3GPP TSG-RAN1 Meeting #42 **R1-050642**

Sophia-Antipolis, France, 20th-21st June, 2005

Agenda Item: **4.1**

Source: **Nortel**

Title: **Pilot pattern design consideration for E-UTRA DL**

Document for: **Discussion**

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>THIS IS **THE WAY**

Pilot Pattern Design Considerations

Jun, 2005

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Introduction

> Reliable channel estimates are essential for performing coherent detection.

> For OFDM transmission through radio channels with fading both in time and in frequency.
  - A channel estimator needs to estimate time-varying amplitudes and phases of all sub-carriers.
  - Pilots required to provide reference values to enable channel interpolator to obtain the channel responses in time-frequency plane.

> Two types of pilot insertion schemes
  - TDM pilot symbol insertion
    - Introduce pilot symbol periodically in time domain
    - All sub-carriers in pilot symbol are used as pilots
    - Suitable to low speed UE with fast frequency selective fading
  - Distributed pilot insertion
    - Pilot sub-carriers are inserted periodically in both time and frequency
    - Suitable to high speed UE

> The purpose of this contribution is to discuss the distributed pilot pattern design principle and to evaluate the relative relations between channel estimation performances with different distributed pilot patterns and densities under different channel conditions.

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Pilot Design Principle (1)

> A two-dimensional interpolation can be performed to estimate points on a time-frequency grid based on the scattered pilots

- To recover the channel responses correctly both in time and frequency from the available pilots, the pilot spacing has to fulfill the Nyquist sampling theorem.
- In general, the denser the pilots density, the better the channel estimation performance and the easier the estimation algorithm.

> However pilot insertion introduces overhead

- The pilot density is a tradeoff between channel estimation performance and SNR loss.

> A optimal pilot design is required to support reliable channel estimates under various channel conditions with lowest overhead

- More critical for MIMO transmission
  - Require multiple channel estimates corresponding to different transmit antenna

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Pilot Design Principle (2)

> There exist both a minimum sub-carrier spacing and minimum symbol spacing between pilots

> The minimum pilot spacings in time and frequency are determined by the channel variation bandwidth in time and frequency.

- In time domain, the bandwidth is equal to the Doppler spread B_d
- In frequency domain, the bandwidth is equal to the maximum delay spread t_{max}.
- The requirement for the pilot spacings in time and frequency s_t and s_f are:

$$s_t < \frac{1}{B_d}$$

$$s_f < \frac{1}{\tau_{max}}$$

> Each channel condition has an optimal pilot design.

> An optimal solution should be found according to the channel scenarios encountered most frequently.

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Pilot Patterns

> Four types of pilot arrangement were investigated:
- Type-1 (Patterns 2, 4 and 5)
  - Shifted distributed pilots in odd (or even) indexed OFDM symbols for each antenna
  - Pilot pattern repeated every 4 OFDM symbols
- Type-2 (Patterns 6, 7 and 8)
  - Shifted distributed pilots in odd (or even) indexed OFDM symbols for each antenna
  - Pilot pattern repeated every 6 OFDM symbols
- Type-3 (Patterns 1 and 3)
  - Shifted distributed pilots in odd (or even) indexed OFDM symbols for each antenna
  - Pilot pattern repeated every 8 OFDM symbols
- Type-4 (Patterns 9-13)
  - Shifted distributed pilots in every OFDM symbols for each antenna
  - Pilot pattern repeated every 4 OFDM symbols

> Type-1, 2 and 3 can be easily extended to MIMO pilot design with adjacent symbol based pair-wise pilots to support STTD (space-time transmit diversity) or with adjacent sub-carrier based pair-wise pilots to support SFTD (space-frequency transmit diversity)

> Type-4 is only suitable to adjacent sub-carrier based pair-wise MIMO pilots if we want to keep the uniform pilot density for all antennas.

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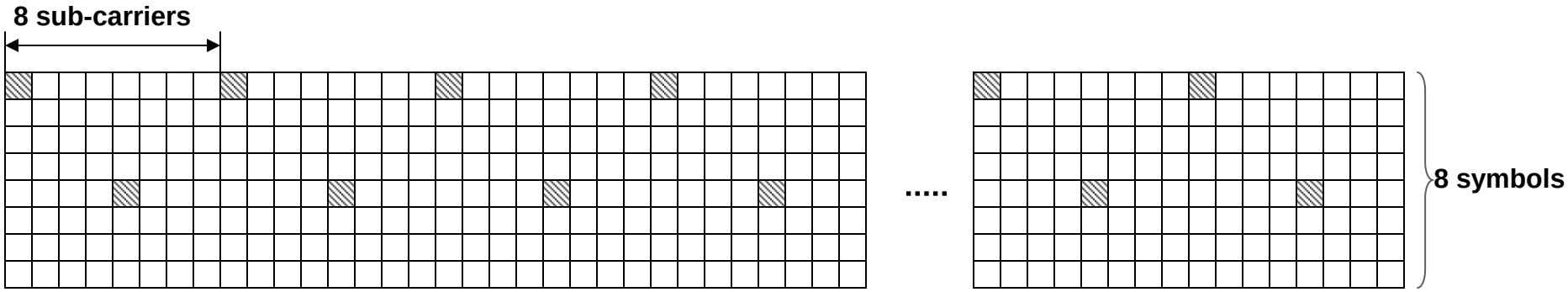
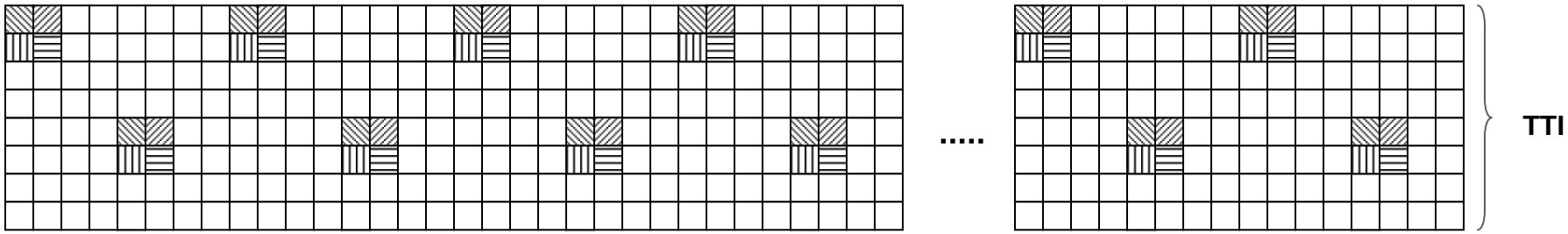
Pattern-1 (Overhead: 1/32 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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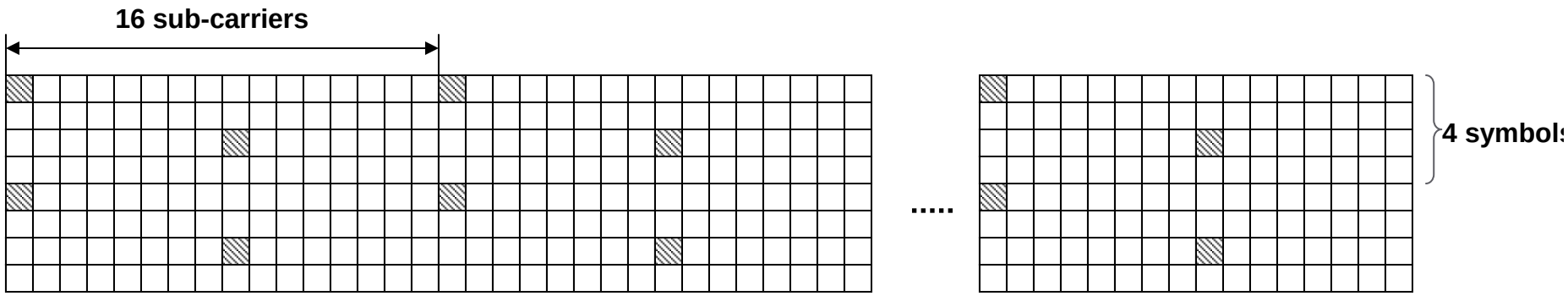
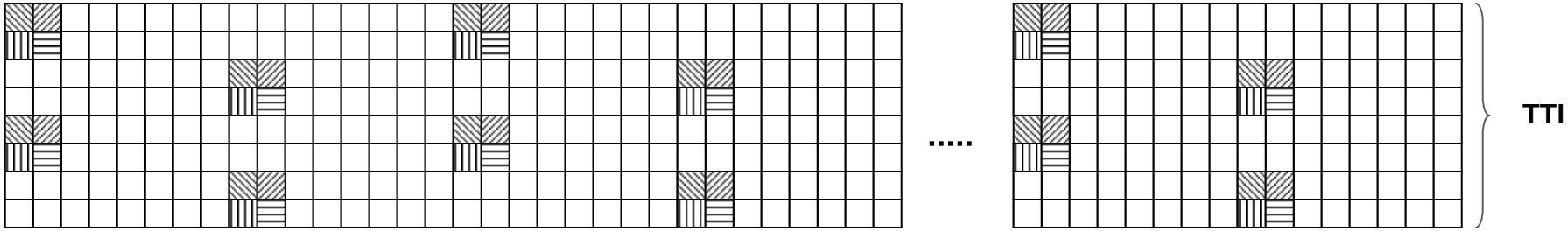
Pattern-2 (Overhead: 1/32 per Antenna)

For single antenna case



For 4antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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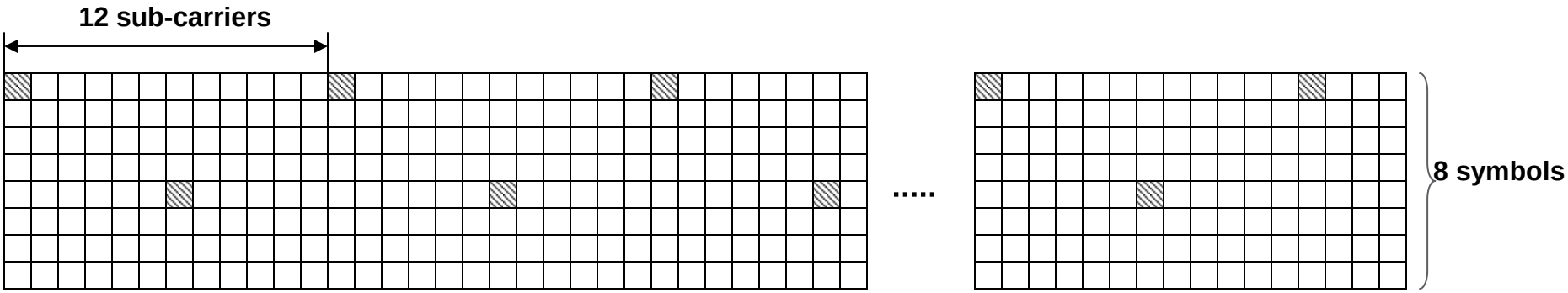
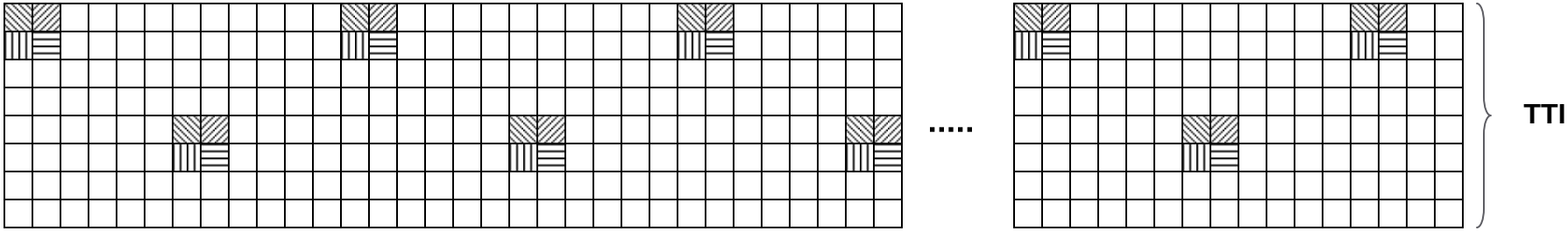
Pattern-3 (Overhead: 1/48 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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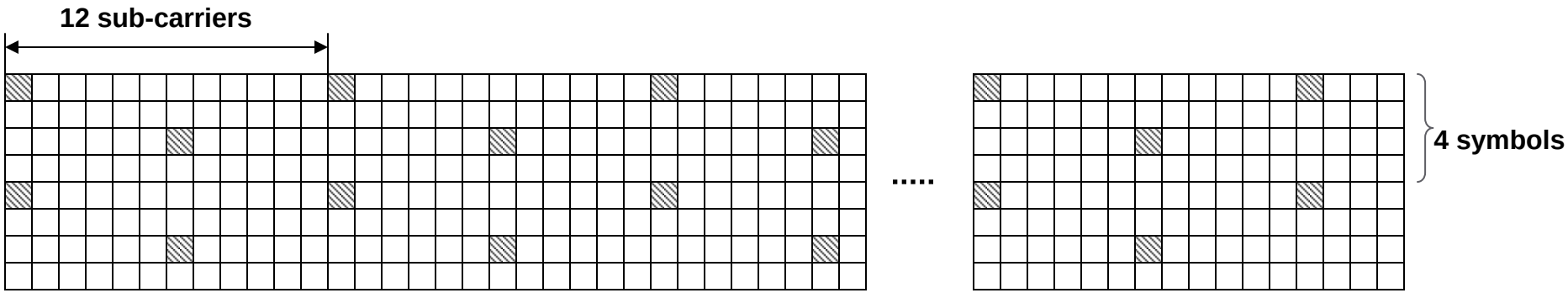
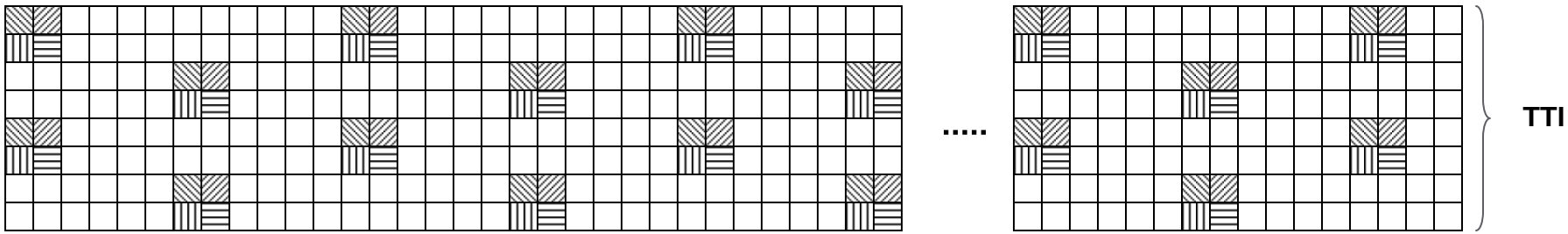
Pattern-4 (Overhead: 1/24 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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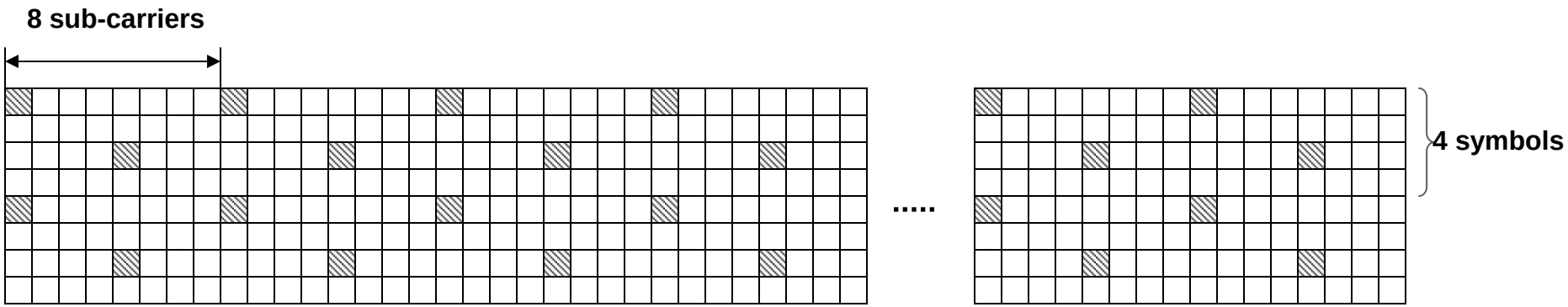
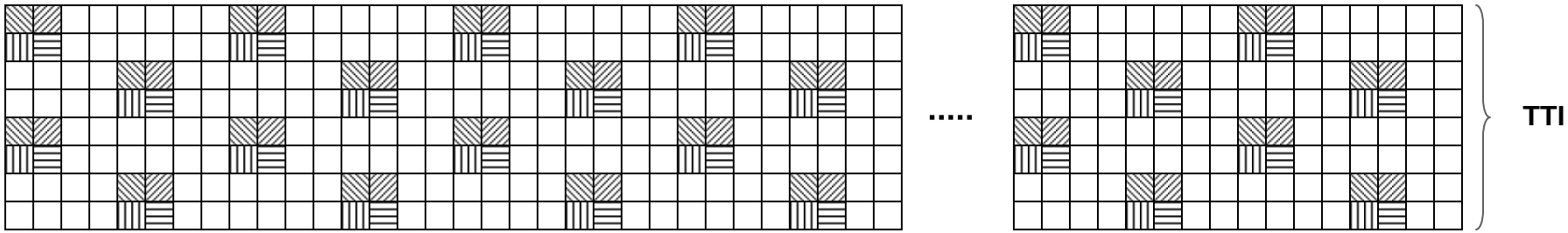
Pattern-5 (overhead: 1/16 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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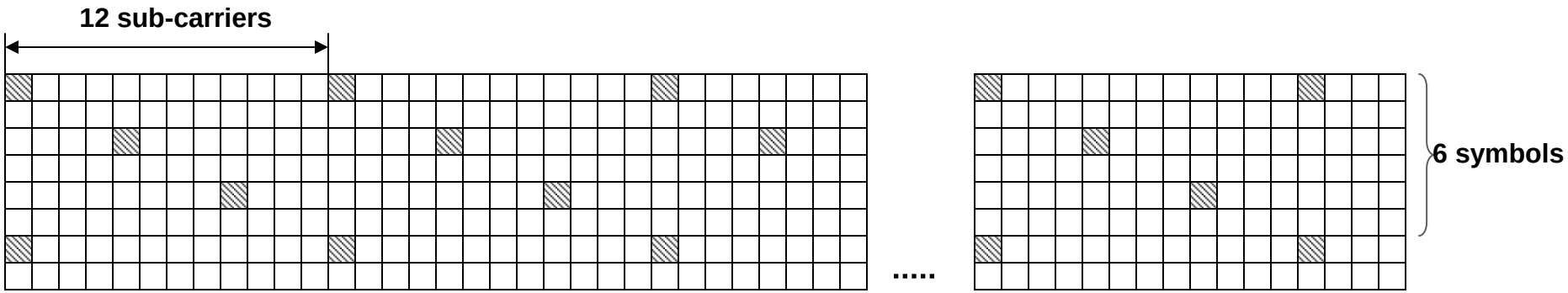
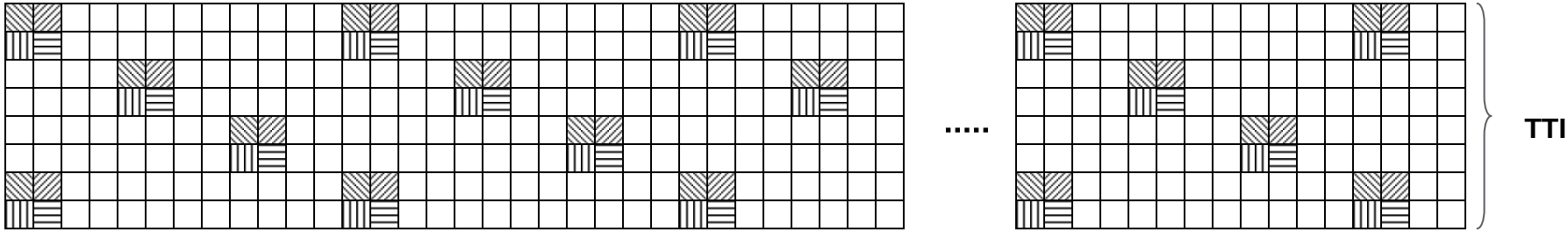
Pattern-6 (Overhead: 1/24 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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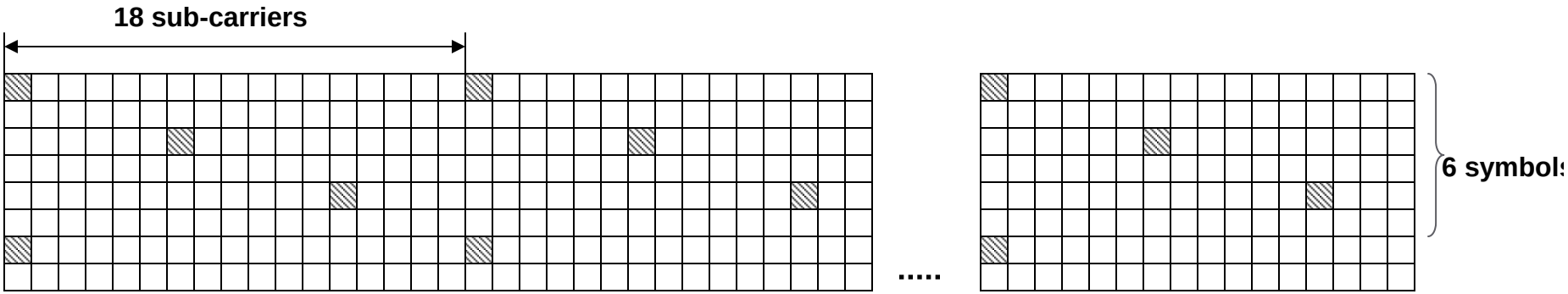
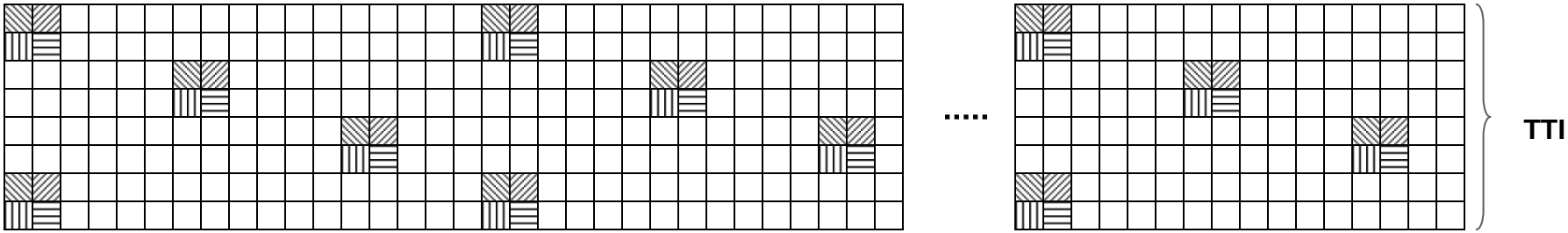
Pattern-7 (Overhead: 1/36 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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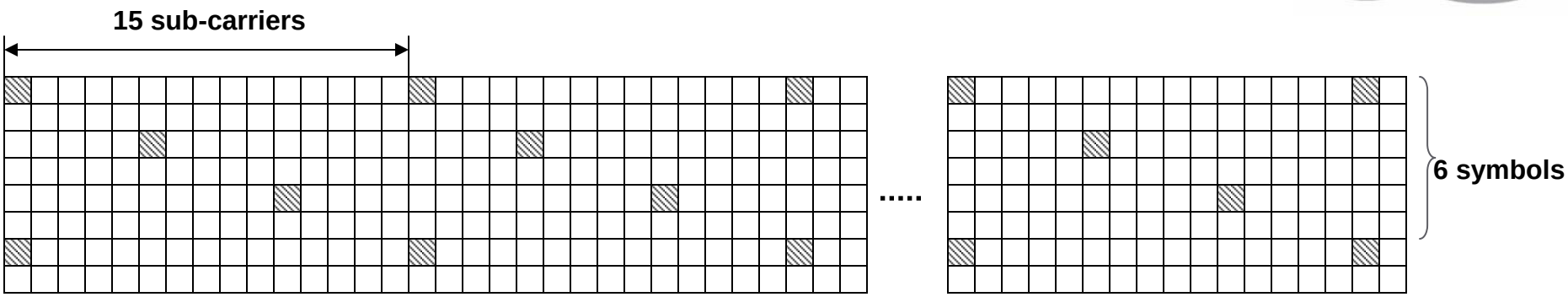
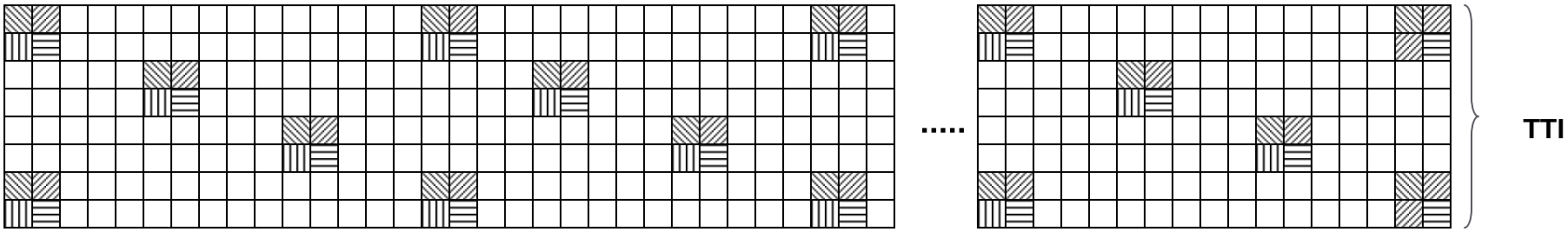
Pattern-8 (Overhead: 1/30 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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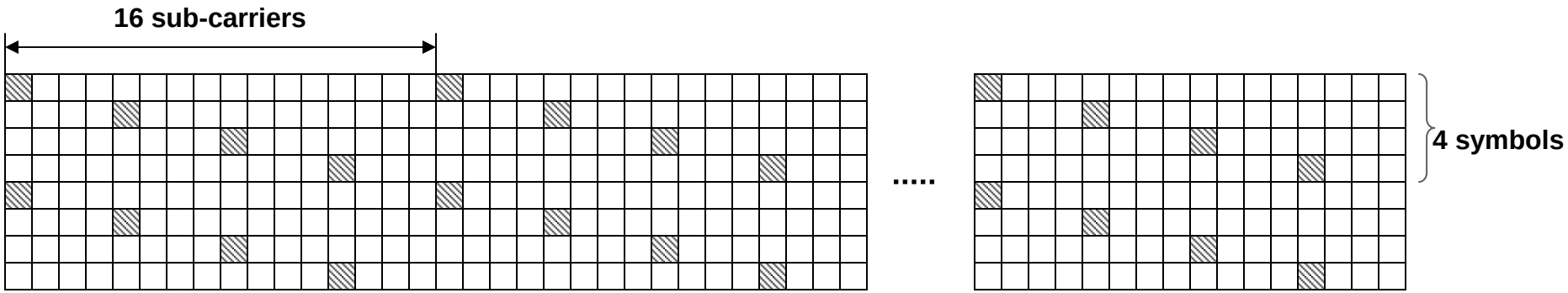
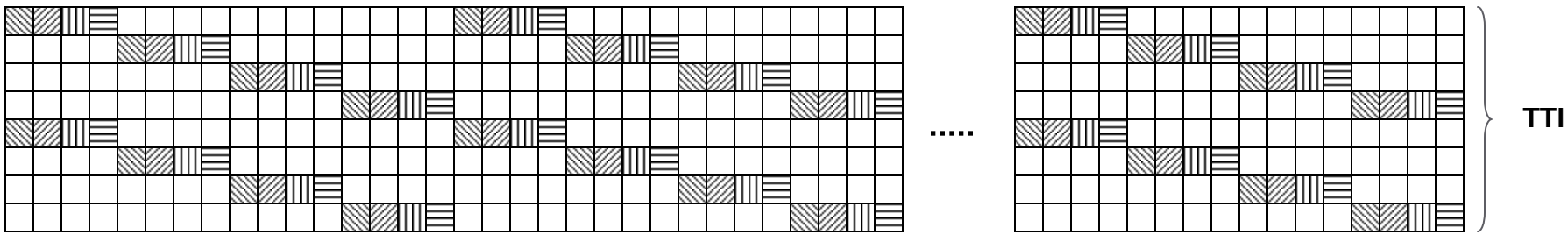
Pattern-9 (Overhead: 1/16 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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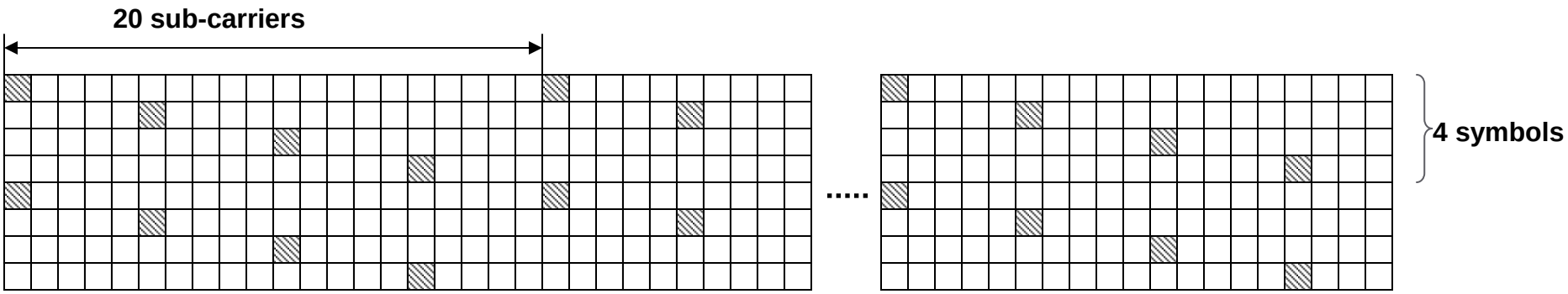
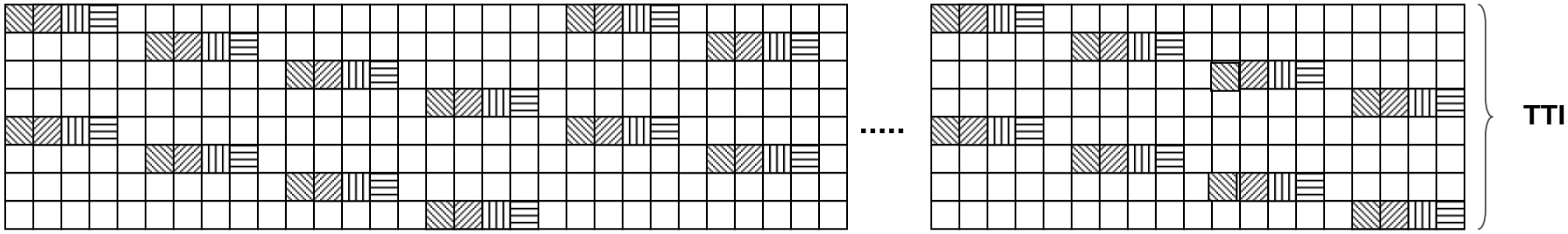
Pattern-10 (Overhead: 1/20 per Antenna)

For single antenna case



For 4 antenna case



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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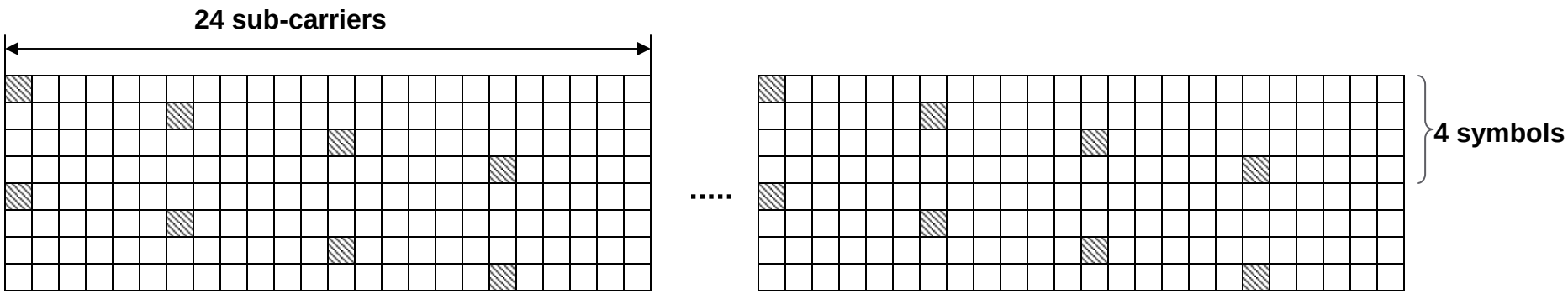
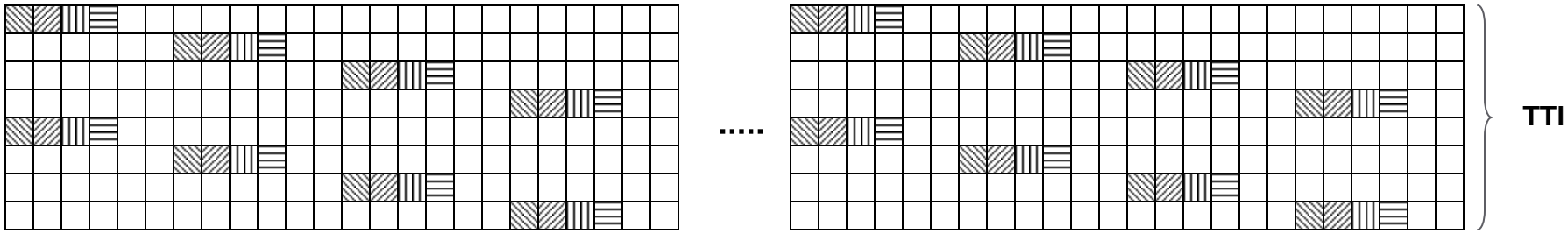
Pattern-11 (Overhead: 1/24 per Antenna)

For single antenna case



For 4 antennas case



Scattered Pilot for Antenna 1 **Scattered Pilot for Antenna 3** **Data**

Scattered Pilot for Antenna 2 **Scattered Pilot for Antenna 4**

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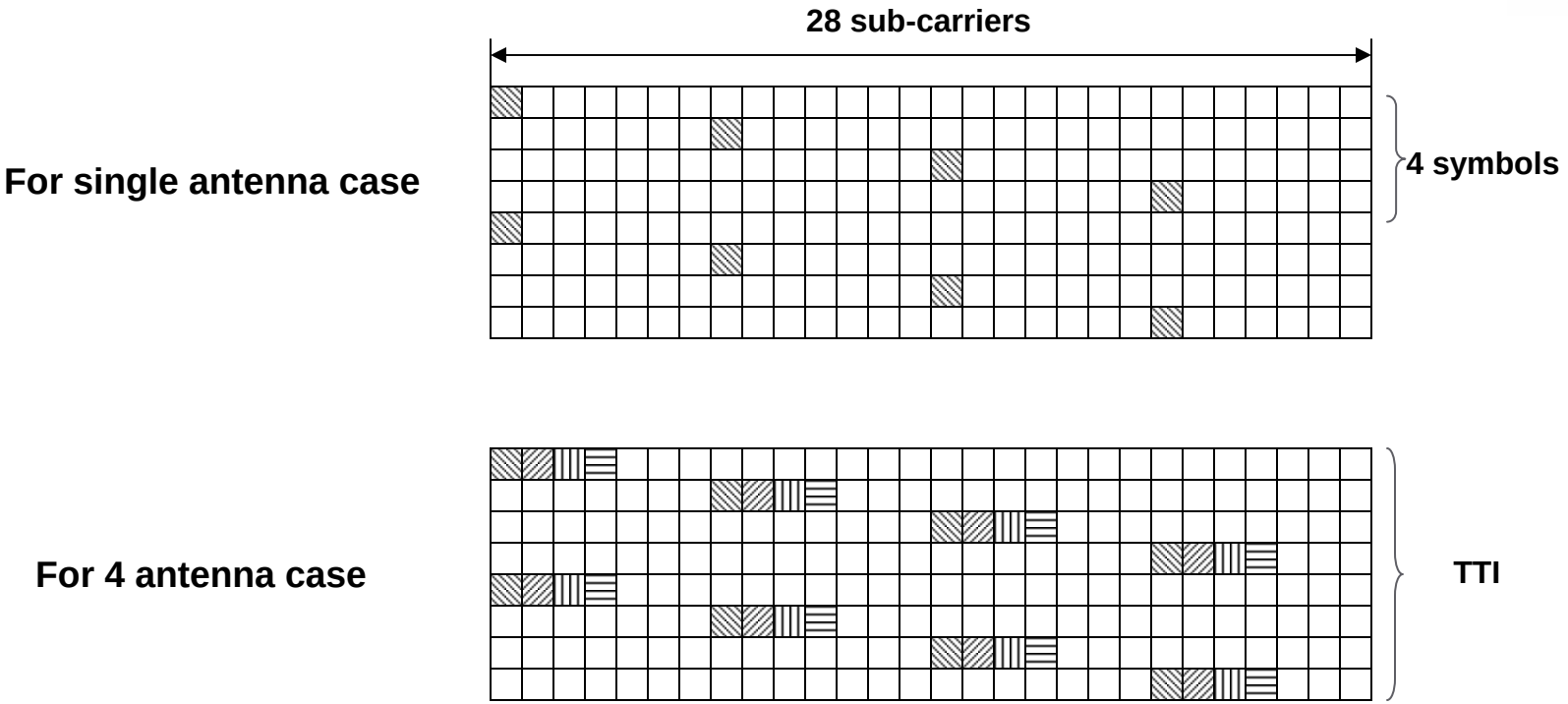
Pattern-12 (Overhead: 1/28 per Antenna)



Scattered Pilot for Antenna 1

Scattered Pilot for Antenna 2

Scattered Pilot for Antenna 3

Scattered Pilot for Antenna 4

Data

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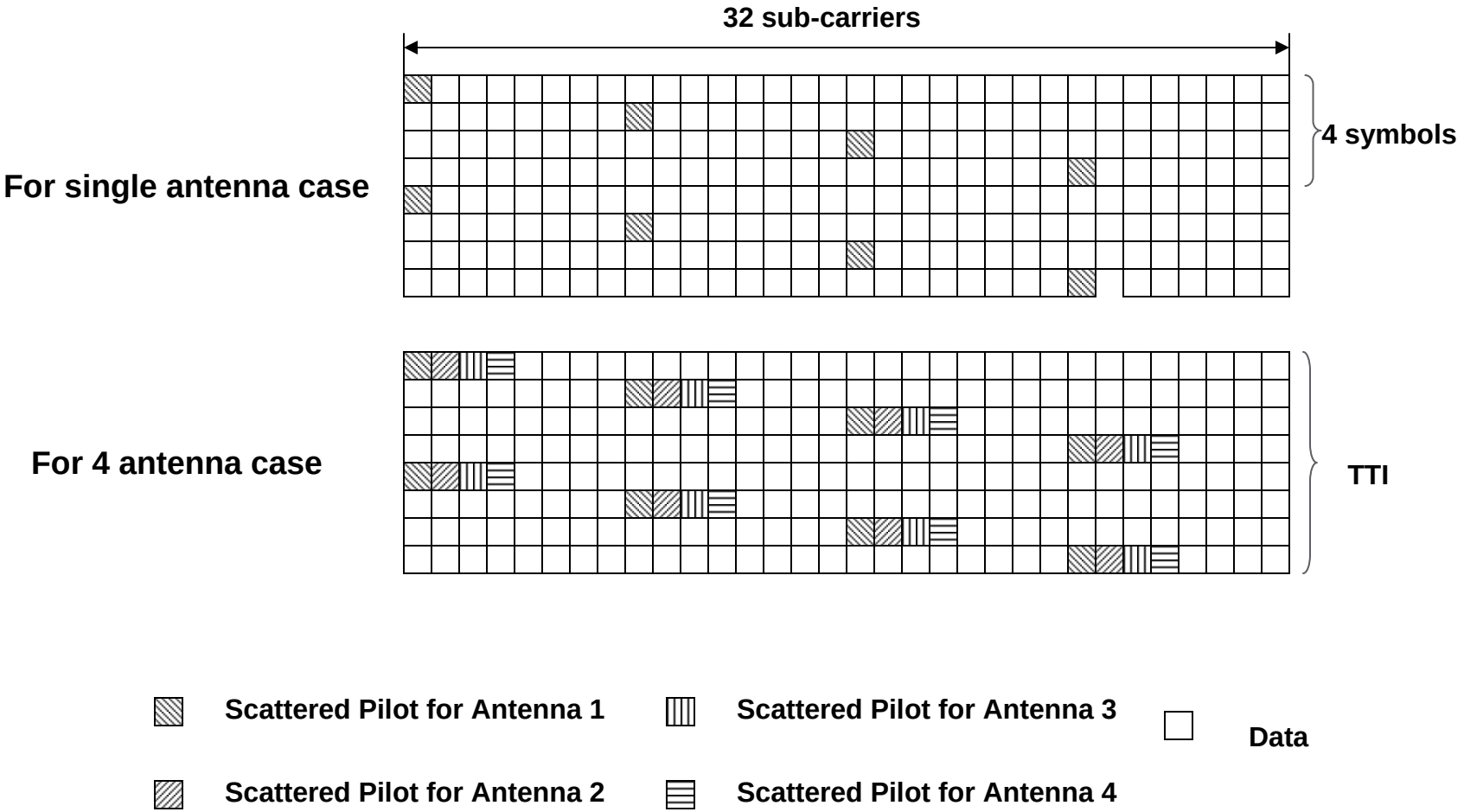
Pattern-13 (Overhead: 1/32 per Antenna)



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Simulation Conditions

> Channel bandwidth: 5 MHz

> Sampling frequency: 6.72 MHz

> FFT size: 512

> Sub-carrier spacing: 13.125 KHz

> OFDM symbol duration: 83.33 us

> Number of used sub-carriers per OFDM symbol: 320

> Carry frequency: 2 GHz

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Channel Scenarios

No.	Channel Scenarios
1	PA, 3km/hr
2	PB, 3km/hr
3	VA, 30 km/hr
4	VA, 60 km/hr
5	VA, 150 km/hr
6	VA, 350 km/hr
7	VB, 30 km/hr
8	VB, 60 km/hr
9	VB, 150 km/hr
10	VB, 350 km/hr

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Channel Interpolation Algorithm

> Two steps channel interpolation:

- First step: 2nd order lagrange interpolator along time dimension
- Second step: 3rd order lagrange interpolator along frequency dimension

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Performance Comparison Criterion

$$SIR = mean\left[10 * \log 10\left(1 + \gamma_{ij}\right)\right]$$

$$\gamma_{ij} = \frac{|H_{ij}|^2}{|H_{ij} - \hat{H}_{ij}|^2}$$

H_{ij} is the known frequency domain channel response for ith sub-carrier at jth OFDM symbol

$\hat{H}_{ij}$ is the estimated frequency domain channel response for ith sub-carrier at jth OFDM symbol

Average is done over all used sub-carriers during 10 TTIs.

- **One TTI consists of 8 consecutive OFDM symbols.**

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Pilot Pattern Performance Comparison (SIR in dB)

Pilot Pattern (overhead per antenna)	Channel Scenarios									
	1	2	3	4	5	6	7	8	9	10
1 (1/32)	125	73	69	58	36	17	30	25	21	15
2 (1/32)	104	48	51	50	46	33	26	22	21	19
3 (1/48)	111	55	56	52	34	15	24	20	17	13
4 (1/24)	116	60	62	61	53	36	30	26	24	22
5 (1/16)	133	80	78	75	59	40	38	34	31	27
6 (1/24)	128	75	72	66	45	26	33	28	24	20
7 (1/36)	113	57	58	56	42	23	26	22	20	16
8 (1/30)	120	65	64	61	43	24	29	24	21	18
9 (1/16)	133	80	78	75	59	40	38	34	30	27
10 (1/20)	123	69	69	67	55	37	33	29	26	24
11 (1/24)	116	60	61	61	52	35	30	26	24	22
12 (1/28)	109	54	55	55	49	34	27	24	22	20
13 (1/32)	104	48	51	50	46	32	26	22	21	19

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Observations and the Conclusions

> For the same pilot arrangement, the higher the pilot density, the better the overall channel interpolation performance:
  - Pilot patterns with 1/16 overhead provide best performance
    - Good performance for all the channels scenarios simulated
  - Pilot pattern 3 with 1/48 overhead has the worst performance
  - Overall reasonable performance can be obtained from pilot patterns with 1/28, 1/30 or 1/32 overhead.

> For the same pilot overhead
  - Type-1 and type-4 pilot arrangements provides the similar performance
    - Same equivalent pilot spacing in time and frequency
    - Type-1 is preferred for the flexibility to be extended to MIMO pilot pattern
  - For speed less or equal to 60 km/h, type-3 pilot pattern provides better channel interpolation performance
    - Denser pilot insertion in frequency
  - For speed larger than 60 km/h, type-1 (4) pilot pattern provides better channel interpolation performance
    - Denser pilot insertion in time
  - Type-2 pilot arrangement is the trade off between type 1 (4) and type 3.

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