Project	**IEEE 802.16 Broadband Wireless Access Working Group <http://ieee802.org/16>**
Title	**Uplink Channel Sounding for TDD OFDMA**
Date Submitted	**2004-08-31**
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Re:	IEEE P802.16-REVe/D4-2004, ballot #14c
Abstract	Optional signaling methodology to support uplink channel sounding in TDD OFDMA systems.
Purpose	Adoption of proposed changes into P802.16e
Notice	

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Uplink Channel Sounding for TDD OFDMA

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1 Introduction

In wireless communication systems, link performance can be improved by adapting the characteristics of the transmitted signal to the current channel conditions. In closed-loop transmit antenna array applications, knowledge of the DL 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 MSS, 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 MSSs on the same time-frequency resources (e.g., concurrent transmission or Spatial Division Multiple Access, SDMA). Whether the BS has only one transmit antenna or multiple transmit antennas, knowledge of the DL channel can also be leveraged to improve performance for example by selecting the best portion of the band in which to allocate a transmission to/from a MSS (band selection). In the current standard, the existing feedback enabling mechanisms cannot provide the full characteristics of the channel as provided by the mechanism proposed in this contribution.

In TDD systems, an effective method for providing DL channel response information to the BS is for the BS to estimate the UL channel from the MSS based on transmissions from the MSS on the UL. The key assumption 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. However, in the current 802.16 standard, if a BS is to derive the DL channel response from measured UL channel responses in a TDD system, the MSS must first transmit on the UL, and that 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 or when permutation zones that are not reciprocal in the uplink-downlink data region structure are used (e.g., PUSC). Rather than relying on UL data transmissions from an MSS, broadband data systems can be designed to support the transmission of sounding signals by an MSS to enable the BS to compute the UL channel response over the bandwidth for selection of non-faded subchannels and/or their use for DL closed loop data transmission.

This contribution defines an optional MSS capability called "CSIT" (Channel State Information at the Transmitter) and describes a signaling methodology for the OFDMA PHY that provides a fast, efficient, and low overhead means for providing the base with the DL channel information necessary for transmission with channel knowledge at the base. The methodology allows UL sounding to be performed independently of UL data allocations. Periodic transmission of UL sounding symbols is also supported by this contribution, which may be important for a mobile environment. The proposal is backward compatible to 802.16d mobiles, with the sounding zone guarded by a safety zone instruction. The proposal is intended for the OFDMA PHY for 802.16e systems operating with a TDD deployment. The proposed signaling methodology 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.

Reference [6] contains additional background material, justification discussion, and performance evaluation results concerning this contribution.

2 Summary of Solution

The proposal contains three main components: The first component is a definition of a new **optional capability** called CSIT (term stands for "Channel State Information at the Transmitter"). The second 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 CSIT capable MSSs 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 estimate of the DL channel response. The Sounding Zone is allocated by leveraging unused bits in the uplink Safety Zone IE and is only allocated when uplink sounding is needed. The third component is the definition of the **sounding instructions** that enable the MSS to determine where in the Sounding Zone it should transmit and the specific sounding waveform(s) that should be used. The sounding instructions are communicated via a specific message (IE) transmitted in the UL-MAP. The sounding waveforms are specifically designed to facilitate accurate UL channel estimation by the BS. The specified solution is independent of the permutation zones to be later used at the downlink.

An example of utilization of the proposed mechanism is depicted in Figure 1 below. Note that the sounding symbol may be independent of the following downlink data region allocation, in a contrast to the situation in Figure 1.

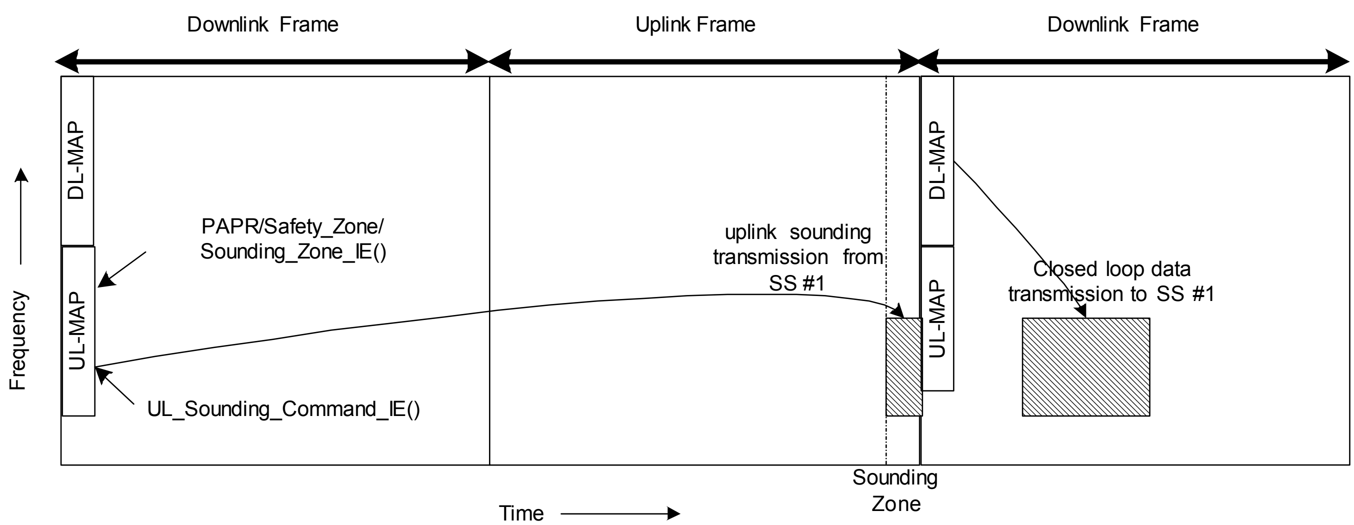

Figure 1. Allocating a Sounding transmission on the uplink sounding zone along with a closed-loop data transmission in the subsequent downlink.

3 Specific Text Changes

---------------------- Beginning of Text Changes -------------------------------------

[Add a new section 11.8.3.7.6]

11.8.3.7.6 OFDMA MSS CSIT capability

This field indicates MSS capability of supporting CSIT (uplink sounding). A bit value of 0 indicates "not supported" while 1 indicates "supported". If this field is omitted, then by default MSS is considered not supporting CSIT.
Capability type A indicates sounding that does not use subcarrier permutations of the downlink. Capability type B indicates sounding over subcarriers distributed according to permutations of the downlink.

Type	Length	Value	Scope
155	1	Bit #0: CSIT capability type A. Bit #1: CSIT capability type B. Bit #2-7: *reserved.*	SBC-REQ (see 6.3.2.3.23) SBC-RSP (see 6.3.2.3.24)

[In Section 8.4.5.4.2, modify the use of the reserved bits in Table 287 to indicate the presence of a Sounding Zone]

Table 287 – PAPR Reduction, Safety Zone, and Sounding Zone Allocation IE Format

Syntax	Size	Notes
PAPR_Reduction_Safety_Sounding_Zone_Allocation_IE( ) {		
OFDMA symbol offset	8 bits	
Subchannel offset	7 bits	
No. OFDMA symbols	7 bits	
PAPR Reduction/Safety Zone/Sounding Zone	1 bit	0 = PAPR reduction allocation 1 = Safety zone allocation
Sounding Zone	1 bit	0 = PAPR/Safety Zone 1 = Sounding Zone Allocation
Reserved	1 bit	
}		

[Add a new section 8.4.6.2.7 "Uplink Channel Sounding in TDD systems". Add the following text.]

Section 8.4.6.2.7 Optional Uplink Channel Sounding in TDD systems

This section describes a signaling mechanism where an MSS transmits channel sounding waveforms on the uplink to enable the BS to determine the BS-to-MSS channel response under the assumption of TDD reciprocity. Only CSIT capable MSSs (as indicated by the SBC-REQ message, see Section 11.8.3.7.6) shall support this signaling. This signaling methodology enables the use of closed-loop transmission strategies. Closed-Loop transmission strategies use knowledge of the channel at the transmitter to improve link performance, reliability, and range. This methodology also provides a means for the BS to determine the quality of the channel response across the signal bandwidth for the purpose of selecting the best portion of the band on which to transmit. The signaling described in this section enables 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. To support downlink channel estimation in a mobile environment, an MSS may be instructed to transmit sounding signals periodically. In this case, the first sounding symbol is transmitted within the frame containing the relevant sounding instruction.

In order to enable uplink sounding, in UL-MAP a BS transmits UIUC=13 with the PAPR_Reduction_Safety_and_Sounding_Zone_Allocation_IE() (Table 287) 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 MSS to transmit sounding signals to enable the BS to rapidly determine the channel response between the BS and the MSS. The BS may command a MSS to transmit a sounding signal (defined below) at one or more OFDMA symbols within the sounding zone by transmitting the UL-MAP message UL_Sounding_Command_IE()to provide detailed sounding instructions to the MSS. If periodic sounding is instructed by the BS, it is the responsibility of the BS to continue to signal the PAPR_Reduction_Safety_and_Sounding_Zone_Allocation_IE() in every appropriate frame. The UL_Sounding_Command_IE() of type A instructs the MSS to transmit specific sounding signal(s) at one or more specific symbol intervals(s) within the sounding zone and specifies the specific sounding frequency band(s) to be occupied within each of these sounding symbol(s). The UL_Sounding_Command_IE() of type B is similar to the UL_Sounding_Command_IE() of type A except the frequency band(s) are allocated according to a specified downlink subcarrier permutation.

For the purposes of sounding the uplink of a CSIT capable MSS of type A, the OFDMA frequency bandwidth within the Sounding Zone is partitioned into non-overlapping sounding frequency bands, where each sounding frequency band contains 18 consecutive OFDMA subcarriers. For the 2048 FFT size, the Sounding Zone therefore contains maximum of 1728/18=96 sounding frequency bands, where 1728 is the number of usable subcarriers (N_{used}). For other FFT sizes, the sounding bands are also 18 subcarriers wide, and the number of possible sounding bands across the signal bandwidth varies accordingly.

As shown in the table below, the sounding instructions for CSIT type A include an assigned set of contiguous sounding frequency bands (called the sounding allocation). The sounding frequency bands are non-distributed for CSIT capability type A and are distributed according to a specified downlink permutation (for example, PUSC) for CSIT capability type B. For CSIT capability B, distributing the sounding frequency bands according to the optional FUSC is supported only for MSSs that support the optional FUSC permutation.

Additionally, for CSIT capability A, the sounding instructions in UL_Sounding_Command_IE() contain two alternate methods of maintaining signal orthogonality between multiple multiplexed MSS sounding transmissions. The first methodology is called “cyclic shift separability” and involves the MSS occupying all subcarriers within the sounding allocation. With this methodology, multiple MSSs use the same sounding sequence (defined below), but each uses a different frequency-domain phase shift to multiply that underlying sounding sequence. In the second methodology, the MSS occupies a decimated set of subcarriers (e.g., every

16th subcarrier, etc.). Multiple MSSs can occupy the same sounding allocation, but each MSS would use a set of non-overlapping subcarriers within the sounding allocation.

The sounding instructions in UL_Sounding_Command_IE() of type B does not allow for multiplexing of sounding transmissions of multiple MSSs over the same bands.

Table ??: UL_Sounding_Command_IE()

Syntax	Size	Notes
UL_Sounding_Command_IE(){		
Extended UIUC	4 bits	0x09
Length	4 bits	Variable
Sounding_Type	1 bit	0 – Type A 1 – Type B
Send Sounding Report Flag	1 bit	
If (Sounding_Type == 0) {		
Num_Sounding_symbols	3 bits	Total number of sounding symbols being allocated, from 1 (“000”) to 2^3=8 (“111”)
Separability Type	1 bit	0: occupy all subcarriers in the assigned bands; 1: occupy decimated subcarriers
if (Separability type==0) {		(using cyclic shift separability)
Max Cyclic Shift Index P	2 bits	“00”: P=4; “01”: P=8; “10”: P=16, “11”: P=32
}		
Else {		(using decimation separability)
Decimation Value D	3 bits	Sound every D^{th} subcarrier within the sounding allocation. Decimation value D is 2 to the power of (2 plus this value), hence 4,8,… up to maximum of 64.
Decimation offset randomization	1 bit	0= no randomization of decimation offset 1= decimation offset pseudo-randomly determined
}		
For (i=0;i<Num_Sounding_symbols;i++){		
Sounding symbol index	3 bits	Symbol index within the Sounding Zone, from 1 (bits “000”) to 2^3=8 (bits “111”)
Number of CIDs	4 bits	Number of CIDs sharing this sounding allocation
For (j = 0; j<Num. of CIDs; j++) {		
Shorted basic CID	12 bits	12 LS bits of the MSS basic CID value
Starting Frequency Band	7 bits	Out of 96 bands at most (FFT size dependent)
Number of frequency bands	7 bits	Contiguous bands used for sounding
Multi-Antenna Flag	1 bit	0=MSS sounds first antenna only 1=MSS sounds all antennas
if (Separability type==0) {		

Cyclic time shift index m	5 bits	Cyclically shifts the time domain symbol by multiples (from 0 to P –1) of N/P where N=FFT size, and P=Max Cyclic Shift Index.
Else {		
Decimation Offset d	6 bits	Relative starting offset position for the first sounding occupied subcarrier in the sounding allocation
}		
Periodicity	2 bits	00=single command, not periodic, or terminate periodicity 01=repeat sounding once per frame until terminated 10= repeat instructions once per 2 frames 11= repeat instructions once per 4 frames
}		
}		
}		
else {		
Permutation	2 bits	0b00 = PUSC perm. 0b01 = FUSC perm. 0b10 = Optional FUSC perm. 0b11 = Adjacent subcarrier perm.
IDcell	6 bits	
Num_Sounding_symbols	3 bits	
for (i=0;i<Num_Sounding_symbols;i++){		
Number of CIDs	7 bits	
For (j=0; j<Number of CIDs; j++) {		
Shortend basic CID	12 bits	12 LS bits of the MSS basic CID value
Subchannel offset	7 bits	The lowest index subchannel used for carrying the burst, starting from subchannel 0
Number of subchannels	3 bits	The number subchannels with subsequent indexes, used to carry the burst.
Periodicity	2 bits	00=single command, not periodic, or terminate periodicity 01=repeat sounding once per frame until terminated 10= repeat instructions once per 2 frames 11= repeat instructions once per 4 frames
}		
}		
}		

Padding	Variable	Pad IE to octet boundary. Bits shall be set to 0
}		

For CSIT capability A, the indices d or m are associated with the first antenna of the MSS. If Multi-Antenna Flag equals 1 then the i^{th} antenna of the MSS corresponds to index d+i-1 or to m+i-1 respectively. If Multi-Antenna Flag equals 0 then only the first antenna performs sounding. The BS shall assign indices to different CIDs such that overlapping of indices is avoided.

[NOTE TO EDITOR: There are two alternative proposals for the sequence values for use in CSIT capability A, and these are contained in two separate contributions: One is entitled "GCL sequences for Uplink Channel Sounding for TDD OFDMA". The other is "PN Sequences for Uplink Channel Sounding for TDD OFDMA". Those contributions will each contain the respective text for determining the values of $s_u(k)$, and this text is to be inserted here.]

For CSIT capability A, if the separability type is zero, then the sequence used by a transmit device (MSS or MSS antenna) associated with the n^{th} index is determined according to:

$$s_{un}(k) = s_u(k)e^{-j\frac{2\pi kn}{P}},$$

where k is the index of the occupied subcarrier (0≤k≤Ls-1, where Ls is the number of occupied subcarriers), P is the max cyclic shift index (from the sounding instructions), n is the assigned cyclic time shift index (also from the sounding instructions), which ranges from 0 to $P - 1$. The sequence $s_u(k)$ is parameterized by u, the latter being a function of the UL_IDcell and the Frame Number.

For CSIT type A, if the separability type is one, then a spacing of D subcarriers (where D is the Decimation value) is maintained between every two occupied subcarriers associated with the same transmit device. Let $\hat{d}$ be the value of the decimation offset d plus the relative offset according to the MSS antenna number (when Multi-Antenna Flag equals 0, then only the first antenna does sounding). If Decimation Offset Randominzation equals 0, then $g = \hat{d}$ otherwise $g = \left(p\left((BaseID + Frame\ Number) \bmod 32\right) + \hat{d}\right) \bmod D$, where $p(x)$ is the value in PermutationBase as defined by Table 309 ("OFDMA downlink carrier allocations") at the location x. The first subcarrier to be occupied is located at the g^{th} subcarrier. The pseudo-random cyclic shift of the decimation offset may be used to combat inter-cell interference. On the other hand, when this pseudo-random cyclic shift is not used, then an alternative strategy for combating inter-cell interference involves assigning each neighboring cell/sector a set of decimation offsets that is different from those used by neighboring cells/sectors.

The two periodicity bits indicate whether the MSS is to periodically repeat the sounding waveforms in subsequent sounding zone without having to receive a subsequent UL_Sounding_Command_IE(). Setting the periodicity bits to 00 has two meanings: Ordinarily, the 00 setting means a single sounding command with no periodicity. However, if periodic sounding is being performed by a specified MSS, then the 00 setting means the specified MSS must stop all sounding over the specified OFDMA symbol.

When the MSS is sounding with CSIT capability B, the pilot subcarriers shall be BPSK modulated with their values corresponding to the sequence $S_u(k)$, where k=0 is associated with the first occupied subcarrier.

If Send Sounding Report Flag is set to one, then any sounding IE (type A or B) encompasses an additional implicit instruction, according to which the MSS shall report the average of the downlink SINR at the neighborhood of the pilot subcarriers. This instruction is equivalent to a Report command with parameter Channel Type request equal to 0b11. A CSIT capable MSS (of type A or type B) shall respond with the appropriate REP-RSP() message on the uplink (see also 11.11 and 11.12) within the same frame used to convey the relevant sounding IE. It is the responsibility of the BS to allocate enough bandwidth to support the proper transmission of this REP-RSP() message. In case a periodic sounding is required, a periodic REP-RSP() shall be sent.

For each occupied subcarrier in a sounding symbol, the SINR at the MSS is estimated based on a non-beamformed transmission that corresponds to the downlink preamble at the first symbol of the frame. The average SINR reported is the average of those estimates. An MSS that transmits over multiple sounding symbols shall address the last symbol in the region for that matter.

If Send Sounding Report Flag is set to zero, then no reports are required to be sent by the specified MSSs.

[Change third row in the second table in Section 11.11]

Channel Type request	1.3	1	00 = Normal subchannel, 01 = Band AMC Channel, 10 = Safety Channel, 11 = Sounding

[Add 5th row to 3rd table in Section 11.12]

Channel Type = 11	Sounding Report	2.4	1	Average SINR. 8 bits in the same format used at Section 8.4.10.3

-------------------------- End of Text Changes --

4 Simulation Results

Maximal ratio combining at the transmitter (MRC@TX), also known as TXAA, is a transmit array processing strategy that can improve the link data rate. The TXAA strategy can make use of the proposed strategies for providing the BS with knowledge of the BS-SS channel response. To show the ability of the TXAA transmission strategy [2][3] to improve the data rate, even at moderate velocities, Figure 2 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. For more details on this figure see [6].

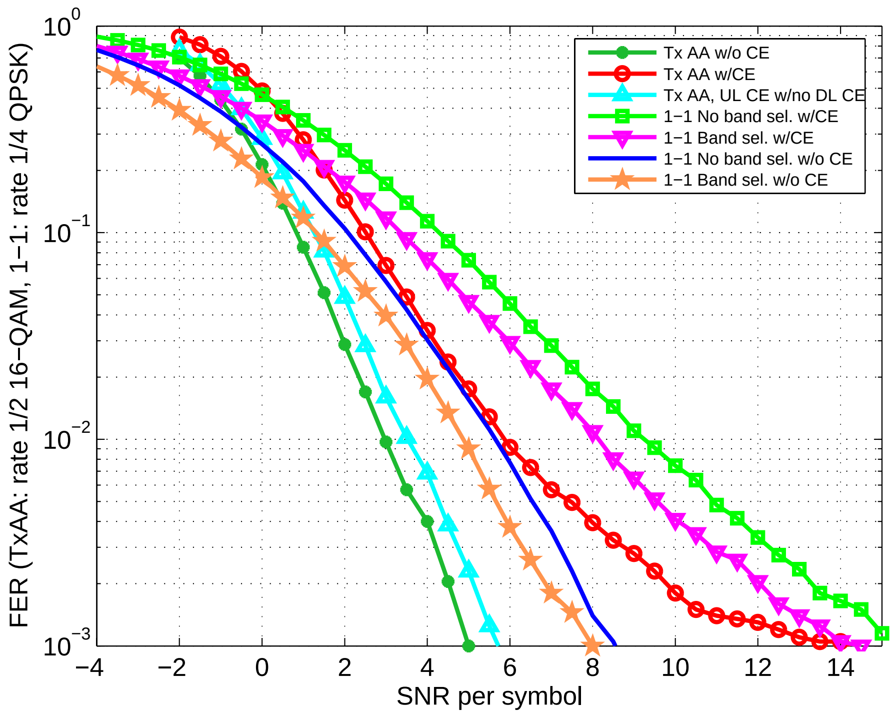

Figure 2. TXAA with 8 transmit antennas versus single transmit antenna for **30 mph** at 2.6 GHz. Comparisons with channel estimation (CE) and without channel estimation (w/o CE). **TXAA case has four times the data rate as the single transmit antenna cases**. Band selection delay for single transmit 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.

Both experiments associated with Figure 2 above and Figure 3 below apply sounding of multiple users over the same bandwidth (corresponding to UL_Sounding_Command_A_IE()).

Figure 3shows the throughput boost achievable by different transmission schemes for ITU Ped. A channel at 3 KmH. The BS has 4 antennas for the multiple antenna case or 1 antenna. In both cases, 8 users reside in the cell (for SDMA, more than 1 can be served). The sounding is noiseless, but samples the entire bandwidth with decimation of 16. The turbo code used by 3GPP WBCDMA was used for rates ½ or ¾ . Modulations used are QPSK and 16QAM only. Repetitions assumed are 1,2,4 or 6.

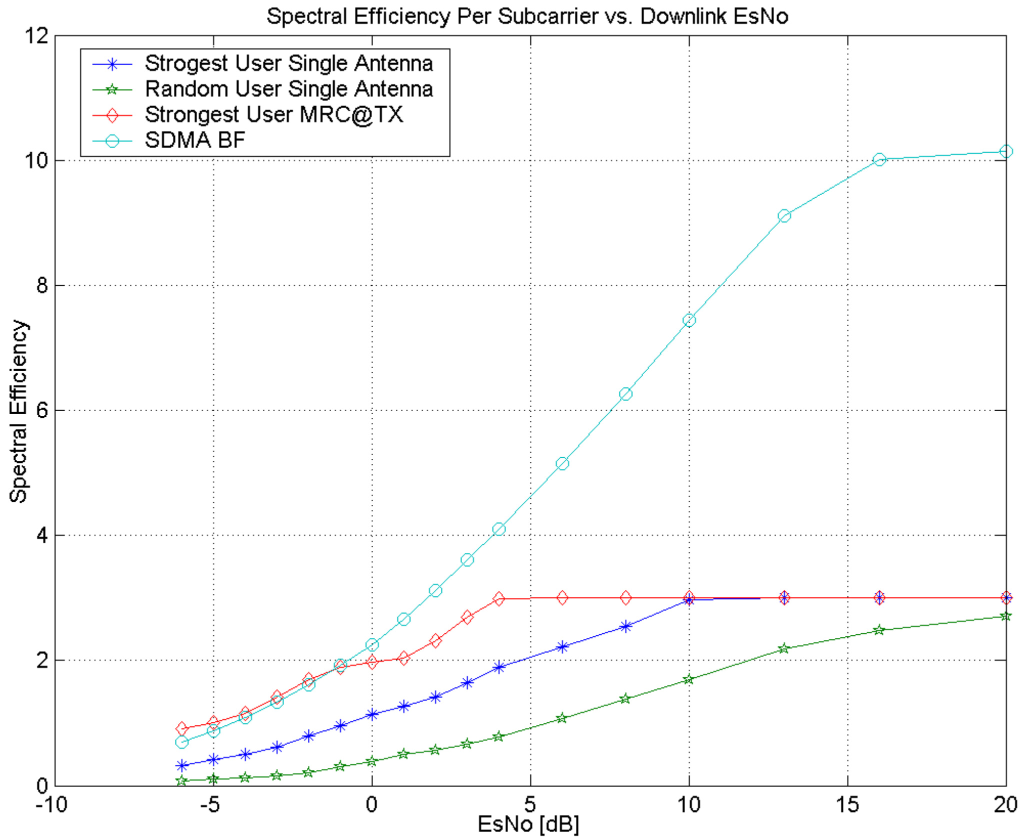

Figure 3: Benefits of channel knowledge at the BS.

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[3] J. K. Cavers, "Single-user and multiuser adaptive maximal ratio transmission for Rayleigh channels," *IEEE Transactions on Vehicular Technology*, vol. 49, no. 6, Nov. 2000.

[4] F. W. Vook, T. A. Thomas, X. Zhuang, "Transmit Diversity and Transmit Adaptive Arrays for Broadband Mobile OFDM Systems," *IEEE WCNC-2003*, New Orleans, LA, March 16-20, 2003.

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