MIMO Considerations for the Downlink Subchannel and Pilot Format Design in IEEE 802.16m

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Venue:

TGm Call for contributions on 802.16m System Description Document, IEEE 802.16m-07/047.

Topic: Frame Structure with attention to multi-antenna techniques

Abstract:

MIMO Considerations for the Downlink Subchannel and Pilot Format Design in IEEE 802.16m

Purpose:

Adoption of recommendations into the 802.16m System Description Document

MIMO Considerations for the Downlink Subchannel and Pilot Format Design in IEEE 802.16m

- Discuss MIMO impact on the design of the subchannel and pilot formats in 802.16m
- Design considerations and recommendations for:
  - Downlink Subcarrier to Subchannel mapping where several basic resource tiles are grouped into subchannels
  - Pilot & Data layout for the basic resource tile
  - Dedicated Pilots and Broadcast Pilots
- Comparisons & evaluations based on throughput simulations accounting for both FER performance and pilot overhead

MIMO in IEEE 802.16m

- MIMO and advanced antenna array techniques are key technologies for meeting the performance requirements of the System Requirements Document
- MIMO and advanced antenna array techniques impact and are impacted by a large portion of the overall system
  - Link adaptation
  - Subchannelization & pilot formats
  - Feedback channels
  - Control channels
  - Cell/sector coordination for interference management
- This contribution: focusing on the MIMO impact on the design of the downlink subchannels & pilot formats

DL Subchannel and pilot format considerations

- Efficiently support high-performance Closed-Loop MIMO transmission methods:
  - Beamforming
  - Single-User MIMO (SU-MIMO)
  - Multi-User MIMO (MU-MIMO)
- Support up to rank 4 transmission
  - 2-stream SU-MIMO for handsets
  - 4-stream SU-MIMO for CPEs / Laptops
  - 4-user MU-MIMO for all MS classes
- Support frequency selective closed-loop transmission
- Support frequency selective scheduling in conjunction with MIMO
- Balance pilot overhead with system performance
- Broadcast versus Dedicated Pilots
  - Dedicated pilots essential for enabling arbitrary number of Tx antennas
  - Dedicated pilot overhead increases with transmission rank
  - Broadcast pilot overhead is fixed for a given number of transmit antennas
  - Dedicated pilots allows base more freedom to compute transmit weights (i.e., weights are not limited to a finite codebook)
- MIMO transmission enablers to consider:
  - Leveraging reciprocity via UL Sounding or regular UL transmission w/dedicated pilots for closed-loop transmission in TDD
  - Codebook feedback
  - Direct/analog feedback
- Self-contained resource blocks better support use of dedicated pilots for closed-loop transmission based on TDD reciprocity

Terminology: Dedicated vs Broadcast Pilots

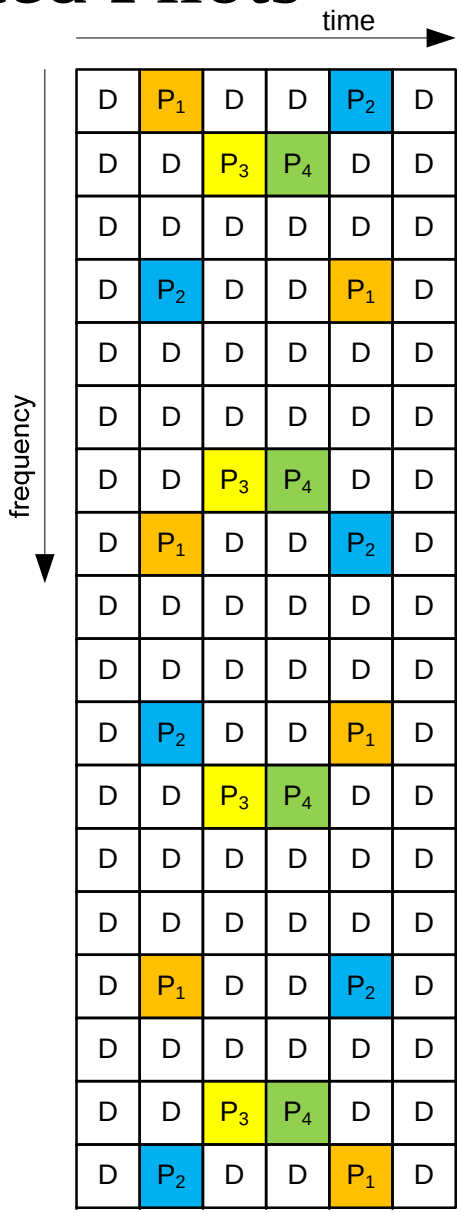
- Broadcast Pilots (sometimes called Common Pilots)
  - Pilot symbols that can be used by any MS for estimating the DL channel
    - Pilot symbols are not beamformed / precoded with the data and are specific to a transmit antenna (or virtual transmit antenna)
    - When beamforming / precoding is used on the data and the pilots are common (not beamformed/precoded), then the MS requires knowledge of (or must determine) the beamforming/precoding vector/matrix being used
- Dedicated Pilots
  - Pilot symbols that are specific to the data allocation and cannot be used by other MSs (those not assigned to the data allocation) to estimate the channel
    - Pilot symbols that are typically beamformed along with the data
    - MS does not need to know the beamforming/precoding vector/matrix
  - Definition from P802.16Rev2/D2 (Dec 2007) – Section 8.4.5.3.4 (STC Zone IE Switch)
    - "The optional Dedicated Pilots fields are used to support the use of open-loop precoding or closed-loop transmissions in which the MS has no knowledge of the precoding / beamforming matrix."
    - "When the data allocations are precoded/beamformed, then setting the Dedicated Pilots bit to 1 means the pilot symbols are precoded / beamformed in the same way as are the corresponding data subcarriers."
      - "In this case, an MS should use only the pilots that are specific to its allocation for channel estimations."

Recommendations for Subcarrier to Subchannel Mapping

- Recommend a Basic Resource Tile (RT) for data subchannels
  - 18 subcarriers x 6 symbols sub-block format
- Several versions of the Basic RT are considered to accommodate the following:
  - Dedicated and broadcast pilots
  - Different numbers of effective transmit antennas & spatial streams
- A subchannel consists of some number (TBD) of these Basic RTs
  - FEC is performed across the RTs that make up a subchannel
  - Rate matching is assumed for flexibility in supporting different numbers of transmit streams / antennas

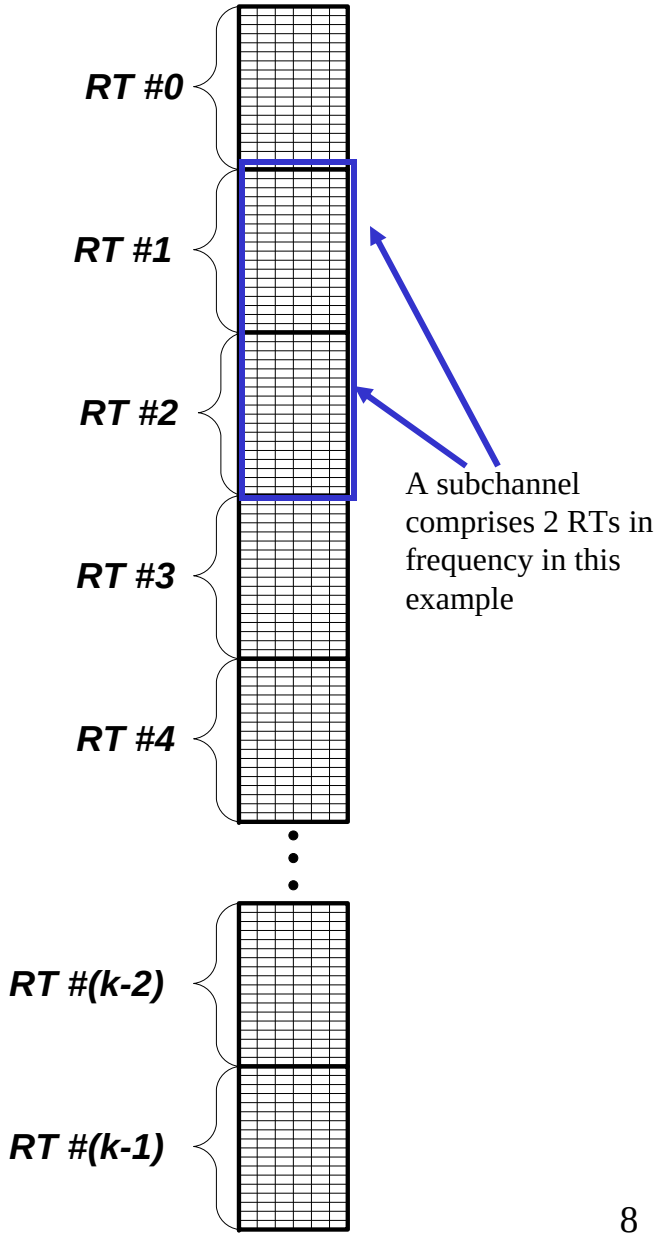
Proposed Resource Tile with Dedicated Pilots

- Supports arbitrary number of Tx antennas with up to 4 spatial streams
- Notation:
  - D=data symbol location
    - Spatial streams represent the third dimension in the diagram to the right
  - Pn=pilot transmitted by stream n.
    - Other spatial streams are null in those positions
    - When number of streams is n, then positions p_{n+1} to p_4 are replaced with data.
      - FEC rate matching is assumed
- Overhead:
  - Pilot overhead depends on the transmission rank:
    - 5.56% overhead for one data stream
    - 11.11% overhead for two data streams
    - 18.52% overhead for four data streams
  - Very small overhead for transmitting a single data stream (when using 4 or more Tx antennas) compared to broadcast pilots
- Channel Estimation:
  - Some simple channel estimators possible (e.g., MMSE, linear interpolation)
  - Rays up to 13.1 usec can be estimated using only a single OFDM symbol for streams 1 and 2 (higher when considering all pilots)
  - Pilots available at RT edges (for streams 1 and 2) to improve channel estimation performance
  - Streams 3 and 4 best used for lower speeds
    - If streams 3 and 4 have lowest modulation and coding rates, then higher speeds may be supported
    - RT designed assuming the transmission mode is most often 2 streams or less
  - Time interpolation/tracking possible for streams 1 and 2 (e.g., MMSE, linear interpolation)



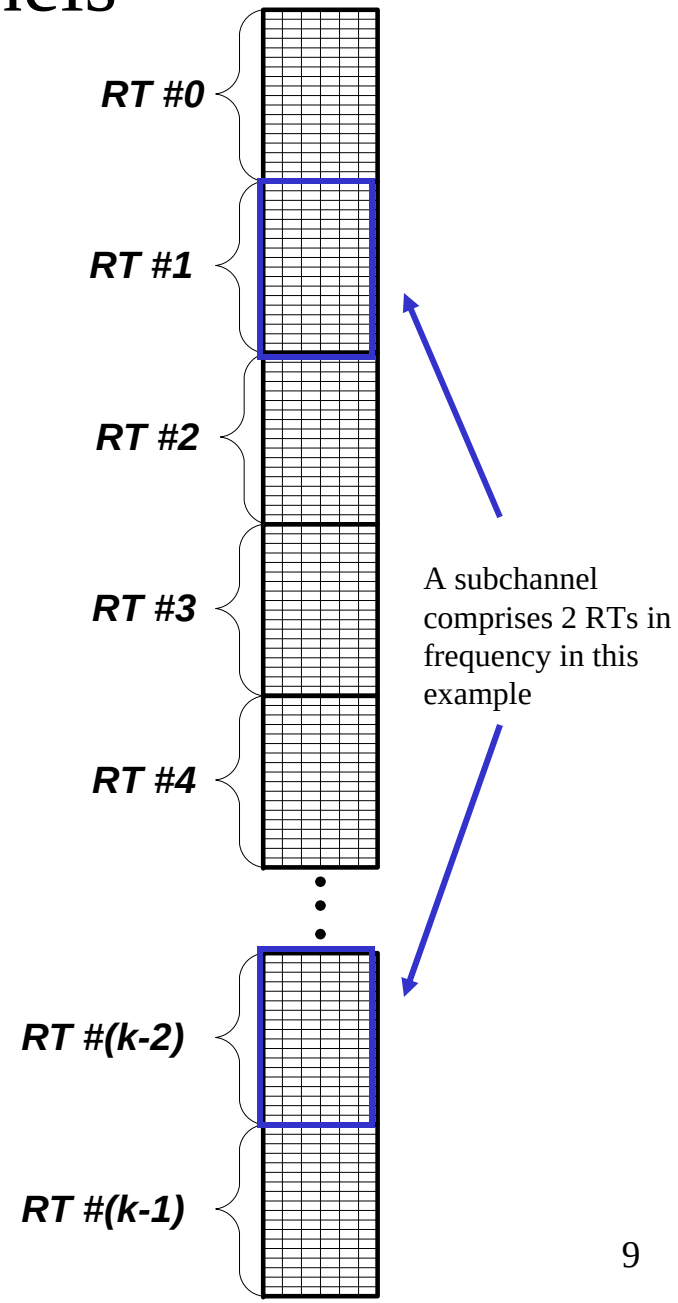
Narrowband Subchannels

- For frequency-selective scheduling and multi-user diversity
- Important for low velocity situations
- Resource blocks comprising a subchannel are adjacent / contiguous in frequency



Diversity Subchannels

- For frequency-non-selective scheduling
  - Important for high velocity situations
- Resource blocks comprising a subchannel are scattered throughout the frequency band (coded together)
- Clear matching of data with the dedicated pilots
  - Avoids the major group restriction in PUSC where all subchannels assigned to a major group had to be beamformed together, which constrained the scheduling of small packets to a single user



Additional Topic: MIMO Midamble

- Multi-antenna DL reference signal that enables the MS to determine the DL multi-antenna channel from the BS TX antennas
- Used for Precoding feedback, CQI & link adaptation, adaptation between MIMO modes, etc.
- Included as an option in 16e (up to 4TX).
- Need this capability in the 802.16m SDD for up to 8 TX

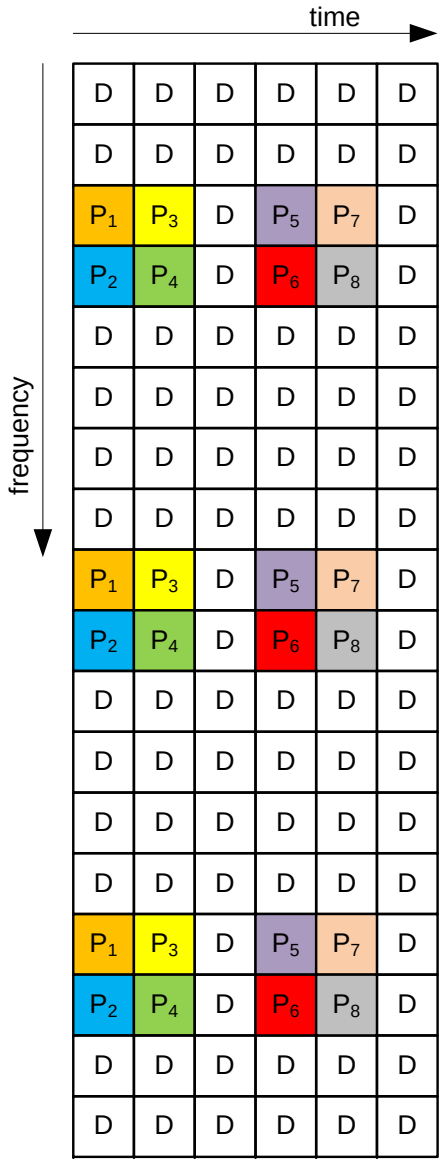
Performance Comparisons

- Downlink with 4 or 8 Tx antennas (l/2 spacing, vertical polarization) and 2 or 4 Rx antennas (l/2 spacing, cross polarized)
- Suburban macro channel w/TU power-delay profile, 3 kph
- Single RT data allocation
- MMSE channel estimation
  - Dedicated pilots: confined to RT
  - Broadcast pilots: over all RTs in frequency with interpolation across RTs in time
- Tx weights for UL sounding in TDD (one weight fixed over a RT):
  - Equal gain singular vectors for SU-MIMO (modulation and coding rate can be different on each stream), number of streams adapted to current channel
  - Regularized ZF for MU-MIMO
- Tx weights for codebook feedback in FDD or TDD (one weight per RT):
  - Equal gain for SU-MIMO (modulation and coding rate can be different on each stream), number of streams adapted to current channel
  - Weights calculated using subspace averaging (see Asilomar 2007 paper*)
- Rx weights for SU-MIMO: successive cancellation
- Rx weights for MU-MIMO: linear MMSE interference suppression
- 4 bit codebook for 4 Tx and 6 bit codebook for 8 Tx *
  - Midamble used for codebook selection for dedicated pilots
  - Broadcast pilots used for codebook selection for broadcast pilots
- UL sounding from all MS antennas simulated with channel estimation
  - Sounding matched to RT, 18dB DL-UL total power difference, power concentration on UL Sounding
- Codebooks chosen using channel estimates
- Codebook indices are fed back error free
- Ideal grouping for MU-MIMO: MSs separated by at least 15^{o} in angle and have selected different codebook entries.

*B. Mondal, et. al., “Rank-Independent Codebook Design from a Quaternary Alphabet,” Asilomar 2007.

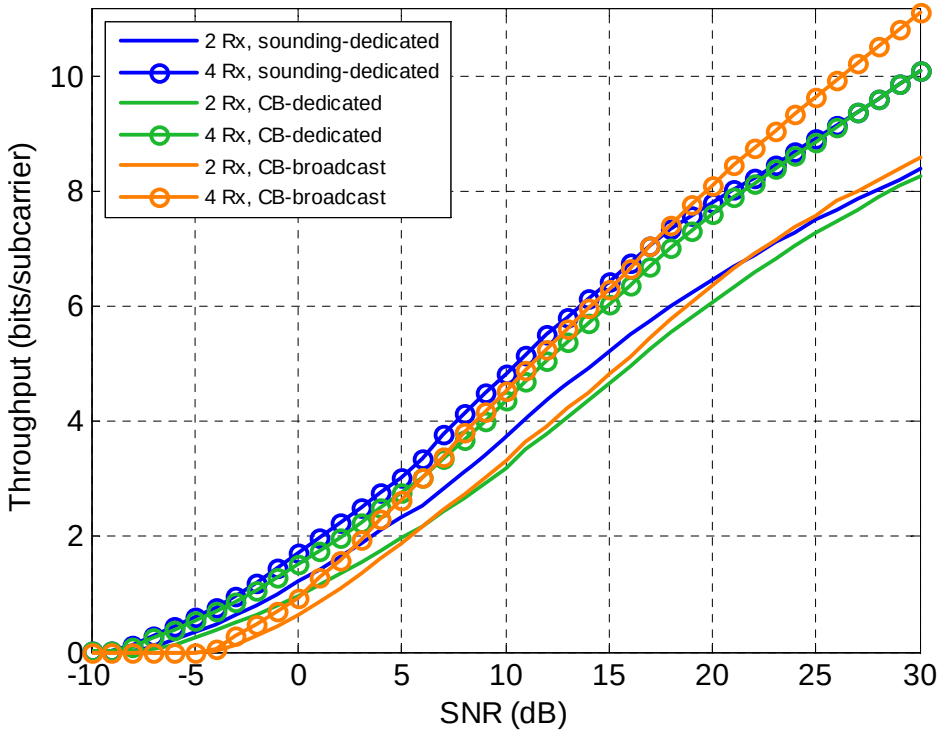
Broadcast Pilot Format Used in Simulations

- Notation:
  - D=data symbol location
  - Pn=pilot transmitted by antenna n
    - Other antennas are null in those positions
    - When number of antennas is n, then positions p_{n+1} to p_8 are replaced with data (FEC rate matching is assumed)
- Format only for comparison purposes to dedicated pilots
- Rays up to 15.2 usec can be estimated using only a single OFDM symbol
- Good time interpolation possible using adjacent resource tiles (RTs)
  - Right at the Nyquist rate (in time) for 350 kph at 2.5 GHz (hence gains available at lower speeds)
- <u>Pilot overhead depends on number of TX antennas:</u>
    - 11.11% overhead for 4 Tx antennas
    - 22.22% overhead for 8 Tx antennas
- Channel estimation in simulations:
  - Three RTs in time plus all RTs in frequency used for channel estimation
  - MMSE channel estimation in frequency followed by MMSE channel estimation in time

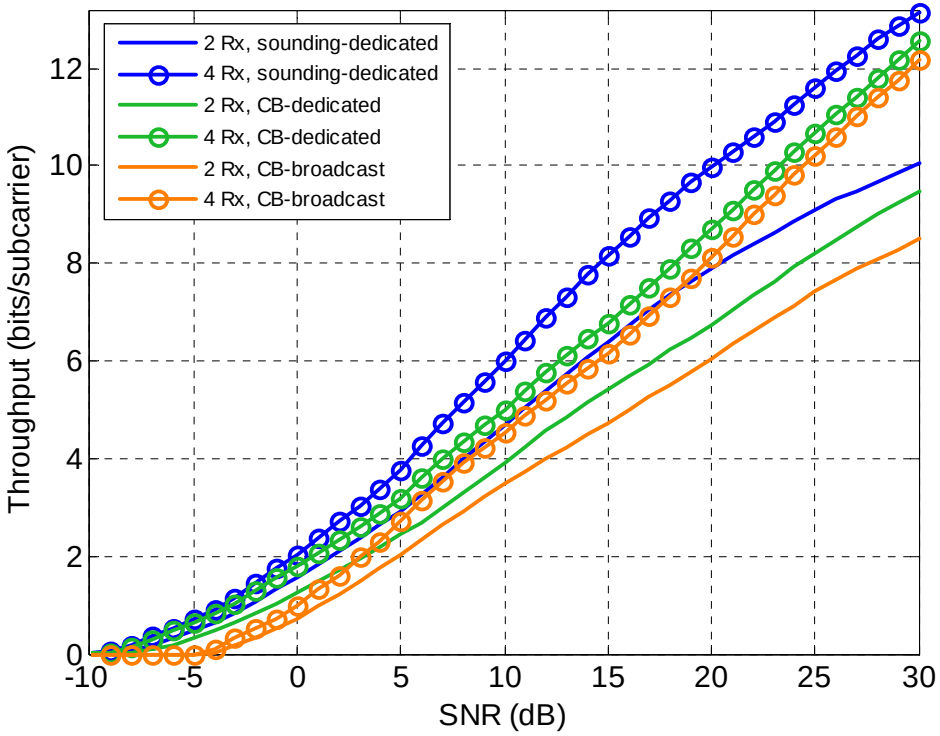


Performance Comparisons for SU-MIMO

4 Tx antennas



8 Tx antennas

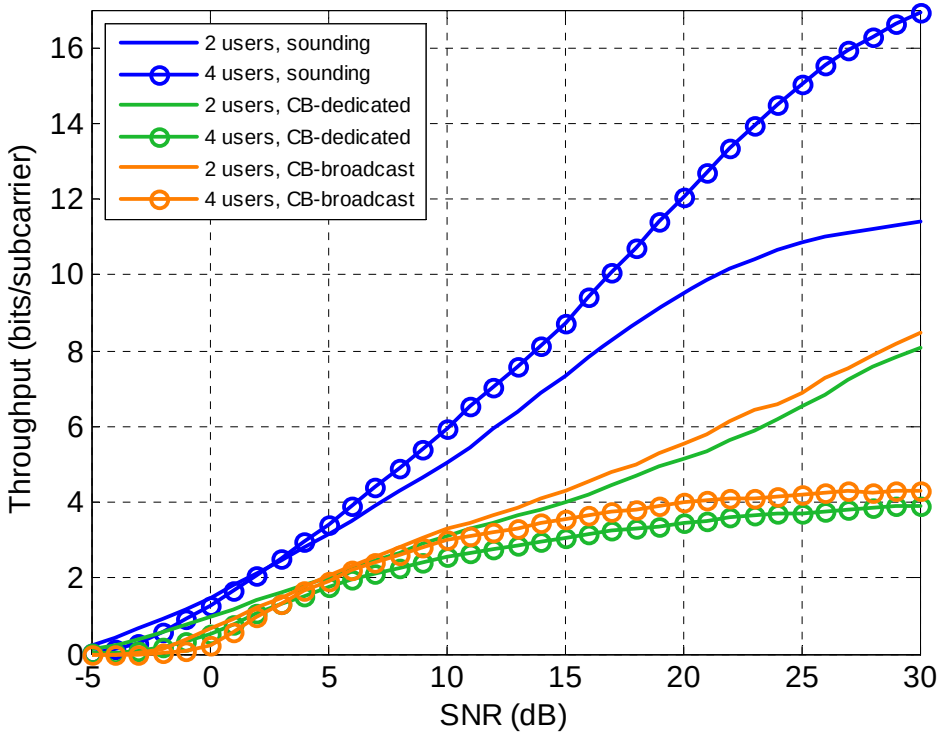


- Benefits seen by using dedicated pilots
  - Better performance at lower SNRs
  - Better performance for 8 Tx antennas

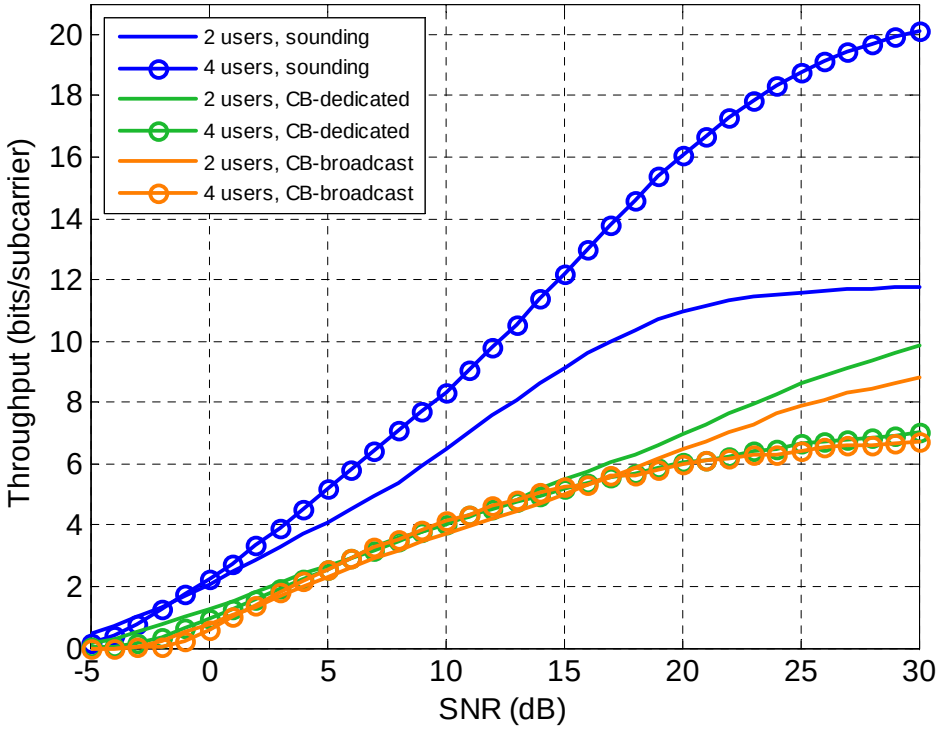
NOTE: pilot overhead is accounted for in the throughput results

Performance Comparisons for MU-MIMO

4 Tx, 2 Rx antennas



8 Tx, 2 Rx antennas



- For sounding (TDD), MU-MIMO provides large throughput gains over SU-MIMO in this channel (at SNRs>5 dB)
- UL Sounding (TDD) & dedicated pilots is better than codebook (CB) feedback for this scenario
- Dedicated pilots provide some advantage for CB with 8 Tx
  - For 4Tx, broadcast pilots are marginally better, but require feed-forward of interferers' codebook entries

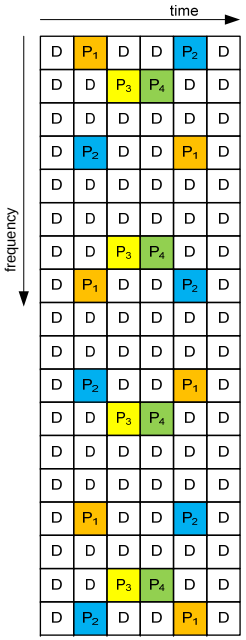
NOTE: pilot overhead is accounted for in the throughput results

Outline of Recommendations for the SDD

- Localized resource tile and subchannel configurations contained in this contribution
  - Resource tile layout for dedicated pilots
    - presented as a baseline for further study/comparison
  - Subchannel allocation modes: diversity & narrowband allocation modes
- Must include support for resource tiles having dedicated pilots for data allocations
- Should include support for resource tiles having broadcast pilots for data allocations
- Include support for a “MIMO Midamble” in the SDD to enable MIMO transmission
- Support for UL Channel Sounding
  - Must fully enable TDD reciprocity-based MU-MIMO
- Optimize MIMO transmission methods for TDD and FDD separately.
  - Best solution for TDD may be different from best solution for FDD

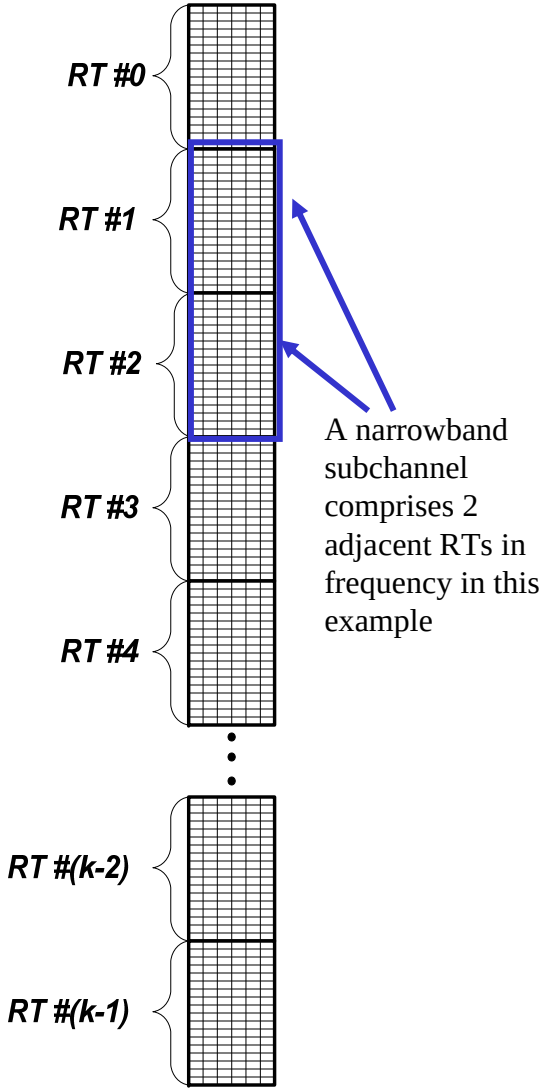
Specific Text Recommendations for SDD Section 11 – PHY Layer (1)

- Section 11.x: localized resource tile format for the downlink data channels
  - A localized resource tile (RT) format is supported with dedicated pilots for self-contained channel estimation. As shown in the figure, the basic RT is 18 subcarriers by 6 symbols and supports an arbitrary number of transmit antennas. The RT supports up to four spatial streams, where each spatial stream can be viewed as the third dimension (not shown) of the RT. In the figure, the symbols labeled "D" are data symbol locations where each spatial stream transmits a data symbol. The symbols labeled Pn are locations where stream n transmits a pilot symbol and all other streams transmit null symbols. Pilot locations for a stream that is not transmitted are replaced with data symbols D. In other words, if the number of transmitted streams is equal to m, then pilot locations Pm+1 through P4 are replaced with data symbols D. FEC rate matching is assumed throughout the RTs that make up a subchannel.
- Above text is proposed as a baseline for further study/comparisons

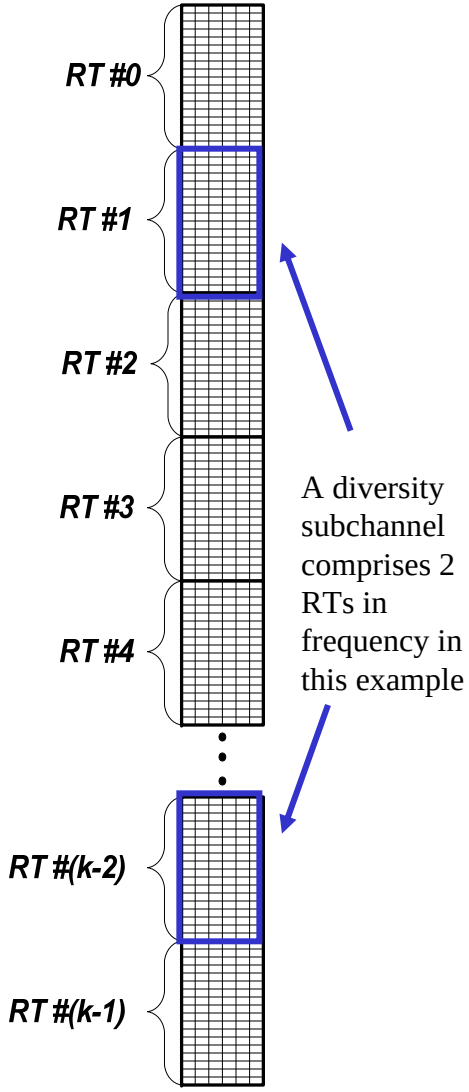


Specific Text Recommendations for SDD Section 11 – PHY Layer (2)

- Section 11.y: Grouping resource tiles into data subchannels
  - A subchannel comprises one or more resource tiles (RTs), where FEC is performed across the RTs that make up a subchannel. Two types of subchannels are defined. First, a narrowband subchannel comprises one to TBD RTs, where all RTs in the subchannel are adjacent in frequency. Second, a diversity subchannel comprises two to TBD RTs, where all RTs in the subchannel are separated in frequency in a manner that is TBD. FEC with rate matching is assumed across the RTs that make up a subchannel.



Narrowband Subchannel



Diversity Subchannel

Specific Text Recommendations for SDD Section 11 – PHY Layer (3)

- Section 11.d: Support for UL Sounding
  - The frame structure supports UL channel sounding for supporting beamforming, SU-MIMO, and MU-MIMO transmission on the DL.
- Section 11.e: Support for MIMO midamble
  - The frame structure supports the scheduling of a MIMO Midamble for sounding the multi-antenna downlink channel to enable SU-MIMO and MU-MIMO.
- Section 11.f: MIMO for TDD
- Section 11.g: MIMO for FDD