Proposal for IEEE 802.16m Uplink Pilot Structures

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Re: IEEE 802.16m-08/016r1 – Call for Contributions on Project 802.16m System Description Document (SDD), on the topic of "UL Pilot Structures"

Purpose: Adopt the proposal into the IEEE 802.16m System Description Document

Scope

- This contribution presents the IEEE 802.16m Uplink MIMO pilot design
  - Uplink pilot structure with boundary pilot design
  - Uplink pilot with adaptive density and allocation
  - Unified pilot structures for diversity and localized uplink channelization
  - Uplink control tile and pilot design

IEEE 802.16m System Requirements

- The TGm SRD (IEEE 802.16m-07/002r4) specifies the following requirements:
  - Section 5.7 Support of advanced antenna techniques:
    - "IEEE 802.16m shall support MIMO, beamforming operation or other advanced antenna techniques. IEEE 802.16m shall further support single-user and multi-user MIMO techniques."
  - Section 6.10 System overhead:
    - "Overhead, including overhead for control signaling as well as overhead related to bearer data transfer, for all applications shall be reduced as far as feasible without compromising overall performance and ensuring proper support of systems features."
  - Section 7.11 Relative Performance and Section 7.2.1 Relative sector throughput and VoIP capacity:
    - 2x performance gain over the legacy system is required
- The proposed pilot structure targets the above requirements by optimizing the pilot overhead for multi-antenna support

Background

- In the legacy 16e system, UL MIMO pilot allocation require large overhead (33% for PUSC, 11-22% for AMC).
- UL PUSC resource unit design is inefficient for both pilot and VoIP packet transmission
- As we consider a new frame structure for 802.16m, we should include a more optimum pilot design.
- With an optimal pilot design, reliable channel estimation should be achieved by using the minimum pilot overhead, under various channel conditions and mobility as required by 16m SRD and EVM:
  - Mobility: optimum performance for: 0-10 km/h; graceful degradation for: 10-120 km/h; connection maintained: 350 km/h
  - Baseline Channel models: ITU Pedestrian B, Vehicular A
- Uplink pilot design, as well as resource unit design, can be aligned with corresponding downlink designs (see C802.16m-08/172r1 and C802.16m-08/175r1)
  - Pilot design considerations are mostly shared by uplink and downlink
  - Uplink pilots are MS specific pilots, similar to downlink dedicated pilot, which can only be used within MS allocated resource blocks.
  - In uplink MU-MIMO scenario, pilots for several MS can multiplexed onto the same resource blocks

Uplink Pilot Design Consideration

- Should support MS at various speed and channel conditions
- Enable BS to use pilot tones from available resource for interpolation to enhance the link performance and reduce overall pilot overhead
- Resource block size should align with basic pilot sub-carrier spacing
  - This can reduce signaling overhead and implementation complexity
- To support application like VoIP, diversity transmission for a MS has relatively small resource granularity. Pilot density and resource block size should adapt to such situation

Overview of uplink pilot design (1/2)

- Roles of Uplink pilot in system design
  - UL channel estimation for coherent demodulation/detection of data at the BS
  - UL control signal detection and demodulation
    - Most UL control signals are detected coherently.
    - Some UL control signals, e.g. ACK , have option to detect non-coherently.

Overview of uplink pilot design (2/2)

- The following pilot designs, as described in C80216m-08_172r1, are also applied to uplink pilot.
  - Pilot spacing constraint validated for downlink pilot should also be applied to UL pilot design, considering channels in both uplink and downlink share the same long term statistic properties, e.g. coherent time and coherent bandwidth
    - Maximum frequency spacing of 12 subcarriers and maximum time spacing of 3 OFDM symbols can be applied to uplink
  - Scattered pilot design
  - Pilot design at resource boundaries
    - Uplink pilots are MS specific pilots, similar to downlink dedicated pilot, which can only be used within MS allocated resource blocks.
    - Channel estimation accuracy at resource boundaries plays important role in overall system performance.
    - Allocate pilots at resource boundaries can enhance link performance without dramatic increasing pilot overhead
  - Pilot design based on density and allocation adaptation is applied to uplink pilot structure
    - Unify the pilot structures for diversity and localized channelization

Pilot Design at Resource Boundaries: Considerations

- Pilot design at resource boundaries, as described in C802.16m-08_172r1, can also apply to uplink pilot. Considerations of this design for uplink pilot are highlighted as following.
  - Extrapolation degrades channel estimation quality, as compared to interpolation. Extrapolation should be prevented as much as possible while keeping similar pilot structure and channel estimation complexity
  - Extrapolation can be prevented or limited by allocating extra pilot sub-carriers at the resource boundaries in time and frequency
    - In order to co-exist with legacy TDD system, user usually is assigned to a resource within one subframe (or 6 OFDM symbols). Sub-carriers at the sub-frame boundary which need extrapolation in **time direction** for channel estimation take a large portion of the total resource and should be prevented.
    - UL Pilots are always allocated within certain resource blocks. extrapolation in **frequency direction** should also be prevented for sub-carriers located at frequency boundaries

Uplink pilot Design at Resource Boundaries: Solutions

- Similar to downlink pilot design in C80216m-08_172r1, solutions of uplink boundary pilot design for uplink pilot are highlighted as following.
  - Extrapolation can be prevented or limited by allocating extra pilot sub-carriers at resource boundaries in time and frequency
  - These boundary pilots keep the basic scattered pilot structure in order to allow BS has the same channel estimation algorithm
  - Overall increase in overhead due to these extra pilots is limited
  - Uplink pilots are not boosted, so the collision between pilots in different sectors is not worse than collision with data tones.
  - In general, a boundary pilot is allocated when extrapolation distance in frequency direction is more than half of the maximum pilot spacing in frequency. In current design, boundary pilot is allocated when extrapolation distance is more than 6 sub-carriers.

Resource Block (RB) and Basic Channel Unit (BCU)

- Resource block (RB) and Basic channel unit (BCU) have the same design for both downlink and uplink. Additional design information can be found in C80216m-08/350.
  - The design is applied to non-legacy support or TDM legacy sub-frame support
  - RB size of 12 sub-carriers x 6 symbols is recommended. RB is used for VoIP(or small) packet transmission.
  - BCU consist of 3 RBs is recommended. BCU is used for data (or large) packet
- For uplink resource, several additional resource units size is defined
    - FDM legacy support
      - Mini-RB: 4x6 (4 sub-carriers by 6 OFDM symbols) is defined to align with legacy PUSC resource allocation
    - Control tile
      - ACK channel, smaller tile is needed to accommodate
        - Non-coherent detection is preferred for ACK channel, no pilots are allocated
        - Coherent detection is optional
      - Dedicated control signal (CQI, PMI, rank, bandwidth request) are code together and fit into smaller tiles
        - Coherent detection is used
        - 4x6, or 6x6 tile size is recommended.

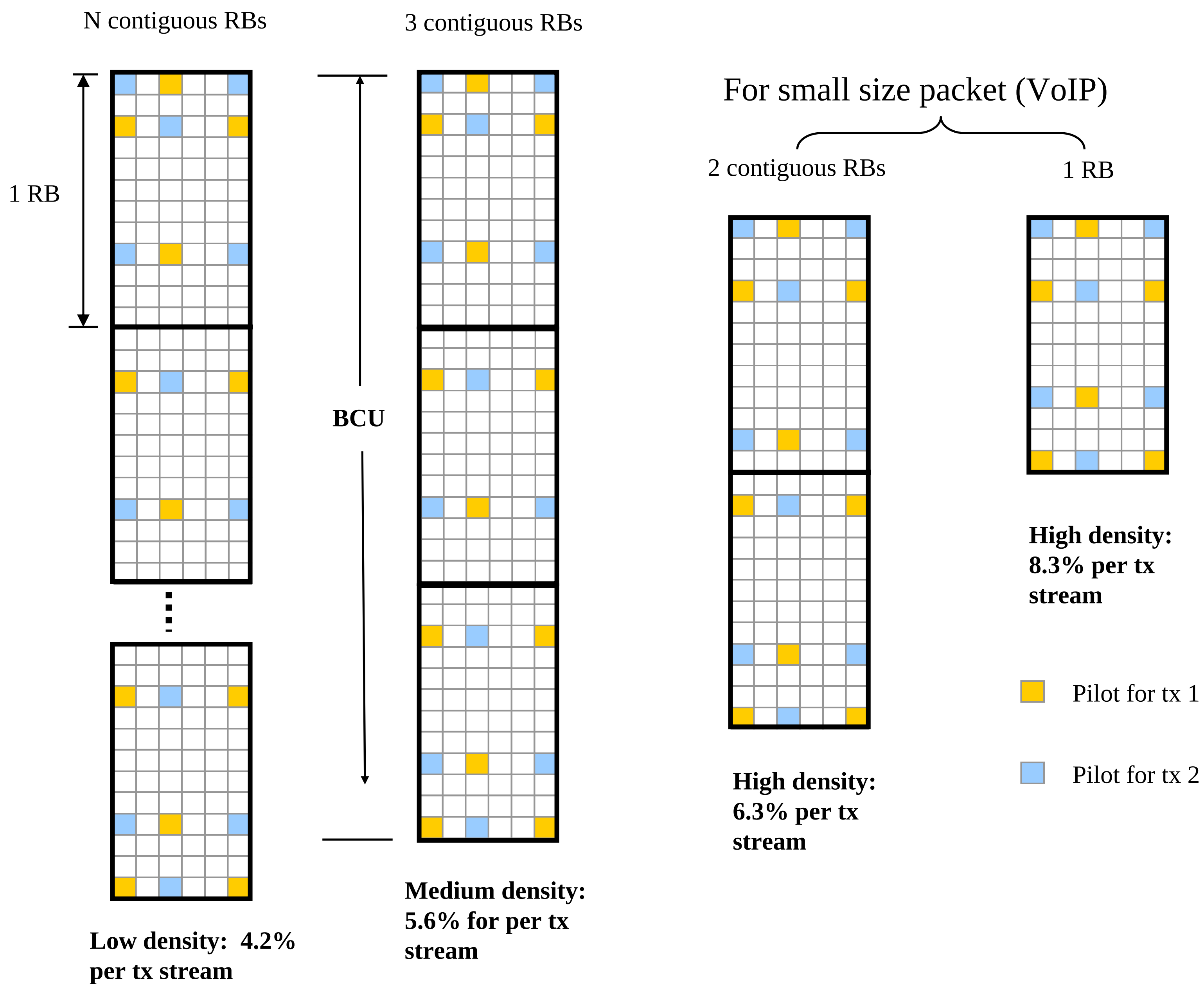
Uplink Pilot design based on adaptive density and allocation (1/2)

- **General design of pilot based on adaptive density and allocation is described in C80216m-08_172r1. The following states how this design applies to uplink pilot.**
- **There are three types of pilots according to their density**
  - **Low density pilot pattern** (3.1% < density < 5.3% per Tx). This is realized in this proposal by uplink pilot (with boundary) for more than one contiguous BCU or more than 3 contiguous RBs, or for extended subframe
  - **Medium density pilot pattern** (density ~5.6% for 1 Tx). This is realized in this proposal by uplink pilot for one BCU or around 3 contiguous RBs
  - **High density pilot pattern** (6.3% < density < 8.3%). This is realized in this proposal by uplink pilot for less than 3 RBs. It is mainly used for VoIP transmission.
- **Pilot density adapts to the size of contiguous resource in time and frequency where pilots are allocated.**
  - Contiguous resource size is scheduled in each uplink sub-frame or extended sub-frame according to overall system optimization.
  - With boundary pilot design in uplink pilot structures, pilot density changes according to contiguous resource size in order to enable BS to have optimal pilot aided channel estimation under the uniformly designed pilot structure, while minimizing overall pilot overhead.

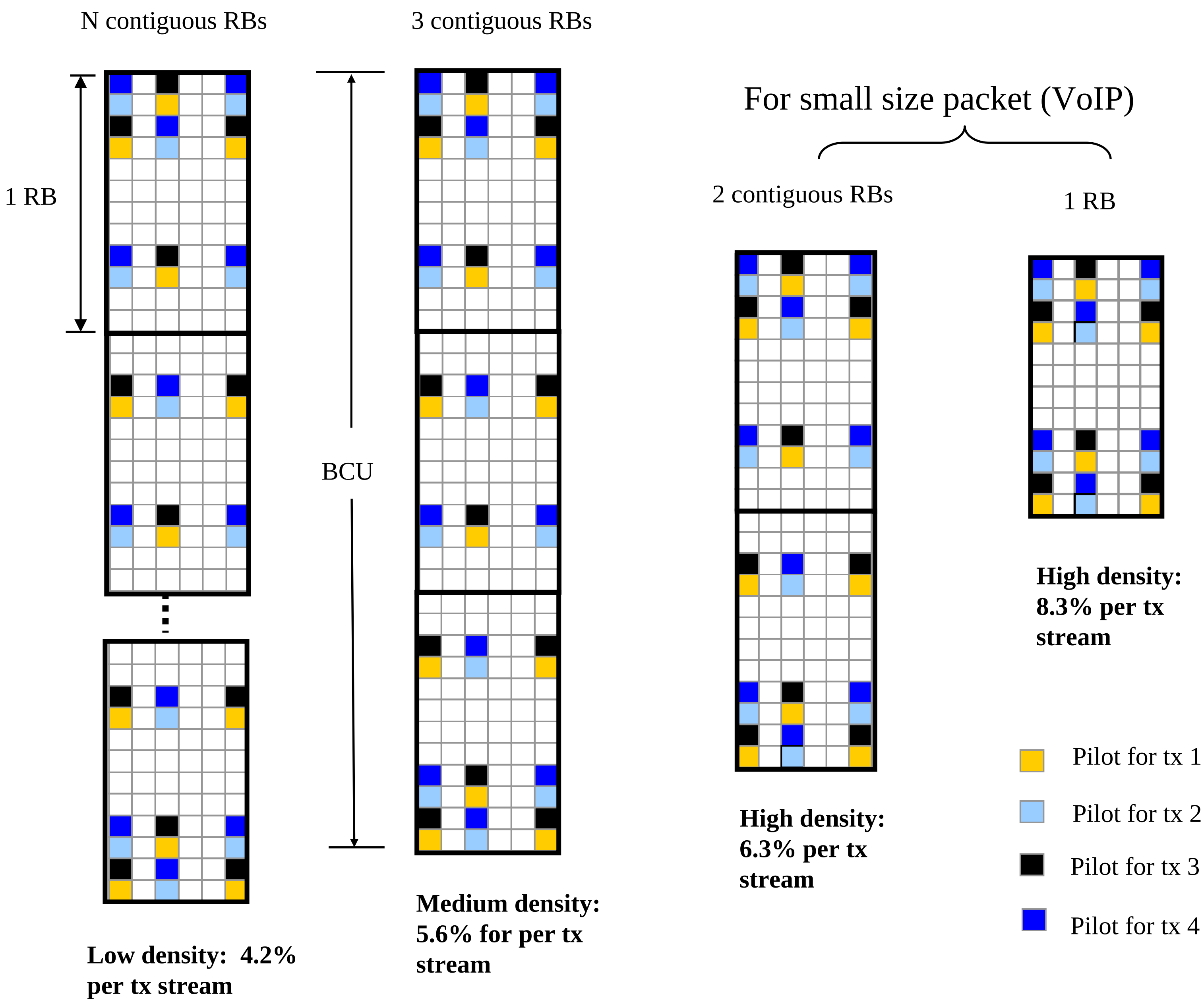
Uplink Pilot design based on adaptive density and allocation (2/2)

- **Uplink pilot design for diversity zone and localized zone can be unified by designing pilot structure based on adaptive density and allocation.**
- **Step 1: Generate pilot structures for different number of contiguous RBs with different density**
  - **Option 1: Extend single RB pilot structure with high pilot density to multiple RB pilot structure with low pilot density**
    - Design pilot structure for one RB with proper boundary pilots allocated. This is the highest pilot density design
    - Extend one RB design to two RB pilot structure
      - Concatenate two one RB pilot structure, either in frequency or in time
      - elimination redundant pilots near the boundary two RBs
      - Adjust pilot spacings in frequency and/or in time to make pilots spreading uniformly
    - Follow the similar procedure as above to extend pilot structure to multiple RBs
      - Pilot density will change from high to low gradually
    - The pilot spacing in frequency and time should be not larger than a pre–designed maximum values
  - **Option 2: Start with multiple RB pilot structure with low pilot density, and generate single RB pilot structure with high pilot density**
    - Pilots are uniformly allocated uniformly in frequency and time with maximum pilot spacing in frequency and time to N RBs (usually N > 3)
      - Boundary pilots are allocated in time and frequency and time boundary accordingly to minimize the extrapolation
    - Reduce pilot structure to N-1 RBs by keeping the boundary pilots.
      - Pilot spacing is adjusted so as to make pilot spread out as uniform as possible.
      - Pilot density will change from low to high gradually
    - Continue the similar procedure to until one RB pilot structure is generated
- **Step 2: According to the size of contiguous resource and MIMO mode, the matching pilot structure and type are chosen**
  - **For localized zone or diversity zone, matching pilot structure should fit into allocated resource for MS**

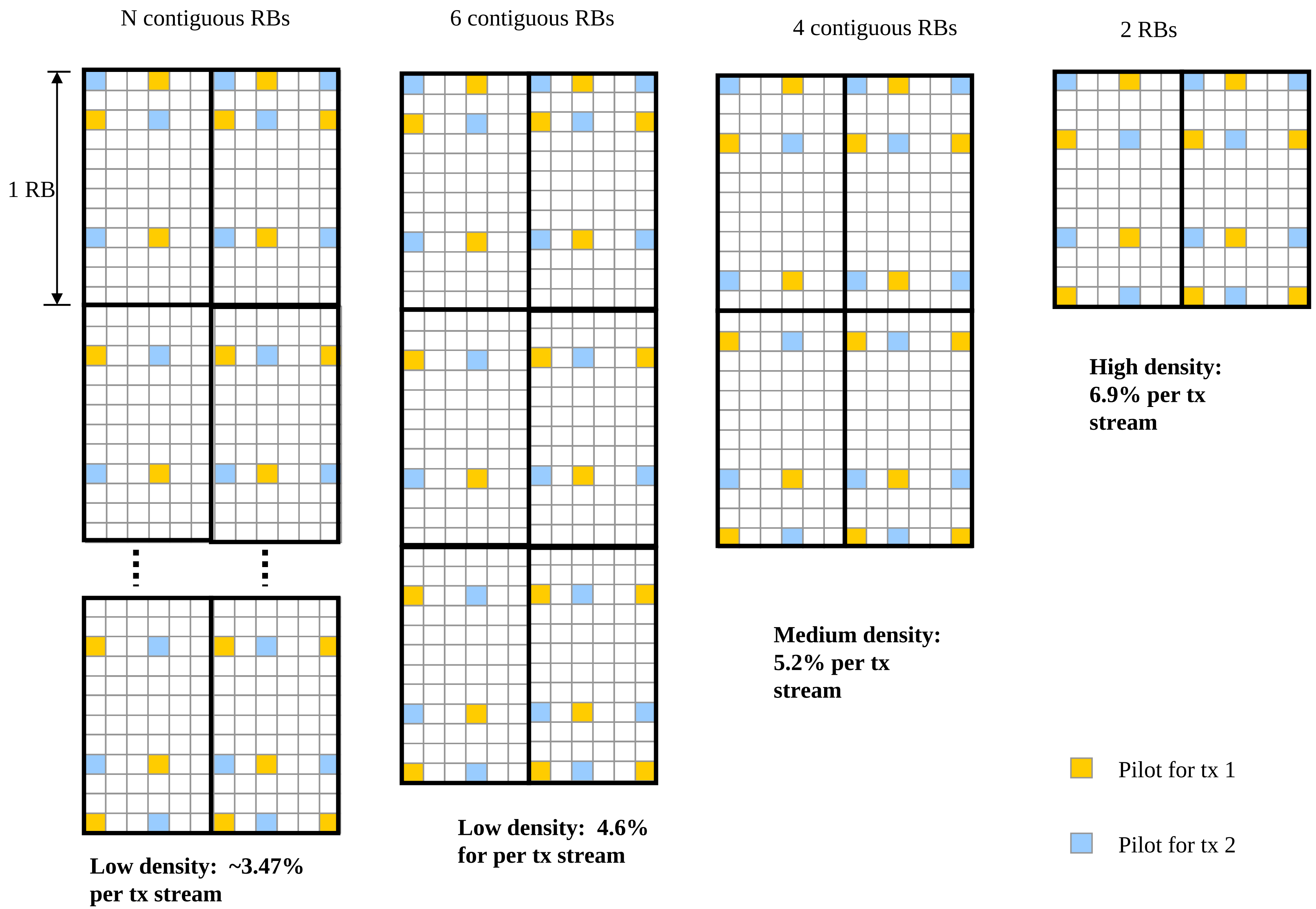
Different Pilot Density based on No. of Contiguous RBs (2Tx)



Different Pilot Density based on No. of Contiguous RBs (4Tx)



Different Pilot Density for Extended Sub-frame (example shown for 2 Tx)

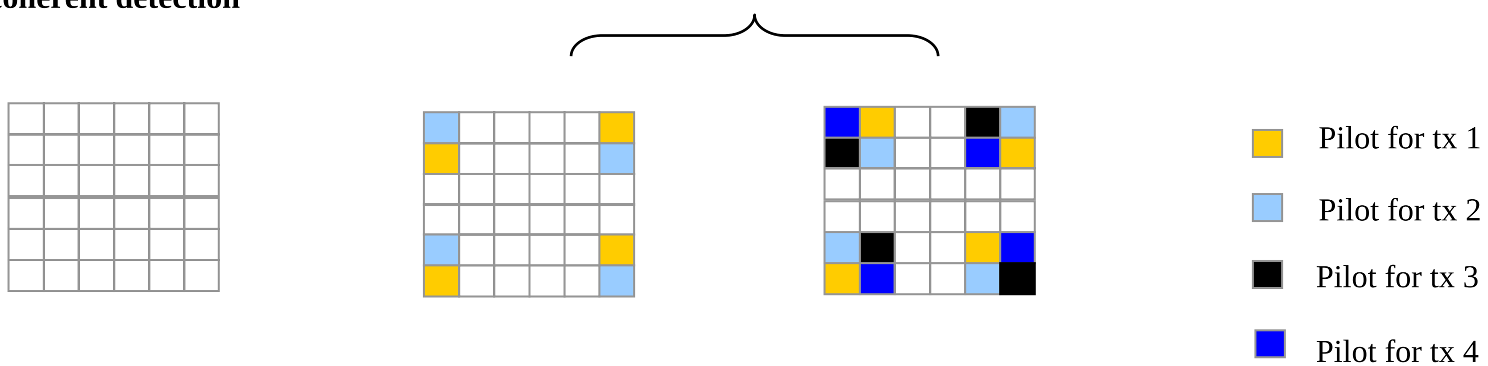


Uplink control resource unit and pilot design

- Considerations on control resource and pilot design
  - Control signal packet is usually small
  - Control signal need be transmitted with more reliability
    - Diversity transmission is applied
  - Control signal need be detected coherently or non-coherently
- Control resource unit is defined as min-RB which can be 4 subcarriers by 6 OFDM symbols. Other sizes is FFS.

Mini-RB for control signal non-coherent detection

Mini-RB for control signal coherent detection



11% per Tx stream

11.1% per Tx stream

Conclusions

- General uplink pilot design principles are described
  - boundary pilot design
  - adaptive density and allocation
- Unified pilot structures for diversity and localized uplink channelization are presented
- Uplink control tile and pilot design are presented

Text Recommendations for SDD
Section 11 Physical Layer

- Section 11.x UL Pilot structure
  - Scattered pilot structure is used in both common and dedicated pilot design
  - Pilot design with adaptive density and allocation
  - Unified pilot structures for diversity and localized uplink channelization
  - Control tile definition and pilot allocation