Proposal for IEEE 802.16m Downlink Pilot Structure for MIMO

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Re: IEEE 802.16m-08/005 – Call for Contributions on Project 802.16m System Description Document (SDD), on the topic of "Pilot structures as relevant to downlink MIMO" and "Downlink Physical Resource Allocation Unit (Resource blocks and Symbol Structures) "

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

Scope

- This contribution presents the IEEE 802.16m downlink MIMO pilot design
  - DL basic MIMO pilot design
  - DL pilot design at resource boundaries
  - Unified common and dedicated pilot design with adaptive density and allocation

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 thorougput 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, DL MIMO pilots are allocated in every OFDM symbol which require large overhead (10-20% for FUSC, 14-28% for PUSC, 11-22% for AMC).
- Other systems, such as LTE and UMB, have adopted more efficient scattered pilot design, which reduces pilot overhead while having the same or better performance.
  - Common pilot overhead: LTE: 4.8% for 1 Tx, 14.4% for 4 Tx, UMB: 3.1% for 1 Tx, 12.5% for 4 Tx
  - In both system, pilot overhead can be further decreased and still meet the requirement target
- As we consider a new frame structure for 802.16m, we should include a more optimum 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

Factors to Consider for Pilot Design

- Pilot overhead
- Channel estimation quality for control channel and traffic burst
- Support of various channel conditions and multi-antenna solutions
- Support of CQI and MIMO channel measurement

Overview of Downlink Pilot Design(1/2)

- Both common pilot and dedicated pilot are proposed for IEEE 802.16m
- Roles of DL common pilot
  - Common pilots are pilots that are not precoded or beamformed with the data tones
  - It is used for 1) broadcast/multicast control channel and message demodulation, 2) non-precoded data demodulation, 3) precoded data demodulation with explicit precoder information included in control signaling, 4) CQI and MIMO channel measurement
  - Channel estimation using common pilots does not need to be confined within a resource block(s) where the traffic burst is assigned. Therefore, the channel estimation performance can be improved with lower pilot density compared to dedicated pilot.
  - We target the common pilot design to support up to 4 MIMO streams
- Roles of DL dedicated pilot
  - Dedicated pilots are pilots that are precoded or beamformed with the data tones
  - It is used for precoded data demodulation when explicit precoder information is not included in control signaling. It can also be used for demodulation of unicast control channel that are precoded together with data.
  - Dedicated pilots typically require higher pilot density within a resource block as channel estimation is confined within one or more RBs assigned to a MS.
  - The advantage of dedicated pilot is that it can support high number of physical transmit antennas
  - We target the dedicated pilot design to support up to 4 MIMO streams

Overview of Downlink Pilot Design (2/2)

- Scattered pilot design, as adopted in LTE and UMB, is proved to be a good design for optimal trade-off between channel estimation performance and overhead
  - Allows 2-dimensional channel interpolation.
  - Support a wide range of mobility scenarios: low or high mobile speed; and small or large channel delay spread.
  - Same pilot pattern can be used for single antenna port or multiple antenna ports.
  - Same pilot design can be used for TDD and FDD, single carrier operation and multi-carrier operation.
  - MS design can be simplified with the above advantages
  - Allows orthogonal pilot planning among sectors
  - Other design approach, such as TDM, FDM or CDM, has its own advantages at certain conditions but can't meet overall design requirements
- Pilot design at resource boundary
  - Depending on factors such as the partition ratio between legacy and 16m system, and the DL to UL ratios, there may only be a small number of 16m DL subframes in each frame
  - Channel estimation accuracy at sub-frame boundary plays more important role in overall system performance.
  - Common pilots at frequency resource boundaries make pilot structure more robust to various channel conditions

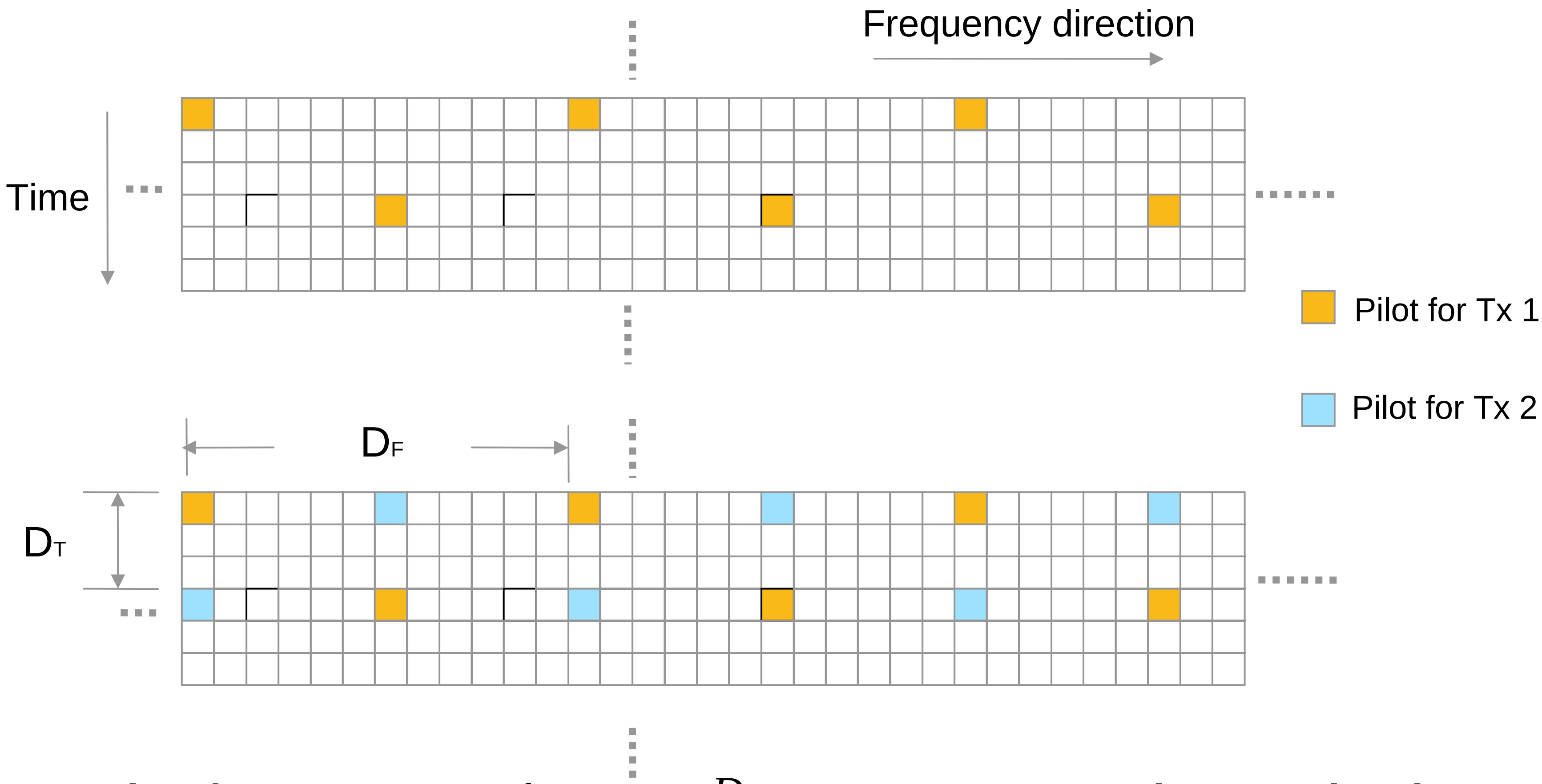
Downlink Pilot Design Consideration

- Should support MS at various speed and channel conditions
- Enable MS 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
- Diversity transmission for a MS has relatively small resource granularity to support application like VoIP. Therefore, a low pilot density is desirable.

Legacy System Pilot Structure

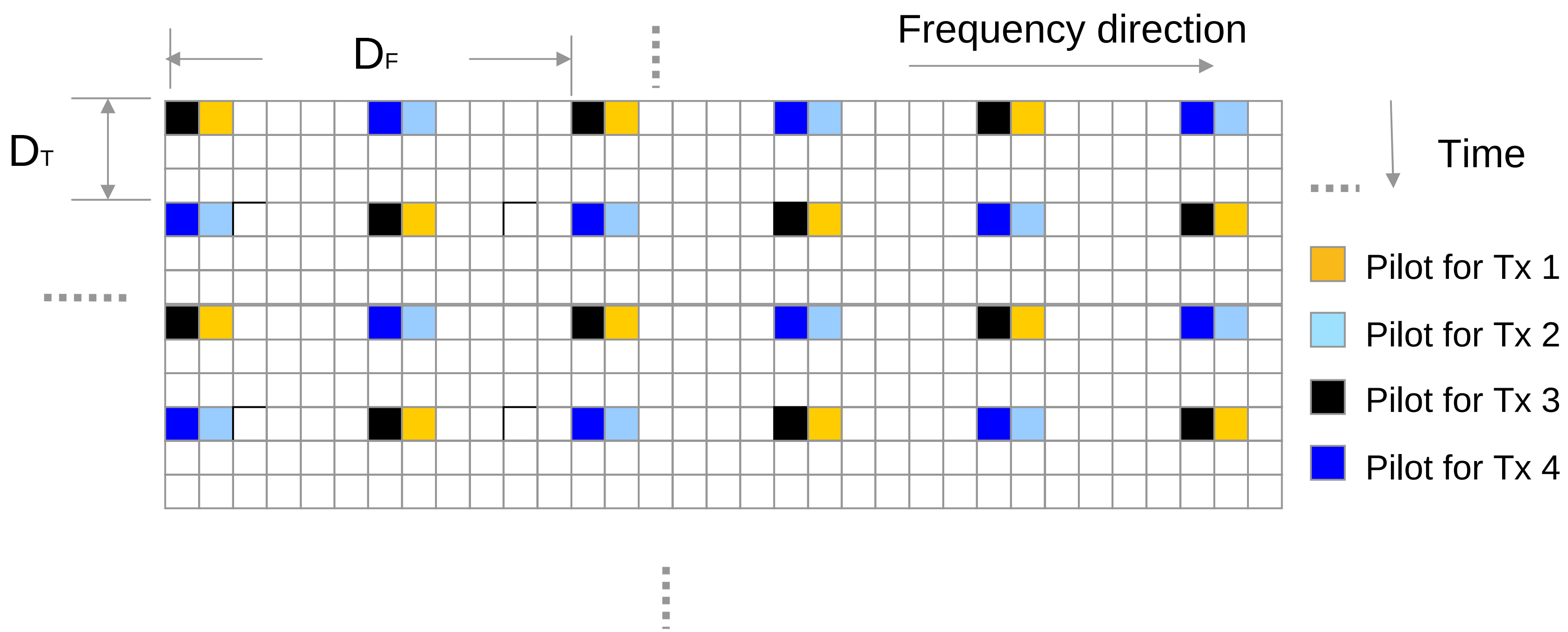
- Legacy pilot structures of PUSC and AMC which are designed for both common and dedicated pilots have the following features:
  - Both of them has pilots allocated to every OFDM symbol for 1 Tx, or every other OFDM symbol for 2/4 Tx.
    - Even at very high speed, pilot allocated to every OFDM symbol is not a efficient way of pilot design
  - Pilot spacing in frequency direction has several settings
    - 12, 10, 4 and 2 in PUSC for 1 Tx, 14 for 2/4 Tx
    - 9 in AMC for 1-4 Tx
    - Uniform pilot spacing design with proper spacing should be more efficient
  - Overhead is 14 (1/2 Tx) and 28% (4 Tx) for PUSC, 11 (1/2 Tx) and 22% (4 Tx) for AMC
    - High pilot density may offer high channel estimation quality
    - Overall throughput may be degraded with reduced available sub-carriers for data traffic.
- Pilot efficiency can be improved by re-design pilot structure
  - Adjusting pilot spacing both in time and frequency to meet current design requirements
  - Unify the pilot structures for common and dedicated pilot
  - Align resource block size with pilot spacing/structure

802.16m Basic Pilot Structure for 1 and 2 Tx Streams



- Pilot sub-carrier spacing in frequency D_F = 6, 8, 10, 12, 14, 16 and 18 are evaluated
- Pilot symbol spacing in time D_T = 3 is designed for supporting mobile speed up to 350km/h
- Pilot overhead for (D_F, D_T) = (12, 3) is 2.78% for 1 Tx, 5.56% for 2 Tx

802.16m Basic Pilot Structure for 4 Tx Streams

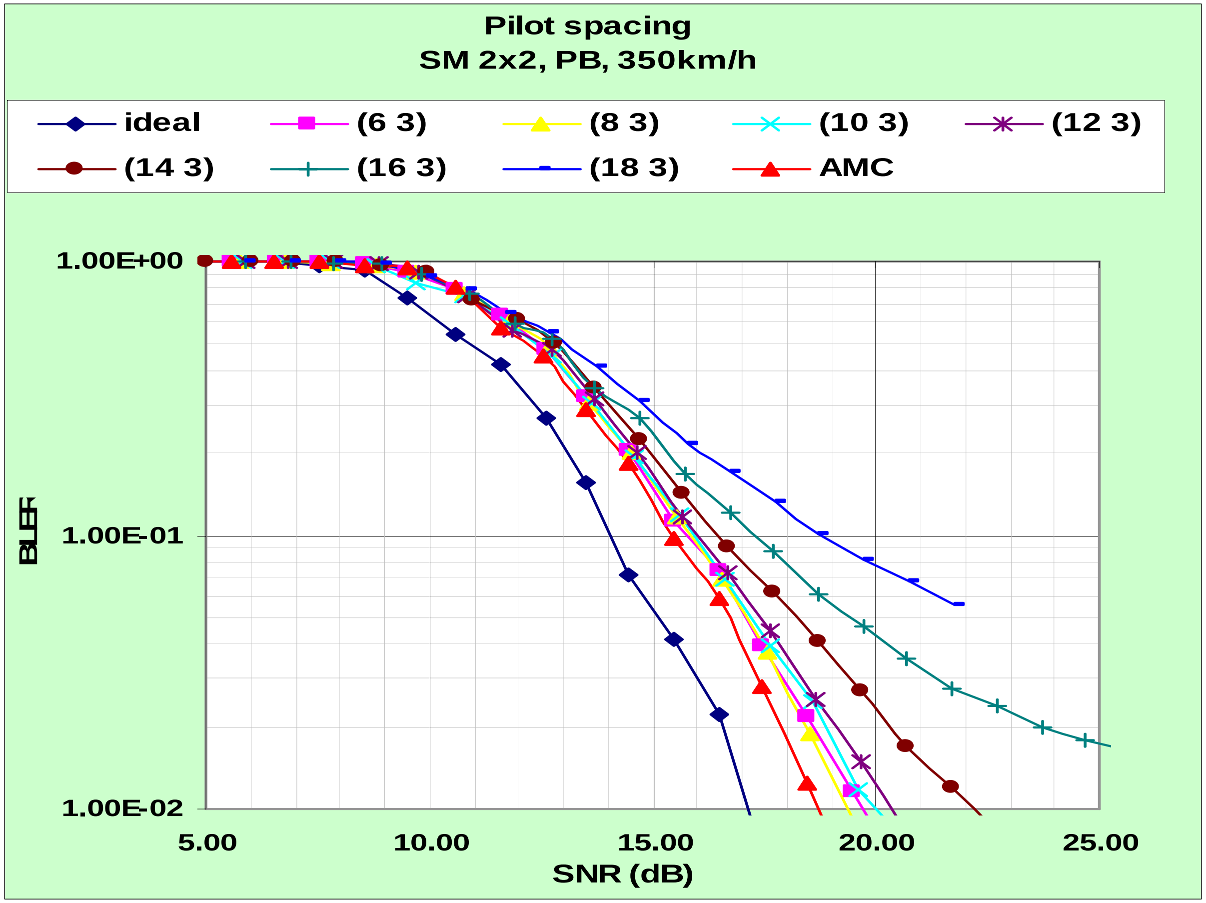


- Pilot overhead for $(D_F^{(1,2)}, D_T^{(1,2)}, D_F^{(3,4)}, D_T^{(3,4)})$ = (12, 3, 12, 3) is 11.1%
- All 4 Tx streams have the same pattern
- Support mobile speed up to 350km/h for 4 Tx streams

Performance Evaluation of Basic Pilot Structure

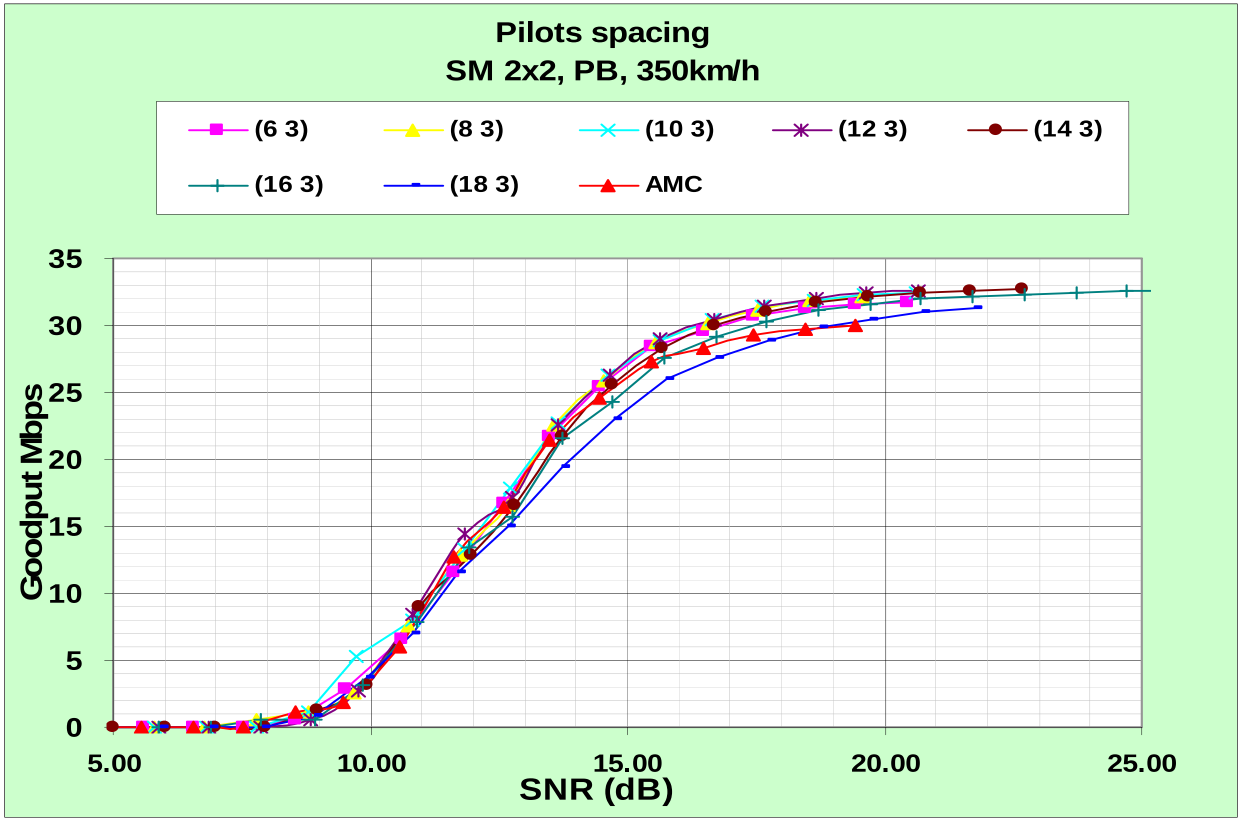
- Purpose of evaluation
  - Determine pilot spacing for basic pilots
    - Meet performance target at various conditions with the lowest overhead
- Simulation conditions
  - Carrier frequency = 2.5GHz, 10MHz bandwidth
  - 1024 FFT size
  - 864 useful subcarriers (excluding DC tone)
  - Pilot power boost level: 3dB above data tone such that total pilot symbol power is kept the same as non-pilot symbol.
  - Channel models: PB and VA, up to 350km/h
  - Channel coding: convolutional turbo code
  - MIMO configurations: SM 2x2, Double STTD 4x2
  - Receiver type: MMSE
  - MCS: QAM-16 R=1/2, block size = 60 bytes

Evaluation Results for Pilot Spacing (1/4)



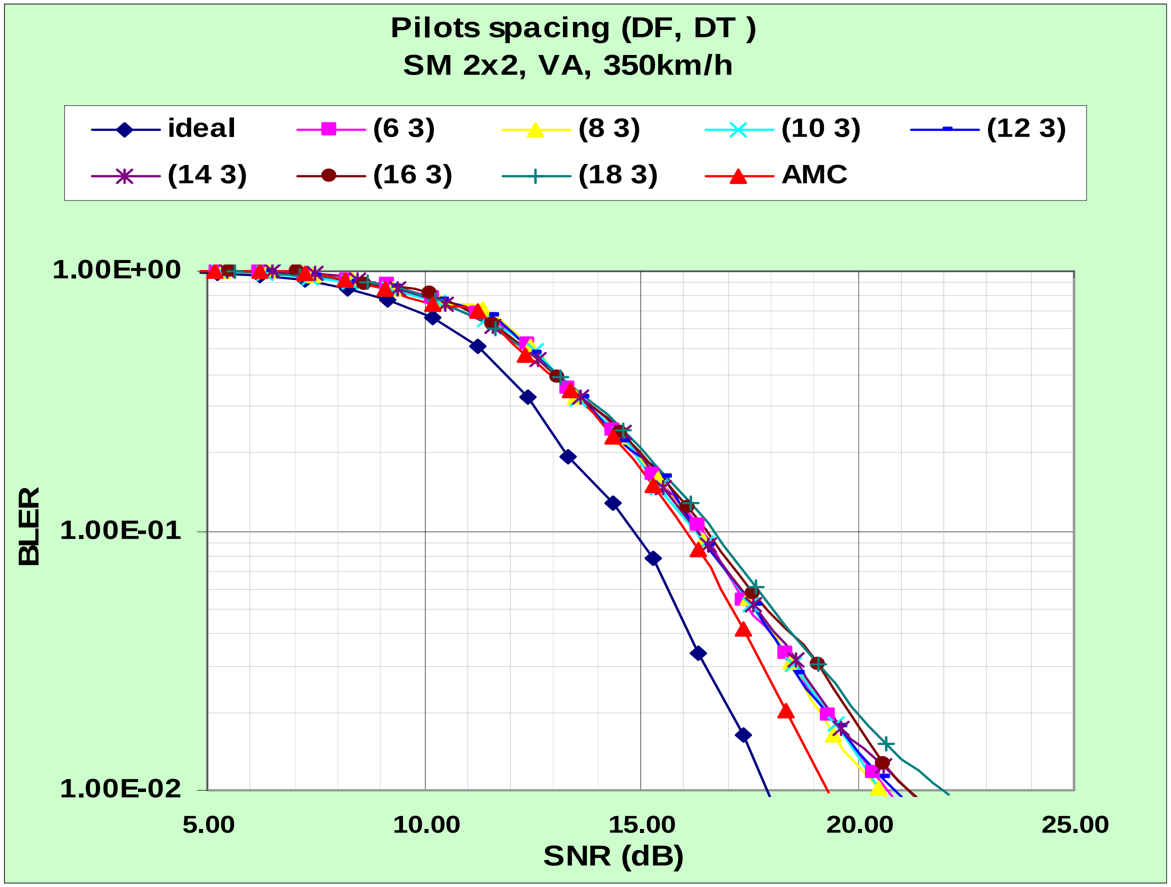
- BLER performances difference for DF= 6 to 12 are within 0.8dB, and becomes >3dB for DF ⩾14
- AMC has the best BLER performance
- Overhead is not taken into account in BLER performance

Evaluation Results for Pilot Spacing (2/4)



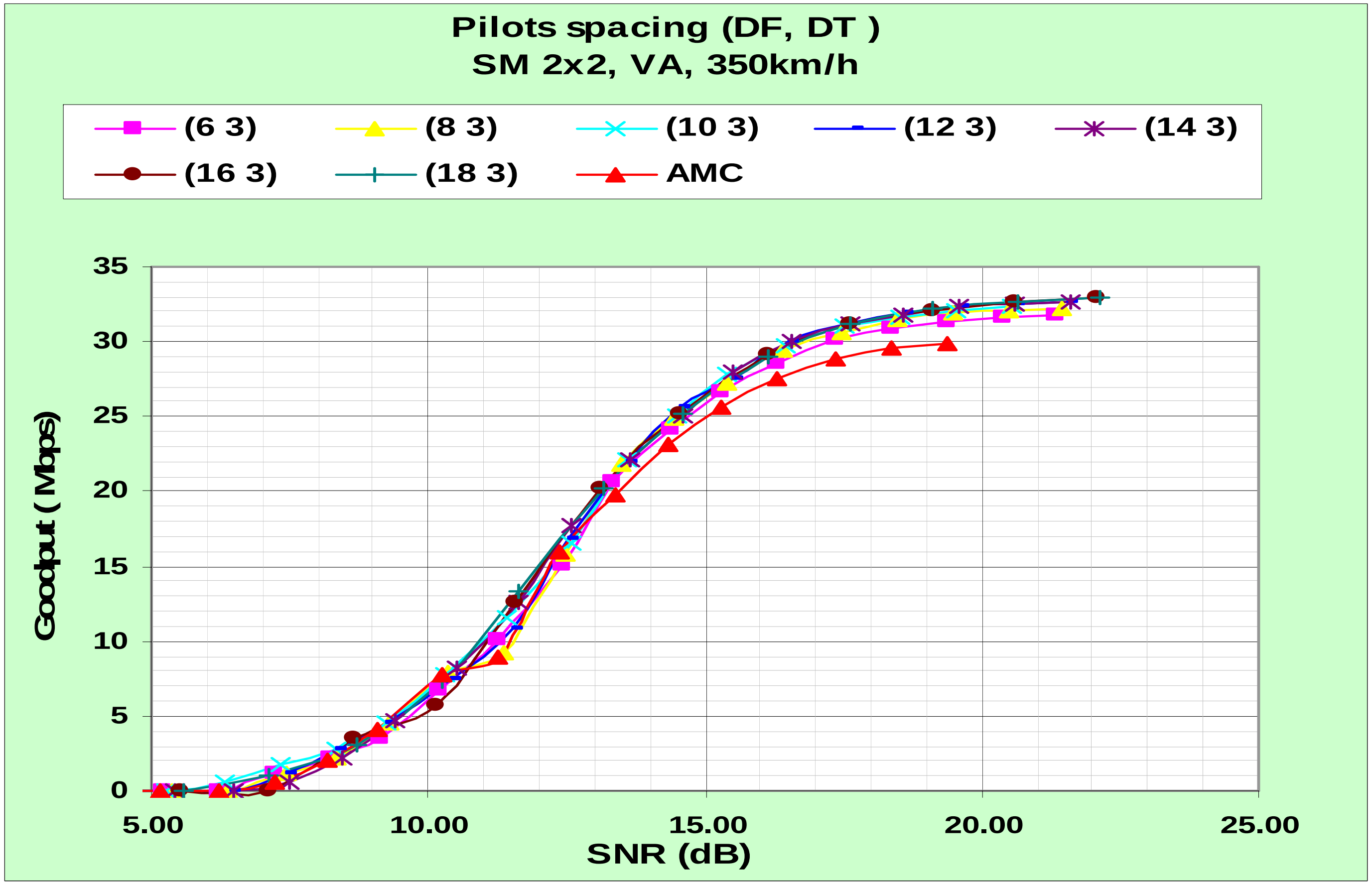
- Goodput = Max Data Rate * (1 – BLER); Max Data Rate = Max # of Info bits in one sub-frame / time duration of a sub-frame.
- Goodput of AMC underperforms to most other cases because of its higher pilot overhead
- Pilot spacing of (D_F D_T) = (12, 3) is the overall best.

Evaluation results for Pilot Spacing (3/4)



- Since VA channel has smaller delay spread, BLER is not very sensitive to D_F between 6 and 14.
- Degradation becomes observable when $D_F \geqslant 16$.

Evaluation Results for Pilot Spacing (4/4)



- Since VA channel has smaller delay spread, BLER is not very sensitive to D_F between 6 and 14.
- Goodput of AMC underperforms to all other cases because of its higher pilot overhead

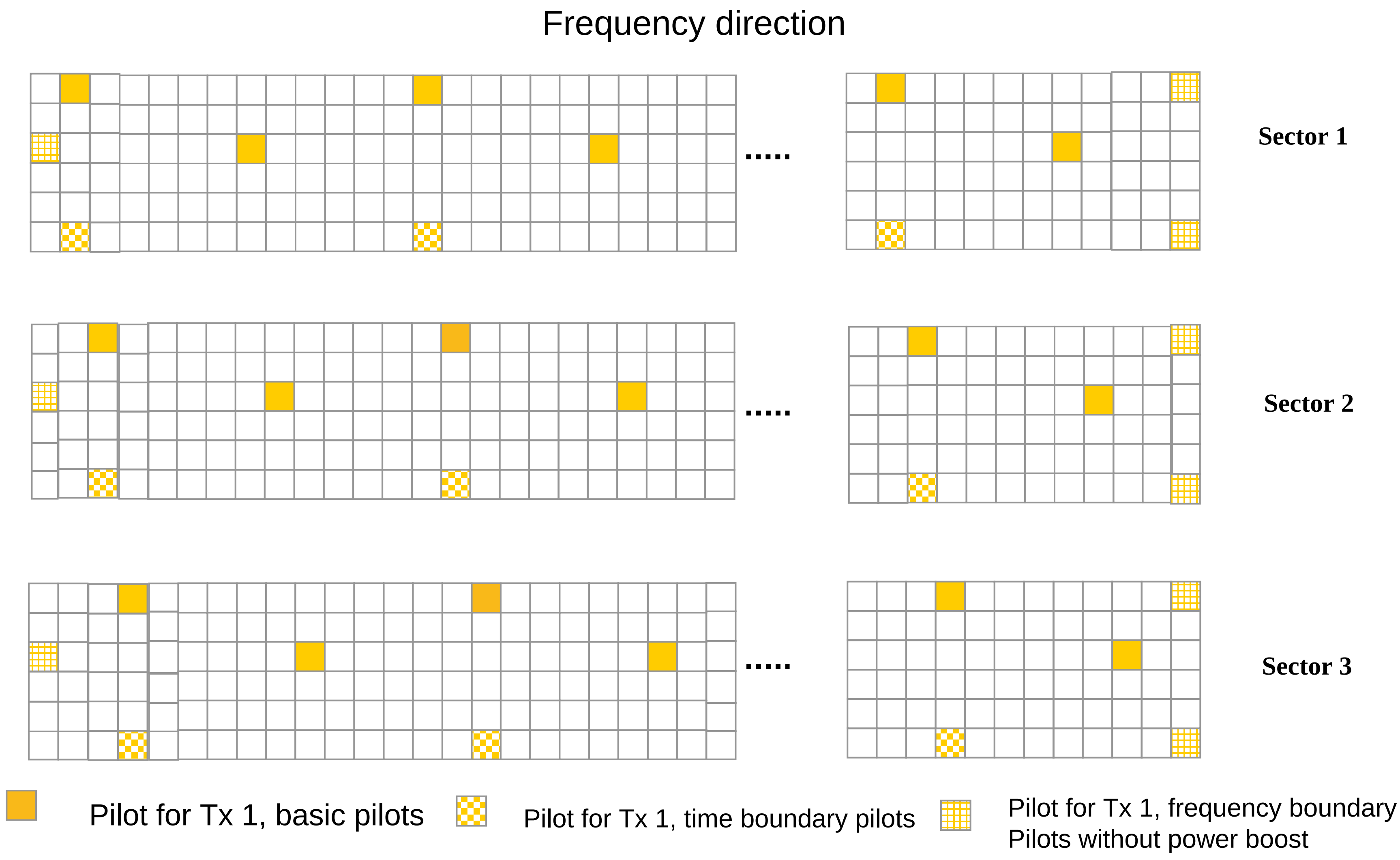
Pilot Design at Resource Boundaries: Considerations

- It is well known that extrapolation degrades channel estimation quality, as compared to interpolation
  - For pilot design with reduced overhead, extrapolation is inevitable
  - Extrapolation usually happens at sub-frame and resource boundary
  - In some cases, the percentage of boundary subcarriers may not be small, so the overall system performance may become much worse with extrapolation
  - Extrapolation should be prevented as much as possible while keeping similar pilot structure and channel estimation complexity
- In order to co-exist with legacy TDD system, the number of consecutive DL 16m sub-frames can be as low as one (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
  - Extrapolation in time direction should be prevented for sub-carriers located at sub-frame boundary
- Pilots may be allocated within certain resource blocks and not span the entire band
  - Extrapolation in frequency direction should also be prevented for sub-carriers located at frequency boundaries

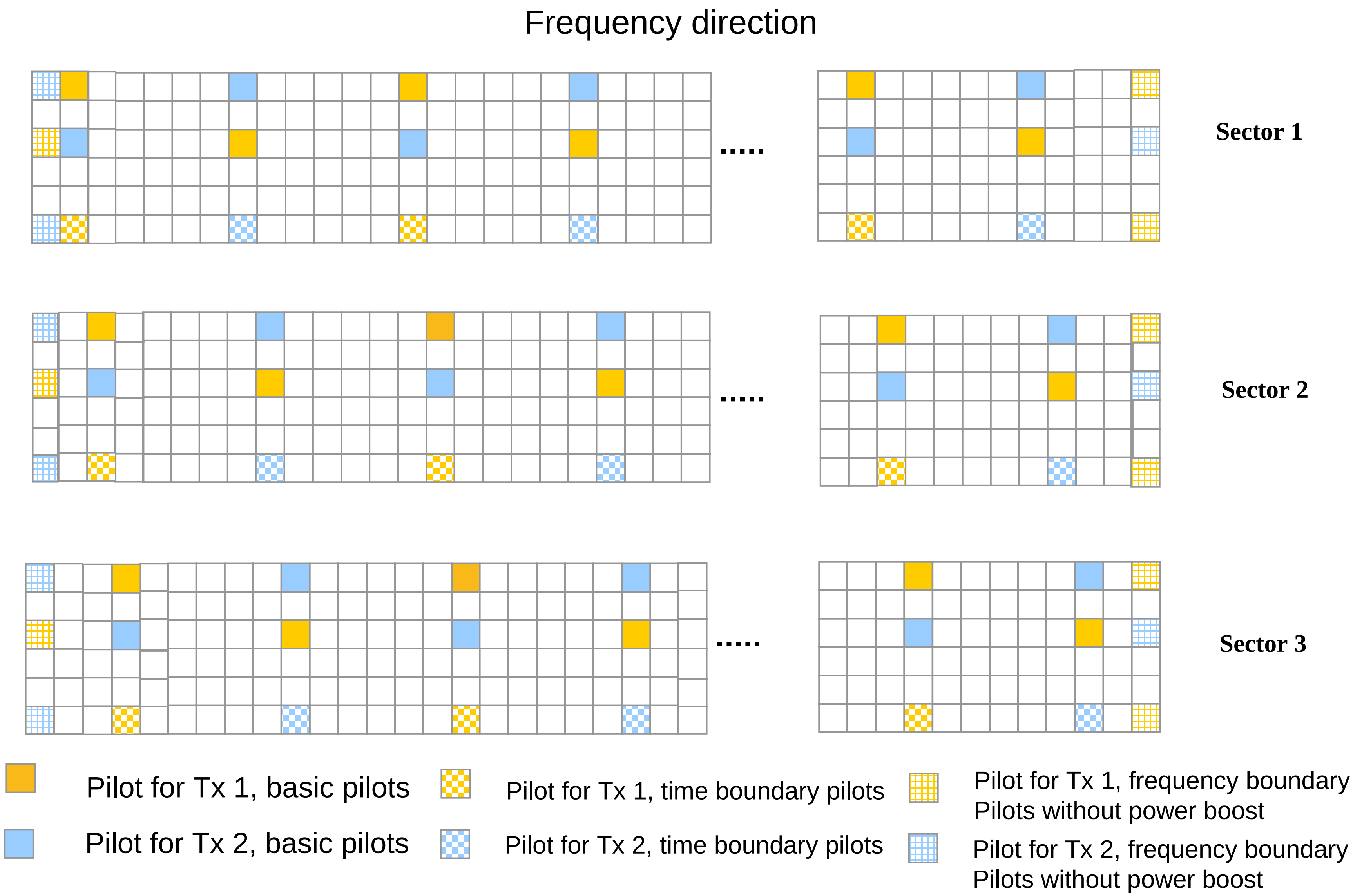
Pilot Design at Resource Boundaries: Solutions

- 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 MS has the same channel estimation algorithm
- Overall increase in overhead due to these extra pilots is limited
- To enable power boosting, basic pilots in different sectors are designed not to collide to each other
  - Sector specific offset is applied to basic pilots and time boundary pilots.
  - To allow the frequency boundary pilots to stay close to the boundary, sector specific offset and power boosting are not applied to frequency boundary pilots. Without power boost, boundary pilots can still improve the channel estimation quality with shortened or eliminated extrapolation
- In general, a boundary pilot is allocated when extrapolation distance in frequency direction is more than half of the basic pilot spacing in frequency. In current design, boundary pilot is allocated when extrapolation distance is more than 6 sub-carriers.

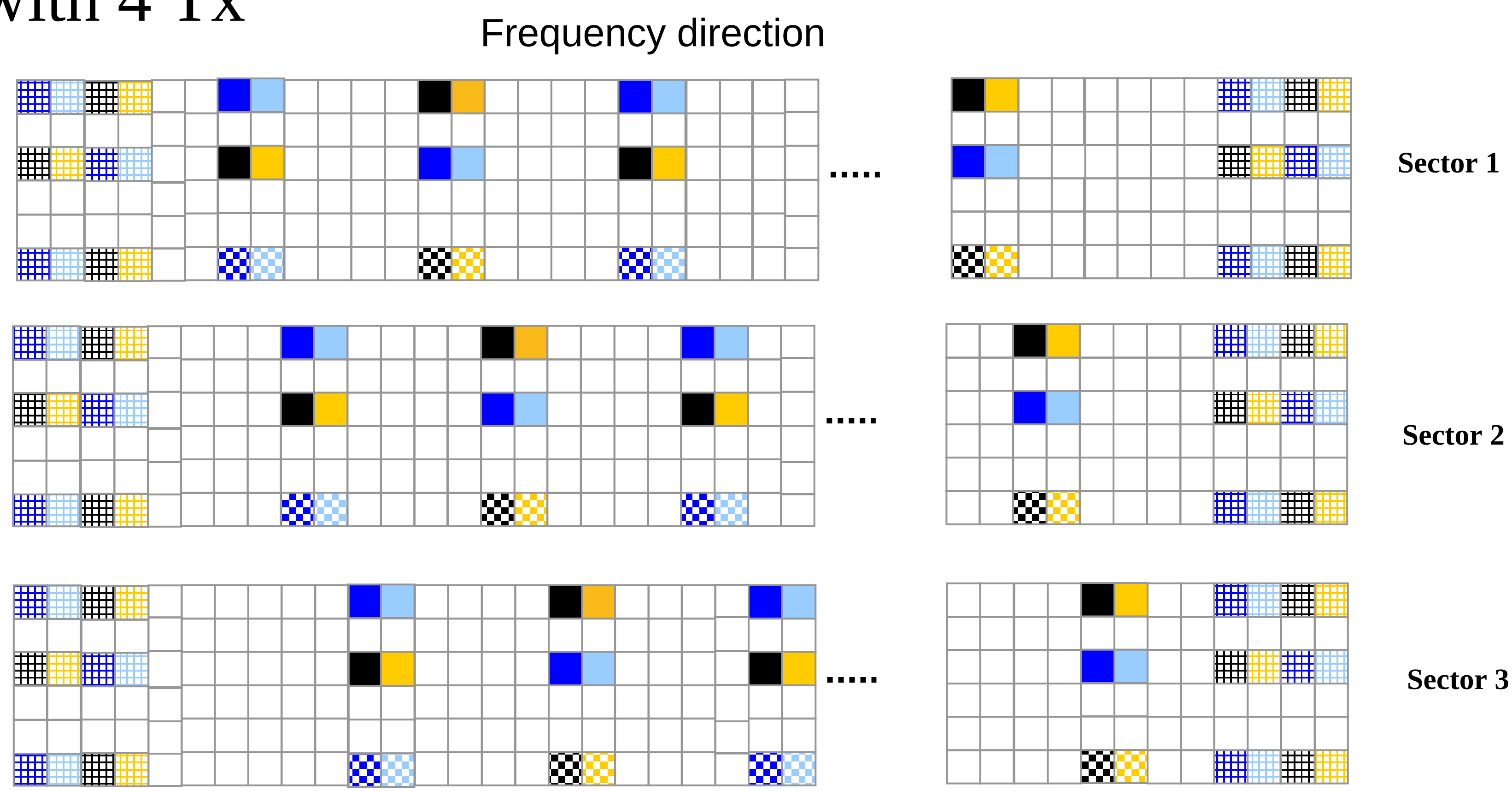
Boundary Pilots for Different Sectors: Single Sub-frame with 1 Tx



Boundary Pilots for Different Sectors: Single Sub-frame with 2 Tx

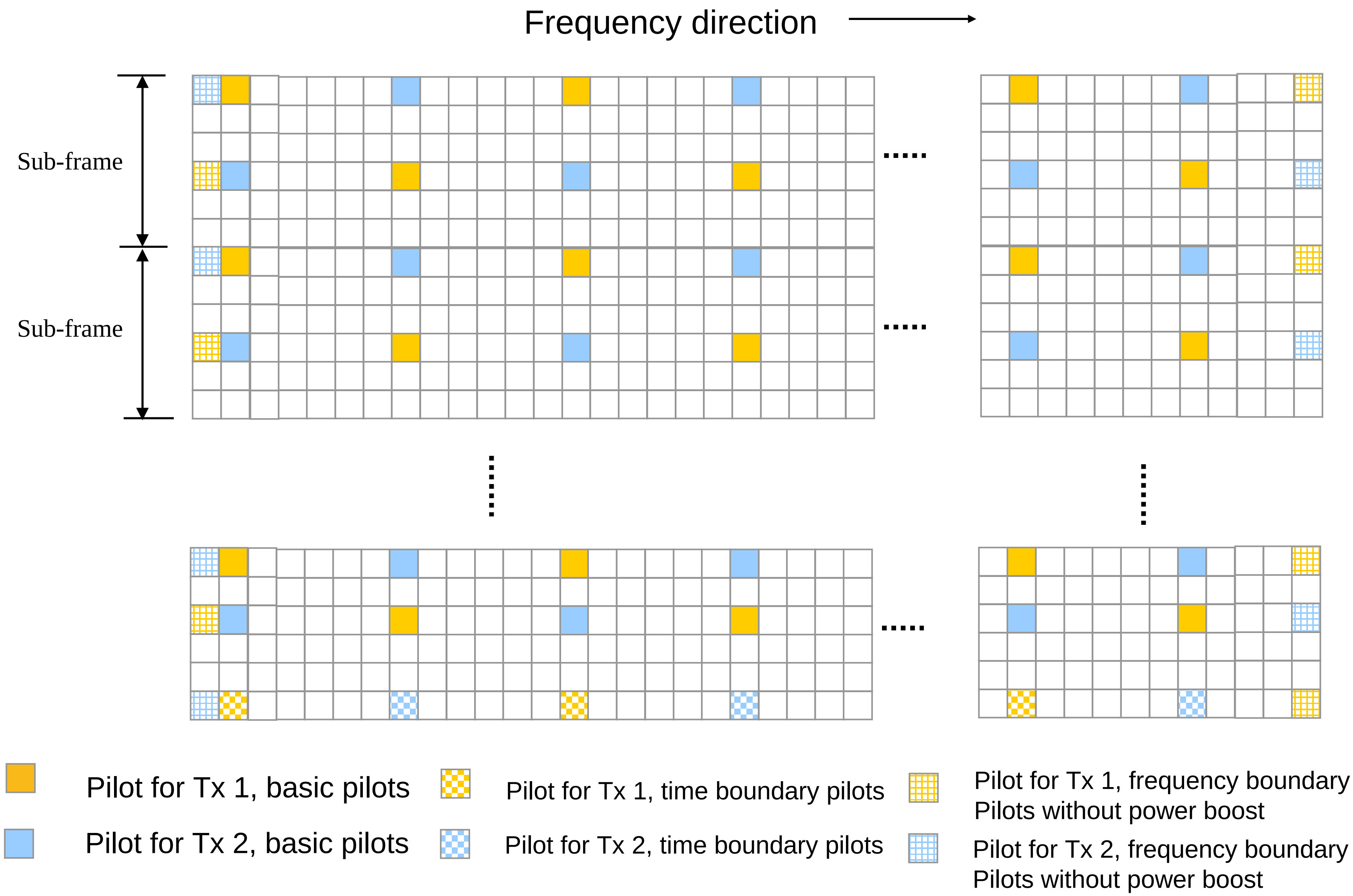


Boundary Pilots for Different Sectors: Single Sub-frame with 4 Tx

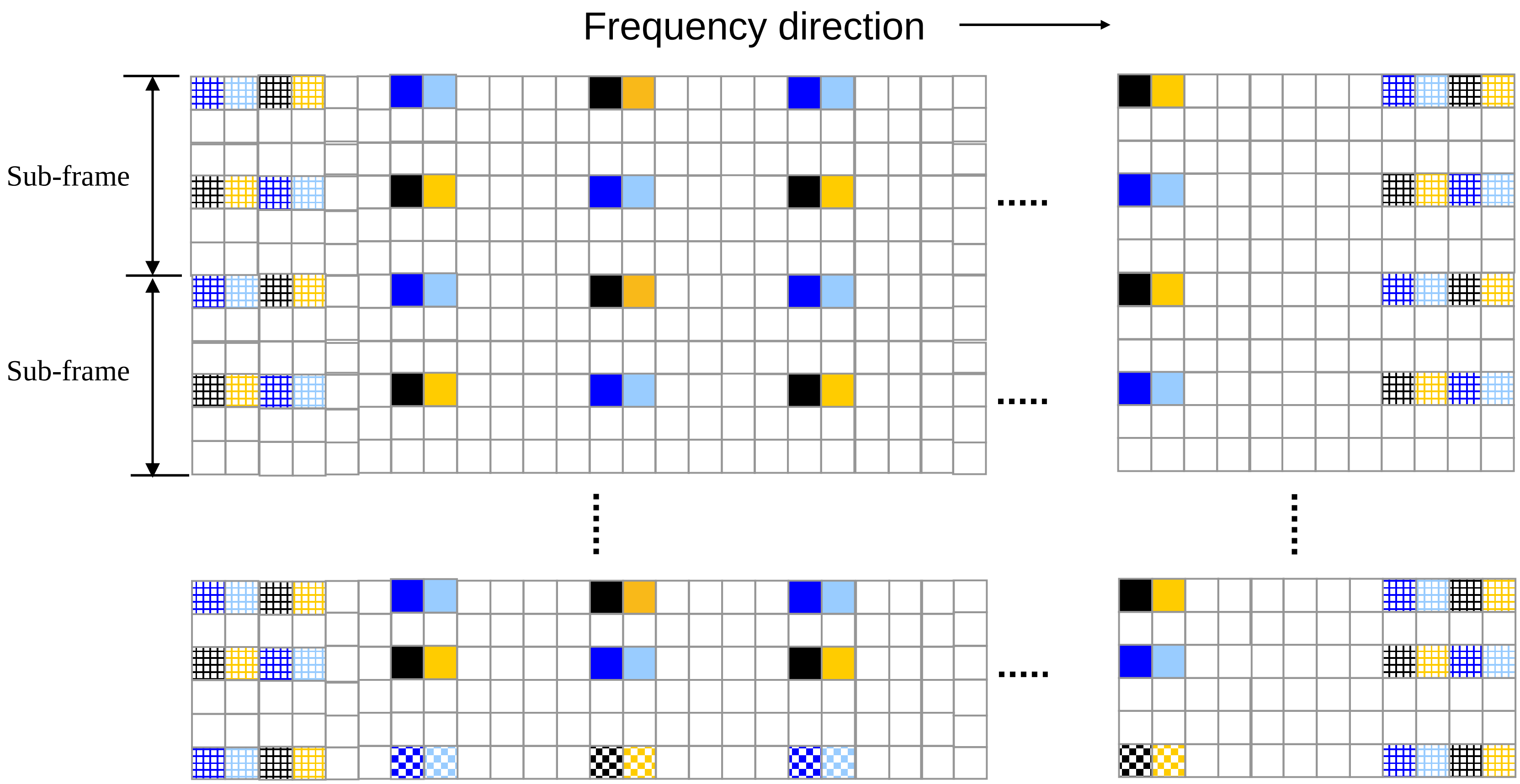


- Pilot for Tx 1, basic pilots
- Pilot for Tx 2, basic pilots
- Pilot for Tx 3, basic pilots
- Pilot for Tx 4, basic pilots
- Pilot for Tx 1, time boundary pilots
- Pilot for Tx 2, time boundary pilots
- Pilot for Tx 3, time boundary pilots
- Pilot for Tx 4, time boundary pilots
- Pilot for Tx 1, frequency boundary Pilots without power boost
- Pilot for Tx 2, frequency boundary Pilots without power boost
- Pilot for Tx 3, frequency boundary Pilots without power boost
- Pilot for Tx 4, frequency boundary Pilots without power boost

Boundary Pilots for Two or more Sub-frames with 2 Tx



Boundary Pilots for Two or more Sub-frames with 4 Tx



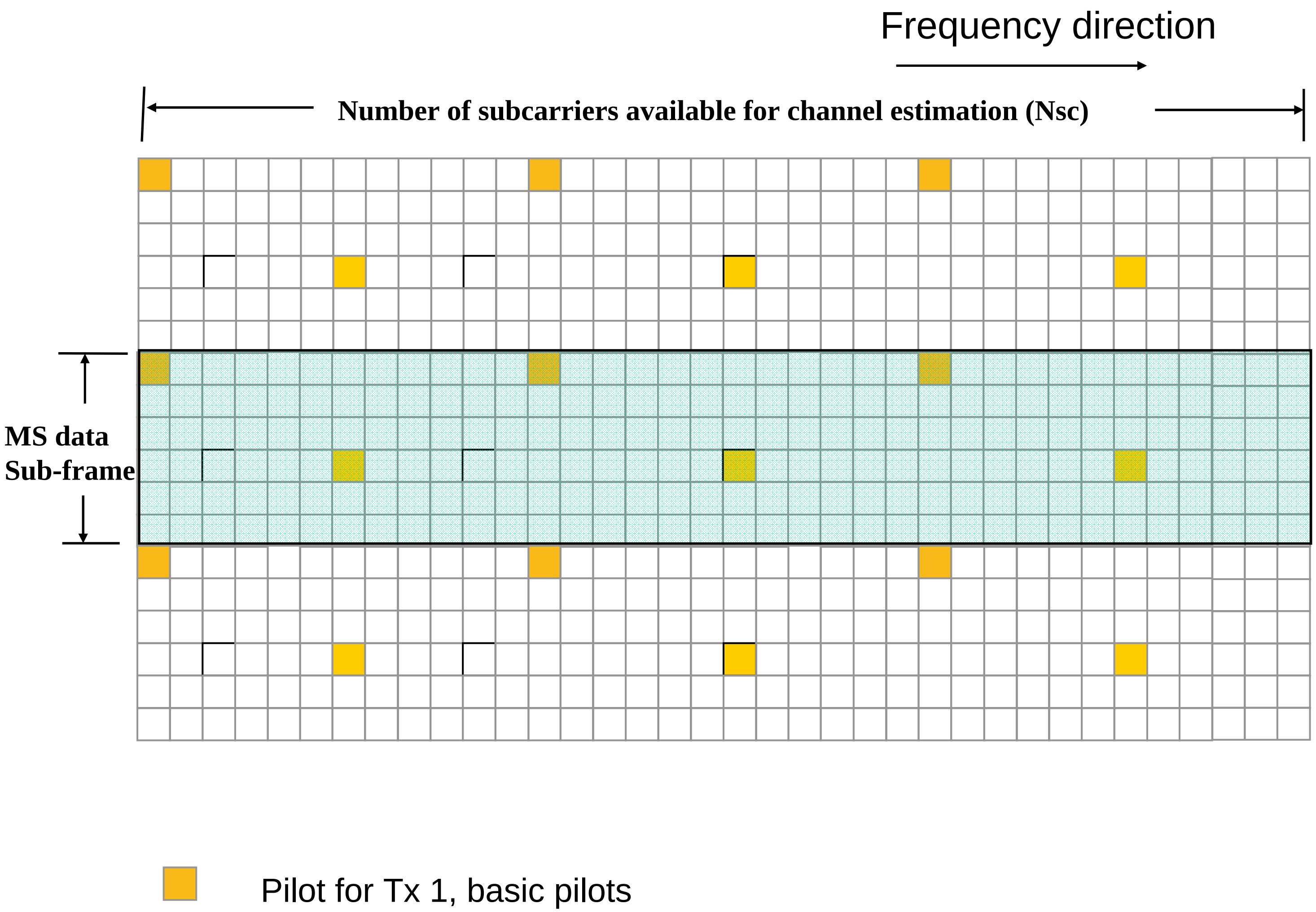
- Pilot for Tx 1, basic pilots
- Pilot for Tx 2, basic pilots
- Pilot for Tx 3, basic pilots
- Pilot for Tx 4, basic pilots
- Pilot for Tx 1, time boundary pilots
- Pilot for Tx 2, time boundary pilots
- Pilot for Tx 3, time boundary pilots
- Pilot for Tx 4, time boundary pilots
- Pilot for Tx 1, frequency boundary Pilots without power boost
- Pilot for Tx 2, frequency boundary Pilots without power boost
- Pilot for Tx 3, frequency boundary Pilots without power boost
- Pilot for Tx 4, frequency boundary Pilots without power boost

Performance Evaluation of Boundary Pilots

- Purpose of evaluation
  - Evaluate benefit of additional pilots at resource boundaries
  - Evaluate the benefit for different resource sizes
- Simulation conditions
  - Carrier frequency = 2.5GHz, 10MHz bandwidth
  - 1024 FFT size
  - 864 useful subcarriers (excluding DC tone)
  - Pilot power boost level: 3dB or 6 dB above data tone, such that total pilot symbol power is kept the same as non-pilot symbol
  - Channel models: PB and VA, up to 350km/h
  - Channel coding: convolutional turbo code
  - MIMO configurations: SM 2x2, Double STTD 4x2
  - Receiver type: MMSE
  - MCS: QAM-16 R=1/2, block size = 60 bytes

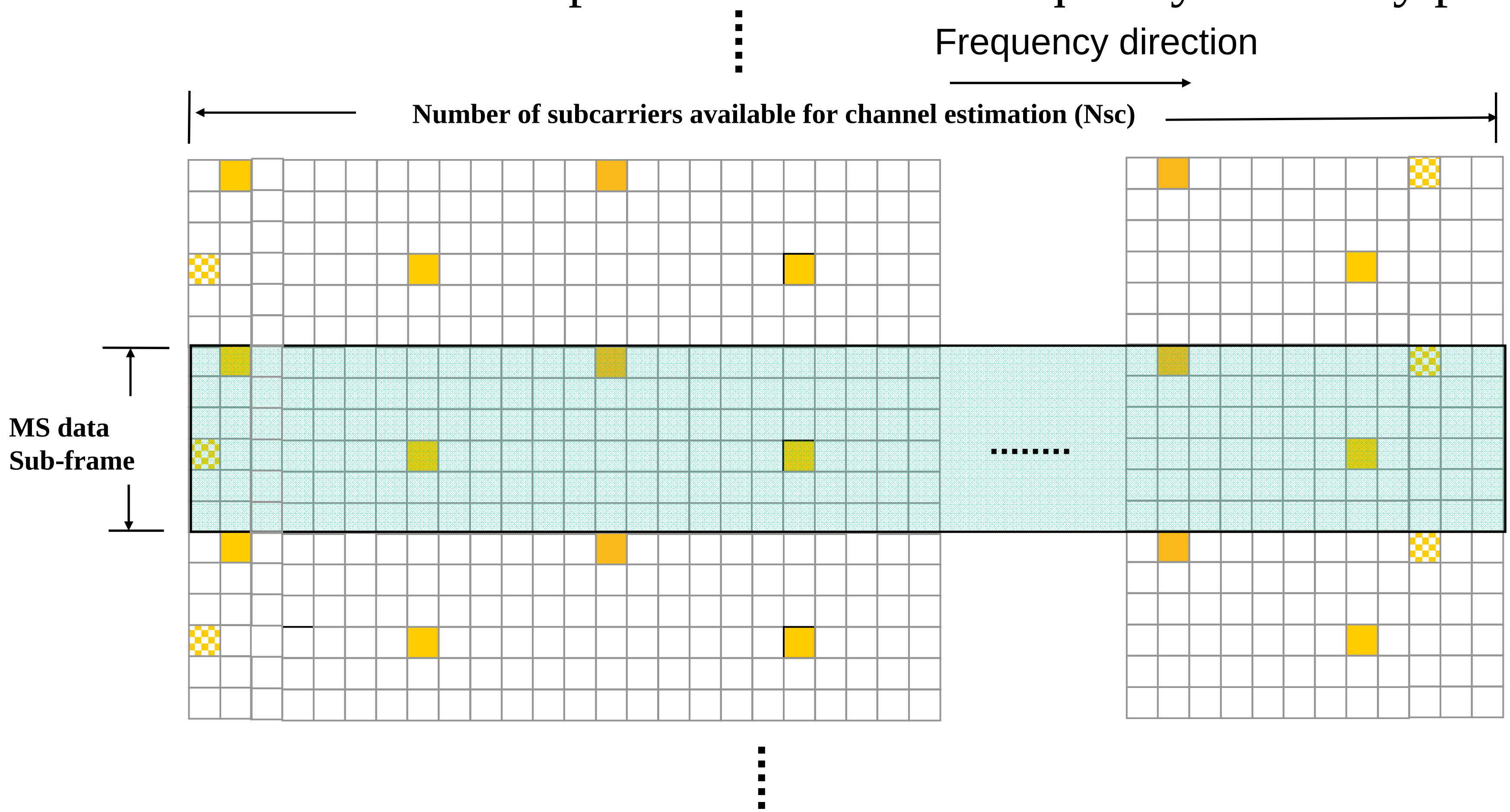
Simulation Scenario 1:

3 sub-frames for interpolation in time without boundary pilots



Simulation Scenario 2:

3 sub-frames for interpolation in time + frequency boundary pilots

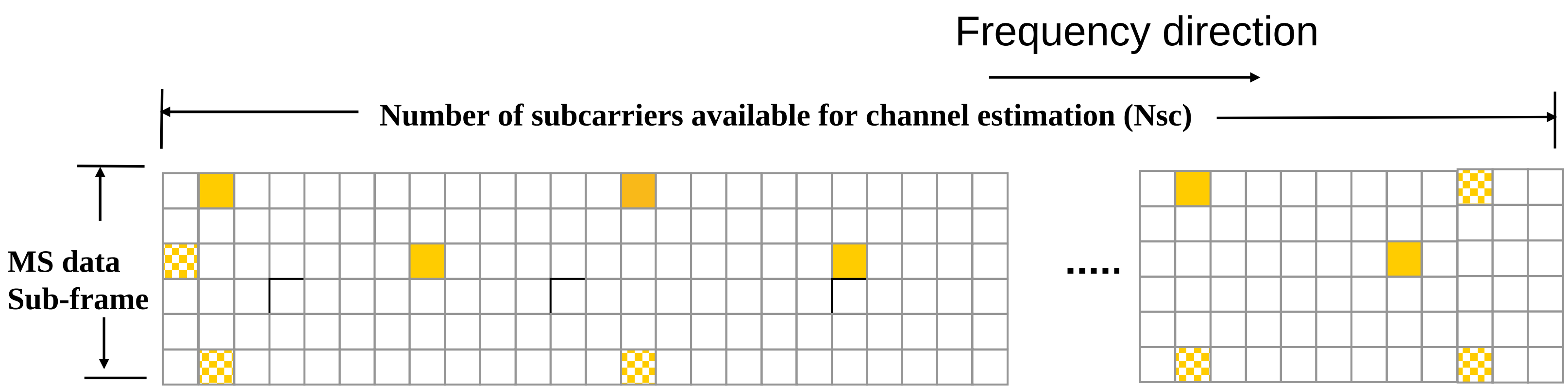


Pilot for Tx 1, basic pilots

Pilot for Tx 1, boundary pilots

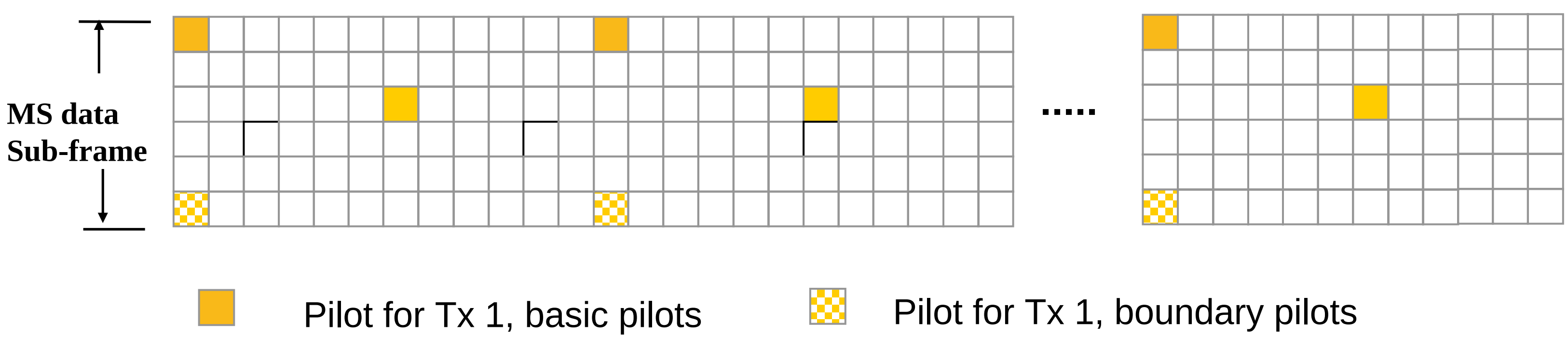
Simulation Scenario 3:

Single sub-frame + boundary pilots in frequency and time



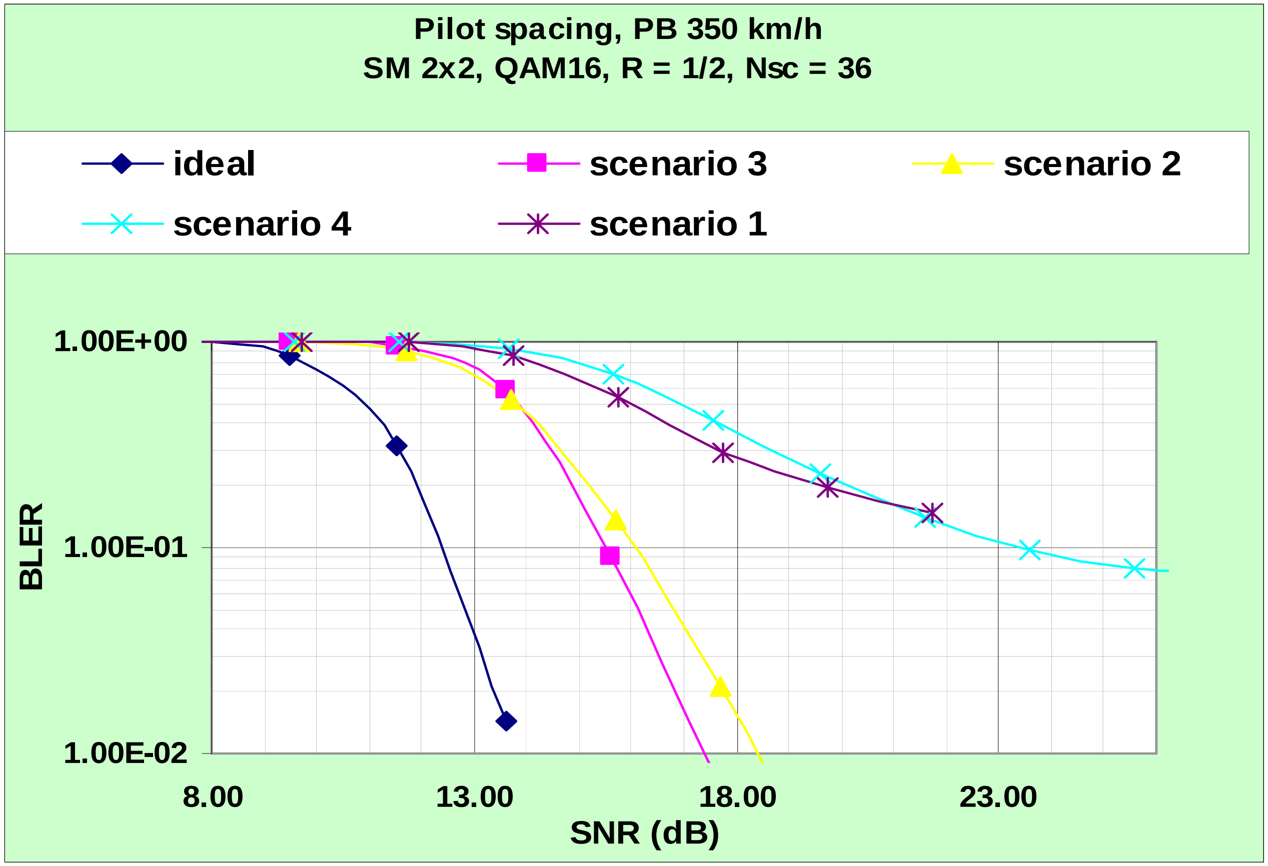
Simulation Scenario 4:

Single sub-frame + boundary pilots in time. No boundary pilots is frequency



Simulation Results of Boundary Pilots (1/3):

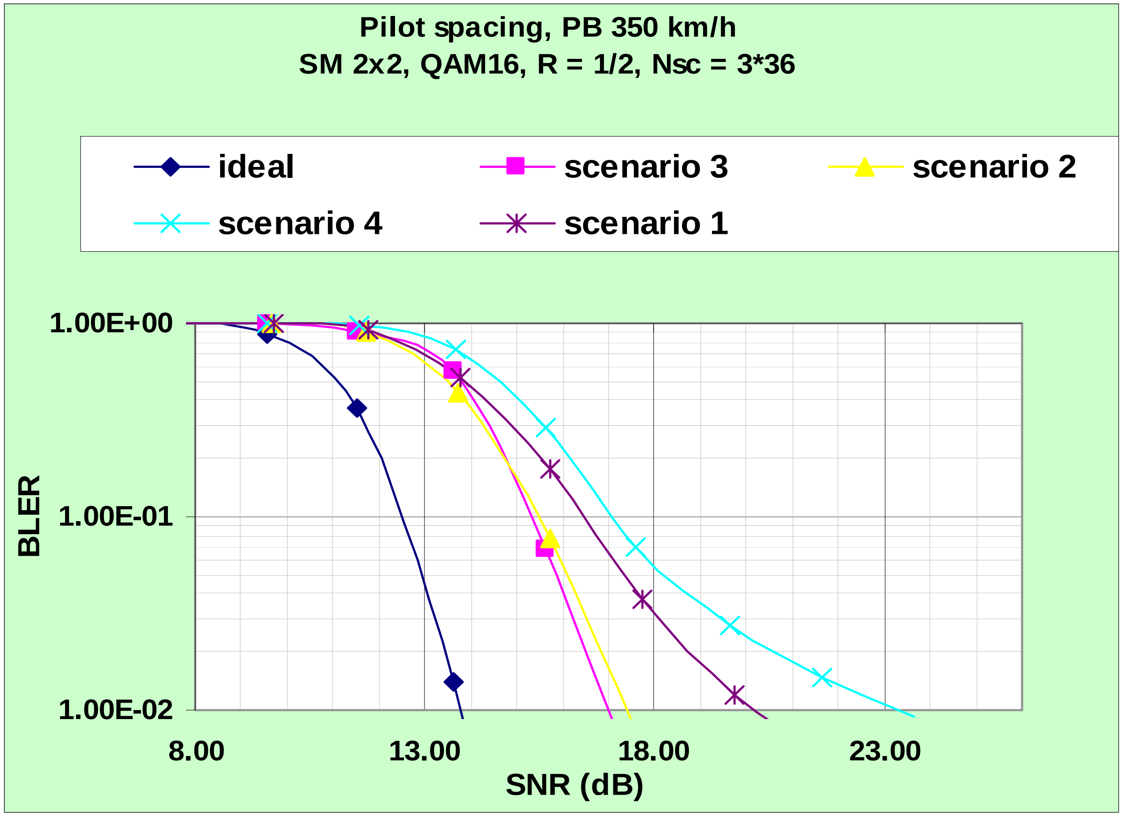
Resource spans 36 sub-carriers in frequency domain



- The simulation is done with resource spanning 36 sub-carriers in frequency
- Scenario 3 and scenario 4, both with pilots allocated at frequency boundaries, show performance advantages over scenarios 1 and 2.
- scenario 1 and scenario 2 can't converge to desired BLER without pilot allocated at frequency boundary
- Scenario 3 shows the best performance with pilots also allocated at sub-frame time boundary.

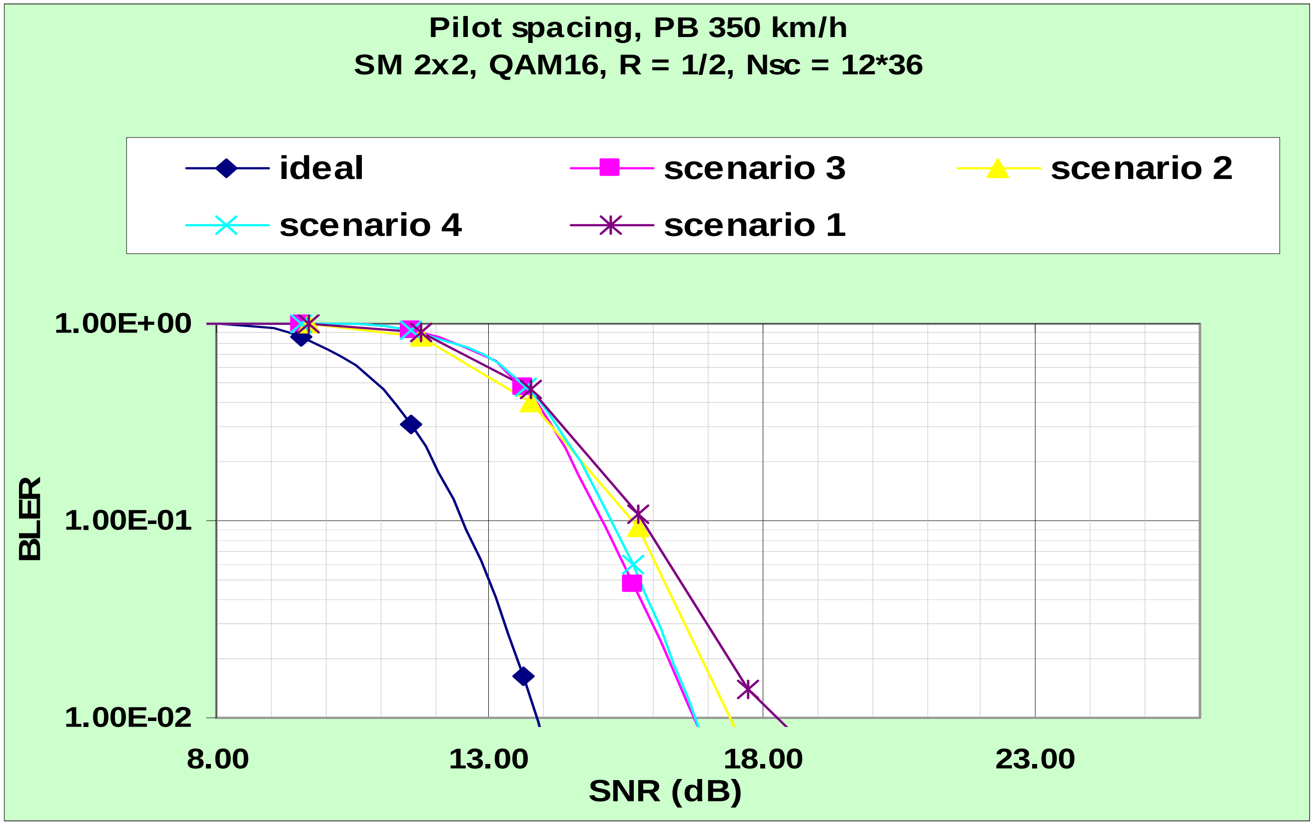
Simulation Results of Boundary Pilots (2/3):

Resource spans 108 sub-carriers in frequency domain



- This simulation is done with resource spanning 108 sub-carriers in frequency
- Scenario 3 and scenario 4, both with pilots allocated at frequency boundaries, show performance advantages over scenarios 1 and 2. The result is slightly better than that shown in previous slide with resource spanning 36 sub-carriers in frequency domain.
- Scenario 1 and cenario 2, without pilot allocated at frequency boundary, still have larger SNR loss, although channel estimation quality at boundary plays less role for wider resource bandwidth
- Scenario 3 shows the best performance with pilots also allocated at sub-frame time boundary.

Simulation Results of Boundary Pilots (3/3):
Resource spans 432 sub-carriers in frequency domain

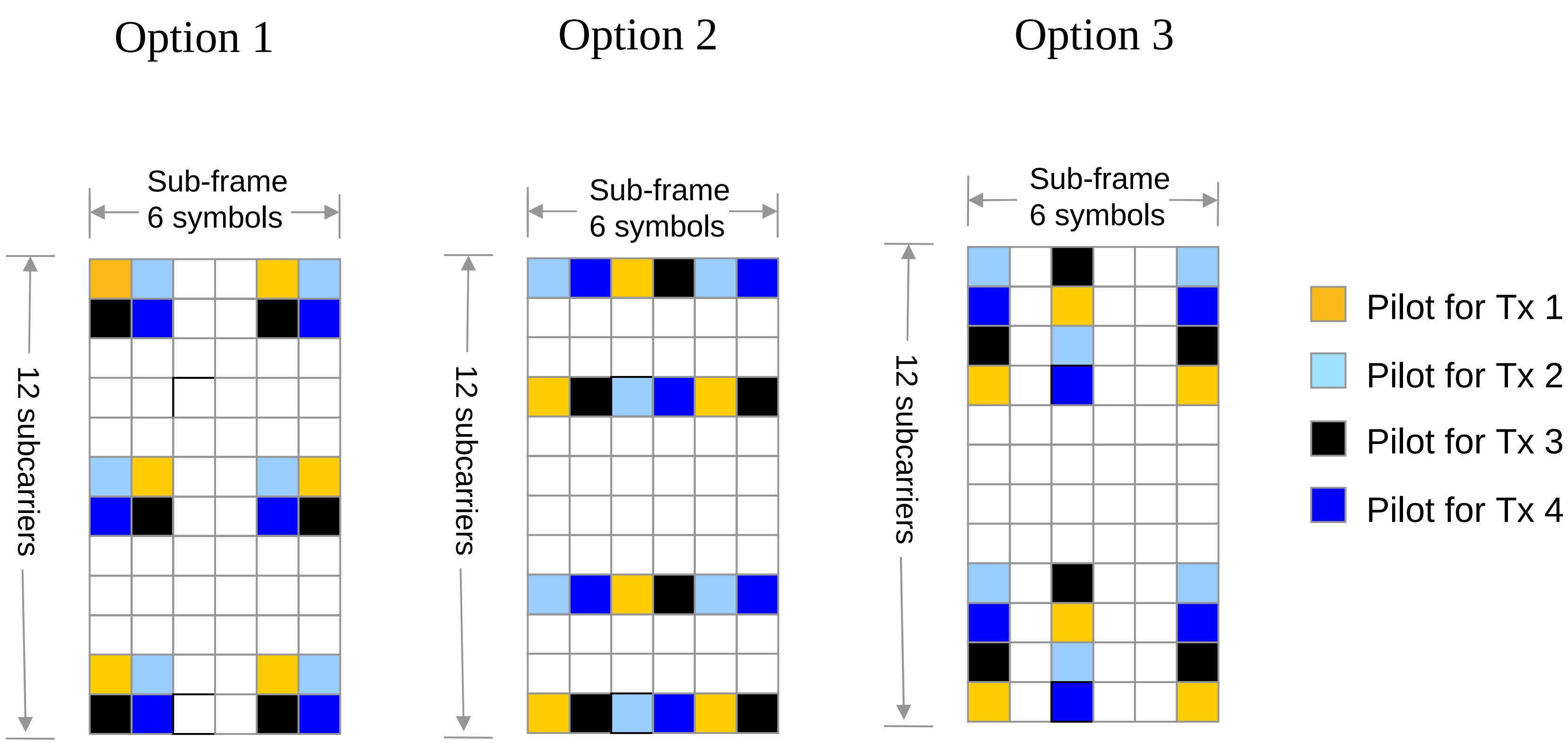


- This simulation is done with resource spanning 432 sub-carriers in frequency
- Since channel estimation is done in a relative much wider band, overall channel estimation quality is less affected by degraded boundary channel estimation error. Difference among performances of all 4 scenarios converges to about 1dB
- Scenario 3 and scenario 4, both with pilots allocated at sub-frame boundary, outperform other two scenarios.

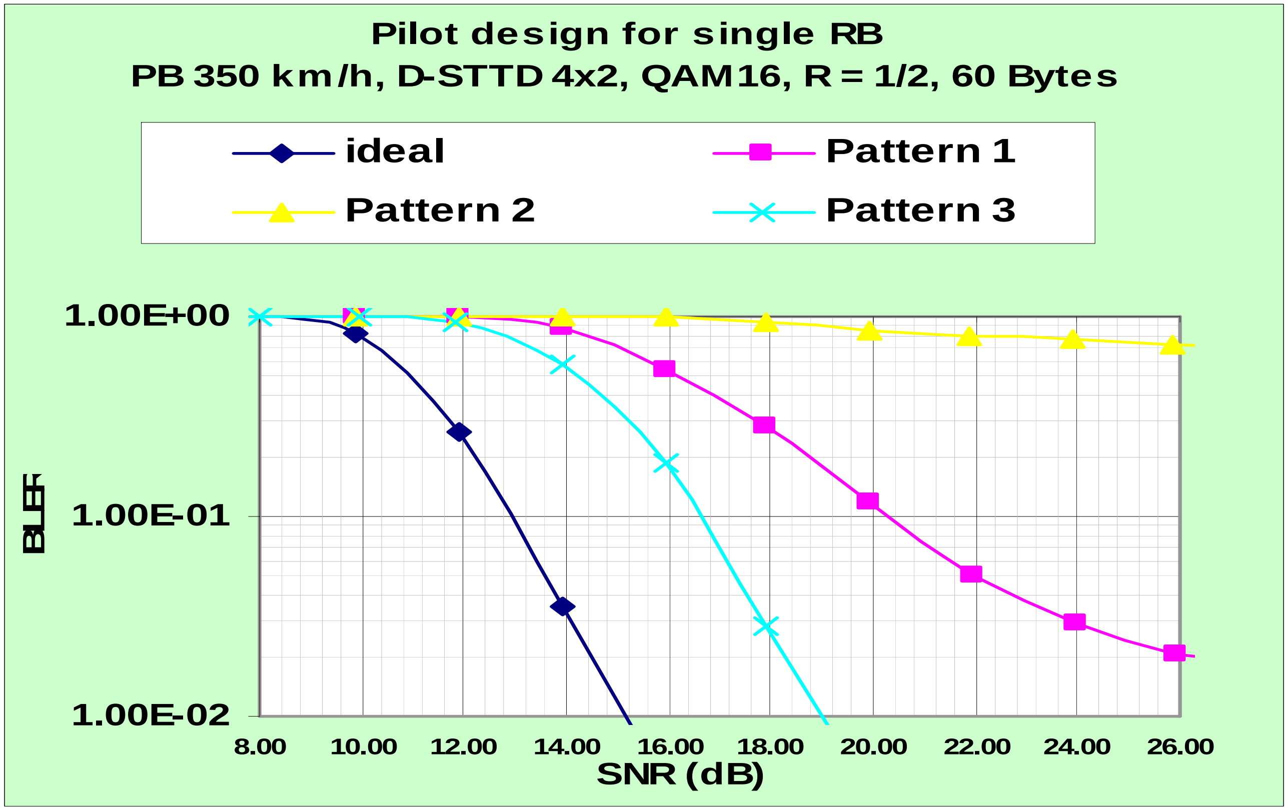
Further Evaluation of 4 Tx Pilot Structure for One RB

- Basic pilot structure with boundary pilots for multiple RBs has been evaluated for various scenarios
- Optimal pilot structure for single RB (or 2-3 RBs) may not be a trivial derivation from multiple RB pilot design
- There are several options for single RB pilots design
  - 6 pilot tones are needed in a single RB for interpolation in time and frequency direction under different channel conditions
- Further evaluation is carried out for examining
  - Efficiency of scattered pilot pattern design
  - Importance of boundary pilot design
- Linear interpolation is used for channel estimation for simple implementation and provides a bottom line performance

4 Tx Pilot Structure Options Evaluated for Single RB

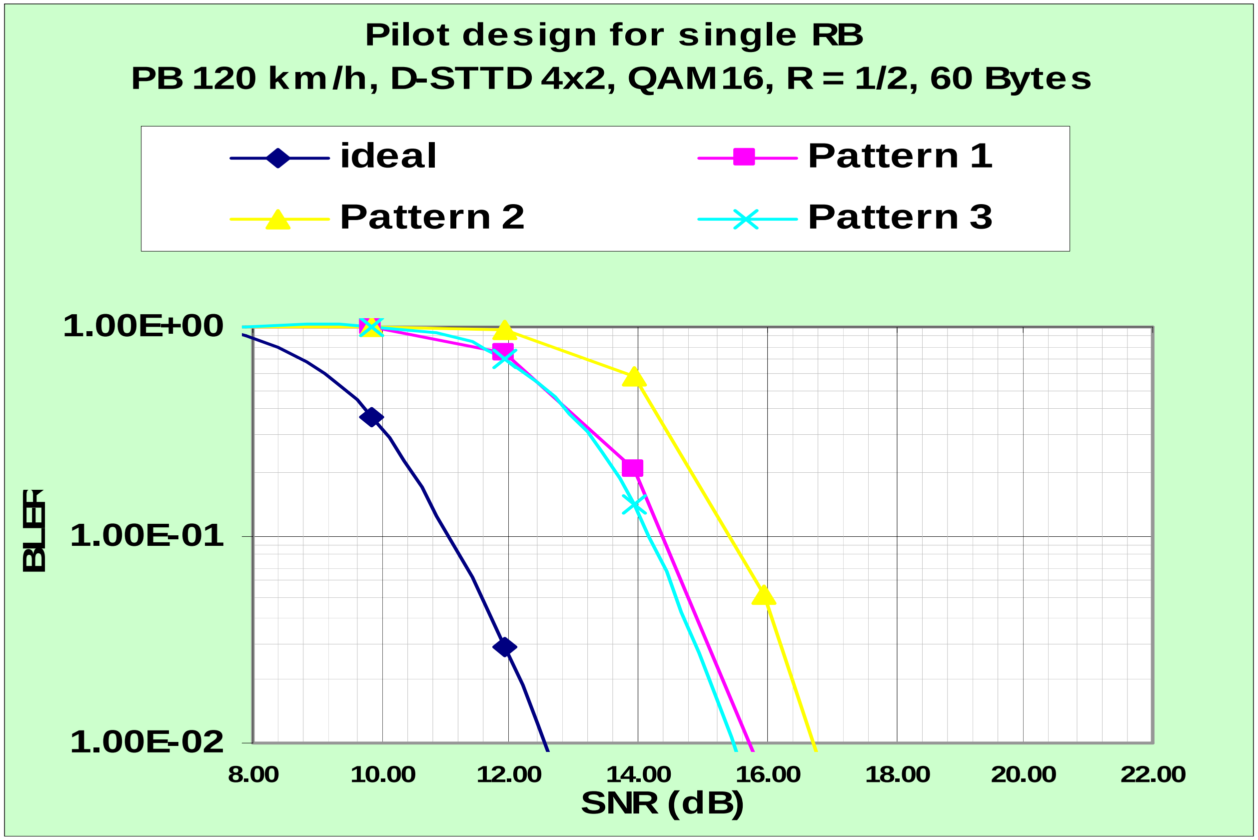


Performance Results of 4 Tx Pilot Structure for Single RB (1/3)



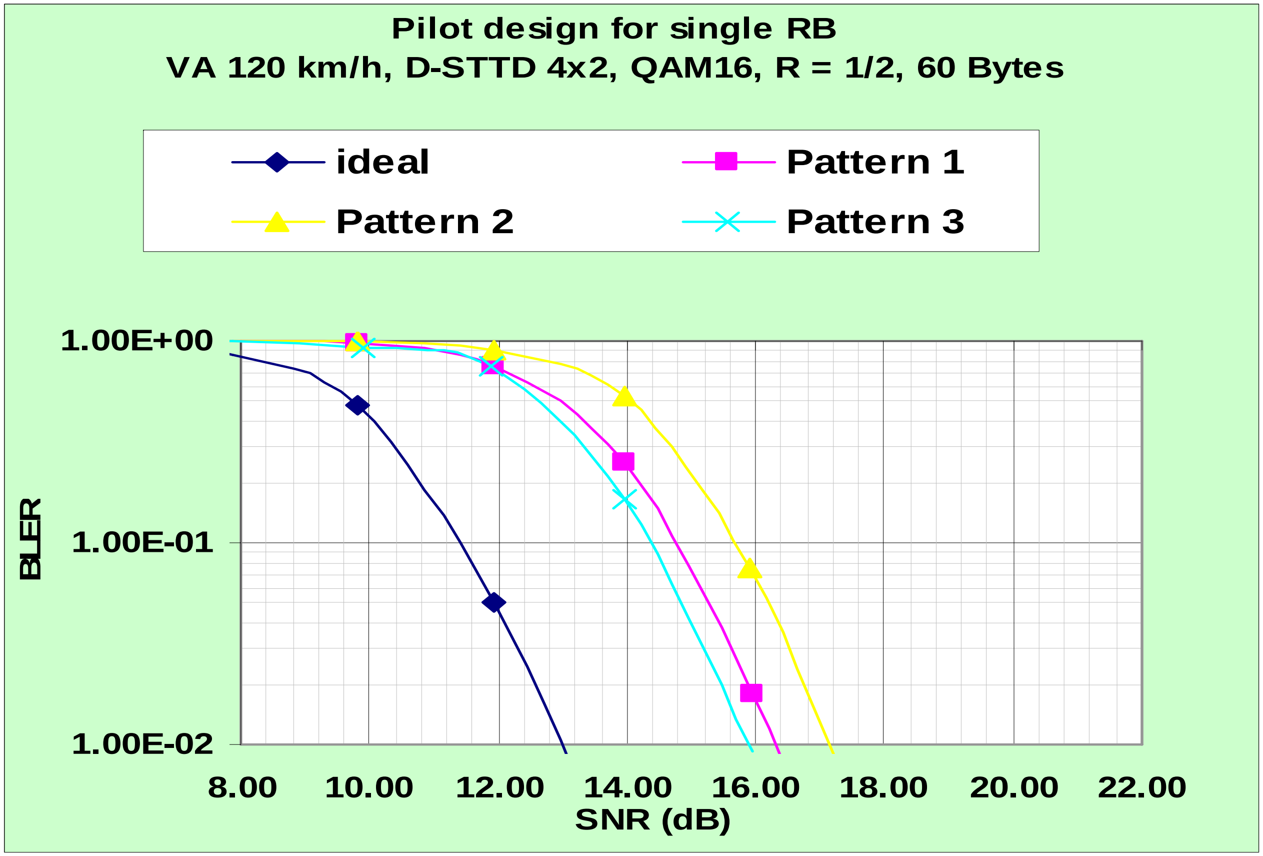
- **At 350km/h, pattern 3 avoids the extrapolation in time direction for all Tx and performs the best.**
- **Pattern 2 needs extrapolation for all tones of one OFDM symbol at one side of sub-frame boundary and can not converge to 10% BLER.**
- **Pattern 1 has a pair of pilot tones at one side of sub-frame boundary for frequency interpolation and a single pilot tone at another side of the boundary which helps to improve performance, but still can not reach 1% BLER**

Performance Results of 4 Tx Pilot Structure for Single RB (2/3)



Pattern 3 outperforms patterns 1 and 2 at PB 120km/h

Performance Results of 4 Tx Pilot Structure for Single RB (3/3)



For VA 120km/h, pattern 3 also outperforms patterns 1 and 2

Summary and Recommendations for Downlink Pilots

- According to simulation evaluation of basic pilot structure, uniformly scattered pilot with frequency sub-carrier spacing of 12 and time symbol spacing of 3 is recommended for each of 4 Tx streams
- Pilots for different Tx streams are separated by different subcarriers in frequency and/or time
- Pilots should also be allocated at both time and frequency boundaries of contiguous resource blocks
- Sector specific offset is applied to the basic pilots to enable pilot power boosting

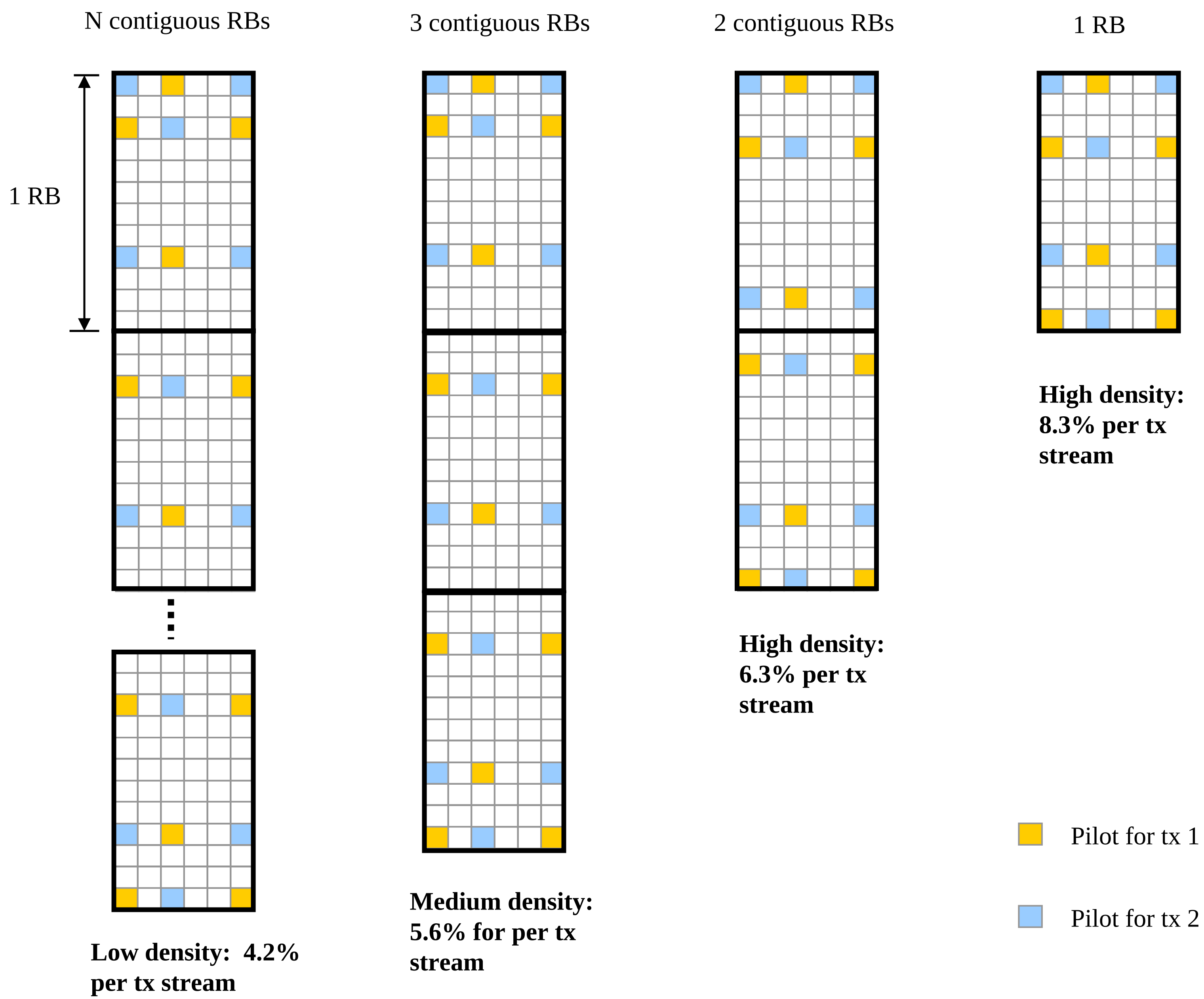
DL Resource Block (RB) and Basic Channel Unit (BCU)

- We define two types of resource unit, one is the resource block (RB). The other is the Basic Channel Unit (BCU).
- Resource Block (RB) is the smallest unit that can be assigned to an MS. It is targeted for VoIP or other small-packet application. A BCU consists of multiple RBs. It is targeted for non-VoIP applications where small granularity of resource size is not required. See IEEE C802.16m-08/175 for details.
- Size of RB and BCU are determined by the following factors
  - To support small packet (e.g. VoIP) transmission, an RB size of 12 sub-carriers by 6 symbols, i.e. 72 tones (including pilots) is chosen for its adequate granularity and flexibility (see IEEE C802.16m-08/177 for details).
  - To support non-VoIP transmission and control signalling, BCU size of 3 RBs is selected (see IEEE C802.16m-08/175 for details).
  - The choice of RB size should also alignment with the pilot design
    - Align with the spacing of basic common pilot pattern so as to save signalling overhead and reduce implementation complexity. From our evaluation in this proposal, optimal spacing in frequency is 12 subcarriers.
- Overall, we recommend an RB size of 12 sub-carriers x 6 symbols.

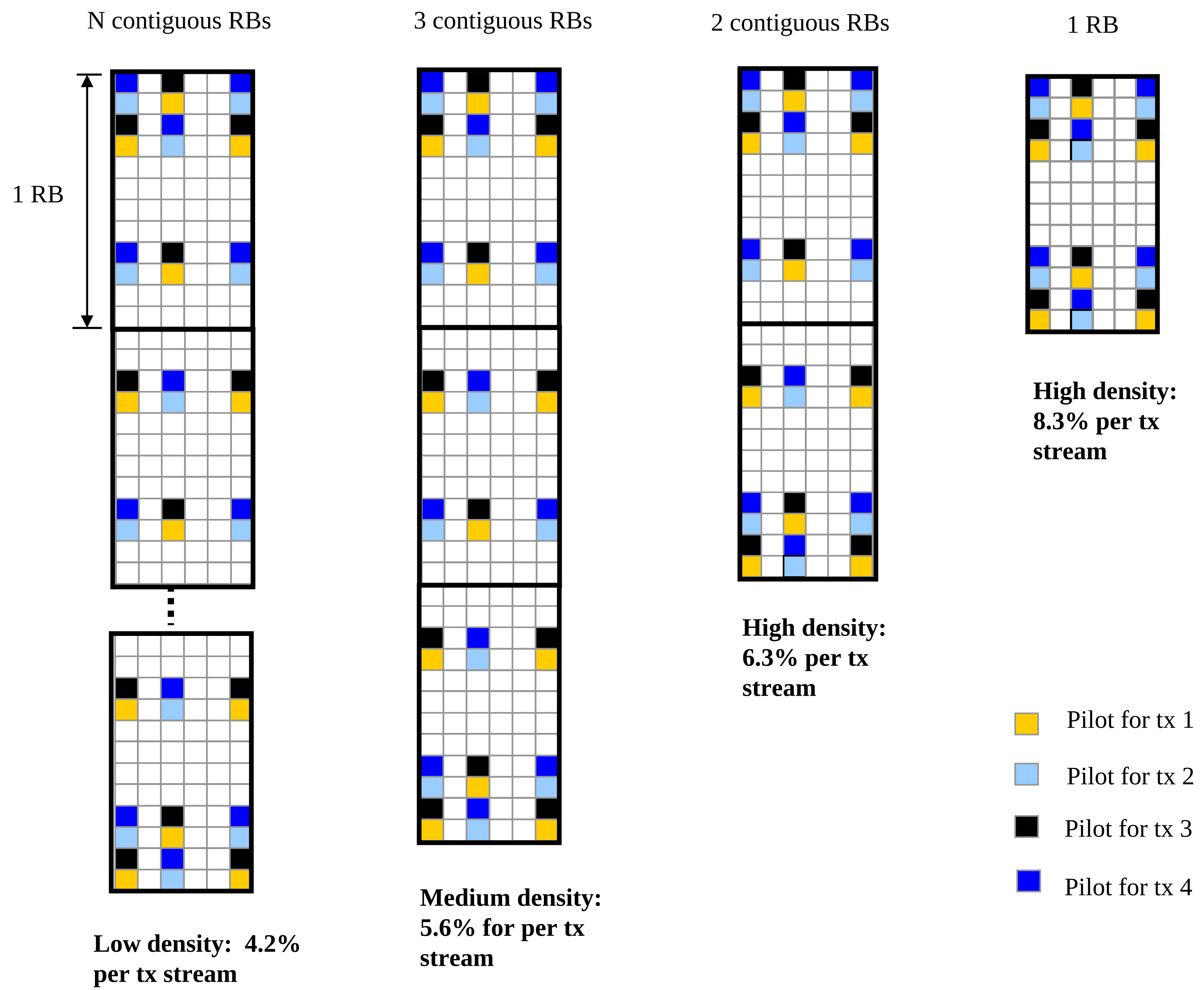
Pilot Structure for Common Pilot and Dedicated Pilot

- The recommended basic and boundary pilot structure from previous slides can be used for both common pilot and dedicated pilot RBs
- For the case of common pilot, the pilot density varies with the number of contiguous RBs assigned for common pilot resource zone which can be a diversity zone or a localized zone (see C802.16m-08/175 for details of proposed channelization).
- For the case of dedicated pilot, the pilot density varies with the number of contiguous RBs assigned to the MS.
- Figures in the next slide illustrate the different pilot density for different number of contiguous RBs.

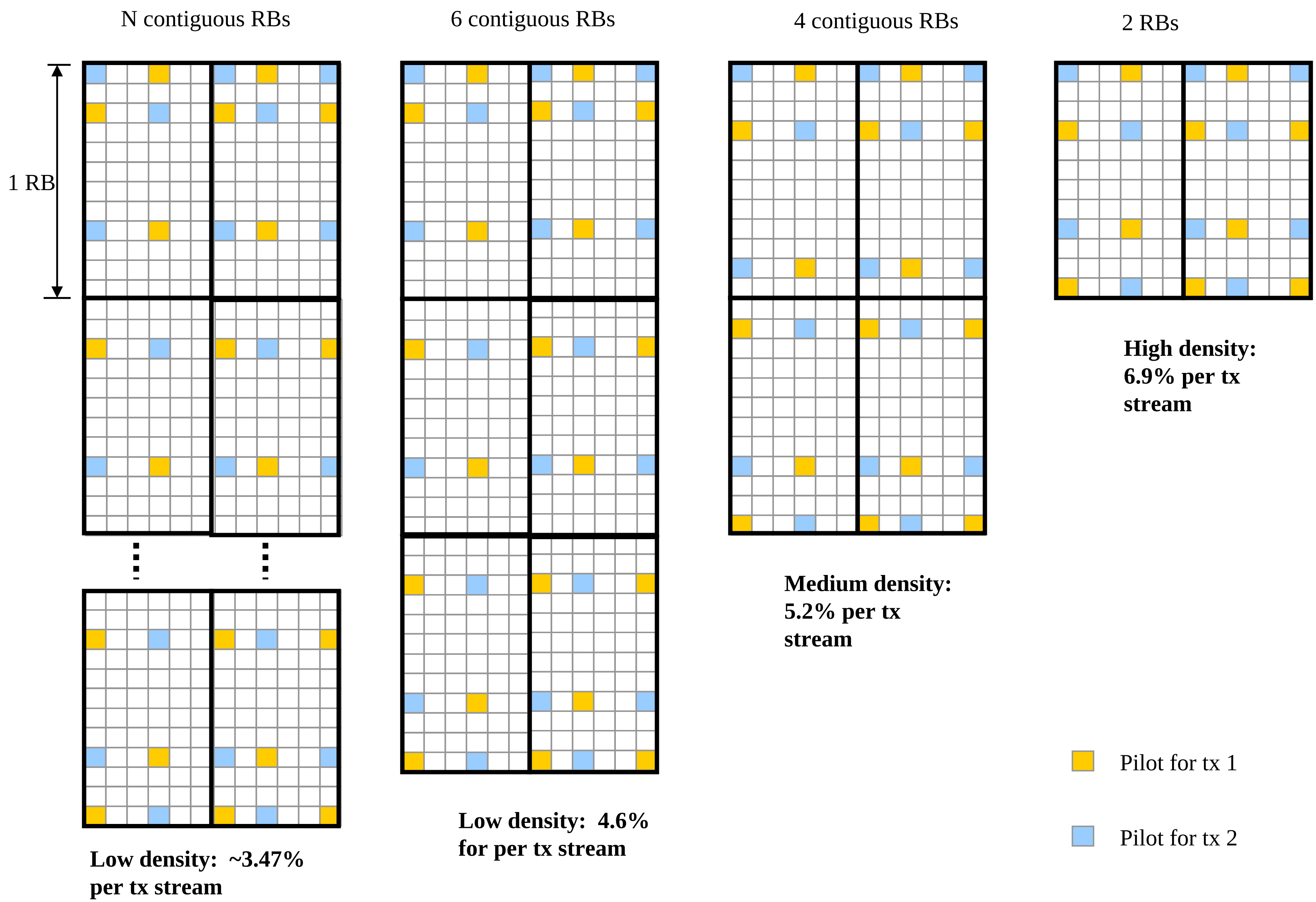
Different Pilot Density based on No. of Contiguous RBs (2Tx)



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



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



Common Pilot and Dedicated Pilot RBs Multiplexing

- In one RB, either common pilots or dedicated pilots are allocated. Common and dedicated pilots do not co-exist in one RB.
- Within a 16m sub-frame, diversity and localized channelization or zones are multiplexed in FDM fashion. See C802.16m-08/175 for details of the proposed 16m channelization.
- A diversity zone consists of common pilot RBs. A localized zone can consist of either common pilot RBs or dedicated pilot RBs.
- To reduce pilot overhead, the recommended number of contiguous common pilot RBs within a diversity or localized zone is at least three.
- Pilots for CQI and MIMO channel measurement can be added on a as-needed basis to an RB (whether it is common or dedicated pilot RB) to facilitate CQI and MIMO channel measurement across the band
  - One example is pilots for additional physical transmit antennas are added to a common pilot RB to enable CQI and MIMO channel measurement of those additional transmit antennas
  - Another example is pilots for all physical transmit antennas are added to a dedicated pilot RB to enable CQI and MIMO channel measurement of all transmit antennas

Conclusions

- A unified common and dedicated pilot structure is proposed
- Maximum pilot spacing of (12, 3) is recommended for DL pilot for each Tx stream
- Pilots are added to time/frequency resource boundary to improve channel estimation performance.
- Sector specific offset is applied to the basic pilots to enable pilot power boosting
- To provide a good trade-off between pilot overhead and channel estimation performance, the pilot density adapts to the number of contiguous RBs assigned to a common pilot zone or to a MS for the case of dedicated pilot.
- The proposed common and dedicated pilot structure targets to support up to 4 MIMO streams.

Text Recommendations for SDD Section 11 Physical Layer

- Section 11.x DL Pilot structure
  - Scattered pilot structure is used in both common and dedicated pilot design
- Section 11.x.1 DL pilot structure
  - Basic pilots are uniformly distributed in frequency and time by spacing of (12, 3)
    - [*Copy the content of slides 10 and 11 into this section*]
  - Boundary common pilots are allocated at the resource boundaries in time and frequency and preserve the scattered pilot structure
    - [*Copy the content of slides 19 20, 22, 22 and 23 into this section*]
- Section 11.x.2 DL unified common and dedicated pilot structure
  - Pilot structure for common or dedicated pilot
    - [*Copy the content of slides 34, 35 and 36 into this section*]