Performance Evaluation for IEEE 802.16m Downlink Pilot Structure

Document Number: IEEE C802.16m-08/618r1

Date Submitted: 2008-07-15

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*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Re: IEEE 802.16m-08/024 Call for Comments on Project 802.16m System Description Document (SDD) on the topic of DL pilot.

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

Scope

- Evaluating pilot structures, and their variations, as proposed by different proponents
- Make recommendation on pilot structures to be adopted in SDD

Summary of Pilot structures proposed

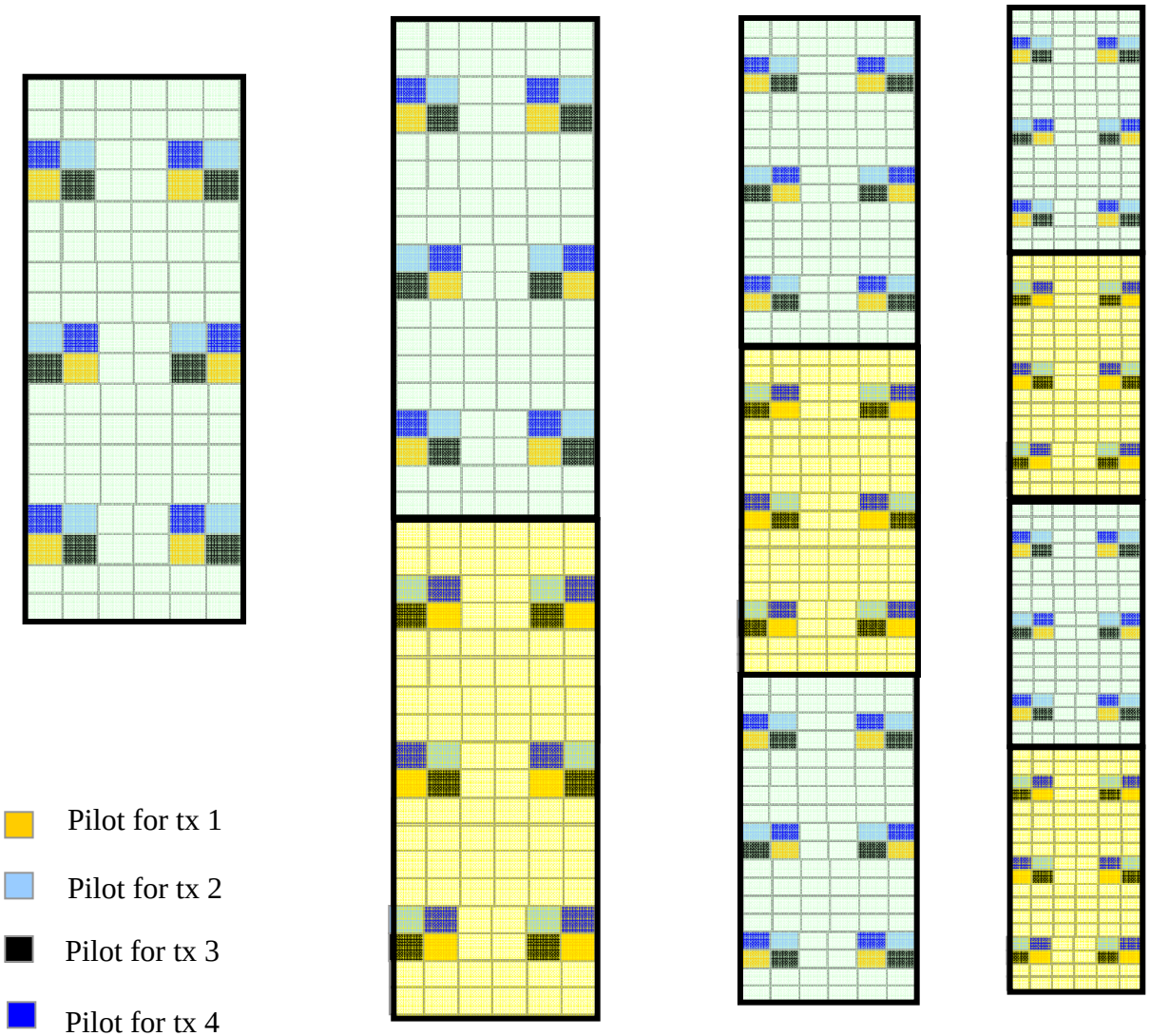
	Common and dedicated pilot	Source
Alcatel Shanghai Bell	Unified	08/433r1
Intel	Unified	Phy-017, harmonized in 08/648
LGE	Unified	Phy-025r2
MediaTek	Dedicated only	Phy-011, harmonized in 08/648
Motorola	Dedicated only	Phy-010
Nortel	Unified	Phy-019 variation for 18x6 PRU
Samsung	Unified	Phy-029, new 2 Tx in 08/672r1

Pilot structures Proposed by Nortel (1/3)

- Nortel proposed unified pilot structure design in March meeting (C80216m-08_172r1). The highlights of the design is described as following
  - Staggered pilot pattern
  - Boundary pilot design at resource boundary for avoiding extrapolation in both time and frequency direction
  - Pilot structure allows 1D channel estimation
  - Unified pilot structure for common pilot and dedicated pilot
- Following these design principles, pilot structure can be derived for single PRU (18x6) and multiple PRUs.

Pilot structures Proposed by Nortel (2/3)

For single and multiple PRUs



Pilot for tx 1

Pilot for tx 2

Pilot for tx 3

Pilot for tx 4

1. **Pilots are allocated at or near the resource boundaries**
2. **Pilot distribution in frequency direction should be as uniform as possible**
3. **Pilot for each Tx antenna is staggered**

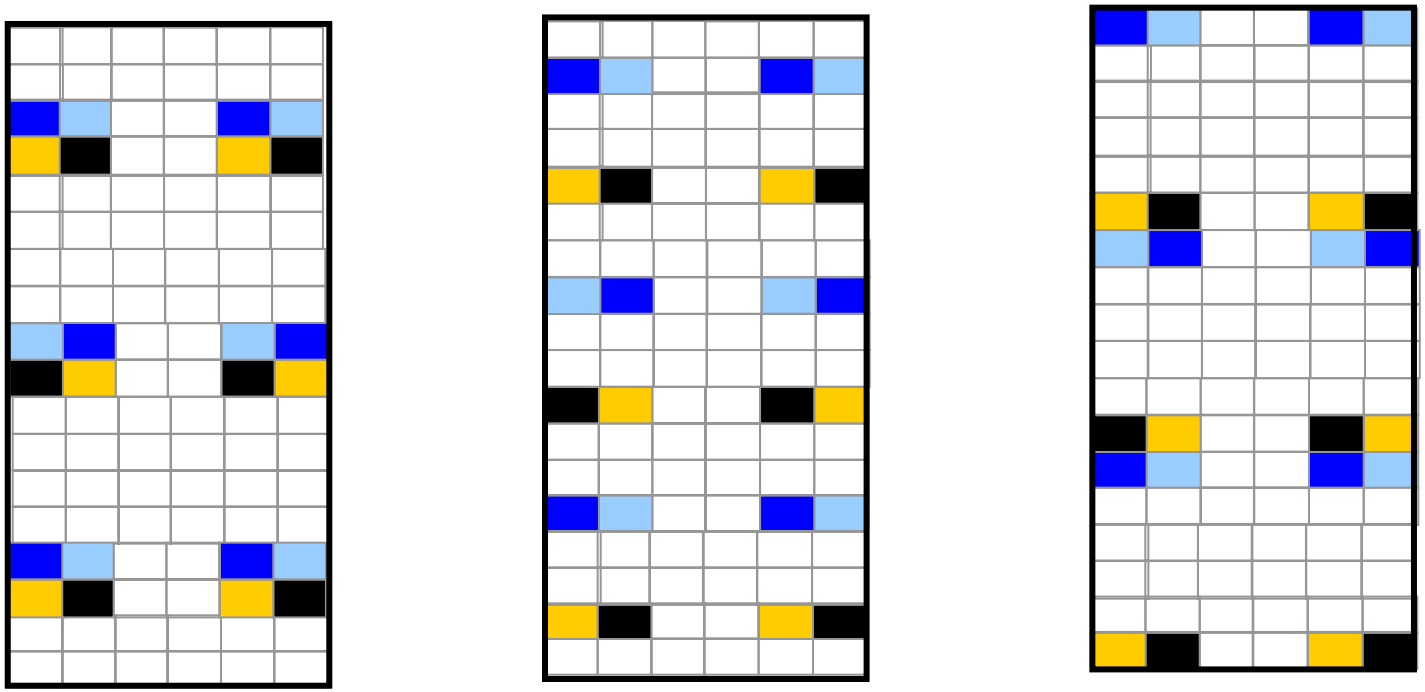
…….

Pilot pattern 1

Pilot pattern 2

Pilot structures Proposed by Nortel (3/3)

For multiple cells



Cell 1

Cell 2

Cell 3

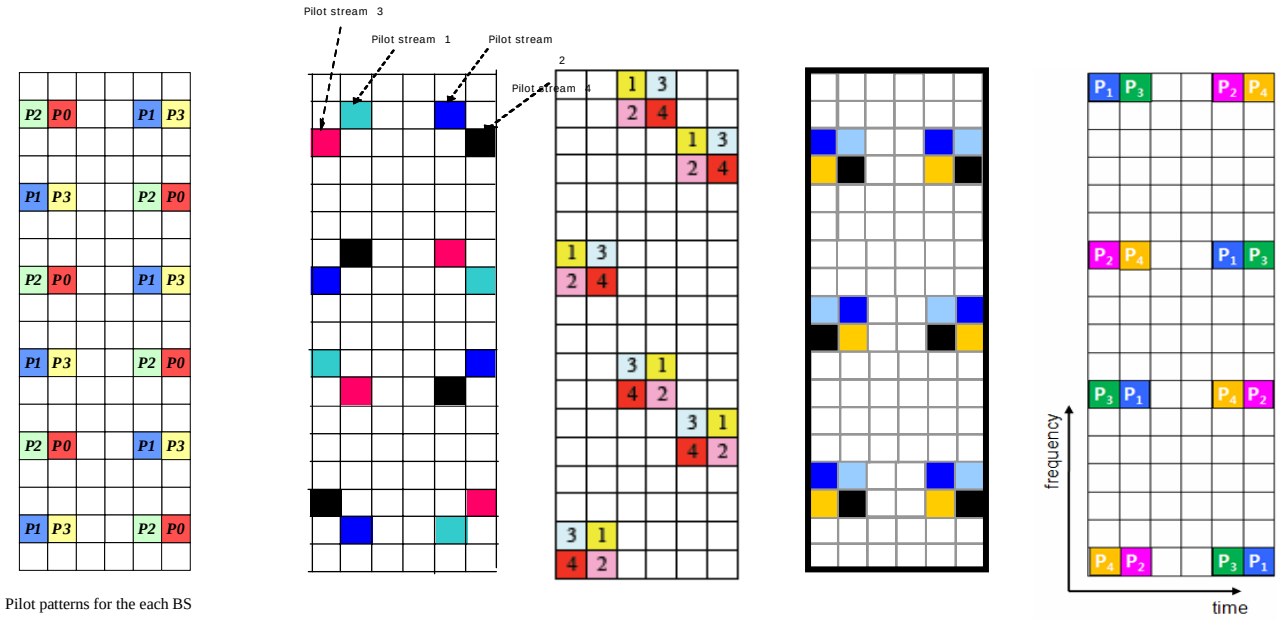
Pilot for tx 1

Pilot for tx 2

Pilot for tx 3

Pilot for tx 4

Unified pilot structure for 4 Tx and Single PRU



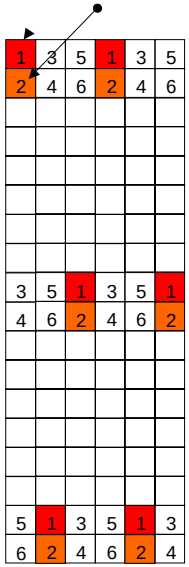
Pilot patterns for the each BS

Alcatel Shanghai Bell **Intel B** **LGE** **Nortel** **Samsung**

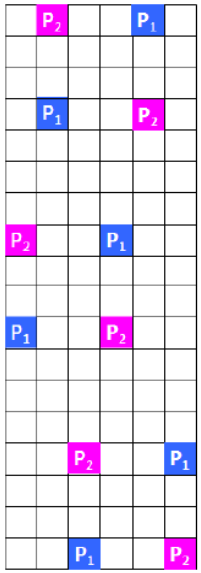
Pilot structure for 1-3 Tx antennas can be derived from these pilot structures, except Samsung's and Intel's

Unified Pilot structure for 2 Tx and Single PRU

which are not derived from pilot structure for 4 Tx



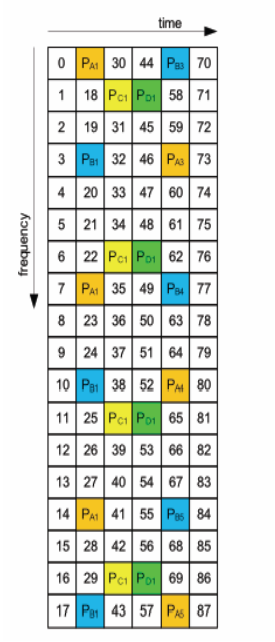
Intel/MediaTek (Harmonized)



Samsung

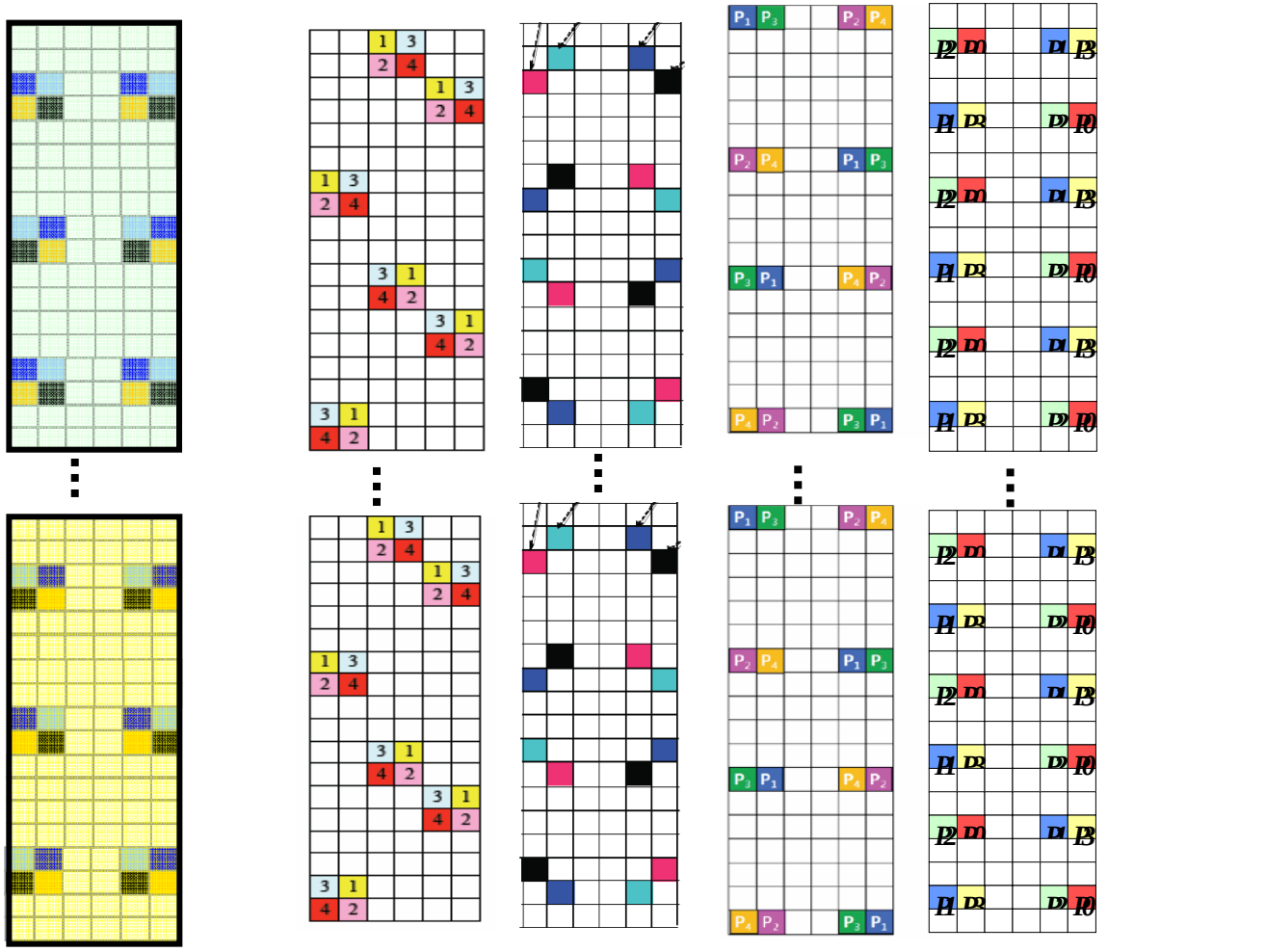
Intel/MediaTek has three variations of the pattern for different cells

Non-Unified Pilot Structures



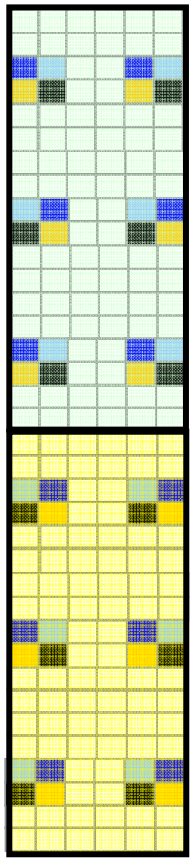
Motorola
Dedicated only

Common pilots for 4 Tx and multiple PRUs

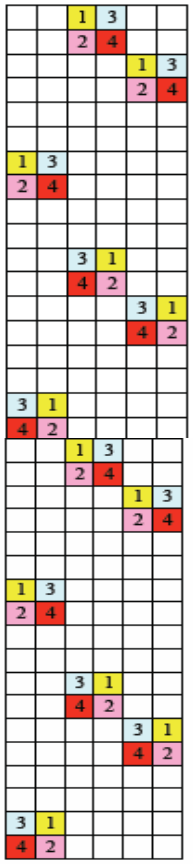


Nortel LGE Intel B Samsung B Alcatel Shanghai Bell

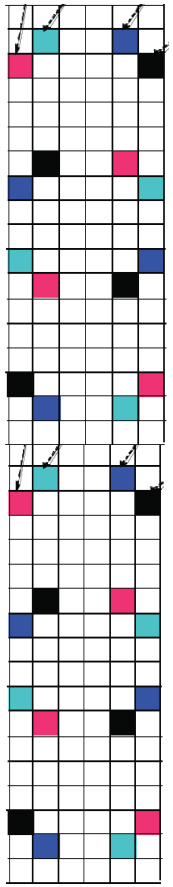
Dedicated pilot for 4 Tx and 2 PRUs



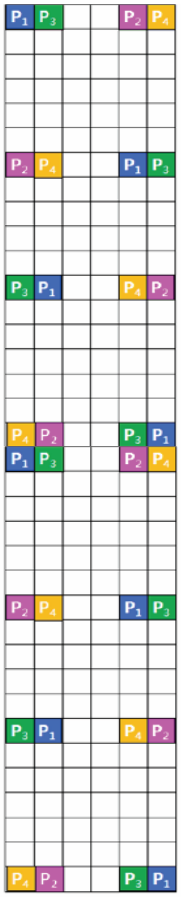
Nortel



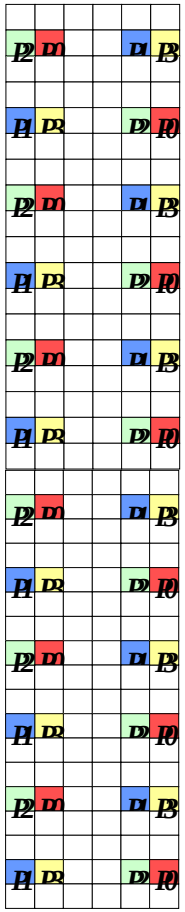
LGE



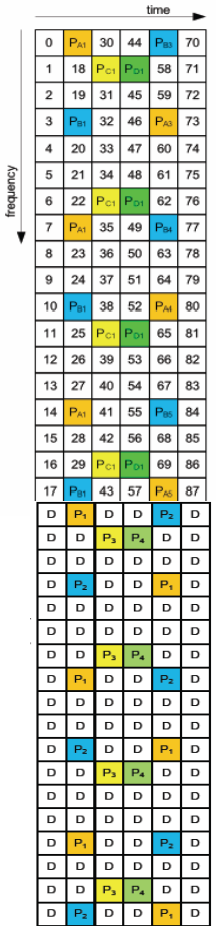
Intel B



Samsung B



Alcatel Shanghai Bell

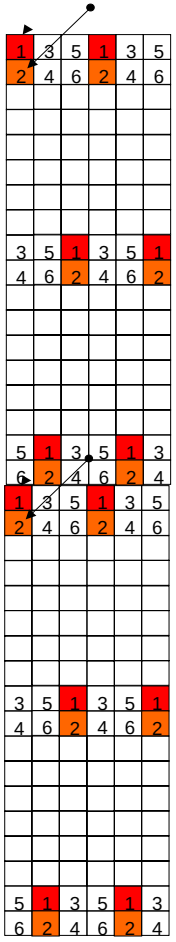


Motorola

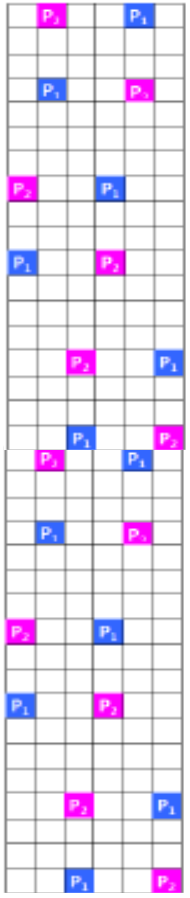
Dedicated Pilot for 2 Tx and two PRUs

which are not derived from pilot structure for 4 Tx

Intel's has three variations of the pattern for different cells



Intel/MediaTek



Samsung A

Evaluation assumption: General

- Adopt the simulation parameters and performance metrics for evaluation pilot patterns as agreed in IEEE C802.16m-08/518
  - VA 240km/h is added to make transition point more clear for some speed sensitive pilot structures
- Pilot structure designs for regular 18x6 PRU are evaluated
  - Pilot structures and their variations are proposed by RG members
- Simulation parameters: 10MHz, 2.5GHz, 1024-FFT with 864 useful subcarriers.

Evaluation assumption: Channel Estimation

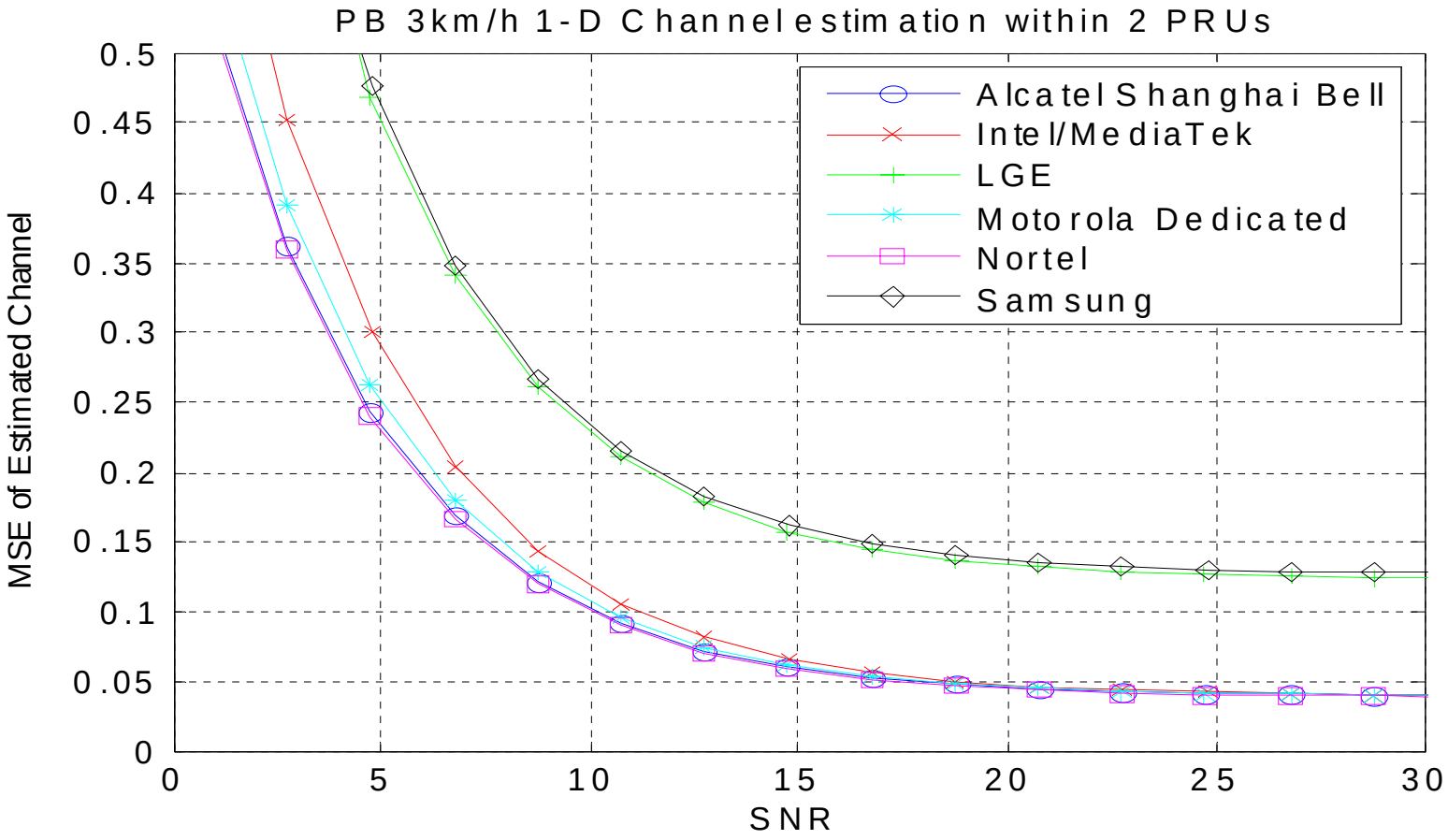
- For testing pilot structure robustness under different channel estimation method, the following channel estimation methods are compared for selected cases:
  - 1-D interpolation without de-noising
  - 1-D interpolation with 1-D MMSE de-noising and estimated channel covariance
  - 2-D MMSE with ideal channel covariance
- For common pilot, channel estimation is over all PRUs in a sub-frame. Data packet is distributed over all PRUs.
  - MIMO scheme: 1 stream, 4x2 SFTD
- Pilot power boosting level: pilot power are boosted by borrowing power from vacant pilot tones for other Tx in the same symbol.
  - Data tone power is not affected
  - Total OFDM symbol power is not affected
  - This is for reason of simple and fare comparison. Optimal pilot boosting level is FFS

Pilot structure evaluation for dedicated pilot

- Evaluation conditions:
  - Data block size is 2 PRUs and allocated in two contuous PRUs
  - Dedicated pilots are allocated over 2 contiguous PRUs PRUs
- Channel estimation methods
  - Channel 1-D interpolation is within 2 PRUs
    - 1-D interpolation adaptive to channel and speed
      - At low speed, time direction interpolation is done first
      - At high speed, frequency direction interpolation is done first
    - 1-D interpolation can be done in two way with different complexity
      - 1-D interpolation without de-noising. It is straightforward interpolation by using pilot tone. Performance is good at high SNR range and complexity is low
      - 1-D interpolation with 1-D MMSE de-noising. It provides good performance at low SNR. Covariance matrix are estimated based on available tones. Complexity is menium
  - 2-D MMSE channel estimation for 1 PRU (each of 2 PRUs)
    - Complexity is the highest
    - Need pre-defined, or estimated covariance matrix

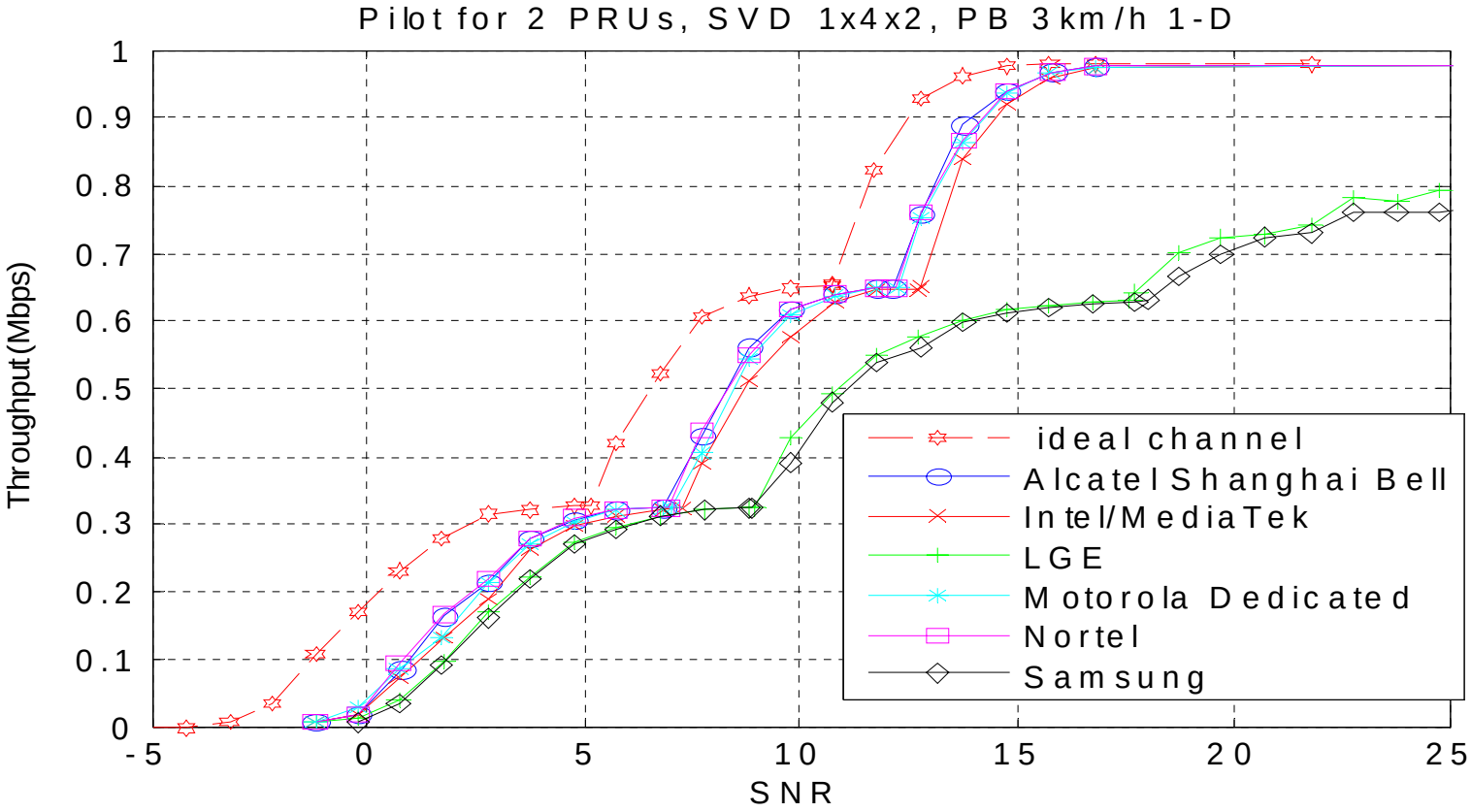
Pilot structure evaluation for dedicated pilot Using 1-D interpolation without de-noising

MSE of 1-D channel estimation within 2 PRUs PB 3km/h



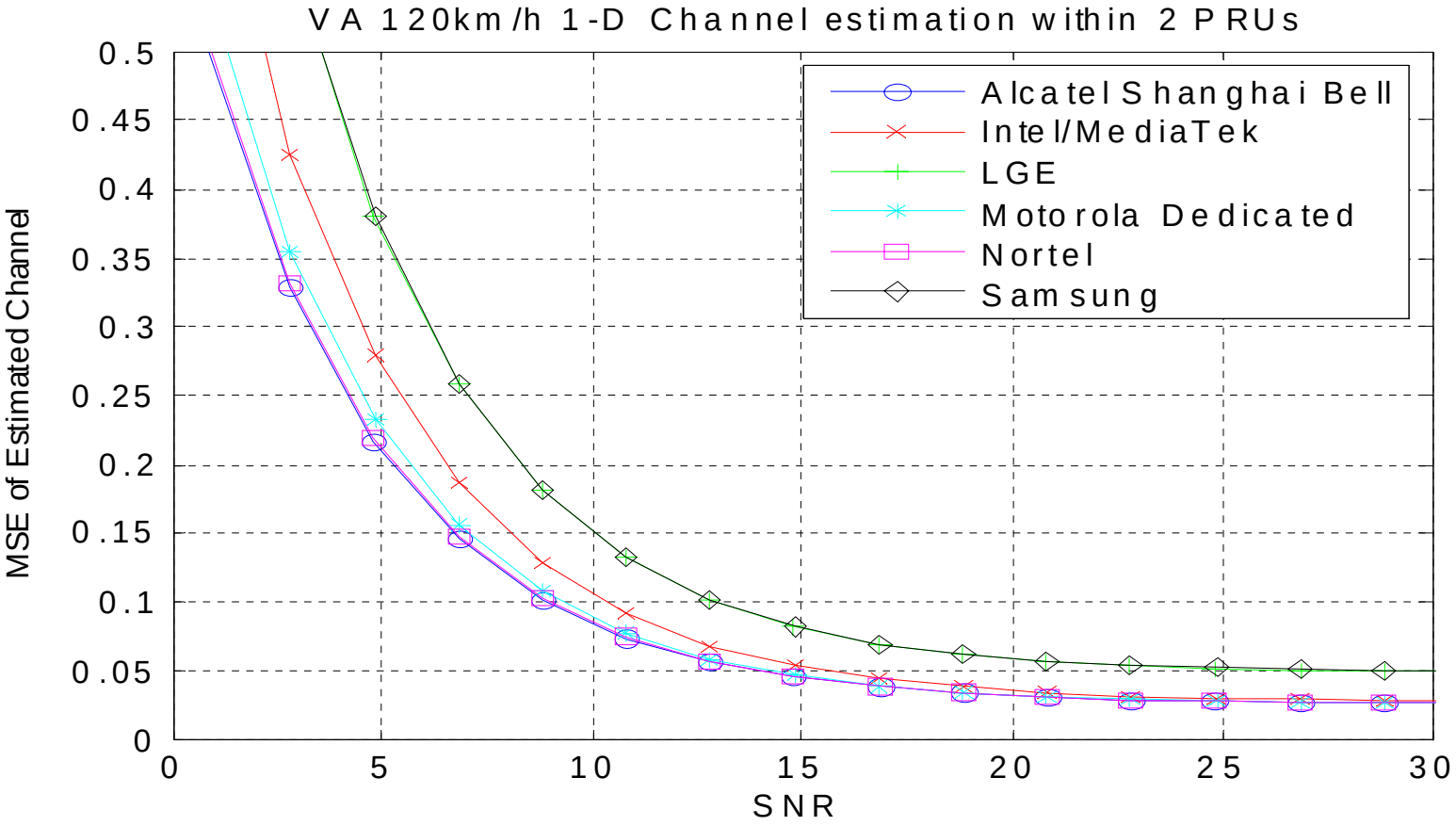
Nortel's and Alcatel Shanghai Bell's are the best at PB 3km/h

Goodput of 1-D channel estimation within 2 PRUs PB 3km/h



Nortel's and Alcatel Shanghai Bell's are the best at PB 3km/h

MSE of 1-D channel estimation within 2 PRUs VA 120km/h



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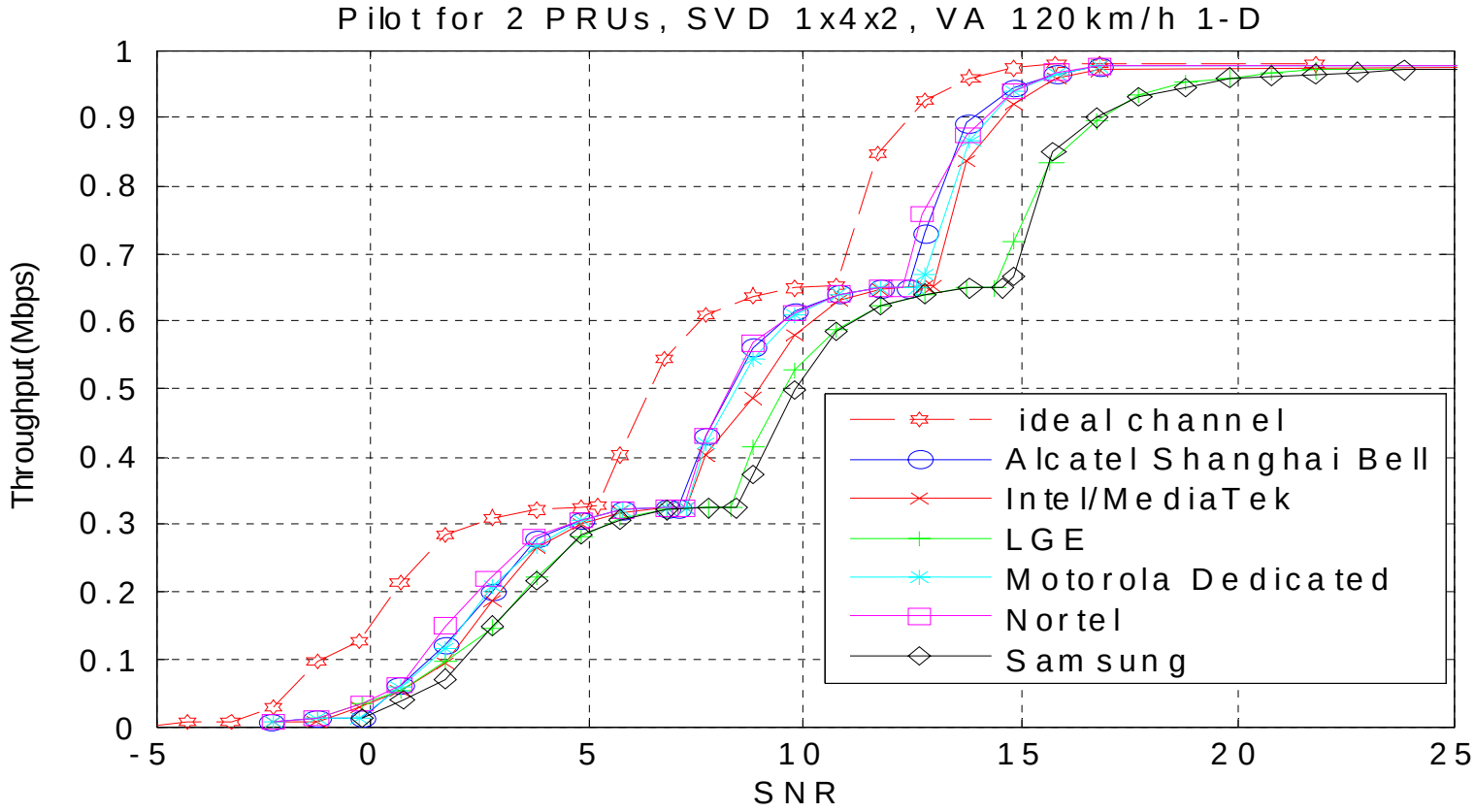
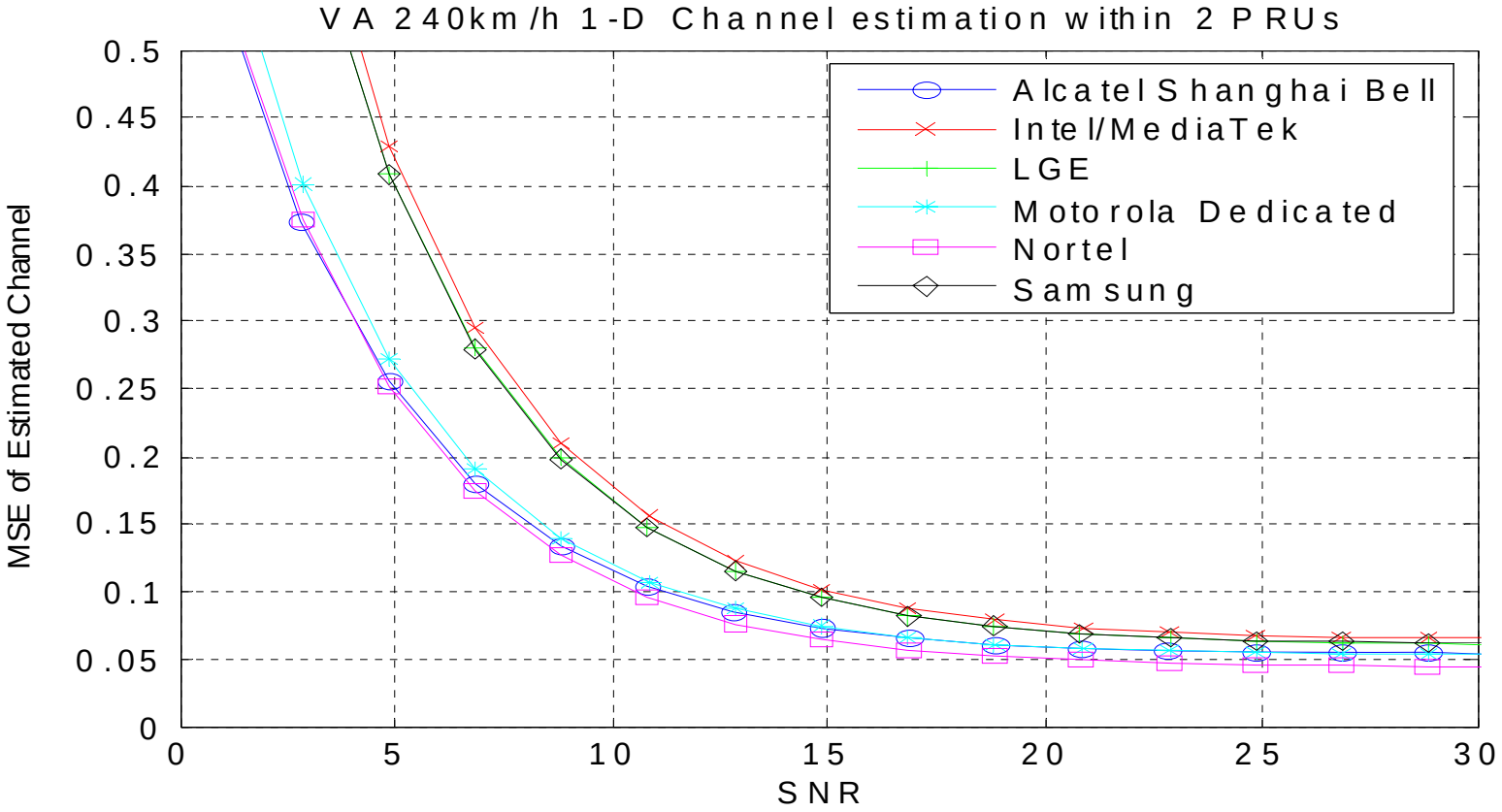
Goodput of 1-D channel estimation within 2 PRUs VA 120km/h



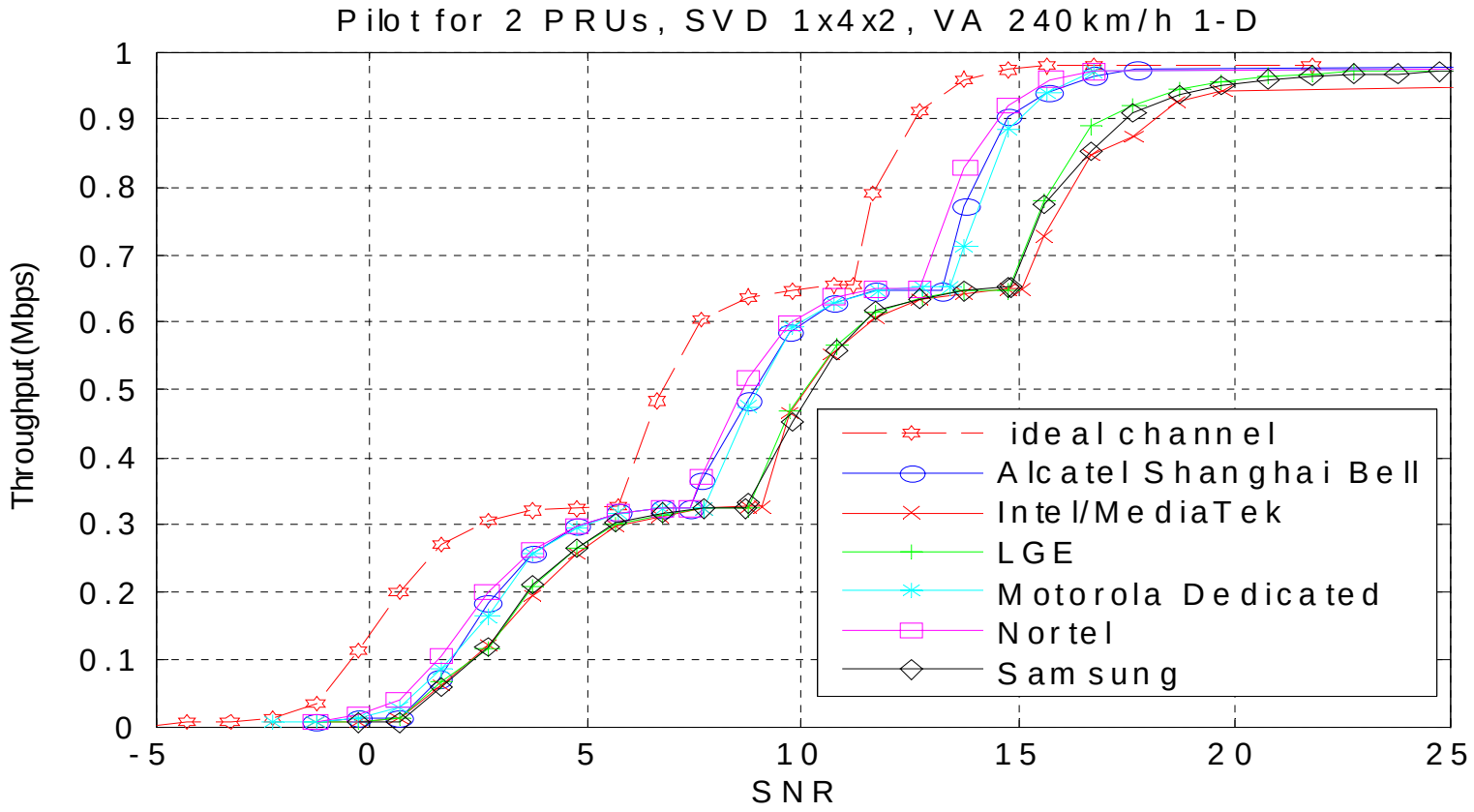
Nortel's and Alcatel Shanghai Bell's are the best at VA 120km/h

MSE of 1-D channel estimation within 2 PRUs VA 240km/h



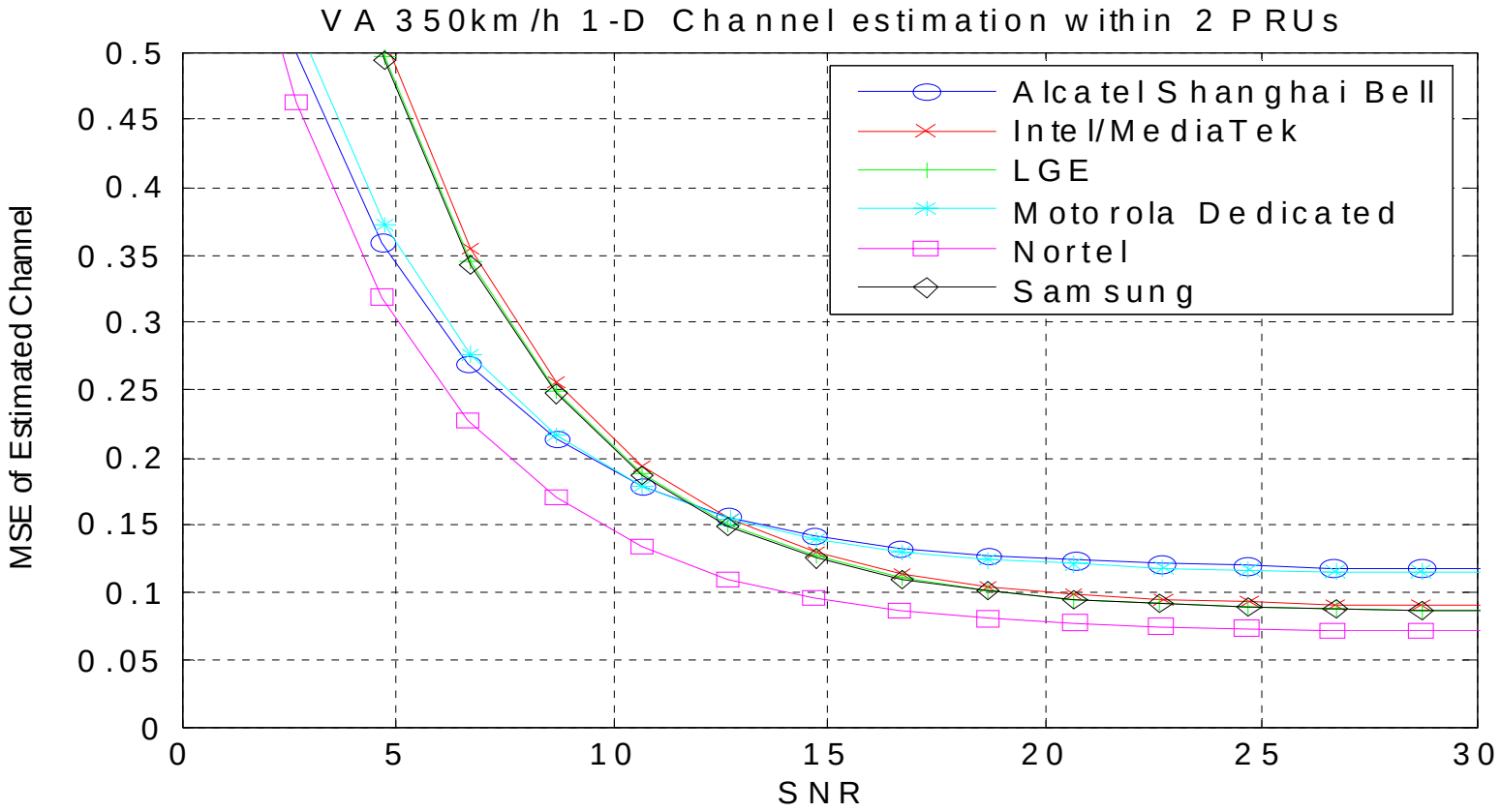
Nortel's is the best at VA 240km/h

Goodput of 1-D channel estimation within 2 PRUs VA 240km/h



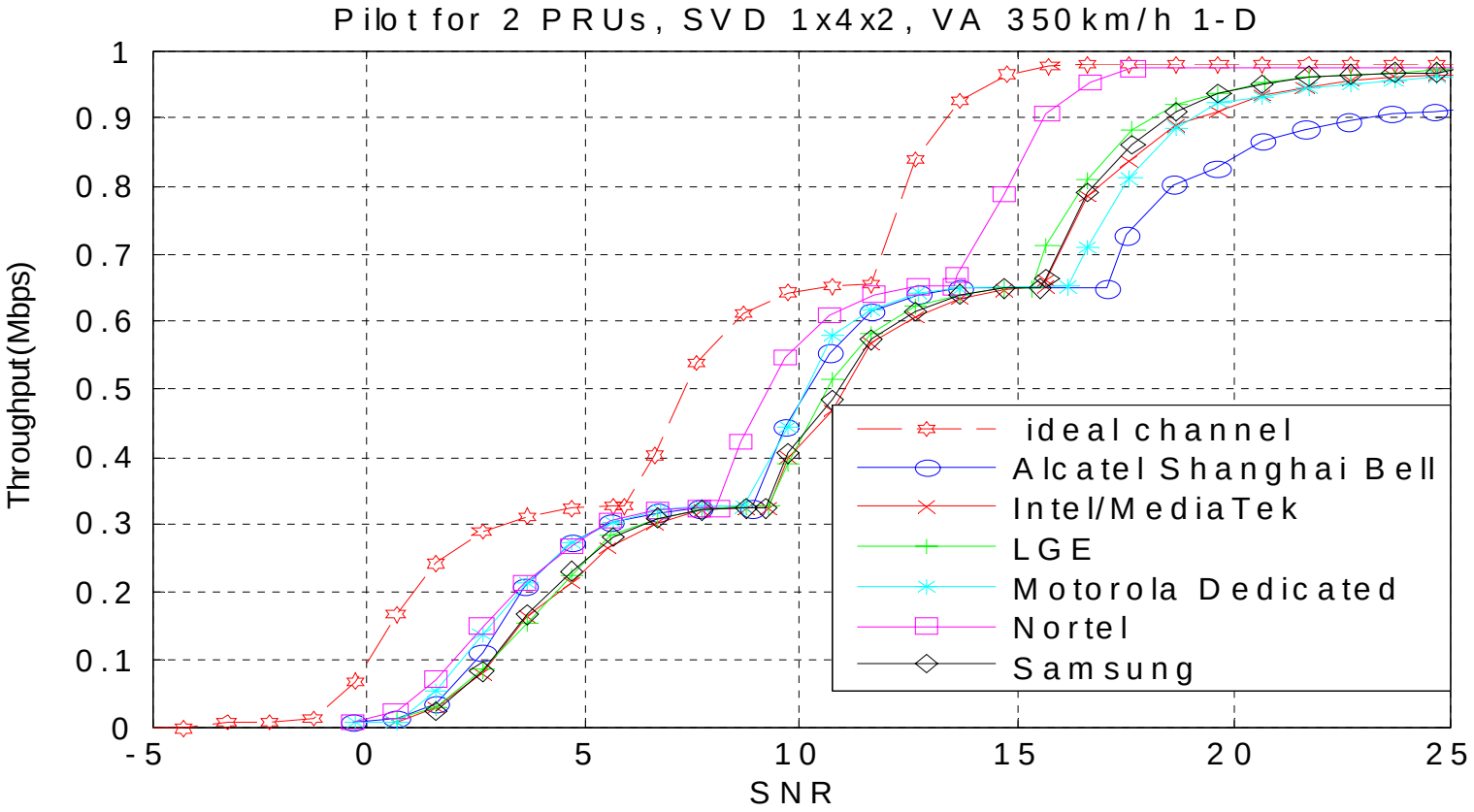
Nortel's is the best at VA 240km/h

MSE of 1-D channel estimation within 2 PRUs VA 350km/h



Nortel's is the best at VA 350km/h

Goodput of 1-D channel estimation within 2 PRUs VA 350km/h



Nortel's outperform others with large gain at VA 350km/h

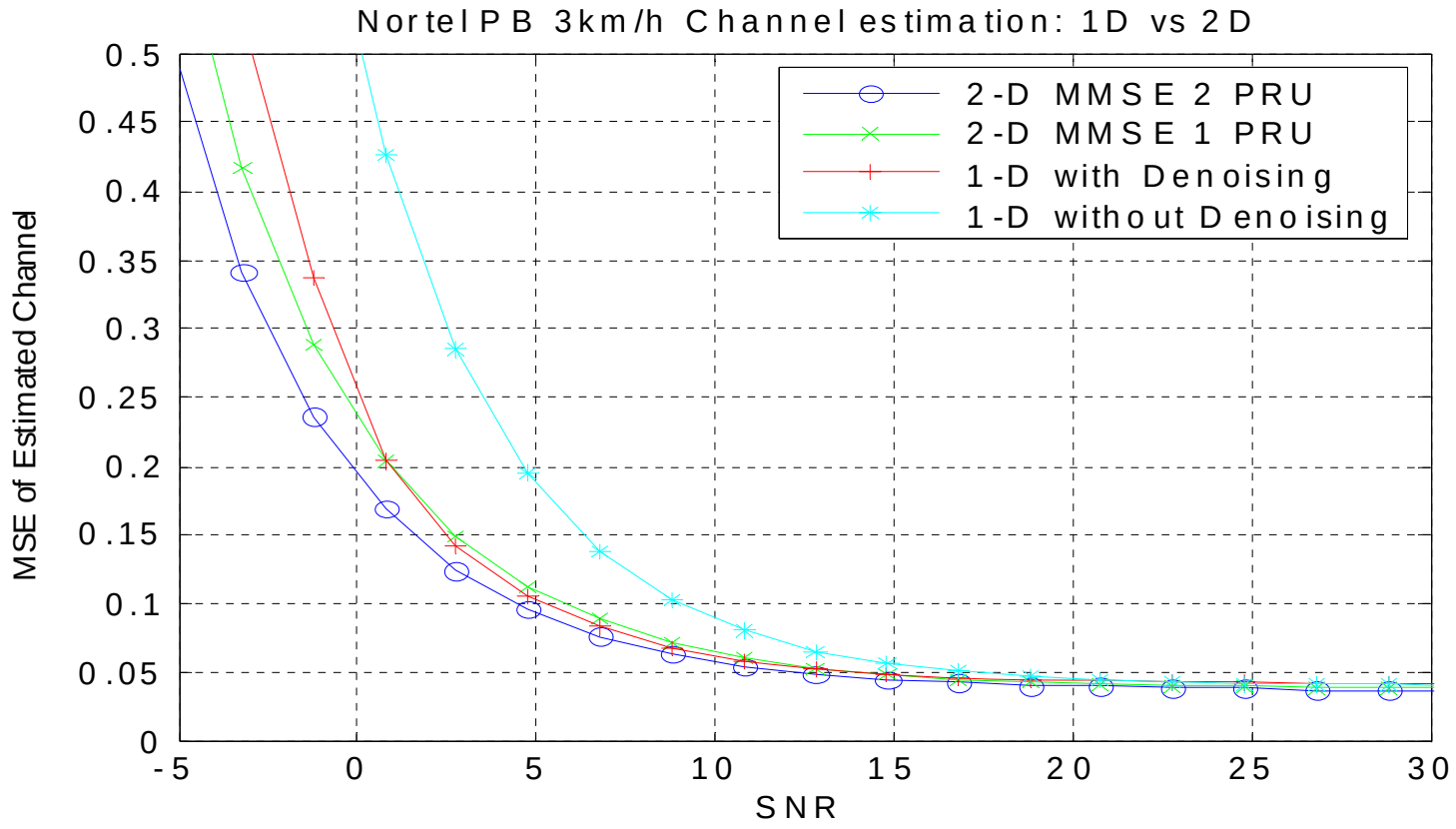
Why Different pilots perform differently within two PRUs

- Different pilot structure are differentiated by the following factors
  - Pilot allocation at time direction boundary symbols, which determines the performance at high speed, especially at 350km/h
    - Motorola's has two boundary symbols have no pilot at all. Alcatel Shanghai Bell's has one boundary symbol without pilot for each Tx. This is why Motorola's and Alcatel Shanghai Bell's perform the worst at 350km/h
  - Pilot spacing and Largest extrapolation distance in frequency direction and number of symbols affected
    - Samsung's, LGE's and Intel/MediaTek's has the same pilot spacing in frequency direction and similar largest extrapolation distance in frequency(~ 17). Intel/MediaTek's has four symbols affected by the largest extrapolation distance, more than others. This is why Intel/MediaTek's perform a bit worse than Samsung's and LGE's at both VA 240km/ha and VA 350km/h
    - Nortel's has smaller pilot spacing and extrapolation distance than others, except Alcatel Shanghai Bell and Motorola.
    - Alcatel Shanghai Bell and Motorola have the smallest frequency spacing before any interpolation. They perform close to the best at low speed.
  - Ability to do time direction interpolation first. This helps to improve performance at low speed, especially for dispersive channel like PB channel
    - Intel/MediaTek and Nortel' has time direction interpolation ability. After time direction interpolation, frequency direction spacing is shortened. Nortel get 6 and Intel/MediaTek's get 8. This further makes Nortel's perform a bit better than Intel/MediaTek's
    - Alcatel Shanghai Bell's has pilot spacing of 6, so it perform almost identical at PB 3km/h, although it has no option to do time direction interpolation first

Channel estimation: 1-D MMSE vs. 2-D MMSE

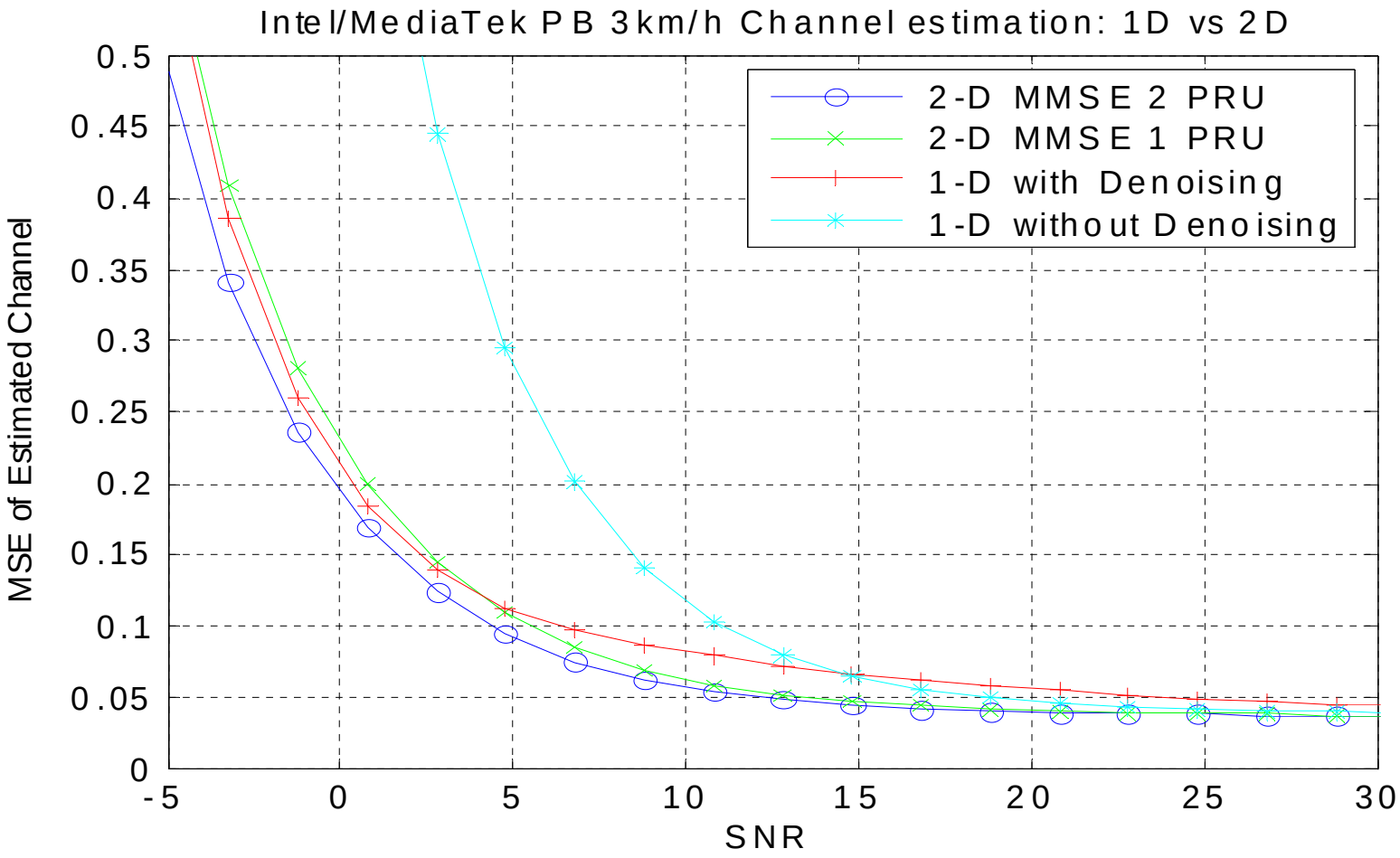
- 1-D MMSE de-noising followed by 1-D interpolation
  - Order of interpolation direction is adapted to channel environment
  - Covariance matrix for 1-D MMSE de-noising is estimated using available tones
- 2-D MMSE
  - Predefined covariance matrix based on to channel delay spread and Doppler
  - Applied to each of two PRUs

1-D MMSE vs. 2-D MMSE: Nortel



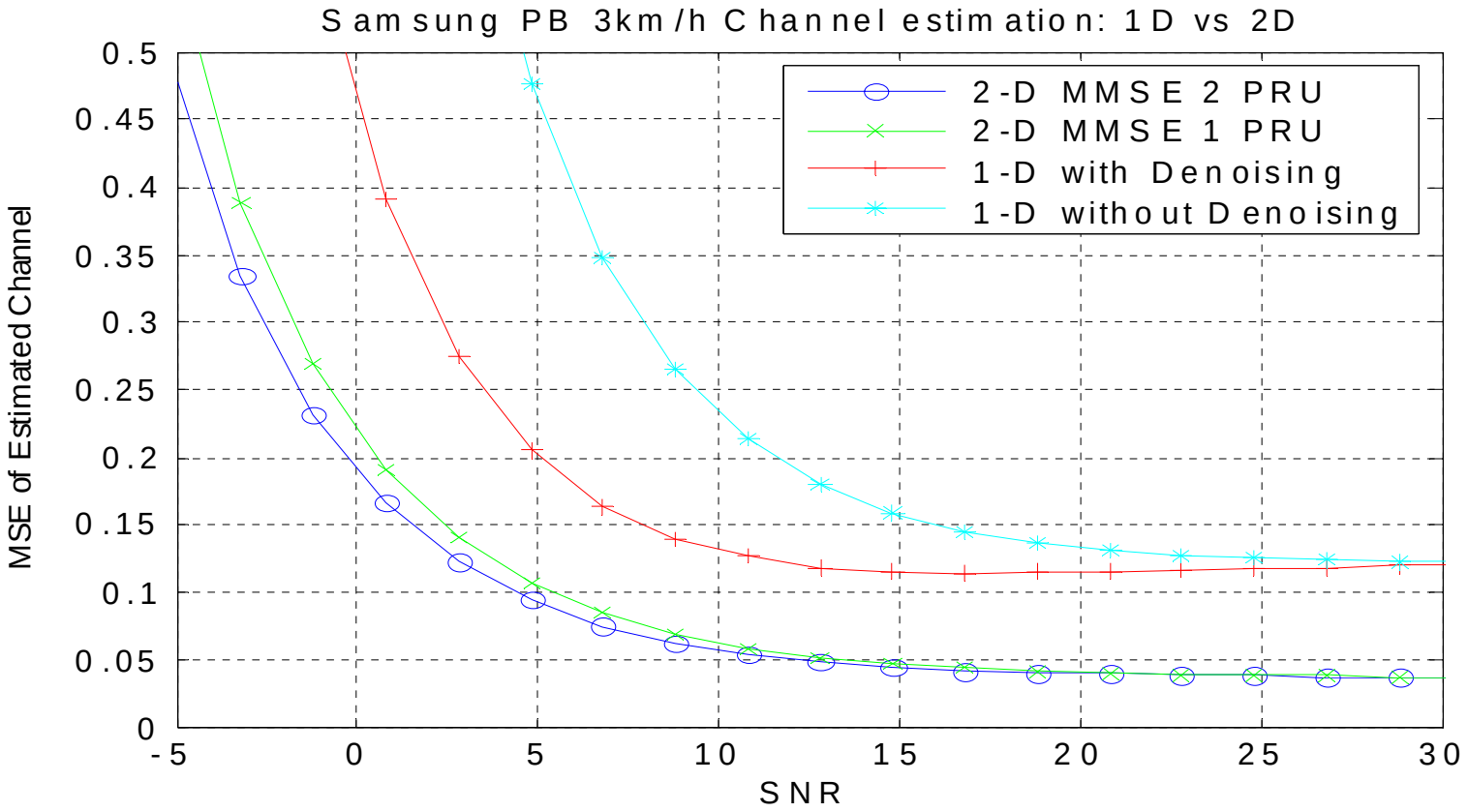
With 1-D MMSE, Nortel pilot structure can achieve near optimal channel estimation quality, especially at medium and high SNR.

1-D MMSE vs. 2-D MMSE: Intel/MediaTek



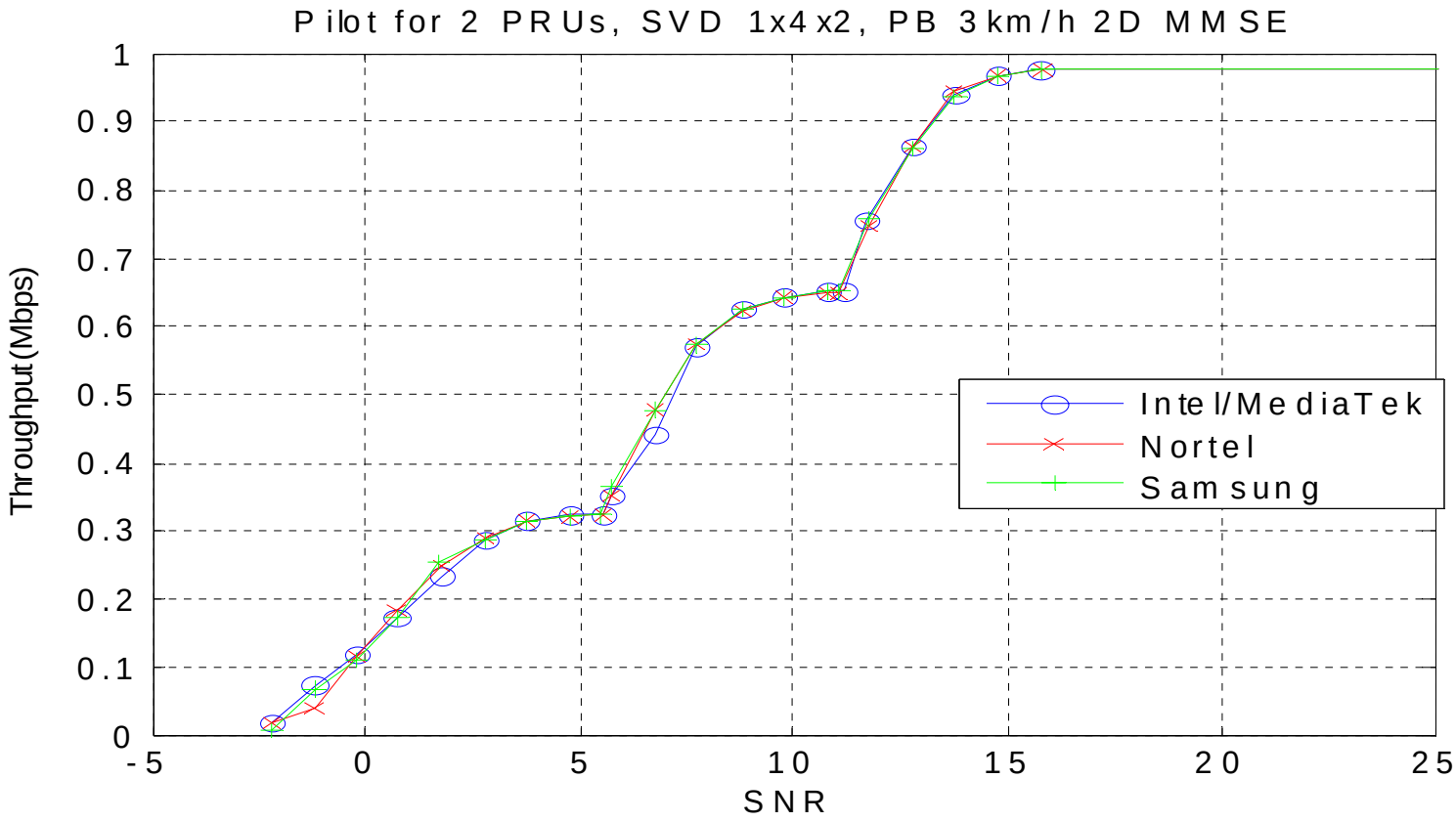
With 1-D MMSE, Intel/MediaTek pilot structure can achieve near optimal performance, especially at low SNR range.

1-D MMSE vs. 2-D MMSE: Samsung



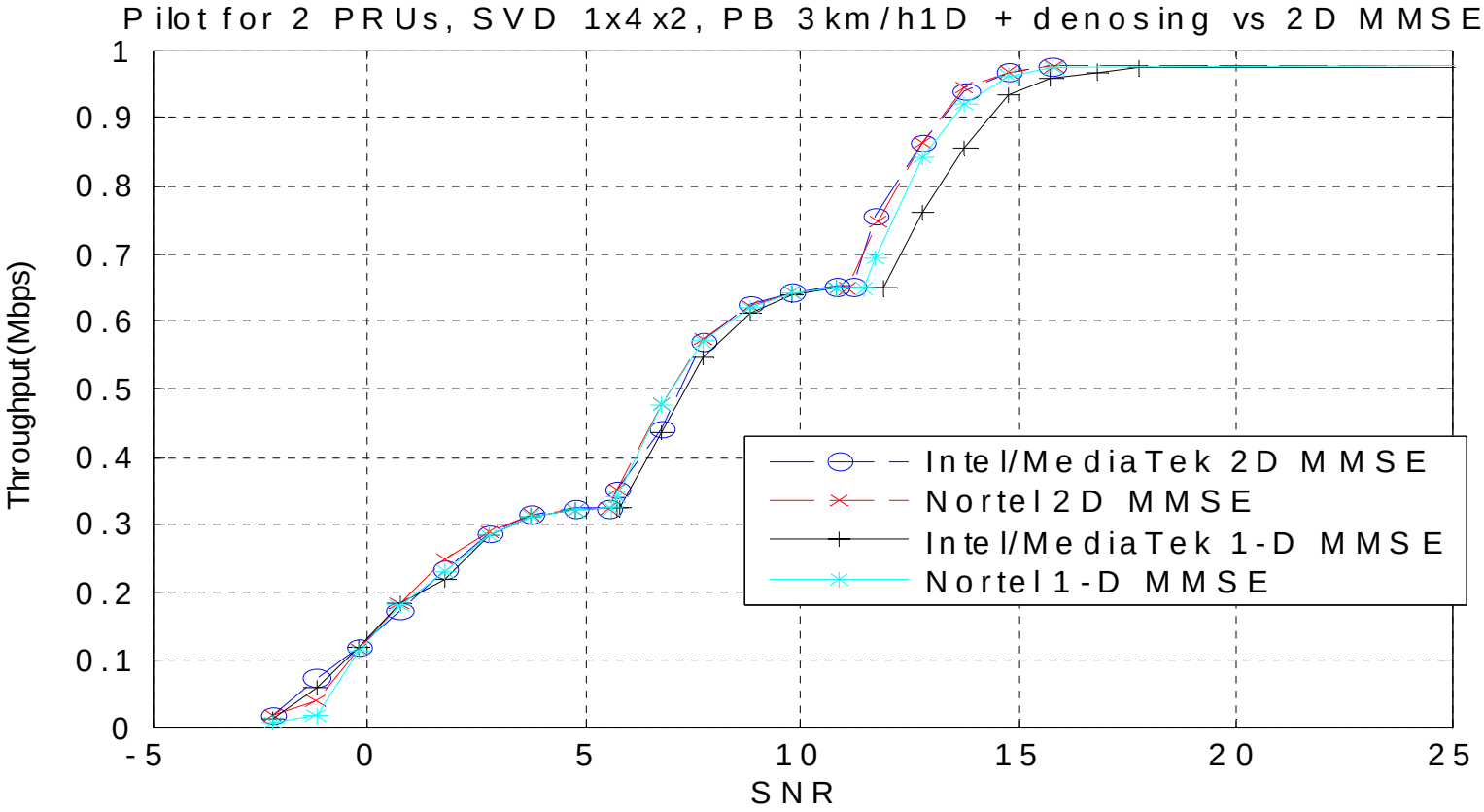
Without time direction interpolation or special treatment, Samsung's pilot structure can't perform well by using 1-D channel estimation methods.

Goodput of 2D MMSE: PB 3km/h



Three pilot pattern perform almost the same with 2D MMSE at PB 3km/h

Goodput of 1D + de-noising vs. 2D MMSE: PB 3km/h

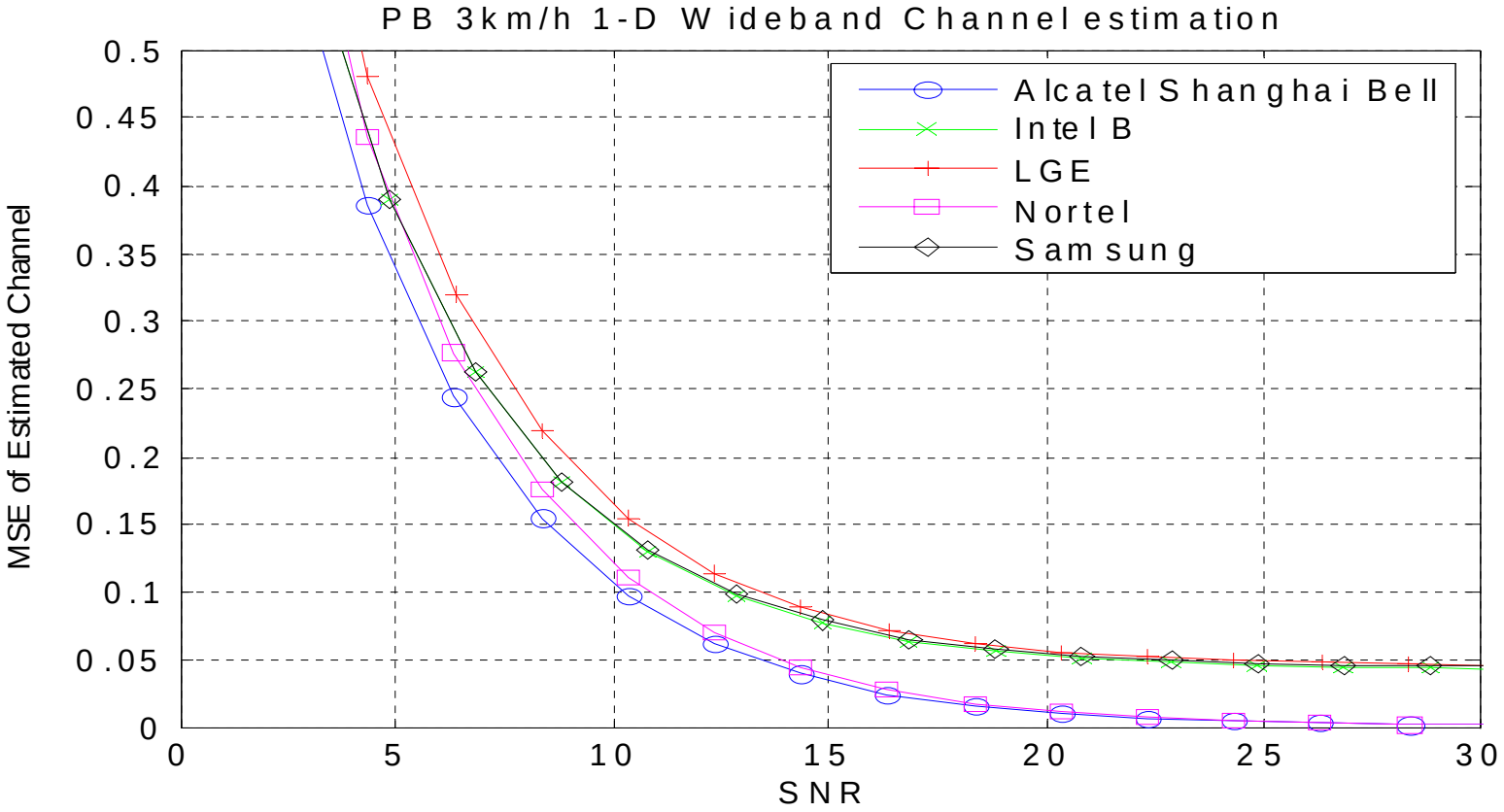


Nortel's pattern perform near optimal over entire SNR ranged simulated, outperform at high SNR

Pilot structure evaluation for common pilot

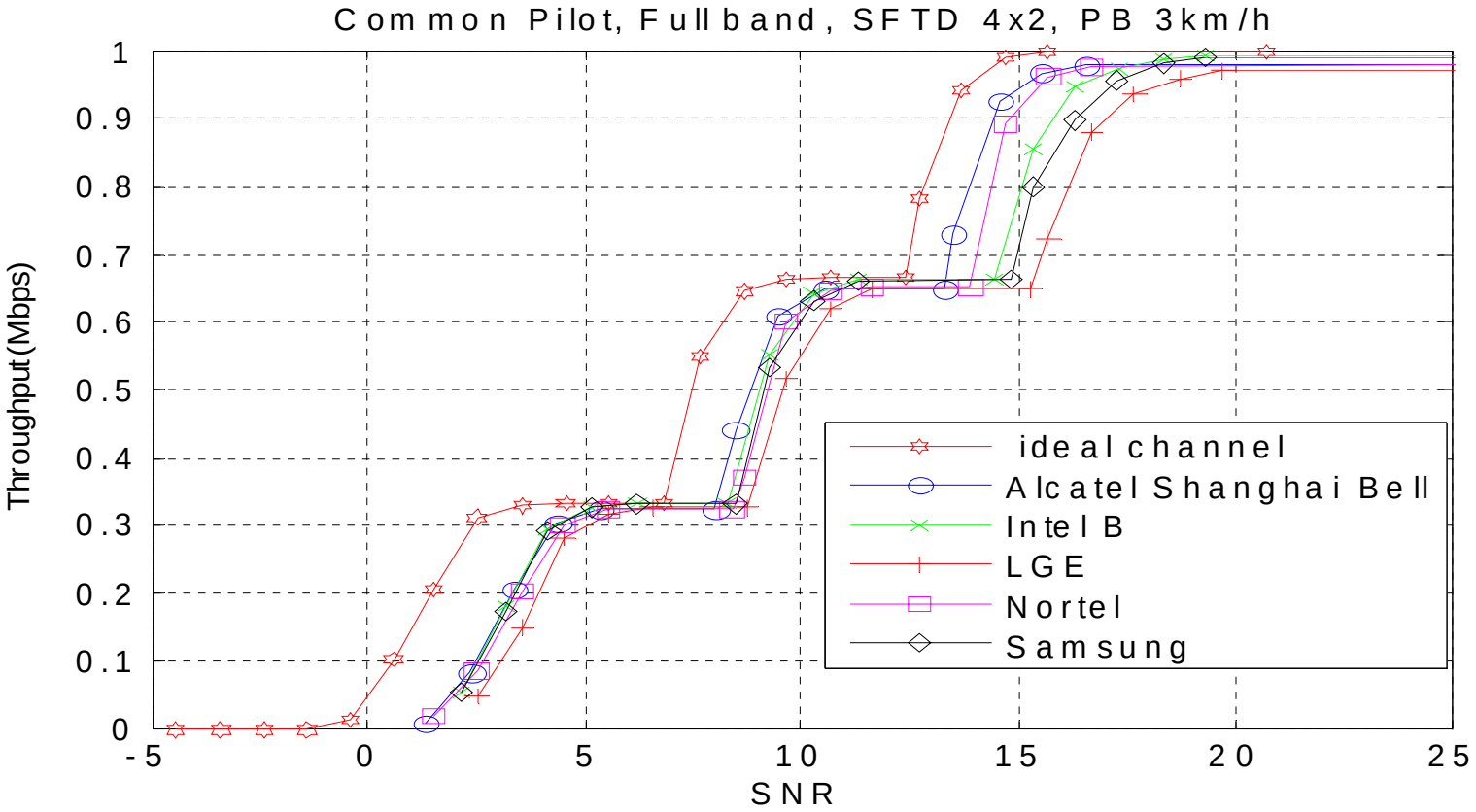
- Evaluation conditions:
  - Tone based distributed data subcarriers. Data block size is 2 PRUs
  - Common pilots are allocated over full bandwidth. 48 PRUs for 10MHz system.
  - Channel interpolation in frequency is second order 1-D
  - No cross sub-frame interpolation. Time direction interpolation is linear 1-D
    - Interpolation across sub-frames can not be guaranteed, since symbol structure permutation may change from sub-frame to sub-frame, according to the current 16m DL PHY definition

MSE of 1-D wideband channel estimation
PB 3km/h



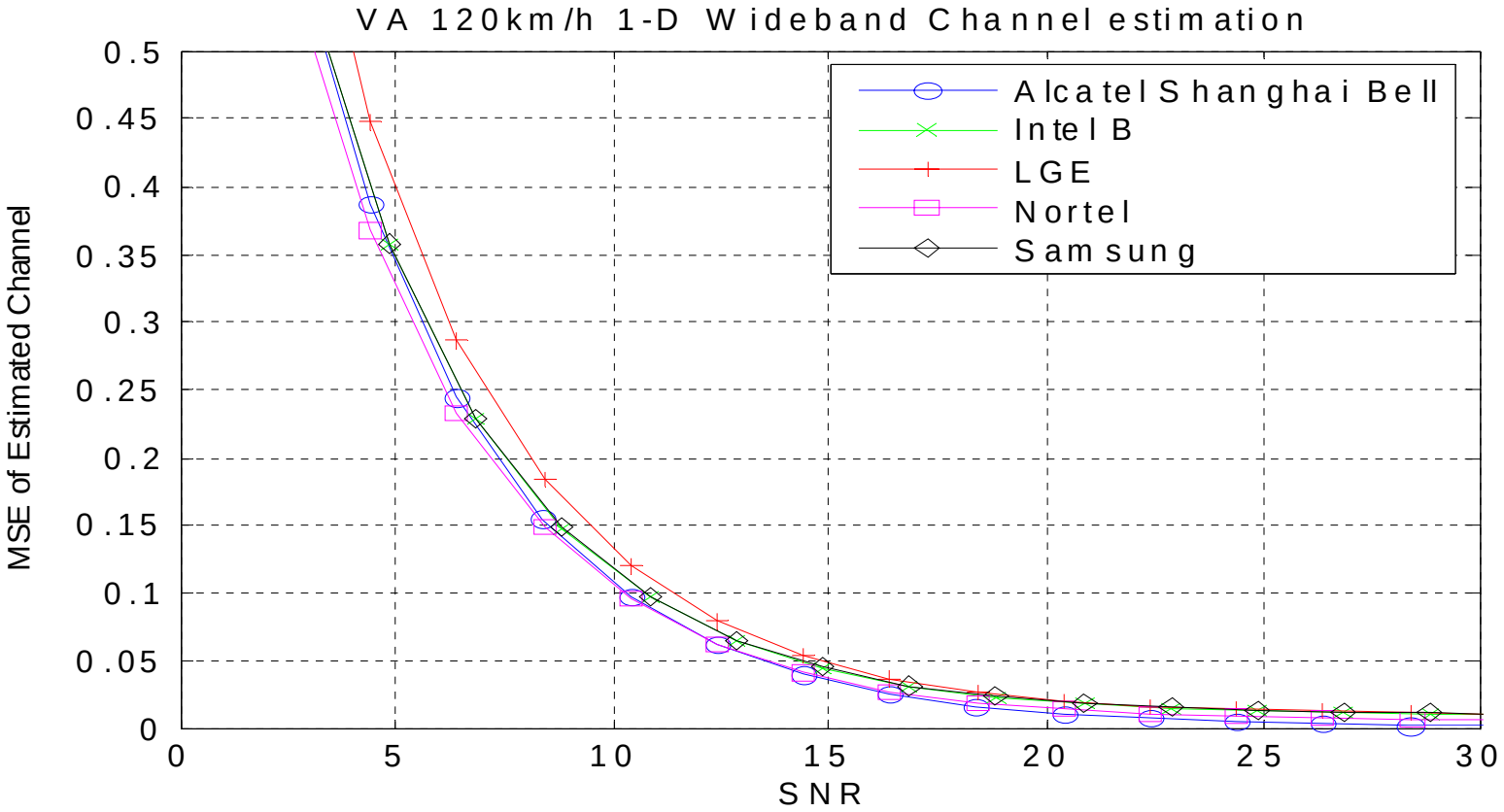
Nortel's and Alcatel Shanghai Bell's are the best at PB 3km/h due to small pilot spacing in frequency

Goodput of 1-D wideband channel estimation PB 3km/h



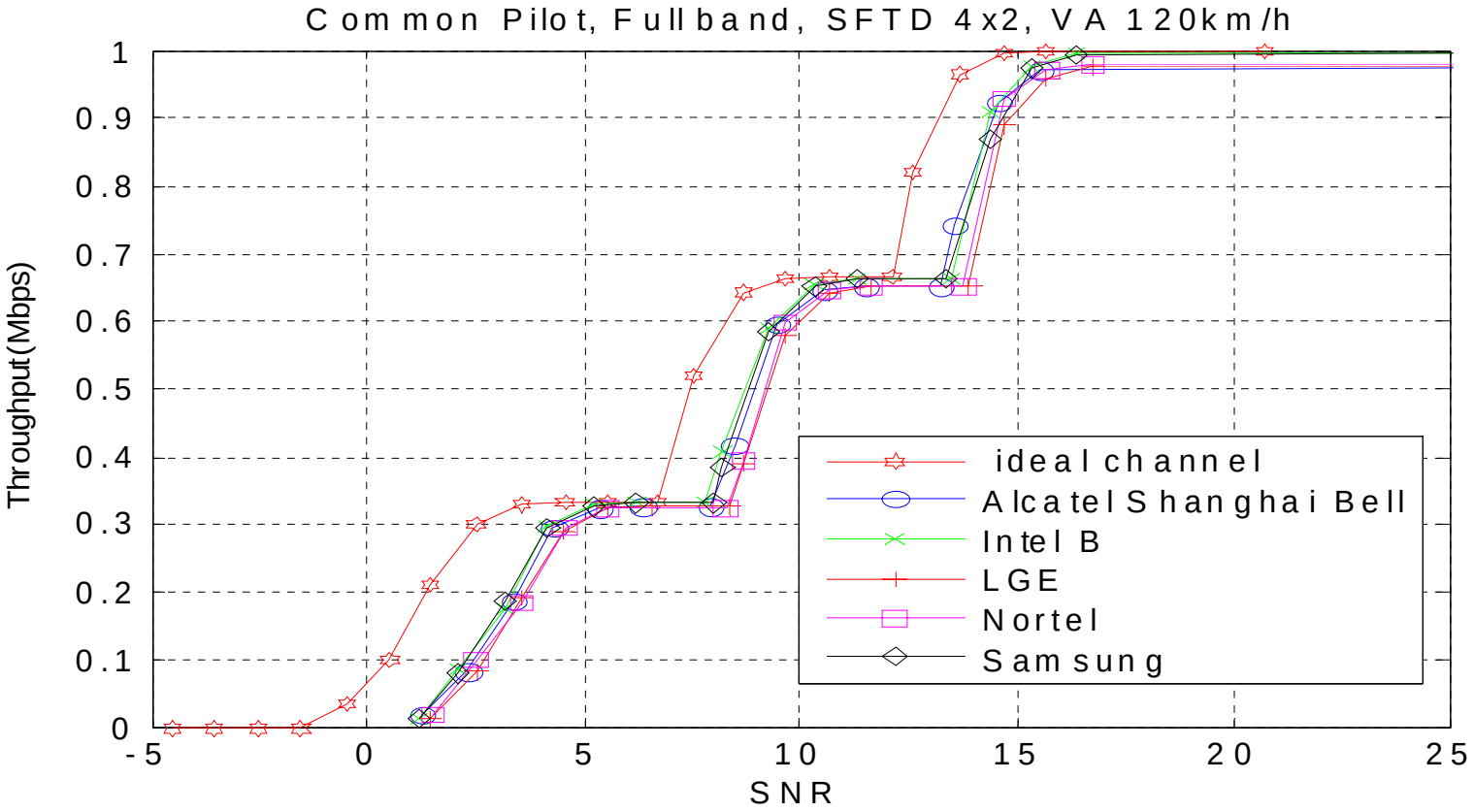
- **Alcatel Shanghai Bell's is the overall best performer at low speed of PB 3km/h, due to its smallest pilot spacing in frequency**
- **Nortel's and Alcatel Shanghai Bell's are the best at high SNR**
- **Intel's, Samsung's and Nortel's are among the best at low SNR**

MSE of 1-D wideband channel estimation
VA 120km/h



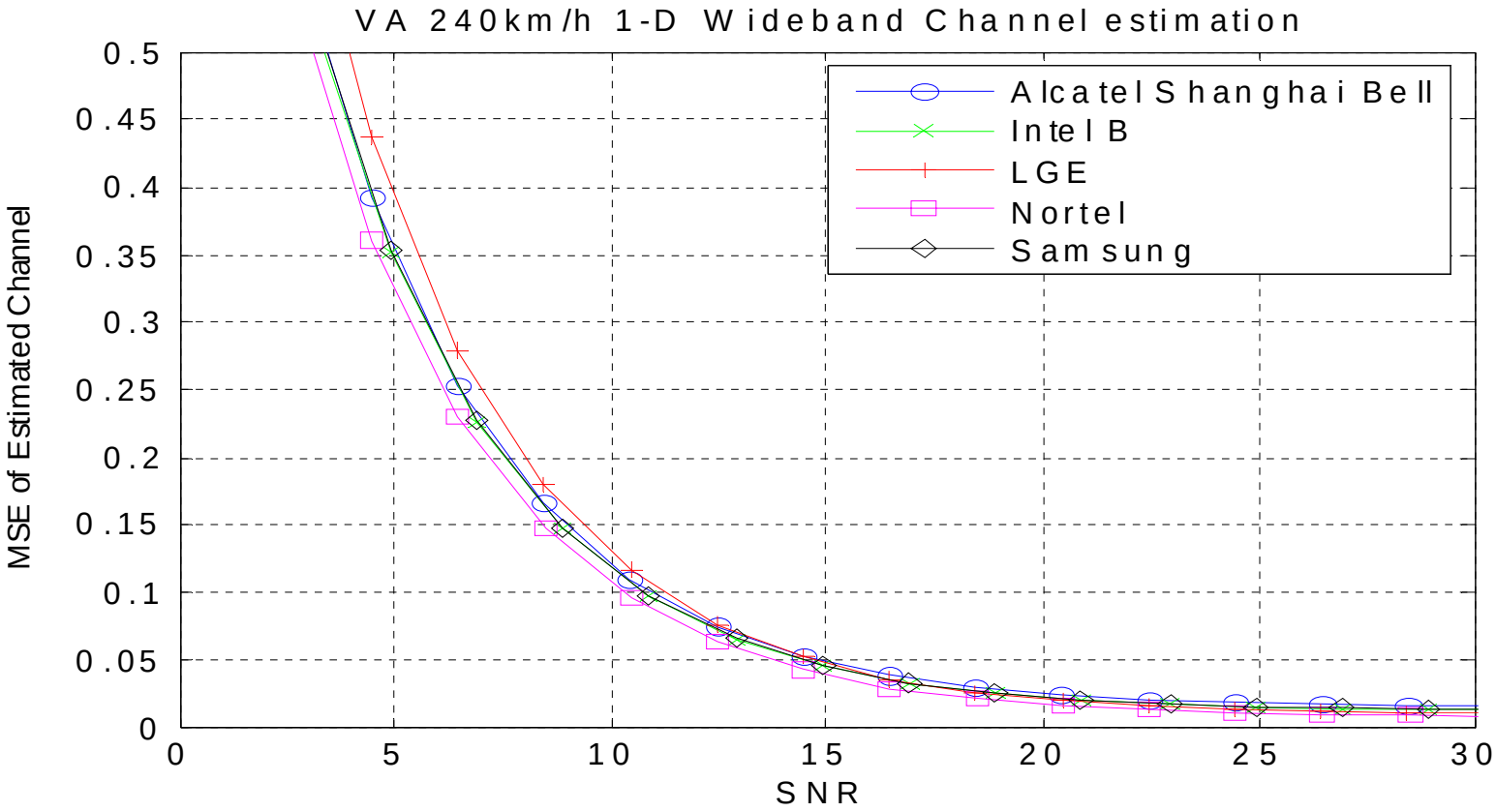
- **Nortel's, Alcatel Shanghai Bell's and Motorola's are close to be the best at VA 120km/h**
- **Nortel's has a slight channel estimated gain at low to medium SNR range**

Goodput of 1-D wideband channel estimation VA 120km/h



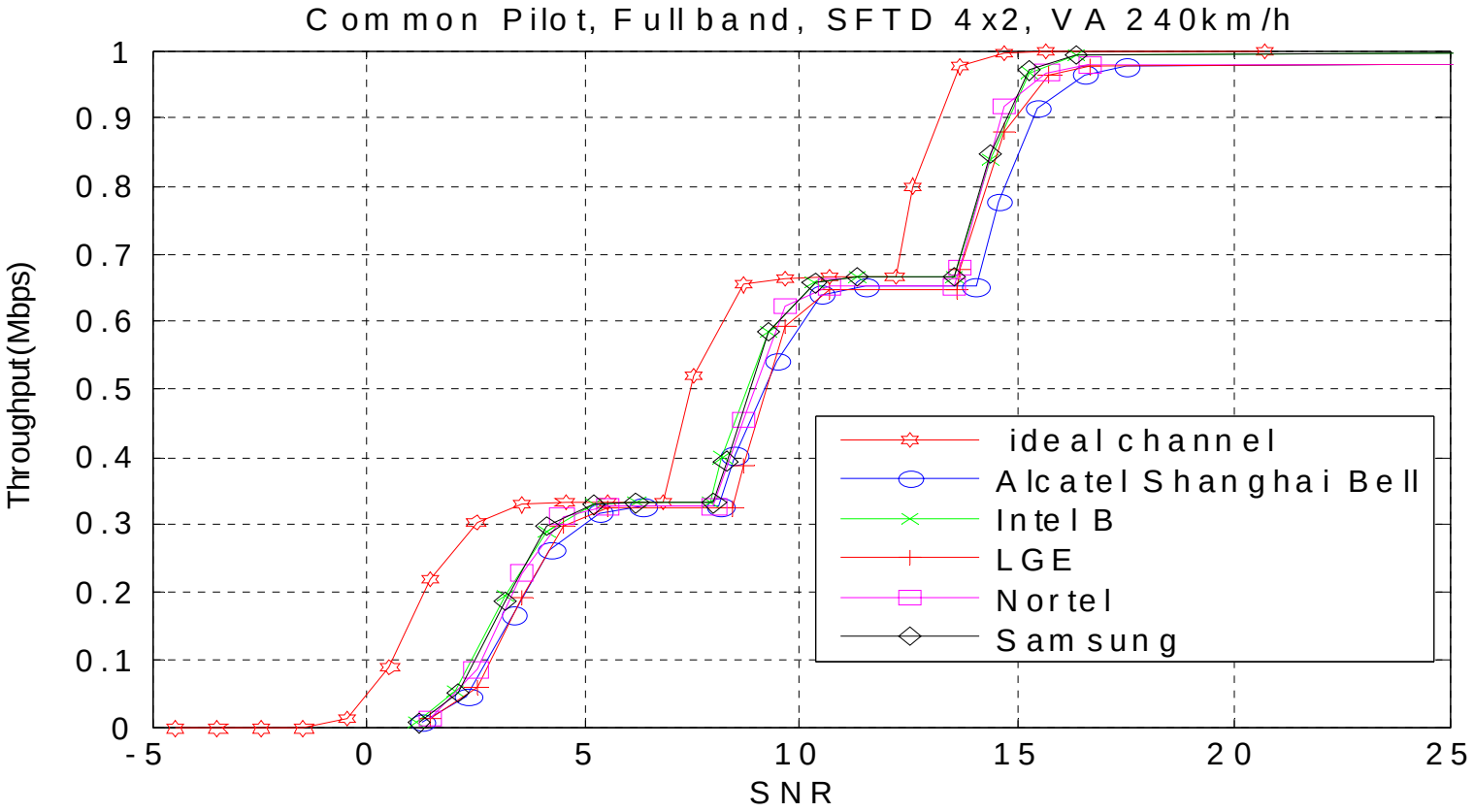
- **Alcatel Shanghai Bell's, Intel's and Samsung's are the best. Nortel's channel estimation gain is offset by high pilot overhead. But it is still close to the best one.**

MSE of 1-D wideband channel estimation
VA 240km/h



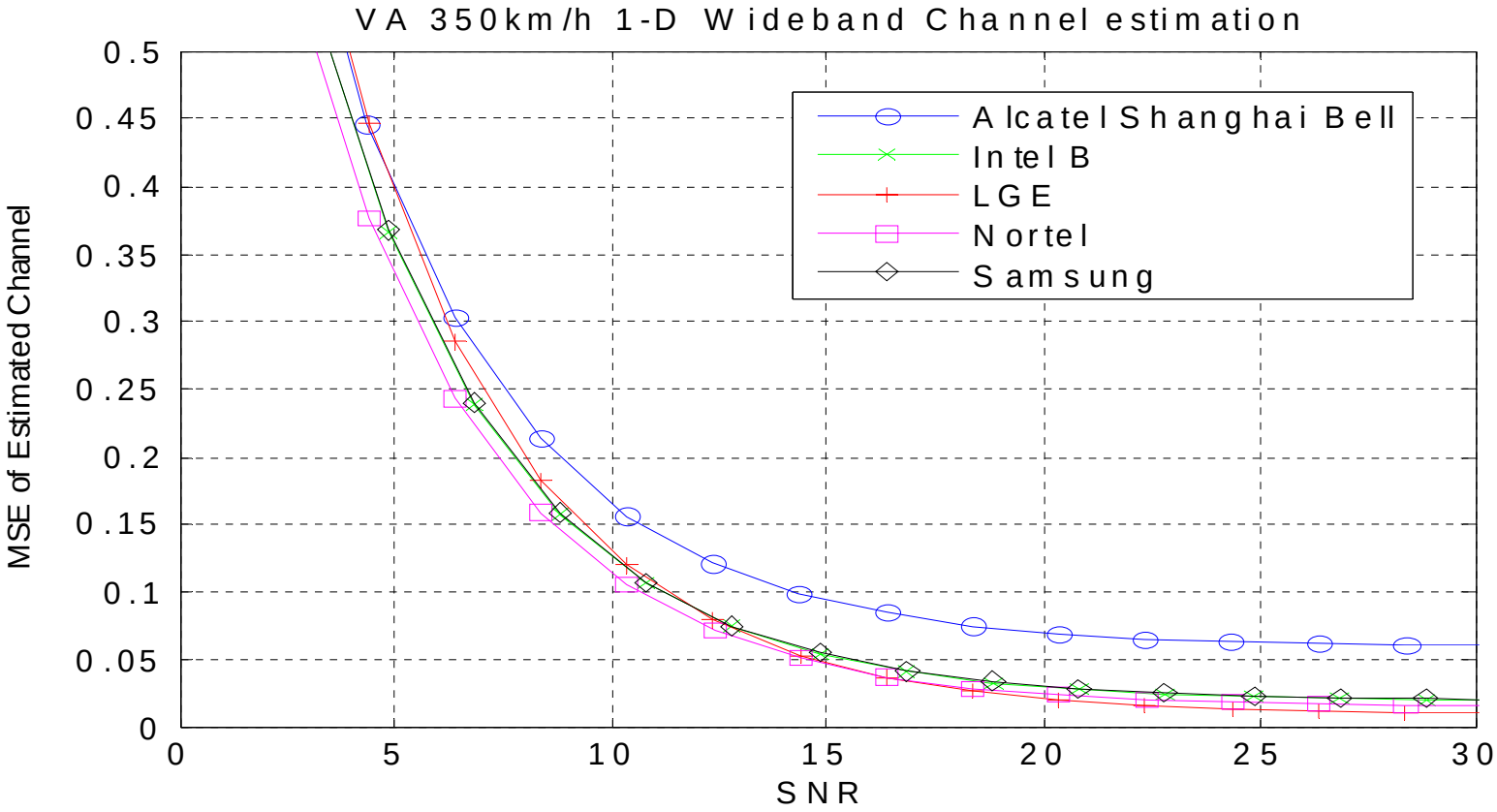
- **Nortel's is the best at VA 240km/h**
- **Alcatel Shanghai Bell's and Motorola's start to show degradation due to extrapolation in time**

Goodput of 1-D wideband channel estimation VA 240km/h



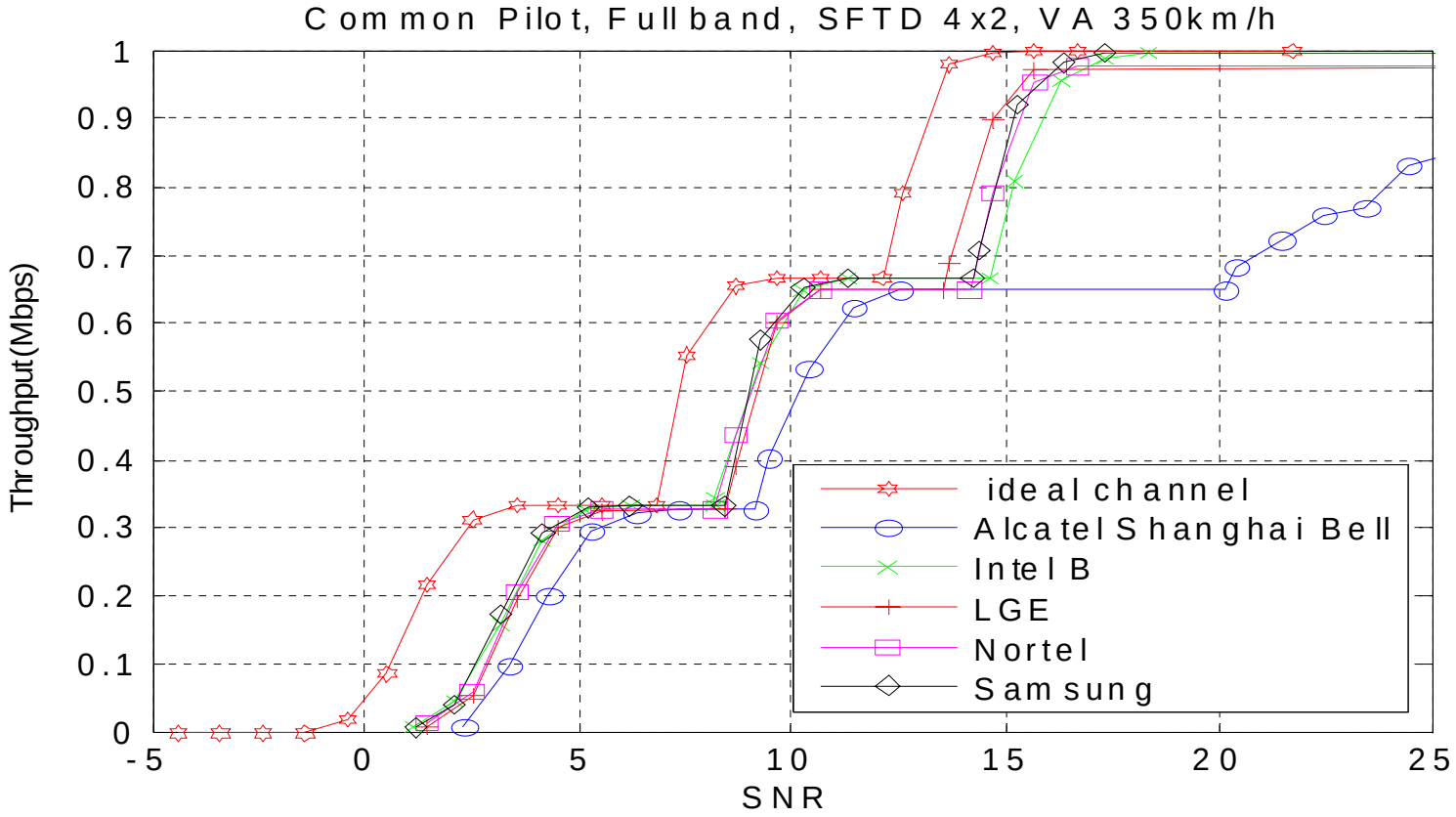
- **Nortel's, Intel's and Samsung's are among the best at VA 240km/h.**
- **Although with higher pilot overhead, Nortel's still among the best**
- **Alcatel Shanghai Bell's show degradation at 240km/h due to time extrapolation**

MSE of 1-D wideband channel estimation
VA 350km/h



- **LGE's and Nortel's are the best at high SNR**
- **Nortel outperform Intel's and Samsung's in the whole SNR range**
- **Nortel's, LGE's and Samsung's are close to be the best at low SNR**
- **Alcatel Shanghai Bell's and Motorola's becomes the worst due to time extrapolation**

Goodput of 1-D wideband channel estimation VA 350km/h



- **LGE's outperform others at high speed and high SNR. This is achieved by allocated pilots at every symbol and no interpolation/extrapolation in time is needed.**
- **Intel's, Samsung's and Nortel's are close to be the best.**

Why Different pilots perform differently in wideband

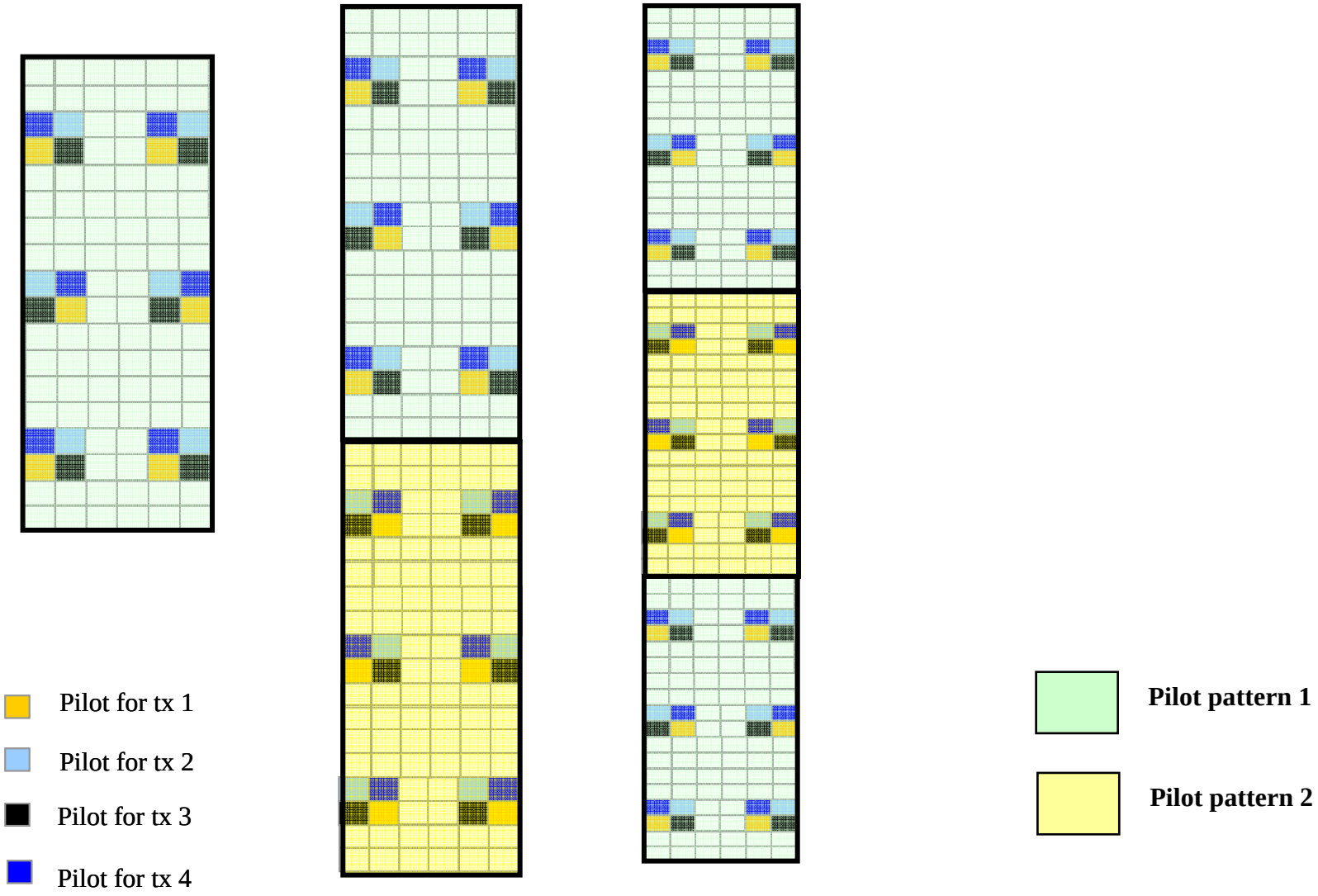
- Different pilot structure are differentiated by the following factors
  - Pilot allocation at time direction boundary symbols, which determines the performance at high speed, especially at 350km/h
    - Alcatel Shanghai Bell's has one boundary symbol without pilot for each Tx. This is why Alcatel Shanghai Bell's perform the worst at 350km/h
  - Pilot spacing in frequency direction, which determines the performance at low speed.
    - Alcatel Shanghai Bell's have the smallest spacing in frequency
    - Nortel's has smaller pilot spacing than others
  - Ability to do time direction interpolation first. This helps to improve performance at low speed, especially for dispersive channel like PB channel
    - Nortel' has time direction interpolation ability. After time direction interpolation, frequency direction spacing is shortened (8) and is close to Alcatel Shanghai Bell's.

Summary

- 2-D MMSE doesn't show significant advantage by channel estimation accuracy, despite its complexity and pre-defined channel statistics. 1-D channel estimation with de-noising should be a practical method for channel estimation performance. 1-D channel estimation without de-noising is also an option at high SNR due to its low complexity
- For dedicated pilot structure of 2 PRUs
  - Nortel's provide best channel estimation quality by using 1-D channel estimation, with or without de-noising.
  - Nortel's can perform the best at both low and high speed.
- For common pilot structure of multiple PRUs
  - Nortel's is among the best channel estimation performers at low and high speed.
- Overall, Nortel's pilot has the most robust structure for
  - Different channel estimation methods with low or high complexity
  - Low mobile speed and very high mobile speed
  - Different frequency dispersive channels
  - Small and large resource allocation

Proposed SDD Text (1/2)

11.5.3.1 Common pilot structure



Proposed SDD Text (2/2)

11.5.3.2 Dedicated pilot structure