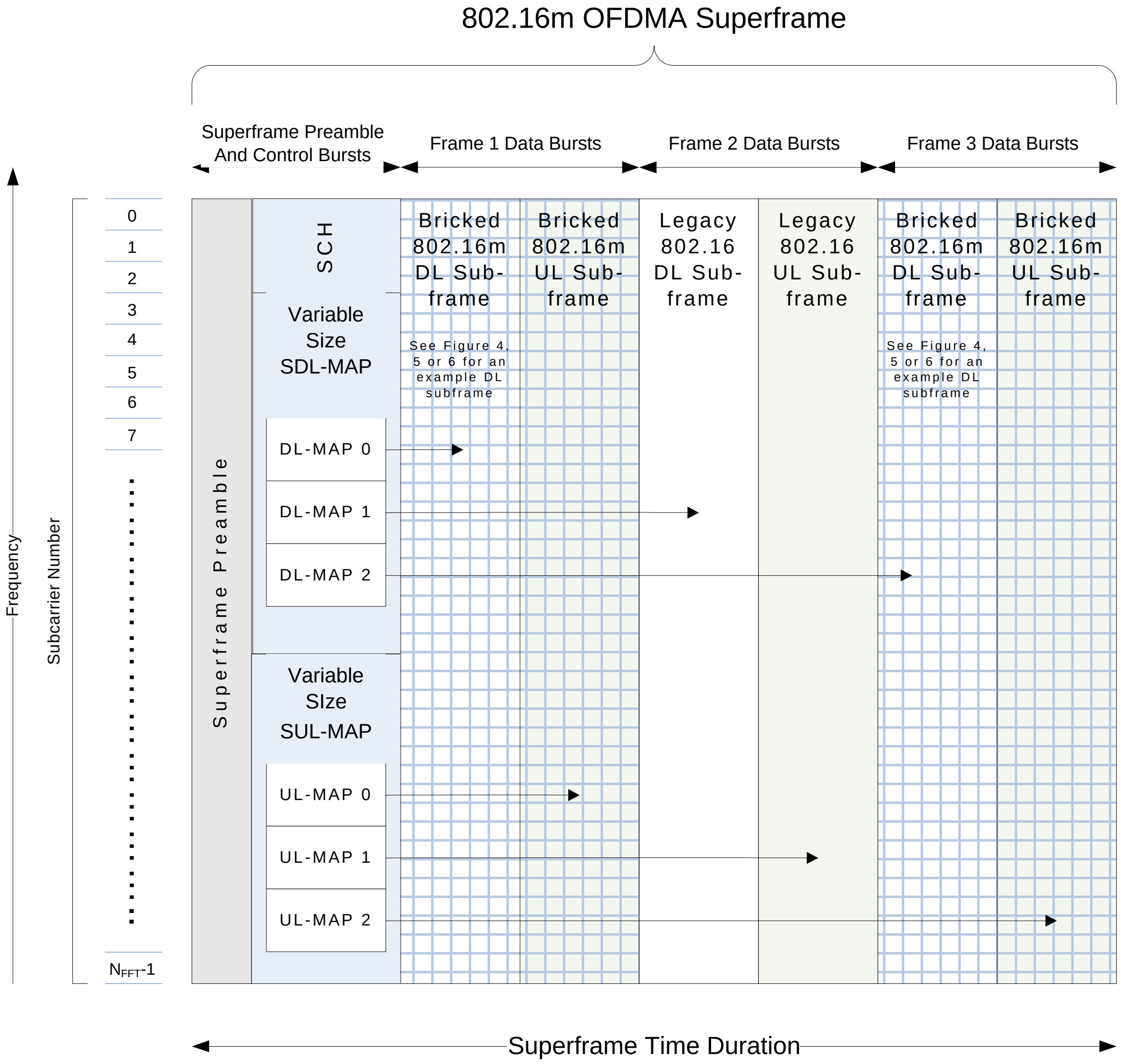


Figure 7: Example brick-based superframe structure for TDD modes of operation. The superframe contains a Superframe Preamble, a Superframe Control Header (SCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tessellated downlink and uplink subframes that support OFDMA user data. For simplicity transmit and receive time gaps are not shown. Figure 4, 5 and 6 show examples of brick-based DL subframes that may comprise the superframe of Figure 7. 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. Note that if the superframe contains only one frame it reduces to the current IEEE 802.16 frame structure.

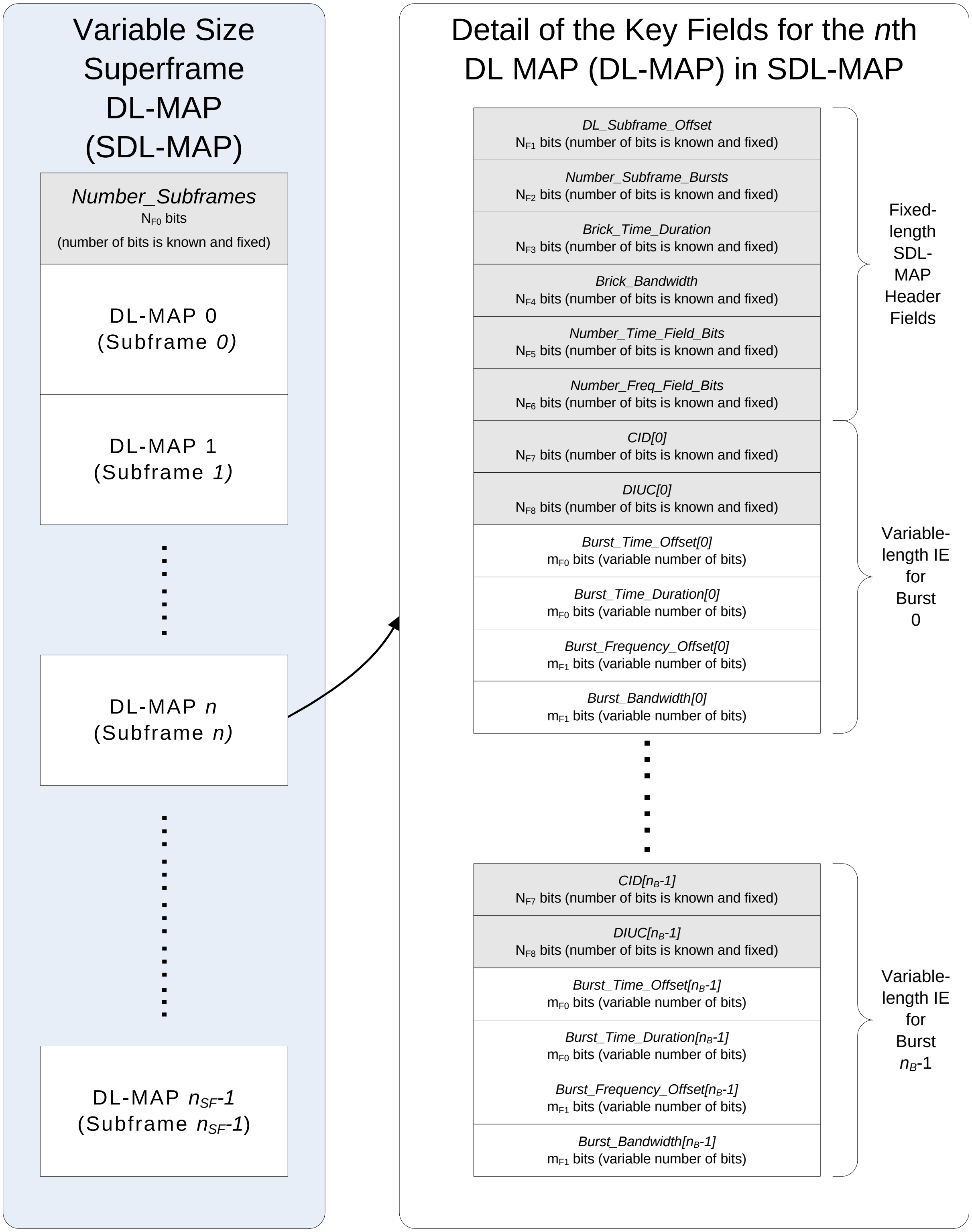


Figure 8: Example fields for the SDL-MAP shown in Figure 7. The detail of the nth DL-MAP within the SDL-MAP is shown on the right. Fields in grey are fixed in length, fields in white are variable in length. Other fields may be added to the SDL-MAP and the SUL-MAP if required. For simplicity they are not shown. Note that if a superframe contains only one frame, only one DL-MAP is required. Hence the structure subsumes the current IEEE 802.16 frame structure.

by both a transmitter and receiver. The specified length shall support the maximum integer-valued subframe offset allowed for an 802.16m implementation. For example, if the offset reference is the Superframe Preamble and maximum number of subframes is 64, N_{F1} is 6 bits. Note that data bursts can directly follow control bursts within the SUL-MAP. For this case the offset for the 0th or first subframe would be 0. The starting address of the *DL_ Subframe_ Offset* field in decimal is

$$Address\_DL\_Subframe\_Offset = N_{F0} \tag{19}$$

3. The length-N_{F2} *Number_ Subframe_ Bursts* field contains the binary representation of a positive integer $n_B \geq 1$ that specifies the number of DL bursts allocated to the nth DL subframe in a superframe. The field's length N_{F2} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum number of 802.16m DL bursts allowed. For example, if the maximum number of DL bursts is 64, N_{F2} is 6 bits. The starting address of the *Number_ Subframe_ Bursts* field in decimal is

$$Address\_Number\_Subframe\_Bursts = \sum_{i=0}^{1} N_{Fi} \tag{20}$$

4. The length-N_{F3} *Brick_ Time_ Duration* field contains the binary representation of a positive integer $c > 1$; integer c specifies the time duration of the r-by-c bricks that tessellate the nth DL subframe in a superframe. The time duration of a brick equals the number of columns c that comprise the brick; it is computed using the equation

$$c = \mathrm{GCD}(\beta_{W,0}, \beta_{W,1}, \cdots, \beta_{W,n_B-1}) \tag{21}$$

where GCD denotes a greatest common divisor algorithm and $\beta_{W,k}$, $k = 0, \ldots, n_B - 1$, burst widths in units of OFDMA symbols. The field's length N_{F3} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum time duration of an 802.16m brick. The maximum time duration of an 802.16m brick shall equal the maximum number of OFDMA symbols allowed for the nth 802.16m DL subframe. For example, if the maximum number of DL OFDMA symbols is 64, N_{F3} is 6 bits. The starting address of the *Brick_ Time_ Duration* field in decimal is

$$Address\_Brick\_Time\_Duration = \sum_{i=0}^{2} N_{Fi} \tag{22}$$

5. The length-N_{F4} *Brick_ Bandwidth* contains the binary representation of positive integer $r > 1$; integer r specifies the bandwidth of the r-by-c bricks that tessellate the nth DL subframe in a superframe. The bandwidth of a brick equals the number of rows r that comprise the brick, it is computed using the equation

$$r = \mathrm{GCD}(\beta_{H,0}, \beta_{H,1}, \cdots, \beta_{H,n_B-1}) \tag{23}$$

where GCD denotes a greatest common divisor algorithm and $\beta_{H,k}$, $k = 0, \ldots, n_B - 1$, burst heights in units of OFDMA subcarriers. The field's length N_{F4} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum bandwidth of an 802.16m brick. The maximum bandwidth of an 802.16m brick shall equal the number of OFDMA subcarriers used in the nth 802.16m DL subframe. For example, if the number of OFDMA subcarriers is 2048, N_{F4} is 11 bits. The starting address of the *Brick_ Bandwidth* field in decimal is

$$Address\_Brick\_Bandwidth = \sum_{i=0}^{3} N_{F_i} \tag{24}$$

6. The length-N_{F5} *Number_ Time_ Field_ Bits* contains the binary representation of a positive integer $m_{F0} \geq 1$ that specifies the lengths of the subsequent variable-length fields *Burst_ Time_ Offset[k]* and *Burst_ Time_ Duration[k],* $k = 0, 1, \ldots, n_B - 1$. The decimal representation of m_{F0} is computed using the operation
$$m_{F0} = \mathit{ceil}(\log_2(n_C)) \tag{25}$$
where $\mathit{ceil}(\log_2(n_C))$ rounds $\log_2(n_C)$ to the nearest integer towards infinity. Integer n_C denotes the number n_C of r-by-c bricks that cover the time duration of the nth tessellated subframe, it is computed using the equation
$$n_C = \frac{N_{Symbls}}{c} \tag{26}$$
N_{Symbls} denotes the number of allowed OFDMA symbols within the nth 802.16m DL subframe and c the brick time duration for the nth 802.16m DL subframe. The field's length N_{F5} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum time duration of an 802.16m brick. The maximum time duration of an 802.16m brick shall equal the maximum number of OFDMA symbols allowed for the nth 802.16m DL subframe. The starting address of the *Number_ Time_ Field_ Bits* field in decimal is
$$\mathit{Address\_Number\_ Time\_ Field\_ Bits} = \sum_{i=0}^{4} N_{Fi} \tag{27}$$

7. The length-N_{F6} *Number_ Freq_ Field_ Bits* contains the binary representation of a positive integer $m_{F1} \geq 1$ that specifies the lengths of the subsequent variable-length fields *Burst_ Frequency_ Offset[k]* and *Burst_ Bandwidth[k],* $k = 0, 1, \ldots, n_B - 1$. The decimal representation of m_{F1} is computed using the operation
$$m_{F1} = \mathit{ceil}(\log_2(n_R))$$
where $\mathit{ceil}(\log_2(n_R))$ rounds $\log_2(n_R)$ to the nearest integer towards infinity. Integer n_R denotes the number n_R of r-by-c bricks that cover the bandwidth of the nth tessellated subframe, it is computed using the equation
$$n_R = \frac{N_{FFT}}{r} \tag{28}$$
N_{FFT} denotes the number of OFDMA subcarriers within the nth 802.16m DL subframe and r the brick bandwidth for the nth 802.16m DL subframe. The field's length N_{F6} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum bandwidth of an 802.16m brick. The maximum bandwidth of an 802.16m brick shall equal the number of OFDMA subcarriers used in the nth 802.16m DL subframe. The starting address of the *Number_ Freq_ Field_ Bits* field in decimal is
$$\mathit{Address\_Number\_ Freq\_ Field\_ Bits} = \sum_{i=0}^{5} N_{Fi} \tag{29}$$

8. The length-N_{F7} *CID[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary representation of the user or connection identifier (CID) for the kth burst in the nth DL subframe. The field's length N_{F7} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum number of 802.16m DL users allowed. The starting address of the *CID[k]* field in decimal is
$$\mathit{Address\_CID}[k] = \sum_{i=0}^{6} N_{Fi} + k\left(2\sum_{i=0}^{1} m_{Fi} + \sum_{i=7}^{8} N_{Fi}\right) \tag{30}$$

Field lengths m_{F0} and m_{F1} are variable and contained within *Number_ Time_ Field_ Bits* and *Number_ Freq_ Field_ Bits* above. Values N_{F_i}, $i = 0, 1, \ldots, 8$, are fixed and known by both the transmitter and receiver.

9. The length-N_{F8} *DIUC[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary Downlink Interval Usage Code (DIUC) for the kth burst in the nth DL subframe. The *DIUC[k]* field specifies the FEC coding and modulation that is to used for the kth burst. The field's length N_{F8} is fixed and known by both a transmitter and receiver. The specified length shall support the maximum DIUC value. The starting address of the *DIUC[k]* field in decimal is

$$Address\_DIUC[k] = Address\_CID[k] + N_{F7} \tag{31}$$

10. The length-m_{F0} *Burst_ Time_ Offset[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary representation of the time offset of the kth subframe burst in units of r-by-c bricks. The reference used for the time offset computation is specified in the preceding *DL_ Subframe_ Offset* field. The field's length m_{F0} is variable and specified in the preceding *Number_ Time_ Field_ Bits* field. The starting address of the *Burst_ Time_ Offset[k]* field in decimal is

$$Address\_Burst\_Time\_Offset[k] = Address\_DIUC[k] + N_{F8} \tag{32}$$

11. The length-m_{F0} *Burst_ Time_ Duration[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary representation of the time duration of the kth subframe burst in units of r-by-c bricks. The field's length m_{F0} is variable and specified in the preceding *Number_ Time_ Field_ Bits* field. The starting address of the *Burst_ Time_ Duration[k]* field in decimal is

$$Address\_Burst\_Time\_Duration[k] = Address\_Burst\_Time\_Offset[k] + m_{F0} \tag{33}$$

12. The length-m_{F1} *Burst_ Frequency_ Offset[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary representation of the frequency offset of the kth subframe burst in units of r-by-c bricks. The reference used for the frequency offset computation is first subcarrier ($0th$ subcarrier). The field's length m_{F1} is variable and specified in the preceding *Number_ Freq_ Field_ Bits* field. The starting address of the *Burst_ Frequency_ Offset[k]* field is

$$Address\_Burst\_Frequecy\_Offset[k] = Address\_Burst\_Time\_Duration[k] + m_{F0} \tag{34}$$

Value m_{F0} is obtained from the preceding *Number_ Time_ Field_ Bits* field.

13. The length-m_{F1} *Burst_ Bandwidth[k]* field ($k = 0, 1, \ldots, n_B - 1$) contains the binary representation of the the bandwidth of the kth subframe burst in units of r-by-c bricks. The field's length m_{F1} is variable and specified in the preceding *Number_ Freq_ Field_ Bits* field. The starting address of the *Burst_ Bandwidth[k]* field in decimal is

$$Address\_Burst\_Bandwidth[k] = Address\_Burst\_Frequecy\_Offset[k] + m_{F1} \tag{35}$$

8 References

1. IEEE 802.16m System Requirements Document, IEEE 802.16m-07/002r4
2. Air Interface for Broadband Wireless Access Systems, P802.16Rev2/D1 (October 2007).
3. Wikipedia definition at http://en.wikipedia.org/wiki/Tessellation
4. Draft Table of Content for the IEEE 802.16m System Description Document, IEEE C802.16m-07/320r1

9 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].

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:

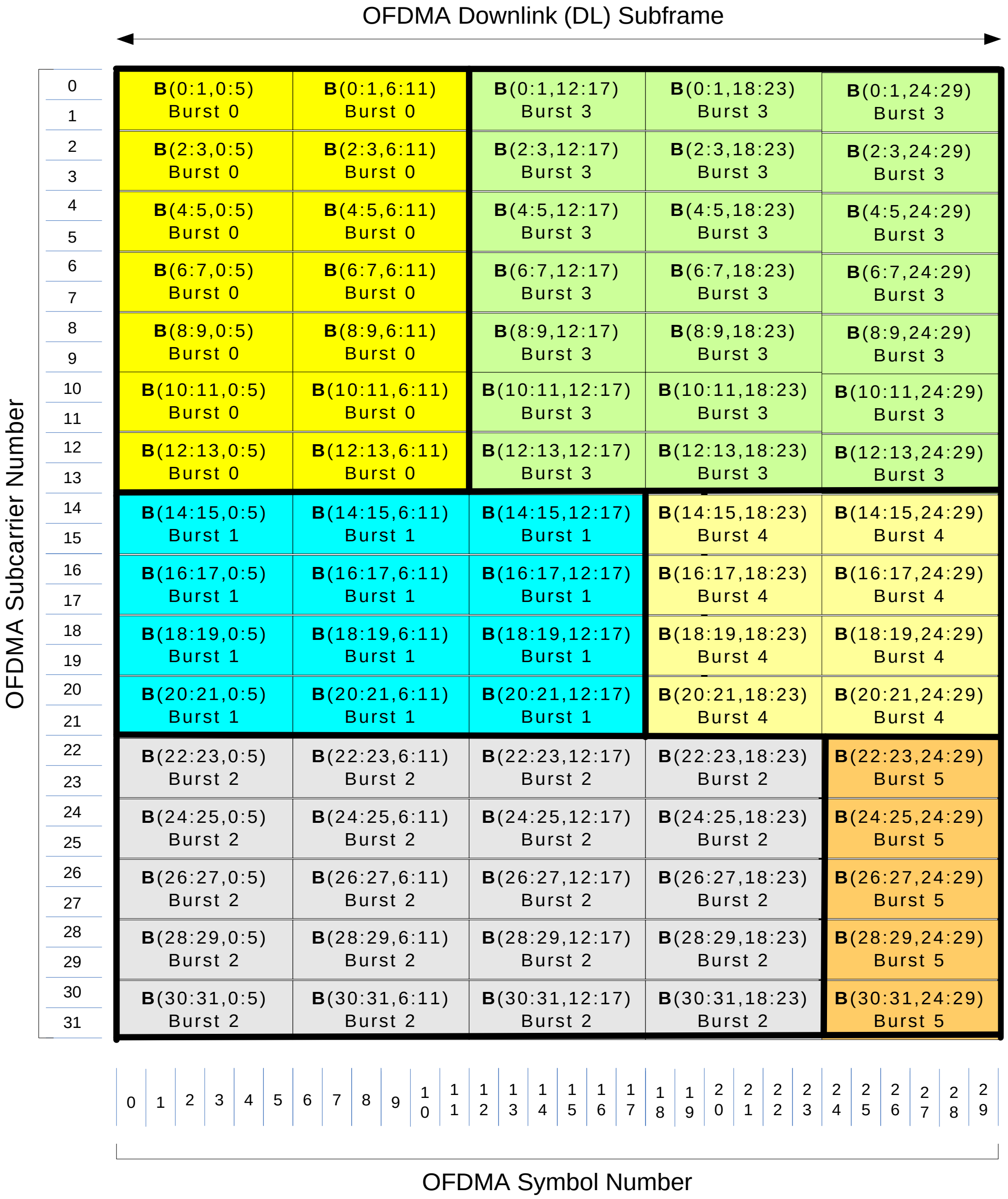
$$\begin{aligned} 0 &\leq p_0 < p_1 < p_2 < \cdots < p_{r-1} \leq N_{FFT} - 1 \\ 0 &\leq q_0 < q_1 < q_2 < \cdots < q_{c-1} \end{aligned}$$

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



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

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.

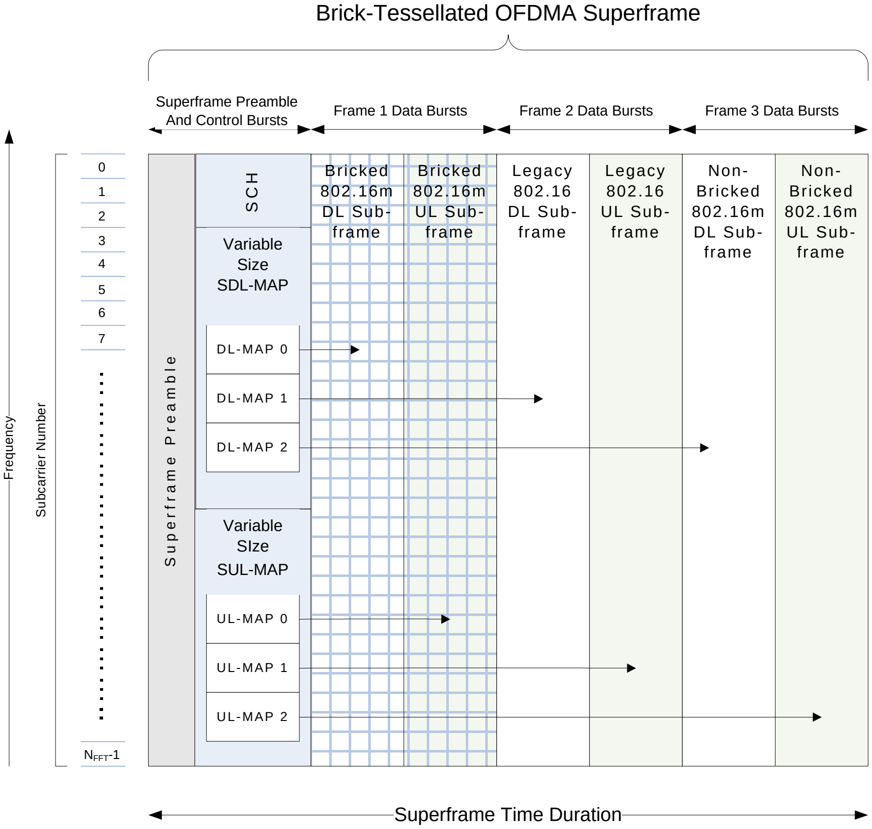


Figure 10: Example brick-based superframe structure for TDD modes of operation. The superframe contains a Superframe Preamble, a Superframe Control Header (SCH), a Superframe Downlink Map (SDL-MAP), a Superframe Uplink MAP (SUL-MAP) and brick-tessellated downlink and uplink subframes that support OFDMA 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.