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Abstract	Optional signaling enhancements to support downlink closed-loop transmission techniques in TDD OFDMA systems.
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Signaling Methodologies to Support Closed-Loop Transmit Processing in TDD OFDMA

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1 Background

Closed Loop Transmission: In wireless communication systems, link performance can be improved by adapting the characteristics of the transmitted signal to the current channel conditions. Techniques that use the knowledge of the channel response at the transmitter are called closed-loop transmission methods. Closed Loop transmission methods offer several important advantages over traditional open-loop methods that do not rely on channel knowledge. In transmit antenna array applications, knowledge of the channel response can be used to increase range and coverage reliability through coherent transmit beamforming. Furthermore, coherent transmit beamforming acts to concentrate the transmitted signal energy towards the SS, which has the additional benefit of reducing the level of interference provided to adjacent co-channel cells. Channel knowledge can also be used by a BS to transmit data streams to multiple SSs on the same time-frequency resources (e.g., concurrent transmission or Spatial Division Multiple Access, SDMA). In spatial multiplexing or MIMO applications, closed loop transmission methods are much more robust to channels that lack adequate scattering compared with open-loop MIMO methods. Even when the BS has only one transmit antenna, channel knowledge can be leveraged to improve performance.

Methodologies for Providing Channel Information to the BS: In general, there are two methodologies for providing a BS transmitter with knowledge of the channel between the BS and SS. The first methodology is called "**feedback**" and involves the SS measuring the DL channel and transmitting a feedback message to the BS. This feedback message must contain enough information to enable the BS to perform the closed-loop transmission on the DL (e.g., a quantized channel response or quantized transmit weights). In broadband channels, the amount of feedback information needed to accurately specify the DL channel response can be significant. The second methodology is called "**uplink channel reuse**" and involves the BS estimating the DL channel based on channel response estimates calculated from signals received from the SS on the uplink. The key assumption behind uplink channel reuse is that the uplink and downlink channels are reciprocal, which is generally the case in Time Division Duplexing (TDD) systems where the transmit and receive hardware are appropriately calibrated. As a result, uplink channel reuse is generally used only in TDD systems. On the other hand, feedback is generally used in Frequency Division Duplexing (FDD) systems where the uplink and downlink channel responses are usually independent.

Advantages of UL Channel Reuse over Feedback: In a TDD system, there are several compelling reasons for employing UL channel reuse rather than feedback. First, UL channel reuse has the ability to leverage uplink data transmissions without additional overhead provided the occupied frequency bandwidth of the UL transmissions encompasses the occupied bandwidth of the subsequent downlink transmission. Second, any feedback scheme must account for the number of antennas at the BS. In a feedback scheme, the SS must be told how many antennas are at the BS because the information to be fed back increases with the number of BS antennas. In contrast, UL channel reuse schemes are independent of the number of BS antennas. Third, the problem of channel estimation is much more difficult in a feedback scheme than in a UL channel reuse scheme. Consider the case where the BS has eight transmit antennas and the SS has a single receive antenna. In an UL channel reuse scheme, the BS must estimate the channel between its eight antennas and the single transmit antenna. In contrast, in a feedback scheme, the air interface must enable the SS to estimate the channel between its antenna and the eight transmit antennas (an eight-source channel estimation problem, which is much more difficult). Fourth, in TDD, feedback schemes tend to have much higher latency between when the channel is estimated and when the DL transmission takes place. In a reuse scheme, the theoretical minimum latency can be just a few OFDMA symbol intervals because uplink transmissions occurring at the end of the UL can be used by the transmission algorithm in the first few symbol intervals of the subsequent DL. However, in a feedback scheme, the channel is measured in a DL portion and fed back on the next UL for use on the next DL. As a result, the theoretical minimum latency for a feedback scheme in TDD is equal to the minimum latency of the reuse scheme plus the duration of the UL. However, if the DL preamble is used to measure the DL channel, then the minimum latency is at least the duration of a complete frame (DL&UL). This difference in latency can have serious consequences on the performance of closed loop transmission schemes in mobile channels.

Limitations in the Current 802.16 OFDMA Specification with Regards to UL Channel Reuse: The current 802.16d OFDMA specification has some limitations with regard to channel reuse for closed loop transmission. Currently, if a BS is to derive the DL channel response from measured UL channel responses in a TDD system, the SS must make a data transmission on the UL, and that data transmission must occupy the same portion of the bandwidth that will be used for the DL closed loop transmission in a subsequent frame. This requirement may be difficult to achieve in broadband OFDMA-style systems especially in scenarios where the UL data traffic levels are significantly less than the DL traffic levels. Rather than relying on UL data transmissions from an SS, broadband data systems can be designed to support the transmission of sounding signals by an SS to enable the BS to compute the UL channel response over the bandwidth that will be used in the DL closed loop data transmission. The purpose of this contribution is to propose such signaling schemes for the adjacent subcarrier permutation mode of the OFDMA PHY.

Outline of this Contribution: Section 2 provides a detailed overview of the proposed solution. Section 3 evaluates the performance of the proposed signaling scheme when used by a closed-loop beamforming strategy (i.e., maximal ratio transmission on a per subcarrier basis) and a Spatial Division Multiple Access strategy on the DL (multiple concurrent DL transmissions). Finally, Section 4 provides the proposed specific text changes to the standard.

2 Summary of Solution

We propose the addition of an optional signaling methodology to the OFDMA PHY that provides a fast, efficient, and low overhead means for providing the base with the DL channel information necessary for closed-loop transmission. The methodology allows UL sounding to be performed independently of UL data allocations. The proposal is intended for the adjacent subcarrier permutation mode of the OFDMA PHY for 802.16e systems operating with a TDD deployment. The proposed signaling methodology provides channel information to the BS transmitter by means of the "uplink channel reuse" methodology and assumes the base station transmit and receive hardware are appropriately calibrated so that the BS can infer the DL channel response from an UL channel response. The proposed scheme provides the signaling strategies and sounding waveform specifications that enable the BS to employ closed-loop transmission in broadband mobile channels.

The key components of the proposal are as follows: The first component is the reservation of a portion of the uplink called the Sounding Zone, preferably near the end of the UL. Within the Sounding Zone, one or more SSs can transmit sounding waveforms that enable the BS to estimate the UL channel response. With appropriately calibrated transmit and receive hardware at the BS, the BS can then translate the estimated UL channel response into an estimated DL channel response. The second component is the definition of the sounding instructions that enable the SS to determine where in the Sounding Zone it should transmit and the specific sounding waveform that should be used. The third component is the signaling methodology for communicating the set of sounding instructions to an SS. The final component is the definition of the sounding waveforms that will be used by the SSs in the Sounding Zone. These sounding waveforms are specifically designed to facilitate accurate UL channel estimation by the BS.

There are two proposed methods for communicating the set of sounding instructions to the SS. The first involves a specific message (IE) transmitted in the UL-MAP that contains the complete set of sounding instructions for one or more SSs. The second involves piggybacking the sounding instructions along with a DL data allocation by means of new IE definitions for the DL-MAP entry. These new IE formats for the DL-MAP serve the dual purpose of simultaneously allocating a DL data transmission and instructing the SS to sound in the sounding zone.

When sounding instructions are piggybacked with a DL data allocation, an opportunity exists for reducing the signaling overhead by matching or "coupling" the sounding instructions to that DL data allocation. More specifically, if the data transmission in the next DL frame will occupy the same portion of the frequency band as in the current DL frame, then the sounding instructions that are piggybacked with the DL data allocation for the current DL frame do not need to specify the frequency band in which to sound. Rather, the frequency band in which to sound in the UL Sounding Zone can be determined from the frequency characteristics of the DL data allocation, thereby eliminating the need to explicitly signal the frequency characteristics of the sounding waveform. On the other hand, if the data transmission in the next DL frame will not occupy the same portion of the frequency band as the current DL data allocation, then the complete set of sounding instructions can still be piggybacked along with the DL data allocation, thereby eliminating the need to separately signal the sounding instructions in the UL-MAP.

These components of the solution are described in more detail in the following subsections.

2.1 Specifying the Location of the UL Sounding Zone

We propose the dynamic allocation of a Sounding Zone in the UL portion of a TDD frame by including in the UL MAP an IE called the UL_Sounding_Zone_Presence_IE(). This IE contains the information needed to specify the characteristics of the Sounding Zone, which is a portion of the UL frame reserved for one or more SSs to transmit sounding waveforms that will enable the BS to calculate the UL channel response between each SS antenna and each BS antenna. Assuming calibrated receive and transmit hardware, the BS can then convert the estimated UL channel response into an estimated DL channel response. This estimate for the DL channel response can then be used to enable closed-loop transmit array processing (e.g., transmit beamforming, maximal ratio transmission, closed-loop MIMO, etc.).

If the current UL frame will not have a Sounding Zone, then the UL_Sounding_Zone_Presence_IE() is simply not included in the UL MAP. This practice allows the flexibility to reserve the sounding zone only when the channel sounding is needed to support closed-loop transmissions.

The UL_Sounding_Zone_Presence_IE() will contain the following two key pieces of information: First, a three bit field will indicate the number of OFDMA symbol intervals that are being allocated to the Sounding Zone. This allows the UL Sounding Zone to contain between 1 and 8 symbol intervals reserved for sounding. Second, a 10 bit field will indicate the position of the Sounding Zone in the UL as measured in OFDMA symbol intervals. This position field provides flexibility in scheduling the Sounding Zone within the UL. Placing the Sounding Zone near the end of the UL improves the performance of the closed-loop transmission methods in mobile channels. However, placing the Sounding Zone closer to the beginning of the UL provides the BS with more time with which to process the sounding signals received in the Sounding Zone before the closed-loop transmission is performed.

2.2 Sounding Zone Construction

The construction of the sounding zone is as follows: The sounding zone will occupy between one and eight OFDMA symbol intervals (specified by a 3 bit field). Currently the OFDMA frequency band is divided into 192 frequency bins, where each bin contains 9 subcarriers. For sounding purposes within the Sounding Zone, we divide the frequency band into 48 sounding frequency bands, each band containing 192/48 = 4 frequency bins, which means that 36 subcarriers are contained in a sounding frequency band. The sounding zone therefore consists of a time-frequency grid of 48 sounding frequency bands by a number of OFDMA symbol intervals between 0 (i.e., no sounding zone) and eight.

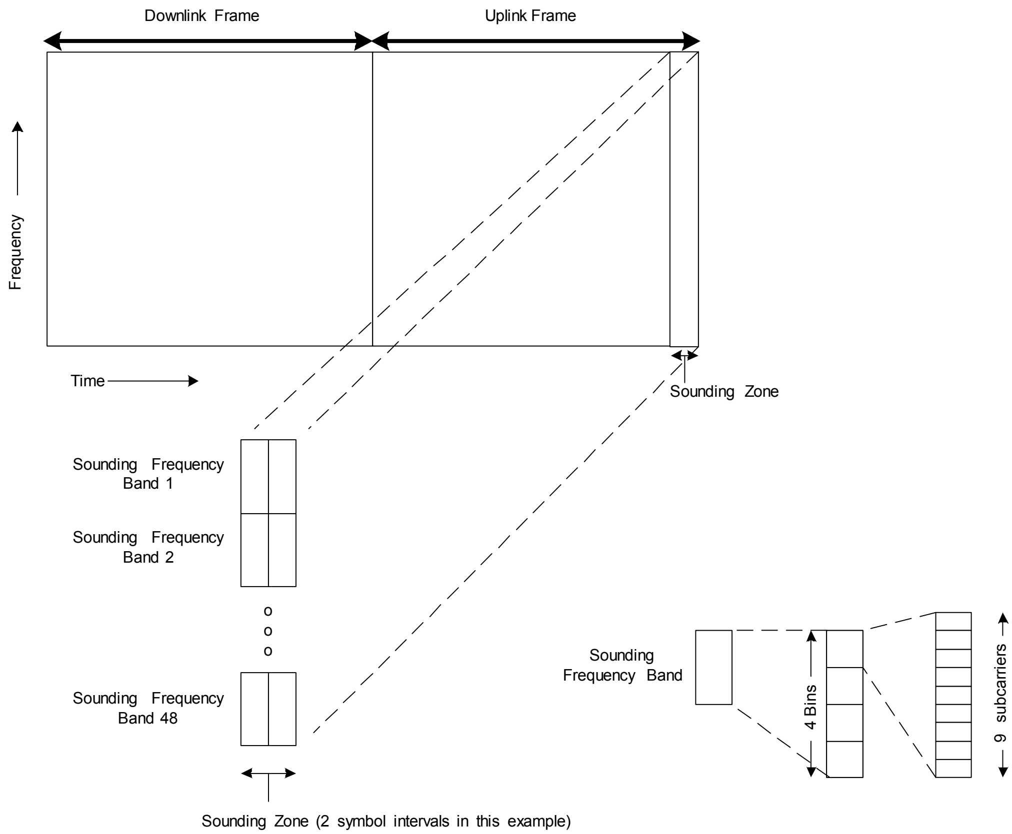

Figure 1. Sounding Zone Construction.

2.3 Sounding Instructions

This subsection describes how subcarriers within the sounding zone are allocated (assigned) to an SS for sounding purposes. The next subsection then describes the frequency domain waveforms that are to be used on those subcarriers.

First, the sounding instructions must specify the time-frequency resource to be used by the SS within the Sounding Zone. We define a sounding allocation to be a contiguous set of adjacent sounding frequency bands within one of the symbol intervals in the Sounding Zone, as shown in Figure 2. The sounding allocation (assignment) then consists of a specification for the symbol interval within the Sounding Zone, first sounding frequency band, and the number of contiguous sounding frequency bands contained in the sounding allocation. Note that this strategy enables the SS to sound either the whole channel bandwidth or a subset of the channel bandwidth.

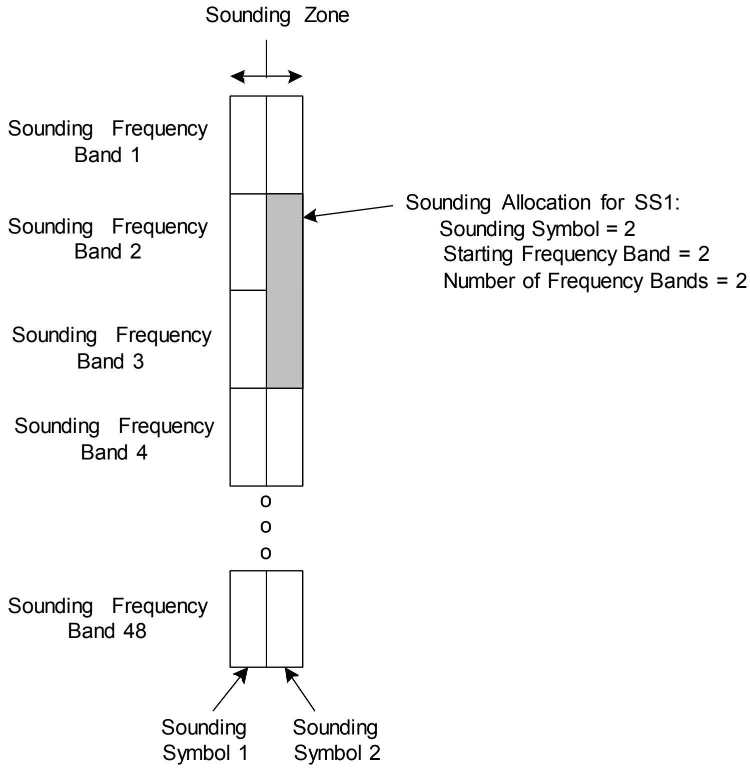

Figure 2. A sounding allocation within the Sounding Zone.

Next, we provide two methodologies for determining how multiple sounding sequences can occupy the same time-frequency resources within a Sounding Zone. Within a given sounding allocation, an SS can either occupy all subcarriers within the sounding allocation, or the SS can occupy a decimated or interleaved (e.g., every m^{th} subcarrier) set of subcarriers within the sounding allocation. When multiple SSs occupy disjoint sets of decimated subcarriers within the sounding allocation, the BS can easily separate the multiple sounding waveforms. When an SS occupies every subcarrier within the sounding allocation, then multiple sounding transmissions from multiple SSs can be separated if the sounding waveforms used by the SSs have low cross-correlation properties. Figure 3 illustrates the two methods for separating multiple sounding waveforms within the same portion of the Sounding Zone. To indicate which methodology is being used to separate multiple sounding waveforms, the sounding instructions include a “separability type” flag, which indicates whether decimated (interleaved) subcarrier sets are being employed (decimation separability) or whether all subcarriers are occupied by different sequences having low cross correlation (sequence separability).

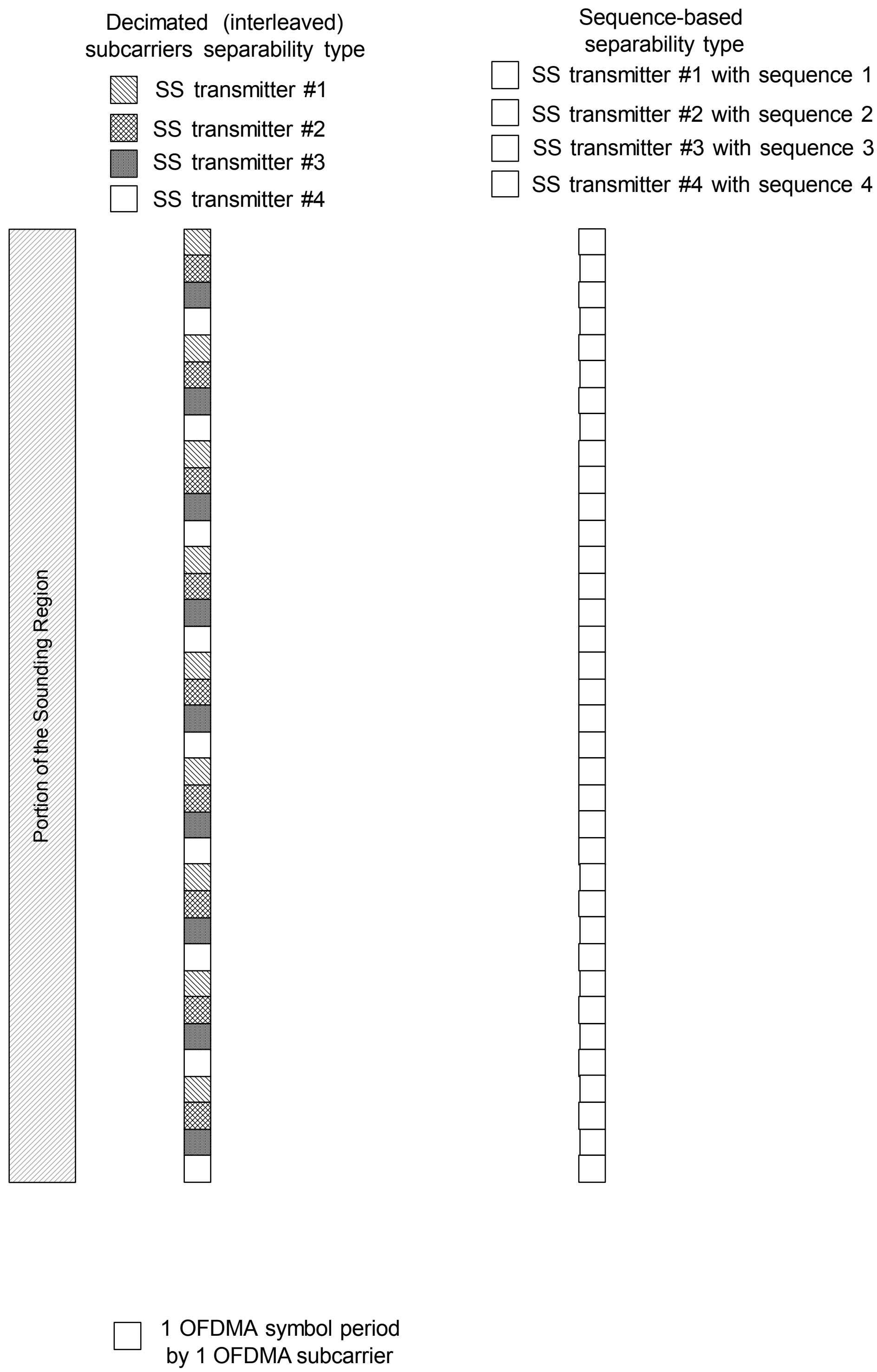

Figure 3. Two methods for separating multiple sounding transmissions on the same time frequency resources within the Sounding Zone. Left: Decimation Separability. Right: Sequence Separability.

If decimation separability is used, then the SS must be told which subcarrier offset to use within the allocation. For example, if every fourth subcarrier is to be occupied across the sounding allocation, then four possible offsets are possible, which means four SSs can occupy the sounding allocation, where each SS uses a different offset. The use of decimation separability allows the SS to concentrate its transmit power on a subset of the subcarriers within the sounding allocation, which, for a given transmit power, enables the received SNR to be increased compared to when all subcarriers are occupied. This is especially helpful for mobile devices operating in low SNR channels because it increases the per-carrier received SNR for channel estimation albeit at the expense of the frequency tracking performance of the channel estimator.

If sequence separability is used, then we propose the use of a single sequence by all SSs that are assigned to the same sounding allocation, but each SS uses a different cyclic time-domain shift of the underlying sequence to enable the BS to separate the multiple transmitted sounding signals. This strategy is described more in the next subsection, which describes the specific sounding sequences that are to be used within a sounding allocation.

Another important aspect of the sounding instructions concerns how to handle an SS that has multiple antennas. To handle this case, the sounding instructions contain a multi-antenna flag to indicate whether only one SS antenna is to transmit a sounding sequence or whether each SS antenna is to transmit a separate sounding sequence. If all SS antennas are to transmit multiple sequences, the sounding from each transmit antenna will occupy the same sounding allocation and will be determined based on the separability type. For sequence separability, each SS antenna will in turn use a different cyclic time-domain shift of the underlying sequence to enable the BS to separately estimate the channel from each SS transmit antenna. If decimation separabililty is used, then each SS antenna will in turn use a disjoint set of decimated (i.e., interleaved) subcarriers (i.e., each SS antenna will employ a different decimation offset).

2.4 Sounding Sequences

The sounding waveforms are chosen to enable the BS to estimate the uplink channel for the frequency band corresponding to the sounding allocation. We propose the use of the Generalized Chirp Like (GCL) waveforms [1], which are non-binary unit-amplitude sequences. A GCL sequence is expressed as

$$s_u(k) = \exp\left\{ -j2\pi u \frac{k(k+1)}{2N_G} \right\}, \quad k = 0 \cdots N_G - 1 \quad \textit{and} \quad u(\text{"}\textit{class index}\text{"}) = 1 \cdots N_G - 1 \qquad (1)$$

where N_G is the length of a GCL sequence (chosen as a prime number as explained below) and u is referred as the class index that is a non-zero integer chosen between 1 and N_G. For different sequence lengths, there are a number of GCL sequences that can be used, which makes them an ideal choice for the sounding strategy being described in this contribution. The GCL sequence has the following important properties:

Property 1: The GCL sequence has constant amplitude, and its N_G -point DFT has also constant amplitude.

Property 2: The GCL sequences of any length have an "ideal" cyclic autocorrelation (i.e., the correlation with the circularly shifted version of itself is a delta function)

Property 3: The absolute value of the cyclic cross-correlation function between any two GCL sequences is constant and equal to $1/\sqrt{N_G}$, when |u1-u2|, u1, and u2 are relatively prime to N_G.

The cross-correlation $1/\sqrt{N_G}$ at all shifts (Property 3) is actually the minimum achievable value for any two sequences that have the ideal autocorrelation property (i.e., the maximum value of the cross-correlation at all shifts is minimized which is equal to $1/\sqrt{N_G}$). This property is important when a number of potential interfering sequences are received, either in a single sector or in a multi-sector environment. The cross correlation property provides some suppression of the interfering signals during the channel estimation process. Hence, the channel of the desired SS can be detected more reliably.

To specify the sounding sequence to use on a given sounding allocation, the SS needs to know the length of the sounding sequence to use, which is equal to the number of subcarriers that the SS will occupy in the sounding allocation. When all subcarriers are occupied in the sounding allocation (separability type = sequence separability), the number of occupied subcarriers is simply the number of sounding frequency bands in the allocation multiplied by the number of subcarriers per sounding frequency band (which is 36). When decimated (interleaved) subcarrier sets are used within the sounding allocation (separability type = decimated separability), then the number of occupied subcarriers is the number of sounding frequency bands in the allocation multiplied by the number of subcarriers per sounding frequency band (36) divided by the decimation factor.

Once the length of the sounding sequence is determined, the value of N_G needs to be determined. In many cases, the required length of the sounding sequence is not a prime number. In this case, we propose to choose N_G to be the smallest prime number that is larger than the desired length, and then truncate the sequences computed according to (1) to the desired length. An alternative is to choose the largest prime number that is smaller than the desired length, then cyclically extending the sequences to the desired length. Note that when either modification is performed, the three properties will only hold approximately, but will hold very well when the sequence is long.

Finally, to determine the sounding waveform, the value of u needs to be determined. We propose the determination of u to be based on the lowest three bits of the CellID of the sector of the BS so that different sectors and different BSs will be assigned different sequence values. The advantage with this idea is that reliable channel estimation can be performed when a BS receives multiple sounding waveforms from co-channel interfering SSs located in adjacent sectors or in adjacent cells. To this end, we propose a sequence "reuse" strategy whereby the values of u from 1 to 32 are divided into eight groups having four sequences. To determine the sounding waveform, the SS determines which group to use based on the CellID, and the sounding instructions contain a two bit sequence index to specify which of the four sequences within the group should be used. This has the effect of allocating different sequence groups to different BS sectors and different BSs. Note that each pair of sequences will have the minimum cross correlation property, whether the pair is from the same group or from different groups.

When sequence-style separability is used (where all subcarriers are occupied in the sounding allocation), multiple sounding transmissions within the same sounding allocation can use the same sequence index. However, the different sounding transmissions can each use a different time-domain cyclic shift value to enable the BS to reliably estimate the multiple channels. In this case, the sequence determined by equation (1) is modified as follows to obtain a set of P orthogonal sequences. The m^{th} orthogonal sequence is then determined as:

$$s_{um}(k) = s_u(k)e^{-j2\pi km/P}, \quad (2)$$

where $s_u(k)$ is given in (1), and m ranges from 0 to P-1. Note that if $P=N/L_{CP}$, where N is the FFT size and L_{CP} is the cyclic prefix length, then the sequences are being shifted by multiples of the cyclic prefix length. In the sounding instructions, the SS will be provided with a variable length field to specify the value of m to be used in (2). The length L in bits of that field is also signaled in the sounding instructions and determines indirectly the value of P, namely: $P=2^L$.

2.5 Uncoupled Sounding Instructions in the UL-MAP

Once the sounding instructions are formulated, we propose several methods for delivering the sounding instructions to an SS. The first is an explicit message in the UL-MAP and is described in this subsection. The other methods involve piggybacking the sounding instructions on data allocations in the DL-MAP (via additional IE definitions) and are described in the next subsections.

The first method for providing sounding instructions to an SS is for the BS to transmit an IE in the UL-MAP containing the sounding instructions. The UL_Uncoupled_Sounding_IE() is an UL-MAP entry that contains a complete set of sounding instructions. The name "uncoupled" means that a complete set of sounding instructions is provided in the IE. The "uncoupled" method is in contrast to the coupled method, wherein the sounding instructions are partially determined by (i.e., coupled with) a specific DL MAP data allocation (as described in the next subsections). As is described below in the Section containing the specific text recommendations, the UL_Uncoupled_Sounding_IE() has the flexibility to simultaneously provide sounding instructions for multiple SSs across multiple OFDMA symbol intervals within the Sounding Zone.

Figure 4 contains a time-frequency diagram showing how the proposed signaling methodology supports closed-loop transmission. First the UL_Sounding_Zone_Presence_IE() in the UL-MAP signals the presence and characteristics of the Sounding Zone, which in this example is one OFDMA symbol interval at the end of the UL frame. Also in the UL-MAP is the UL_Uncoupled_Sounding_IE() which instructs SS#1 to transmit sounding in the UL Sounding Zone. In the next DL frame, the BS transmits to SS#1 on the same frequency band that was sounded by the SS in the prior UL frame.

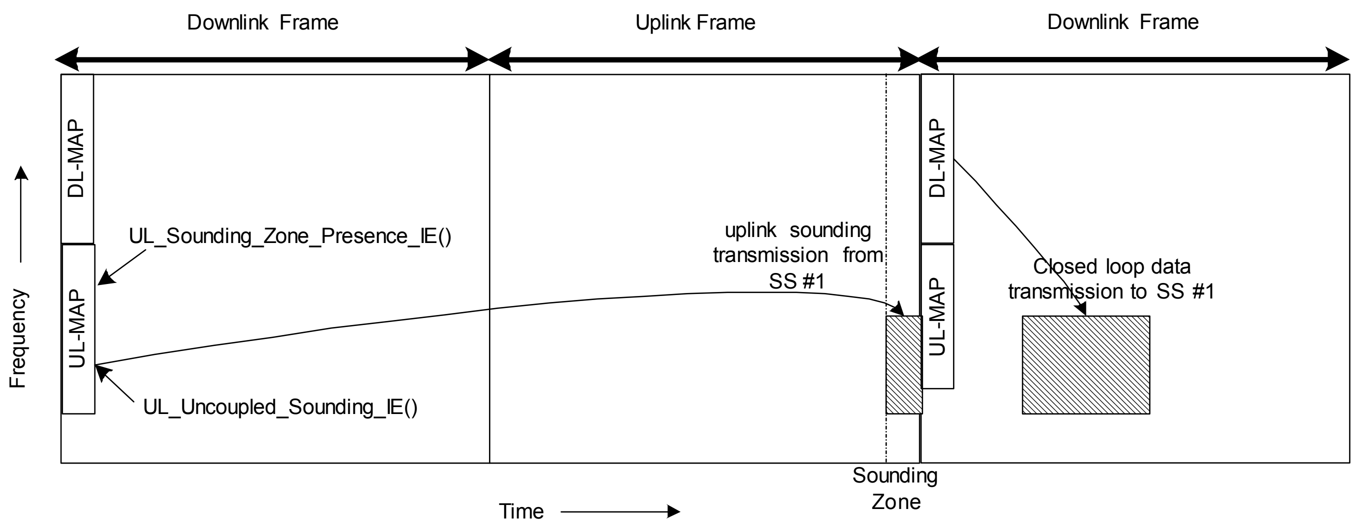

Figure 4. Uncoupled Sounding Mode: Direct uplink sounding resource assignment along with a closed-loop data transmission in the subsequent downlink.

2.6 Combining Sounding Instructions with DL-MAP Allocations

To improve the efficiency of communicating the sounding instructions, a DL-MAP data allocation can be combined with the sounding instructions in one DL-MAP IE entry. There are two cases to consider here, which results in the construction of two DL-MAP IE formats:

The first IE format is called the DL-MAP_Coupled_Sounding_IE() and contains the contents of the usual DL-MAP IE structure plus an abbreviated set of sounding instructions that leaves out the sounding frequency band information, namely the starting sounding frequency band and the number of contiguous sounding frequency bands. In this case, the SS should infer the starting sounding frequency band and the number of contiguous sounding bands directly from the frequency occupancy of the data allocation. This acts to reduce the amount of information needed in the sounding instructions for cases where the closed-loop data transmission in the next DL frame has the same frequency occupancy as the data allocation in the current DL frame. Figure 5 shows a timing diagram of how closed-loop transmission is supported with the DL-MAP_Coupled_Sounding_IE(). The DL-MAP_Coupled_Sounding_IE() contains both a data allocation in the current DL along with sounding instructions for the Sounding Zone of the current UL. The frequency occupancy of the UL sounding transmission coincides with the data allocation of the DL of the current frame. Furthermore, the frequency occupancy of the closed-loop transmission in the DL of the next frame coincides with the UL sounding in the current frame.

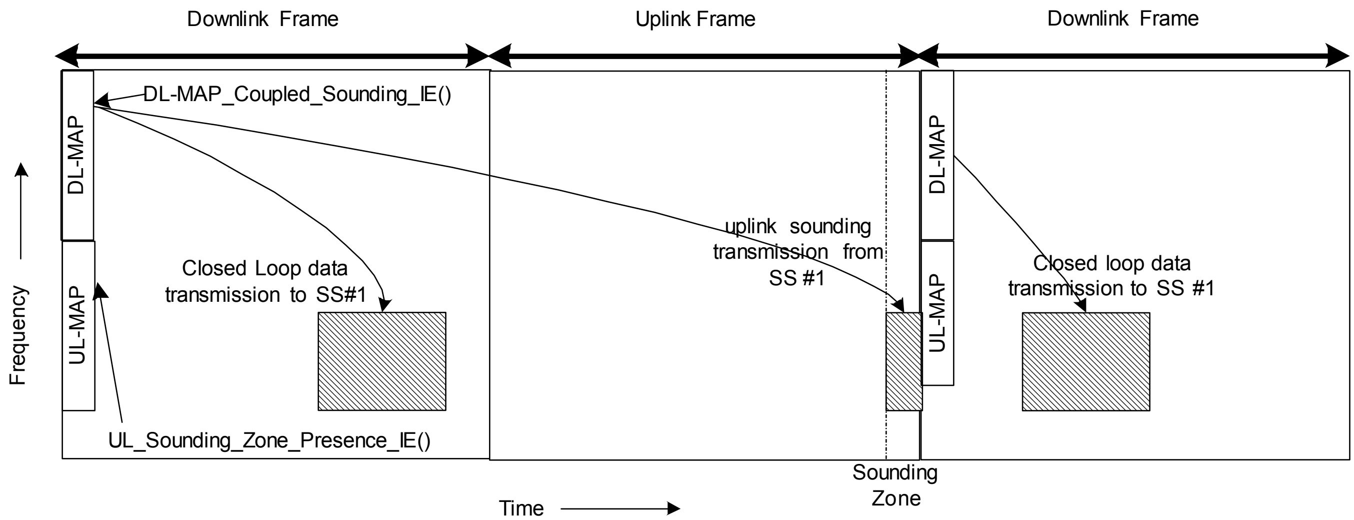

Figure 5. Combining DL data allocations with coupled sounding instructions. The DL-MAP_Coupled_Sounding_IE() simultaneously allocates a data transmission in the DL plus sounding in the UL. The frequency occupancy of sounding waveform is determined by the frequency occupancy of the data transmission in the DL.

The second IE format is called the DL-MAP-Uncoupled_Sounding_IE() and contains the contents of the usual DL-MAP IE structure plus a complete set of sounding instructions. This IE format would be used in cases where the closed-loop data transmission in the next DL frame will occupy a different portion of the DL frequency band from the data allocation in the current DL frame (which eliminates the viability of the coupled sounding method).

Figure 6 shows a timing diagram of how closed-loop transmission is supported with the DL-MAP_Uncoupled_Sounding_IE(). The DL-MAP_Uncoupled_Sounding_IE() contains both a data allocation in the current DL along with a complete set of sounding instructions for the Sounding Zone of the current UL. The frequency occupancy of the UL sounding transmission is unrelated to the data allocation of the DL of the current frame. As before, the frequency occupancy of the closed-loop transmission in the DL of the next frame coincides with the UL sounding in the current frame.

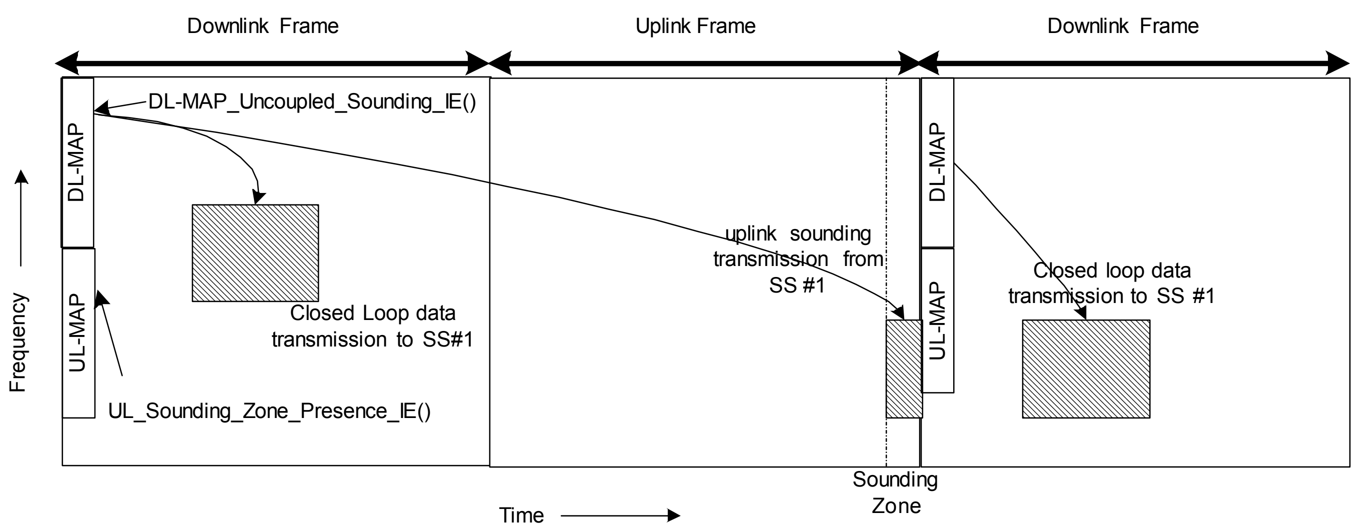

Figure 6. Combining DL data allocations with uncoupled sounding instructions. The DL_Uncoupled_Sounding_IE() simultaneously allocates a data transmission in the DL plus sounding in the UL.

2.7 Combining Sounding Instructions with MIMO transmissions to enable Closed-Loop MIMO transmission

Similar to the non-MIMO case in the previous section, we propose to piggyback sounding instructions on MIMO transmissions so as to provide efficient channel sounding in support of closed-loop MIMO transmission. Two additional IE formats are defined in a manner similar to what was done for the non-MIMO case in the previous subsection. The first IE format (MIMO_DL_Basic-Coupled_Sounding_IE()) combines the contents of the MIMO-DL-basic IE format from accepted contribution C802.16d-04/80r1 with a partial set of sounding instructions (where the frequency information is not explicitly signaled). The second IE format (MIMO_DL_Basic-Uncoupled_Sounding_IE()) combines the contents of the MIMO-DL basic IE format from accepted contribution C802.16d-04/80r1 with a complete set of sounding instructions. The timing diagrams for the MIMO transmission cases are similar to the timing diagrams shown in the previous section.

3 Performance Evaluation

In this section, we provide simulation results to show how well closed loop transmit array processing can perform with the proposed method for providing uplink channel knowledge to the BS. We examine the performance of two closed-loop transmission methods. The first method is the transmit adaptive array (TXAA) concept, or maximal ratio transmission [2][3], adapted for an OFDM system [4]. The second method is a multi-stream version of TXAA where multiple data streams are concurrently beamformed in the frequency domain to multiple users based on zero-forcing transmission criteria. This second method is a form of Spatial Division Multiple Access (SDMA) and uses the spatial domain to multiplex multiple users on the same time-frequency resources.

The simulation uses a COST-259-style spatial channel model consisting of a single scattering zone having 100 discrete multipath rays, a 2 μsec RMS delay spread, a 15° multipath angular spread with respect to the BS antenna array, and a 360° multipath angular spread with respect to the SS antenna. For the closed-loop methods, the BS has a uniform linear array of eight antennas with five-wavelength spacing between the antenna elements. The BS array is assumed to be perfectly calibrated so that the UL channel response equals the transpose of the DL channel response. The SS uses a single antenna.

The OFDMA system uses a 2048 FFT size with an 11.2 kHz subcarrier spacing at a 2.6 GHz carrier frequency. The cyclic prefix length is 256 (11.16 μsec) and the total OFDMA symbol duration is 100.45 μsec. The OFDMA frame consists of 50 OFDMA symbol intervals with a 50% DL-UL TDD split. The data allocation format on the DL is 4 bins in frequency by 6 bins in time, where each bin is nine-subcarriers by one OFDMA symbol interval with a pilot symbol on the middle (fifth) subcarrier of the bin. For these simulations, the 3GPP turbo code with max log map decoding was used. Although 802.16- OFDMA does not employ this specific form of FEC, the use of the 3GPP turbo code should not significantly alter the basic results and conclusions being presented.

For the closed-loop methods, the UL channel sounding was performed over the same frequency bandwidth occupied by the downlink allocation. The per-subcarrier SNR for each sounding transmission on the uplink during the UL channel sounding was 5 dB in all cases. Eight SS units simultaneously sounded the uplink channel using the sequence separability mode where each SS unit employed a different time-domain cyclic shift value across the same time-frequency sounding allocation (P=8). (The per-carrier SINR to a single SS was – 8.5 dB (negative 8.5 dB) due to having 8 simultaneous users each at a 5 dB per carrier SNR). Although eight users simultaneously sounded the UL on the same time-frequency sounding allocation, the downlink transmissions involved only one user at a time (for the case of maximal ratio transmission) or four concurrent transmissions to four users (for the case of transmit SDMA). The reason for simulating eight simultaneous UL soundings is to show that the proposed UL sounding method has the ability to efficiently estimate the UL channel response from many users simultaneously, thereby minimizing the required sounding resources on the UL. To estimate the UL channel responses of the eight SS units, the BS uses a relatively straightforward multi-user MMSE channel estimation algorithm [5]. To estimate the channel during the closed-loop transmission on the DL, the SS uses a relatively straightforward single-source MMSE channel estimator to compute the log likelihood ratios (LLRs) required by the turbo decoder. For the purposes of this simulation, the delay between the UL channel sounding and the downlink closed-loop transmission was assumed to be eight OFDMA symbol intervals. This assumption was based on having the UL sounding zone located at the end of the UL and the DL transmissions occurring several symbols after the start of the subsequent DL.

In the simulations, the closed-loop methods were compared against a single transmit, single receive antenna scenario. In these comparisons, the closed-loop methods used the same total transmit power as the single-antenna transmission cases so as to show a transmit-power-fair comparison. Two cases for the single transmit single receive case were simulated: the case where the BS transmitted on the best frequency band and the case where no band selection was employed. For the frequency band-selection case, the SS is assumed to measure the DL channel response on the DL preamble and feedback to the BS the best band that is to be used for data transmission. As a result, a latency of 57 OFDMA symbol intervals was assumed to occur between the time point at which the SS determines the best band (from the DL preamble) and the time point at which the DL transmission on that frequency band occurs. Downlink channel estimation in the single transmit, single receive antenna case uses a relatively straightforward single-source MMSE channel estimator to compute the log likelihood ratios (LLRs) required by the turbo decoder.

We show several plots of decoded frame error rate versus received SNR per symbol for the TXAA and TX-SDMA cases with eight antennas at a BS as well as the single BS antenna case. In these plots, the following curves are shown, where the phrase in brackets is the label used on the plot (where the TXAA algorithm is either single user or multi-user (SDMA) depending on the particular plot):

- [TXAA w/o CE] – TXAA transmit weights computed based on ideal (but delayed) UL channel knowledge and ideal aggregate DL channel knowledge.
- [TXAA w/CE] – TXAA transmit weights computed based on channel estimates obtained on the UL during the sounding interval, and the SS performs channel estimation on the DL during data reception.
- [TXAA, UL CE, w/no DL CE] – TXAA transmit weights computed based on channel estimates obtained on the UL during the sounding interval, and the SS has ideal aggregate DL channel knowledge. (This and the previous curve provide a direct view of the performance of the UL sounding methodology proposed in this contribution.)
- [1-1, no band sel w/o CE] – Single transmit antenna, single receive antenna, no selection of the best frequency band on which to transmit, and the SS has ideal knowledge of the DL channel response.
- [1-1, no band sel w/ CE] – Single transmit antenna, single receive antenna, no selection of the best frequency band on which to transmit, and the SS estimates the DL channel response.
- [1-1, band sel w/o CE] – Single transmit antenna, single receive antenna, ideal selection of the best frequency band on which to transmit (assuming a 57 OFDMA symbol interval latency as described above), and the SS has ideal knowledge of the DL channel response.
- [1-1, band sel w/ CE] – Single transmit antenna, single receive antenna, ideal selection of the best frequency band on which to transmit (assuming a 57 OFDMA symbol interval latency as described above), and the SS estimates the DL channel response.

Figure 7 and Figure 8 show how the proposed UL sounding strategy enables the TXAA algorithm to have significantly improved range performance over a single antenna by comparing single user TXAA to the single transmit antenna cases for rate ½ turbo-coded 16QAM. Figure 7 is for the case of zero velocity, and Figure 8 is for the case of 30 mph velocity at 2.6 GHz. For the zero velocity case with channel estimation, TXAA is achieving a roughly 5 dB improvement in required SNR for a 10^{-2} decoded FER over the single transmit antenna case with best band selection. Note the significant gains achieved by using band selection in the single transmit single receive antenna case at zero velocity. (The TXAA algorithms were not using band selection). At a 30 mph velocity, TXAA with channel estimation has a 12 dB gain over the single transmit single receive cases having ideal channel knowledge. Note how at a 30mph velocity, the gains from band selection were trivial, which is largely due to the long delay (57 bauds, or a little over one frame duration) between when the best band is determined and the data is transmitted. The poor performance of the single transmit case with no band selection and with channel estimation is largely due to the large spacing between pilot symbols.

Figure 9 shows how the proposed UL sounding strategy enables the ability to multiplex multiple simultaneous DL transmissions to multiple users on the same time-frequency resources by comparing the performance of four-user SDMA transmission to the single transmit single receive antenna cases. In Figure 9, each SDMA user is provided ¼th the data rate of the data rate used for the single transmit single receive antenna cases. Each

SDMA user is also provide ¼ of the total transmit power so as to maintain a fair comparison in terms of overall transmit power. As a result, the SDMA scheme has the same overall system-level data rate as the single transmit single receive antenna cases but has divided that data rate and transmit power among multiple users simultaneously. However, as shown in Figure 9, the SDMA scheme achieves a significant gain in terms of reducing the required SNR for a 10^{-2} decoded FER, even with channel estimation at a 30 mph velocity.

To show the ability of TXAA to improve the data rate, even at moderate velocities, Figure 10 shows the performance of the single-user TXAA strategy having four times the data rate as the single transmit antenna cases. The TXAA strategy is using rate ½ turbo coded 16QAM, whereas the single transmit antenna case is using rate ¼ turbo coded QPSK. Note that even with four times the data rate, the TXAA strategy achieves a 2dB reduction in required SNR for a 10^{-2} decoded frame error rate.

As mentioned earlier, using a feedback scheme in a TDD system rather than UL channel sounding tends to result in a higher latency between the time when the channel is estimated and when the DL data transmission takes place. To compare the effect of this extra latency, Figure 11 compares the performance of single-user TXAA with a 57-symbol latency (to model feedback) with the performance of single-user TXAA with an eight-symbol latency (to model UL channel sounding) in a 30 mph channel at 2.6 GHz. All other parameters are the same as those in the previous examples. The 57-symbol latency is somewhat representative of the at least one-frame latency inherent to a feedback scheme. For the 57-symbol latency case, ideal perfect feedback is assumed, and the corresponding results for channel estimation are for channel estimation performed only during the DL data transmission (with perfect but delayed channel knowledge used to compute the transmit weights.) For the 8-symbol latency case, the results shown with channel estimation are for channel estimation performed both during the UL sounding and during the DL data reception. Note the large degradation in performance that results from the excessive latency caused by the feedback scheme in TDD systems. The extra latency with feedback can destroy the viability of closed-loop transmission techniques in moderate velocity channels.

Finally, Figure 12 compares 8-antenna TXAA to a single transmit antenna for the case where both the UL sounding and the DL data transmissions occupy the entire bandwidth. All other parameters are identical to the previous examples. In this case, the sounding by eight simultaneous SS units also encompasses the entire bandwidth of a single UL sounding symbol. The velocity is 30 mph at a 2.6 GHz carrier frequency. The pilot format on the downlink is the adjacent subcarrier permutation that provides a single pilot tone every 9^{th} subcarrier. Note the roughly 8 dB of gain being provided by the TXAA strategy with channel estimation over the single transmit antenna case with ideal channel knowledge. The TXAA strategy with channel estimation provides about 12 dB of gain over the single antenna case with channel estimation in a mobile channel. Spacing the pilot symbols closer than every 9^{th} subcarrier would improve the channel estimation performance for the single transmit antenna case.

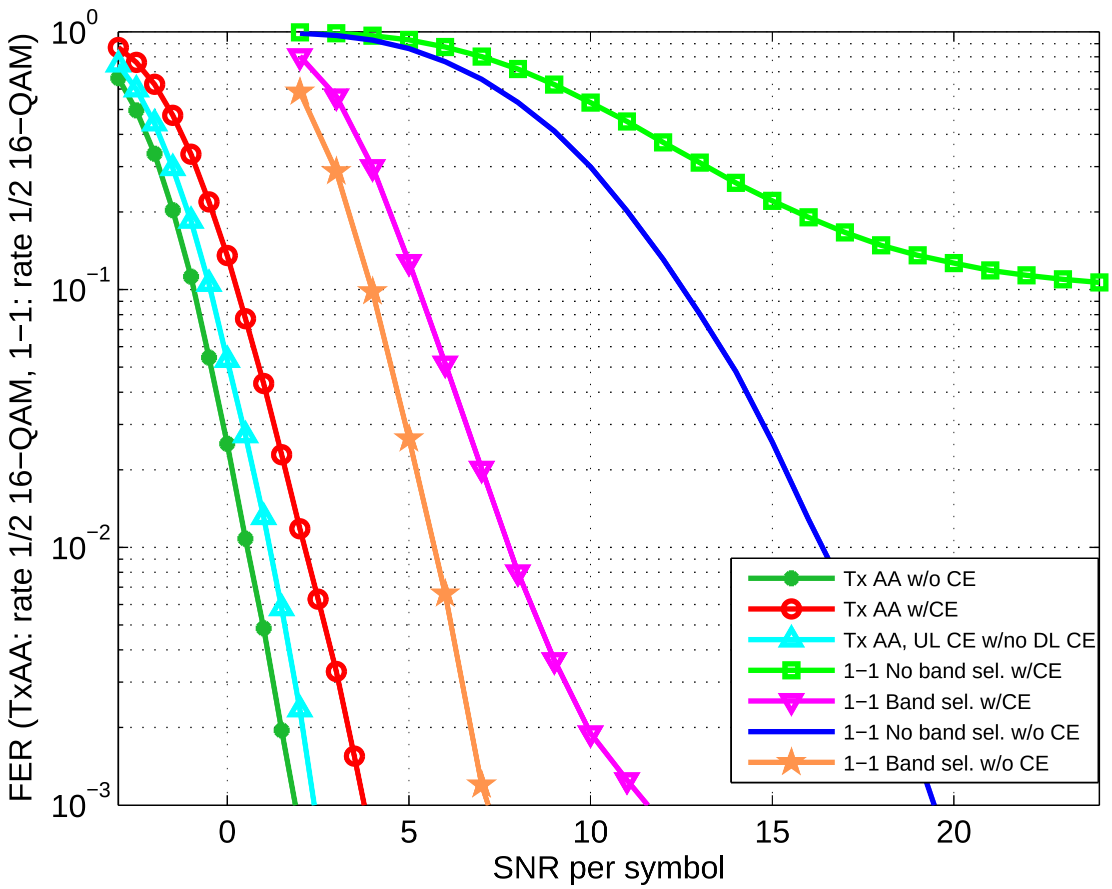

Figure 7. TXAA with 8 transmit antennas versus single transmit antenna, **0 mph** at 2.6 GHz. Comparisons with channel estimation (CE) and with ideal channel knowledge (w/o CE). Equal data rates in the TXAA cases and the single transmit antenna cases. Band selection delay for single transmit antenna cases = 57 symbol intervals, TXAA sounding delay = 8 symbol intervals. Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. DL transmissions are to a single user at a time.

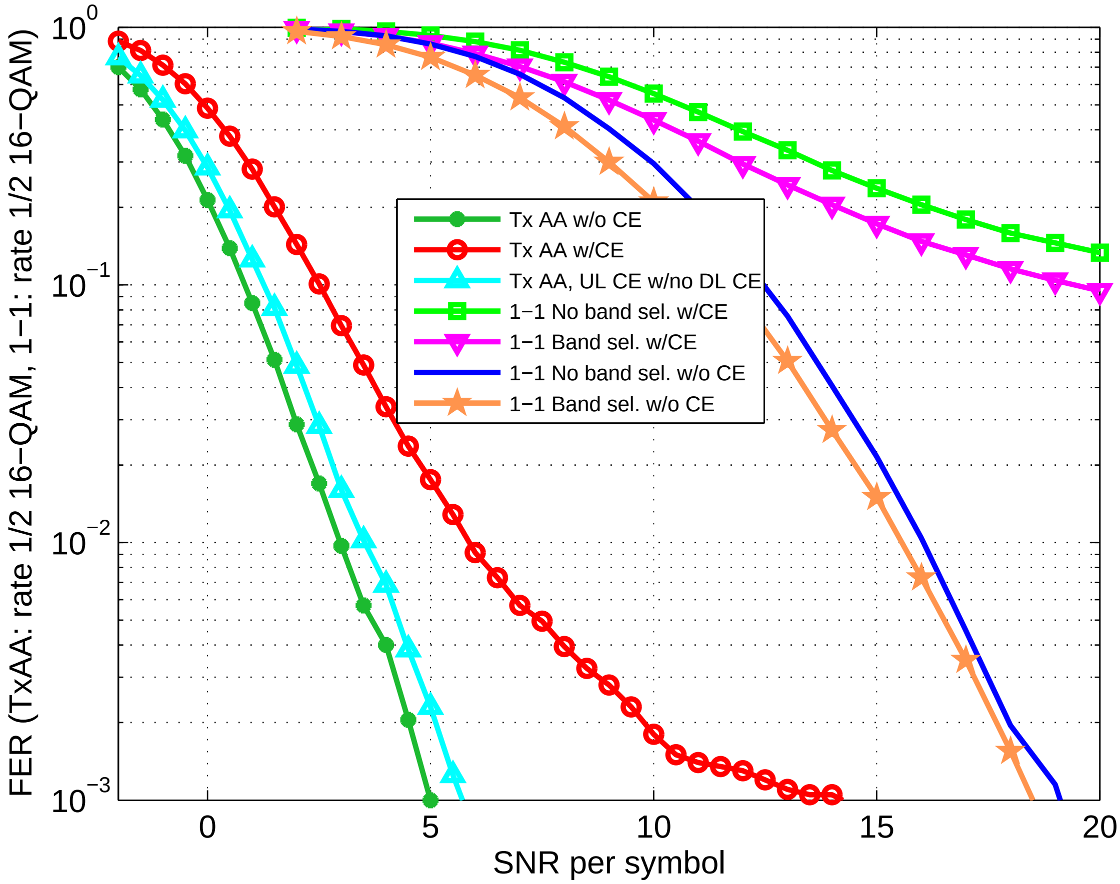

Figure 8. TXAA with 8 transmit antennas versus single transmit antenna, **30 mph** at 2.6 GHz. Comparisons with channel estimation (CE) and with ideal channel knowledge (w/o CE). Equal data rates in the TXAA cases and the single transmit antenna cases. Band selection delay for single transmit antenna cases = 57 symbol intervals, TXAA sounding delay = 8 symbol intervals. Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. DL transmissions are to a single user at a time.

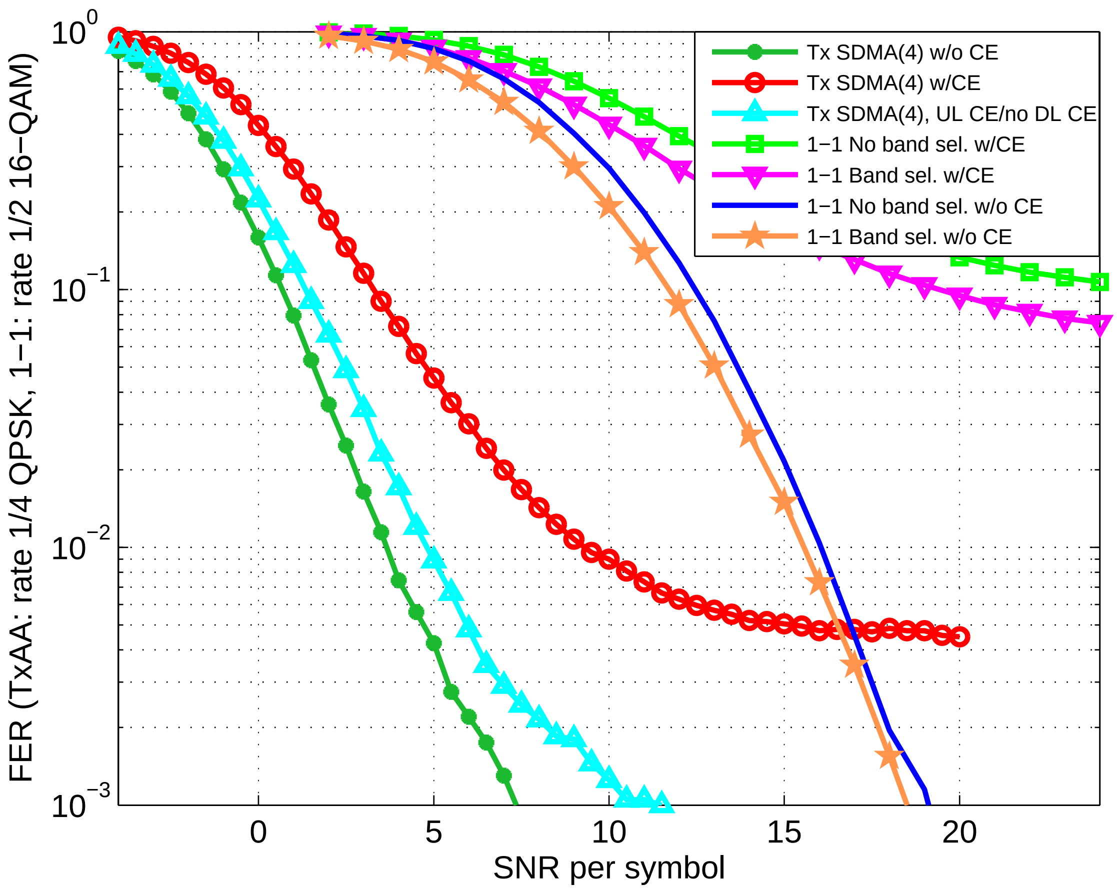

Figure 9. TX-SDMA with 8 transmit antennas and 4 concurrent DL users versus single transmit antenna, **30 mph** at 2.6 GHz. Comparisons with channel estimation (CE) and with ideal channel knowledge (w/o CE). Sum of the data rates of the 4 SDMA users equals the data rate of the single transmit-single receive antenna case. Band selection delay for single transmit antenna cases = 57 symbol intervals, TXAA sounding delay = 8 symbol intervals. Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. **DL transmissions are to four users at a time for the SDMA case**.

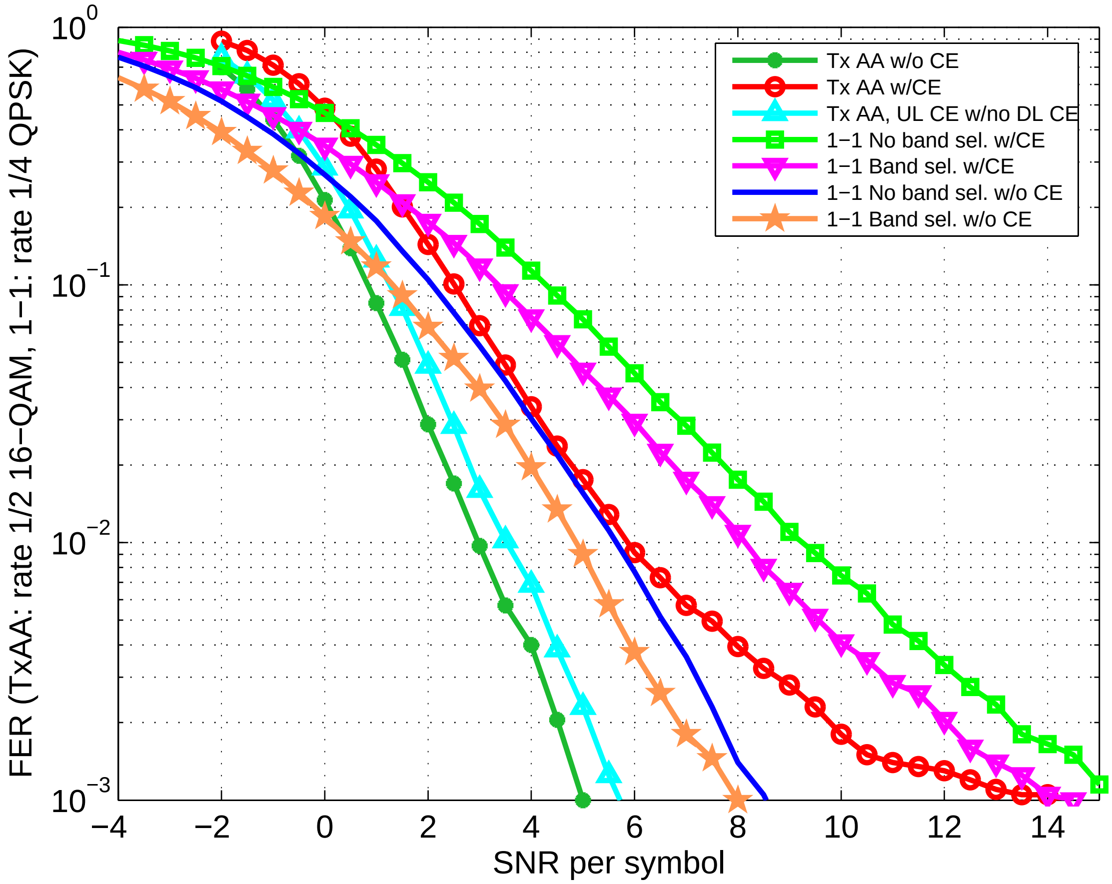

Figure 10. TXAA with 8 transmit antennas versus single transmit antenna for **30 mph** at 2.6 GHz. Comparisons with channel estimation (CE) and without channel estimation (w/o CE). **TXAA case has four times the data rate as the single transmit antenna cases**. Band selection delay for single transmit antenna cases = 57 symbol intervals, TXAA sounding delay = 8 symbol intervals. Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. DL transmissions are to a single user at a time.

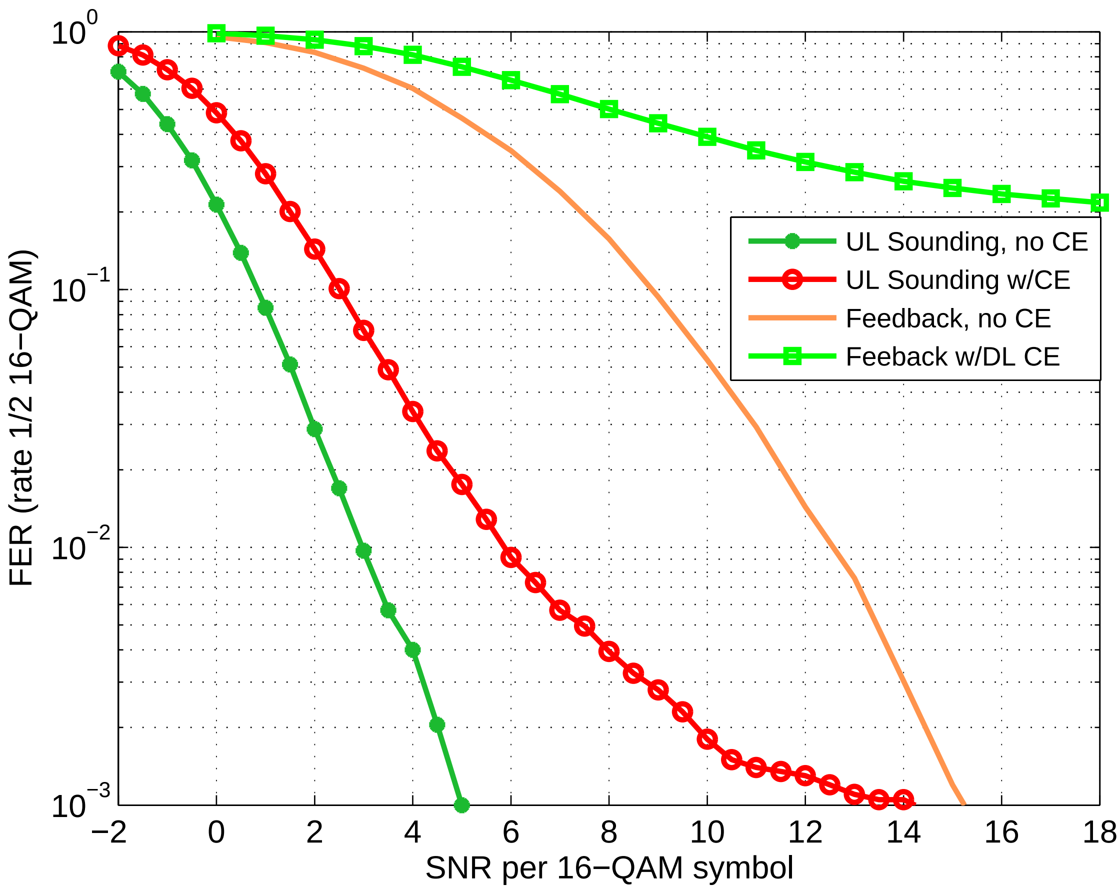

Figure 11. TXAA with 8 transmit antennas: **comparison of feedback and UL channel reuse (sounding)**. UL channel reuse has an eight-symbol sounding delay. Feedback has ideal perfect feedback with a 57-symbol delay. Comparisons with channel estimation (w/CE) and with ideal channel knowledge (no CE). Velocity = **30 mph** at 2.6 GHz. For the UL sounding: Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. DL transmissions are to a single user at a time.

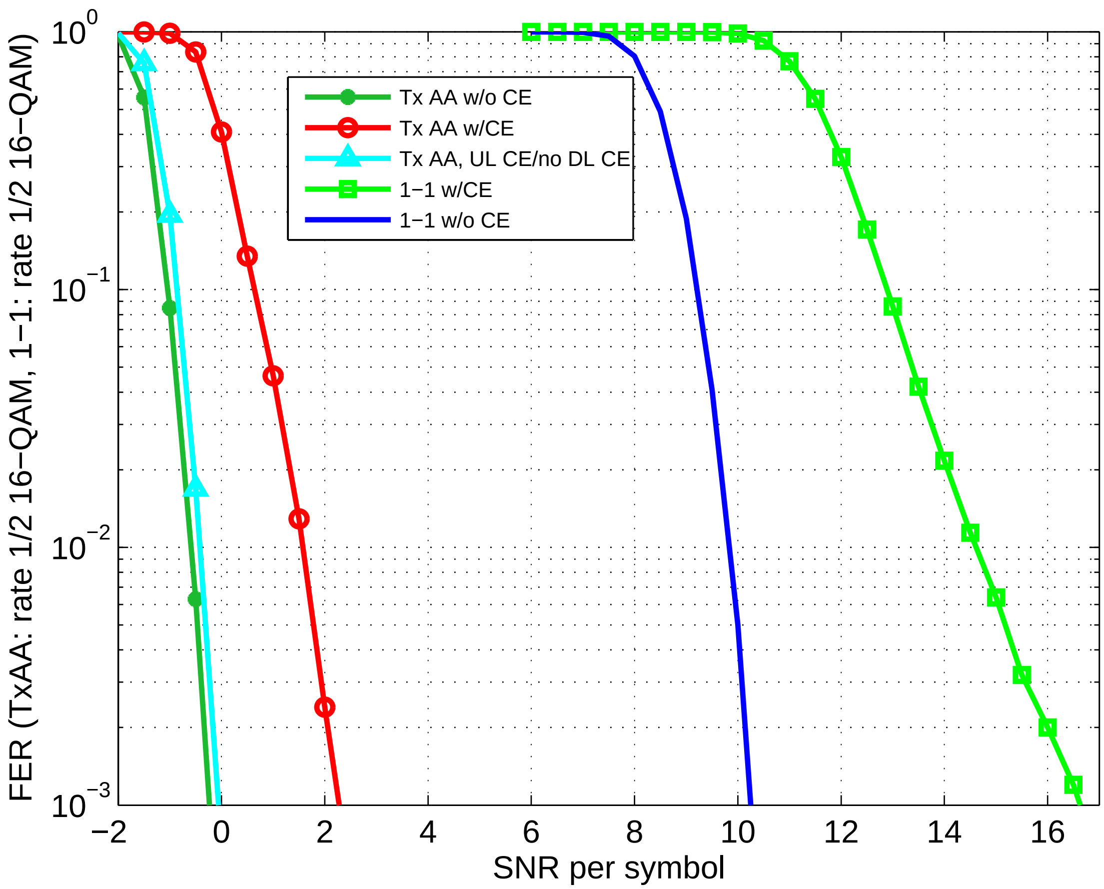

Figure 12. TXAA with 8 transmit antennas versus single transmit antenna with **UL sounding and DL data transmissions both occupying the entire bandwidth**. Comparisons with channel estimation (CE) and with ideal channel knowledge (w/o CE). Velocity = 30 mph at 2.6 GHz. TXAA sounding delay = 8 symbol intervals and no band selection for the single antenna cases. Equal transmit power and data rate for all cases. Eight users concurrently sound on the same UL sounding allocation, where each SS has an UL per carrier SNR of 5 dB. DL transmissions are to a single user at a time.

4 Specific Text Changes

[Add a new section 8.4.?… "Support for Closed-Loop Transmission in TDD systems". Add the following text.]

Section 8.4.?

This section describes the optional signaling that supports optional closed-loop transmission strategies. Closed-Loop transmission strategies use knowledge of the channel at the transmitter to improve link performance, reliability, and range. The optional signaling described in this section enable the BS to measure the uplink channel response and translate the measured uplink channel response to an estimated downlink channel response when the transmit and receive hardware are appropriately calibrated. This signaling is intended for the adjacent channel permutation mode in TDD deployments.

Section 8.4.?.1: Sounding Zone Definition

In UL-MAP, a BS may transmit UIUC=15 with the UL_Sounding_Zone_Presence_IE() to indicate the allocation of an UL sounding zone within the frame. The Sounding Zone is a region of one or more OFDMA symbol intervals in the UL frame that is used by the SS to transmit sounding signals to enable the BS to rapidly determine the channel response between the BS and the SS. The BS may command a SS to transmit a sounding signal (defined below) at one or more OFDMA symbols within the sounding zone by using one of several options. First, sounding instructions can be transmitted in the UL-MAP message UL_Uncoupled_Sounding_IE() to provide detailed sounding instructions to the SS, and this IE format is described below. Second, sounding instructions can be combined with DL-MAP allocations by the transmission of either of the following DL-MAP messages: DL_MAP_Coupled_Sounding_Allocation_IE(), or DL_MAP_Uncoupled_Sounding_Allocation_IE() where these two IE formats are also described below.

The definition of a sounding zone in UL_Sounding_Zone_Presence_IE() allows for efficient scheduling of the sounding signals that a SS will use to send the sounding signal(s), because only the relative position of the sounding symbol in the sounding zone needs to be specified. Otherwise, to indicate the absolute sounding symbol offset, a 10-bit field would need to be used in each UL_Sounding_Zone_Presence_IE() to each SS to be sounded.

Table ?? UL_Sounding_Zone_Presence_IE()

Syntax	Size	Notes
UL_Sounding_Zone_Presence_IE(){		
Extended UIUC	4 bits	0x03
Sounding Zone Length	3 bits	Duration of the sounding zone (up to 8 OFDMA symbols)
OFDMA symbol offset	10 bits	Starting symbol of the sounding zone
}		

Section 8.4.?.2: Uncoupled Sounding Instructions in the UL-MAP

The SS-specific sounding instructions can be transmitted from the BS to a SS in the MAP message UL_Uncoupled_Sounding_IE() where a CID is included. The definition of the sounding zone is in the UL_Sounding_Zone_Presence_IE(). The UL_Uncoupled_Sounding_IE() instructs the SS to transmit specific sounding signal(s) at one or more specific symbol intervals(s) within the sounding zone and specifies the specific frequency band(s) to be occupied within each of these sounding symbol(s). In this case, the sounding frequency allocations are independent (uncoupled) from the presence or absence of any DL data assignments to the SS in the DL-MAP.

Table ??: UL_Uncoupled_Sounding_IE()

Syntax	Size	Notes
UL_Uncoupled_Sounding_IE(){		
Extended UIUC	4 bits	0x04
Multi-CID mode	1 bit	If 1,then multiple CIDs will have the same sounding instructions, multi-antenna mode must be 0, and each CID uses the separability parameter determined by the CID's order in the CID list If 0, then there is only one CID per Sounding Symbol and it is included below.
If Multi-CID mode==1, {		
N_CID	2 bits	Number of CIDs sharing this sounding allocation
For (i=0;i<N_CID;i++) {		
CID	16 bits	CID value
}		
}		
Num_Sounding_symbols	3 bits	Number of sounding symbols this SS uses, from 1 (“000”) to 2^3=8 (“111”)
for (i=0;i<Num_Sounding_symbols;i++){		
If Multi-CID mode==0, {		
CID	16 bits	
}		
Sounding symbol index	3 bits	Symbol index within the zone, from 1 (bits “000”) to 2^3=8 (bits “111”)
Starting Frequency Band	6	Out of 48 bands
Number of frequency bands	6	Contiguous bands used for sounding
Sounding sequence index	2 bits	Sequence index within a 4-

		member group
Separability Type	1 bit	0: occupy all subcarriers in the assigned bands; 1: occupy decimated subcarriers
L=Length of Separability Parameter below	3 bits	Define the length in bits of the next field, which varies from 1 (bits "000") to 2^3=8 (bits "111")
if (Separability type==0) {		
Separability Parameter = Cyclic time shift index	Variable length L	Cyclically shift the time domain symbol by multiples (from 0 to 2^L-1) of a CP length
}		
Else {		
Separability Parameter = Decimation offset	Variable length L	Relative starting offset position among the 2^L possibilities for the first sounding subcarrier
}		
Multi-antenna sounding mode	1 bit	0: sound the first SS antenna; 1: sound all the SS antennas, using the above-defined sequence as the starting shift or decimation offset for the first antenna, and stepping through the remaining shifts or decimation offsets for each additional SS antenna
}		

After receiving the contents of the UL_Uncoupled_Sounding_IE(), the SS will calculate the signal values that are to be used on the subcarriers that it will occupy in the Sounding Band as follows:

$$s_u(k) = \exp\left\{-j2\pi u \frac{k(k+1)}{2N_G}\right\}, \quad k = 0 \cdots L_S - 1$$

where L_s is the number of subcarriers that are occupied in the sounding band (calculated below), k increments in order across the occupied subcarriers, N_G is the smallest prime number that is larger than L_s, and u is calculated from the assigned 2-bit sounding sequence index and the CellID of the BS as follows:

v1=1 + decimal value of lowest 3 bits of the CellID

v2=1 + decimal value of the sequence index

u=((v1)(v2)-1)mod(N_G-1)+1

The length of the sequence required in the sounding band is calculated as follows:

If separability type == 0

Ls = (Number of frequency bands) * 36

else

Ls = (Number of frequency bands) *36 / (2^L)

endif

Finally, if the separability type is zero, then the values of $s_u(k)$ are further modified as follows:

$$s_{um}(k) = s_u(k) e^{-j2\pi k m/(2^L)},$$

where $s_u(k)$ is given in above, L is the length of the assigned separability parameter in bits, and m is the assigned cyclic time shift index, which ranges from 0 to $2^L - 1$. If the multi-antenna mode is set to 1 for a multi-transmit-antenna SS, then the i^{th} SS antenna (where i=1,2,…, number of SS antennas) transmits $s_{u(m+i-1)}(k)$ according to the preceding equation.

Section 8.4.?.3: Coupled Sounding Instructions in the DL-MAP

The SS-specific sounding instruction can also be transmitted from the base to a SS as part of the DL-MAP information. The following DL-MAP_Coupled_Sounding_IE() shall not be used unless the UL_Sounding_Zone_Presence_IE() is present in the same frame. DL-MAP_Coupled_Sounding_IE() allocates a DL data transmission and also commands the SS to transmit at one or more specified symbols within the UL Sounding Zone using the specified sounding signals. In this case, the sounding frequency band information is implicitly derived from the subcarriers occupied by the DL allocation (thus the name "coupled sounding") rather than being specifically signaled.

Table ??: DL-MAP_Coupled_Sounding_IE():

Syntax	Size	Notes
DL-MAP_Coupled_Sounding_IE(){		
Extended DIUC	4 bits	
If (INC_CID==1) {		
N_CID	8 bits	If >1,then multiple CIDs will have the same sounding instructions, multi-antenna mode must be 0, and each CID uses the separability parameter determined by the CID's order in the CID list
For (n=0;n<N_CID;n++){		
CID	16 bits	
}		
}		
OFDMA Symbol Offset	10 bits	
Subchannel offset	5 bits	
Boosting	3 bits	
No. OFDMA Symbols	9 bits	
No. Subchanels	5 bits	
Num_sounding_symbols	3 bits	Number of sounding symbols this SS uses
for (I=0;I<Num_sounding_symbols;I++){		
Sounding symbol index	3 bits	Symbol index in the zone
Sounding sequence index	2 bits	Sequence index
Separability type	1 bit	0: occupy all subcarriers in the assigned bands; 1: occupy decimated subcarriers
Length of the Separability Parameter (L)	3 bits	Defines the length of the next field, which varies from 1 (bits "000") to 2^3=8 (bits "111")
If (Separability type==0) {		
Separability Parameter = Cyclic time shift index *m*	Variable length	Cyclically shift the time domain symbol by multiples (from 0 to 2^L-1) of $N/(2^L)$
}		

Else {		
Separability Parameter = Decimation offset	Variable length	Relative starting offset position among the 2^L possibilities for the first sounding subcarrier
}		
Multi-antenna sounding mode	1 bit	0: sound the first antenna; 1: sound all the antennas, using the above-defined sequence as the starting shift or decimation offset for the first antenna, and stepping through the remaining shifts or decimation offsets for each additional antenna
}		

Section 8.4.?.4: Uncoupled Sounding Instructions in the DL-MAP

To allocate a DL transmission while specifying a set of sounding instructions, the BS may transmit the DL-MAP_Uncoupled_Sounding_IE() as in the following table. The fields in this table follow the corresponding definitions in the DL-MAP_IE() format plus the corresponding definitions in the UL_Uncoupled_Sounding_IE(). The difference between the DL-MAP_Uncoupled_Sounding_IE() and the DL-MAP_Coupled_Sounding_IE() is that the first includes the Starting Frequency Band and the Number of bands fields, whereas the second does not.

Table ??: DL-MAP_Uncoupled_Sounding_IE()

Syntax	Size	Notes
DL-MAP_Uncoupled_Sounding_IE(){		
Extended DIUC	4 bits	
If (INC_CID==1) {		
N_CID	8 bits	If >1,then multiple CIDs will have the same sounding instructions, multi-antenna mode must be 0, and each CID uses the separability parameter determined by the CID's order in the CID list
For (n=0;n<N_CID;n++){		
CID	16 bits	
}		
}		
OFDMA Symbol Offset	10 bits	
Subchannel offset	5 bits	
Boosting	3 bits	
No. OFDMA Symbols	9 bits	
No. Subchanels	5 bits	

Num_sounding_symbols	3 bits	Number of sounding symbols this SS uses
for (I=0;I<Num_sounding_symbols;I++){		
Sounding symbol index	3 bits	Symbol index in the zone
Starting Frequency Band	6	Out of 48 bands
Number of bands	6	Contiguous bands used
Sounding sequence index	2 bits	Sequence index within a 4-member group
Separability type	1 bit	0: occupy all subcarriers in the assigned bands; 1: occupy decimated subcarriers
Length of the Separability Parameter (L)	3 bits	Define the length of the next field, which varies from 1 (bits “000”) to 2^3=8 (bits “111”)
If (Separability type==0) {		
Separability Parameter (Cyclic time shift index *m*)	Variable length	Cyclically shift the time domain symbol by multiples (from 0 to 2^L-1) of $N/(2^L)$
}		
Else {		
Separability Parameter (Decimation offset)	Variable length	Relative starting offset position among the 2^L possibilities for the first sounding subcarrier
}		
Multi-antenna sounding mode	1 bit	0: sound the first antenna; 1: sound all the antennas, using the above-defined sequence as the starting shift or decimation offset for the first antenna, and stepping through the remaining shifts or decimation offsets for each additional antenna
}		

Section 8.4.?.5 Support for Closed-Loop MIMO Transmission

To support closed-loop MIMO transmission a BS may transmit a MIMO_DL_Basic_Uncoupled_Sounding_IE() with a DIUC value of 0x05. The MIMO_DL_Basic_Uncoupled_Sounding_IE() combines the contents of the MIMO_DL_Basic_IE() with the uncoupled sounding instructions as defined in the DL-MAP_Uncoupled_Sounding_IE(). An additional Closed-Loop MIMO field indicates the type of Closed-Loop MIMO transmission that is being allocated: single layer or multi-layer to a single CID or multiple concurrent layers to multiple CIDs.

Table ?? MIMO_DL_Basic_Uncoupled_Sounding_IE()

Syntax	Size	Notes
MIMO_DL_Basic-Uncoupled_Sounding_IE(){		
Extended DIUC	4 bits	0x05
Length	4 bits	Length in Bytes
Num_Region	4 bits	
for (i = 0; i< Num_Region;i++) {		
OFDMA Symbol offset	10 bits	
Subchannel offset	5 bits	
Boosting	3 bits	
No. OFDMA Symbols	9 bits	
No. subchannels	5 bits	
Matrix_indicator	2 bits	STC matrix (see 8.4.8.4.)

		Transmit_diversity = transmit diversity mode indicated in the latest TD_Zone_IE().
		if (Transmit_Diversity = 01)
		{
		00 = Matrix A
		01 = Matrix B
		10 – 11 = Reserved
		}
		elseif (Transmit_Diversity = 10)
		{
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}

Closed-loop MIMO flag	2 bits	00 = Open-loop 01 = Closed-loop TxAA (meaning the following Num_layer=1) 10 = Closed-loop MIMO 11 = Closed-loop SDMA

Num_layer	2 bits	
for (j = 0; j< Num_layer; j++){		
if (INC_CID == 1) {		
CID	16 bits	
}		If multiple different CIDs corresponding to multiple SSs are assigned here, then each SS will have the same sounding instructions, multi-antenna mode must be 0, and each SS uses the separability parameter determined by its CID's order in the CID list
Layer_index	2 bits	
}		
}		
Num_Sounding_symbols	3 bits	Number of sounding symbols this SS uses, from 1 (bits "000") to 2^3=8 (bits "111")
for (i=0;i<Num_Sounding_symbols;i++){		
Sounding symbol index	3 bits	Symbol index in the zone, from 1 (bits "000") to 2^3=8 (bits "111")
Starting frequency band	5 bits (or 6 bits)	Out of 32 (or 48) bands
Number of bands	5 bits (or 6 bits)	Contiguous bands used for sounding
Sounding sequence index	2 bits	Sequence index within a pre-defined 4-member group (several groups are pre-defined to be used in different sectors)
Separability flag	1 bit	0: sound all subcarriers in the assigned bands; 1: sound decimated subcarriers
Length of Separability Parameter ("L")	3 bits	Define the length of the next field, which varies from 1 (bits "000") to 2^3=8 (bits "111")
if (Separability flag==0) {		
Separability Parameter (Cyclic time shift index *m*)	Variable length	Cyclically shift the time domain symbol by multiples (from 0 to 2^L-1) of $N/(2^L)$
}		
Else {		

Separability Parameter (Decimation offset)	Variable length	Relative starting offset position among the 2^L possibilities for the first sounding subcarrier
}		
Multi-antenna sounding mode	1 bit	0: sound the first SS antenna; 1: sound all SS antennas, using the above-defined sequence as the starting shift or decimation offset for the first antenna, and stepping through the remaining shifts or decimation offsets for each additional antenna
}		

To support closed-loop MIMO transmission, a BS may also transmit a MIMO_DL_Basic_Coupled_Sounding_IE() with a DIUC value of 0x05. The MIMO_DL_Basic_Coupled_Sounding_IE() combines the contents of the MIMO_DL_Basic_IE() with the coupled sounding instructions as defined in the DL-MAP_Coupled_Sounding_IE(). An additional Closed-Loop MIMO field indicates the type of Closed-Loop MIMO that is being allocated: single layer or multi-layer to a single CID or multiple concurrent layers to multiple CIDs.

Table ??: MIMO_DL_Basic_Coupled_Sounding_IE()

Syntax	Size	Notes
MIMO_DL_Basic-Coupled_Sounding_IE(){		
Extended DIUC	4 bits	0x05
Length	4 bits	Length in Bytes
Num_Region	4 bits	
for (i = 0; i< Num_Region;i++) {		
OFDMA Symbol offset	10 bits	
Subchannel offset	5 bits	
Boosting	3 bits	
No. OFDMA Symbols	9 bits	
No. subchannels	5 bits	
Matrix_indicator	2 bits	STC matrix (see 8.4.8.4.)

		Transmit_diversity = transmit diversity mode indicated in the latest TD_Zone_IE().
		if (Transmit_Diversity = 01)
		{
		00 = Matrix A

		01 = Matrix B
		10 – 11 = Reserved
		}
		elseif (Transmit_Diversity
		=
		10)
		{
		00 = Matrix A
		01 = Matrix B
		10 = Matrix C
		11 = Reserved
		}

Closed-loop MIMO flag	2 bits	00 = Open-loop 01 = Closed-loop TxAA (meaning the following Num_layer=1) 10 = Closed-loop MIMO 11 = Closed-loop SDMA (SS reacts by using different receive and channel estimation algorithms accordingly)
Num_layer	2 bits	
for (j = 0; j< Num_layer; j++){		
if (INC_CID == 1) {		
CID	16 bits	
}		If multiple different CIDs corresponding to multiple SSs are assigned here, then each SS will have the same sounding instructions, multi-antenna mode must be 0, and each SS uses the separability parameter determined by its CID's order in the CID list
Layer_index	2 bits	
}		
}		
Num_Sounding_symbols	3 bits	Number of sounding symbols this SS uses, from 1 (bits "000") to 2^3=8 (bits "111")
for (i=0;i<Num_Sounding_symbols;i++){		
Sounding symbol index	3 bits	Symbol index in the zone, from 1 (bits "000") to 2^3=8 (bits "111")
Sounding sequence index	2 bits	Sequence index within a

		pre-defined 4-member group (several groups are pre-defined to be used in different sectors)
Separability flag	1 bit	0: sound all subcarriers in the assigned bands; 1: sound decimated subcarriers
Length of Separability Parameter (“L”)	3 bits	Define the length of the next field, which varies from 1 (bits “000”) to 2^3=8 (bits “111”)
if (Separability flag==0) {		
Separability Parameter (Cyclic time shift index *m*)	Variable length	Cyclically shift the time domain symbol by multiples (from 0 to 2^L-1) of $N/(2^L)$
}		
Else {		
Separability Parameter (Decimation offset)	Variable length	Relative starting offset position among the 2^L possibilities for the first sounding subcarrier
}		
Multi-antenna sounding mode	1 bit	0: sound the first antenna; 1: sound all the antennas, using the above-defined sequence as the starting shift or decimation offset for the first antenna, and stepping through the remaining shifts or decimation offsets for each additional antenna
}		

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