R1-050387
RAN1 41 Athens, Greece
May 9-13, 2005
Agenda item: 13.2

E-UTRA Downlink Multiple Access Study

Texas Instruments

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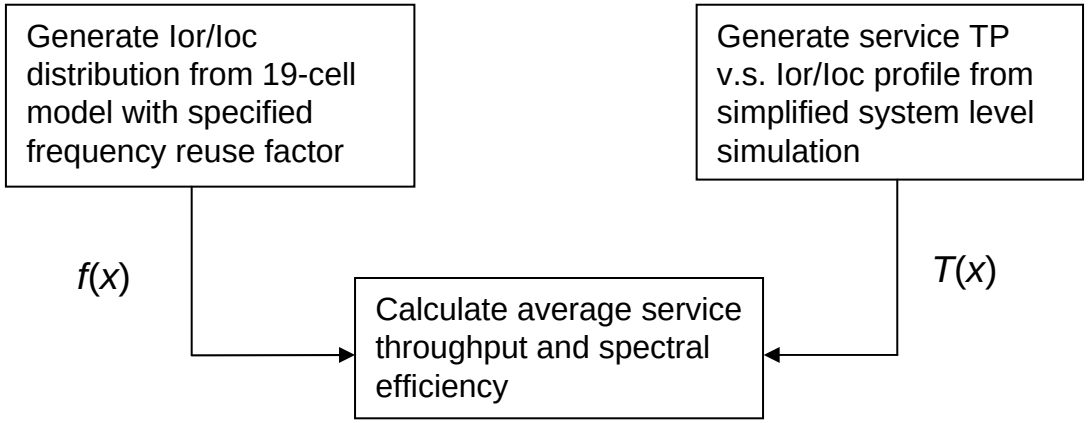
Outline

- Initial study of different technologies for E-UTRA LTE:
  - Simplified system level simulation
- Studied aspects of LTE Downlink:
  - OFDM vs. CDMA
  - Frequency reuse (1:1 vs 1:3) and higher order modulations (QPSK, 16-QAM, 64-QAM, 256-QAM)
  - MIMO OFDM
  - Link-level study of inter-tone spacing

Simulation Methodology (for Initial Study)

- Simplified system level simulation:
  - Fast link adaptation: adaptive MCS, max C/I scheduling
  - TDM: 1 user per TTI, 10 users dropped in a sector
  - Full data buffer at Node B, no data traffic model (optimistic)
  - Low UE speed



$$T_{AV} = \int f(x)T(x)dx \quad , \quad SE = \frac{T_{AV}}{W}$$

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OFDM vs. CDMA

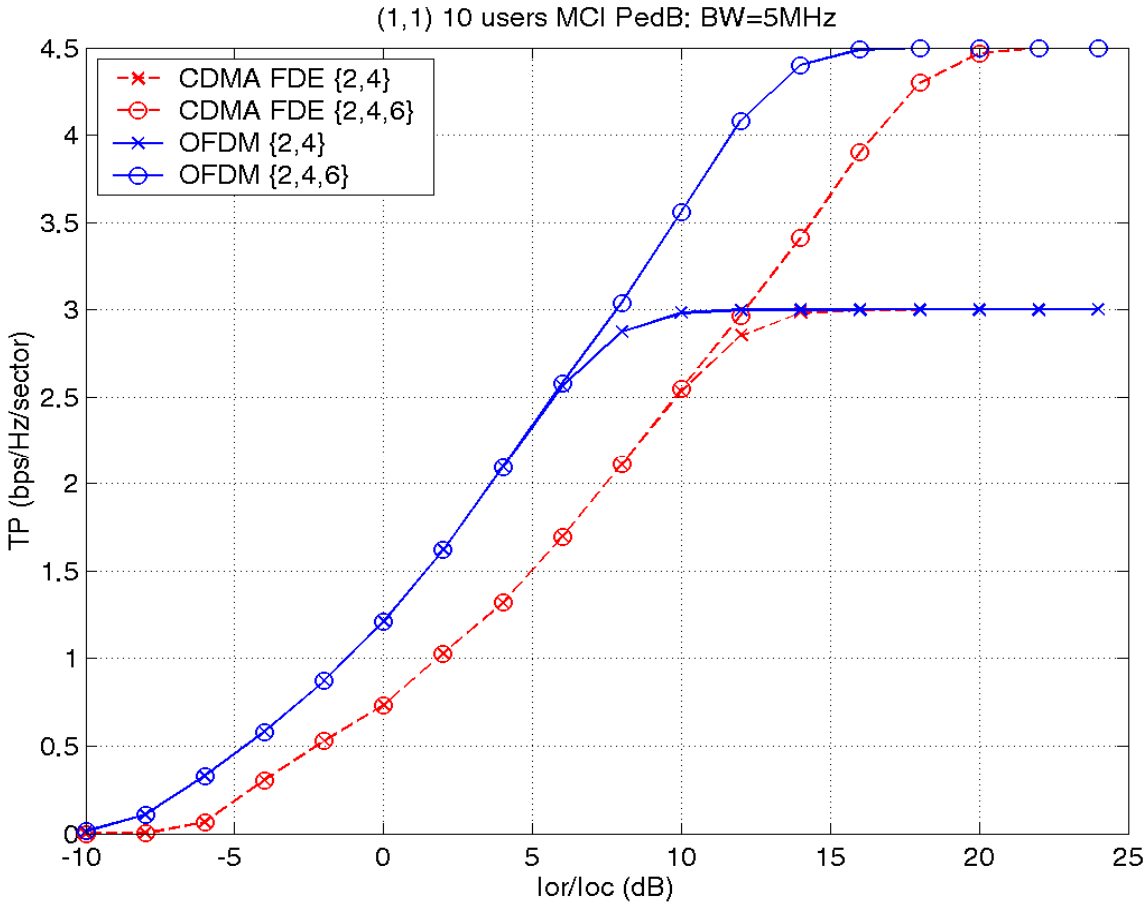
OFDM vs. CDMA

- OFDM gives gain over CDMA due to its ISI avoidance
  - No need for equalizer. CDMA equalizer may not be practical for:
    - Larger bandwidth (>=5 MHz)
  - Good MIMO receiver: important especially for high spatial correlation
    - Practical for MIMO OFDM
    - Hard to design for MIMO CDMA

Simulation Parameters: CDMA vs. OFDM for 1x1 & 2x2

- 5 MHz bandwidth: OFDM FFT size = 512, CDMA SF = 16, frequency reuse 1:1
- All codes/tones are used for data transmission
- MCS:
  - Set 1: {QPSK, 16QAM} + Turbo code rate 0.25 – 0.75 → {2,4}
  - Set 2: {QPSK, 16QAM, 64QAM} + Turbo code rate 0.25 – 0.75 → {2,4,6}
- MIMO:
  - 2x2 VBLAST
  - Spatial correlation: 0 and 0.5
- OFDM receiver:
  - Single antenna: scalar MF
  - MIMO: spatial LMMSE and IMMSE
- CDMA receiver:
  - Single antenna: frequency domain equalizer (FDE) with LMMSE criterion
  - MIMO: space-time FDE LMMSE

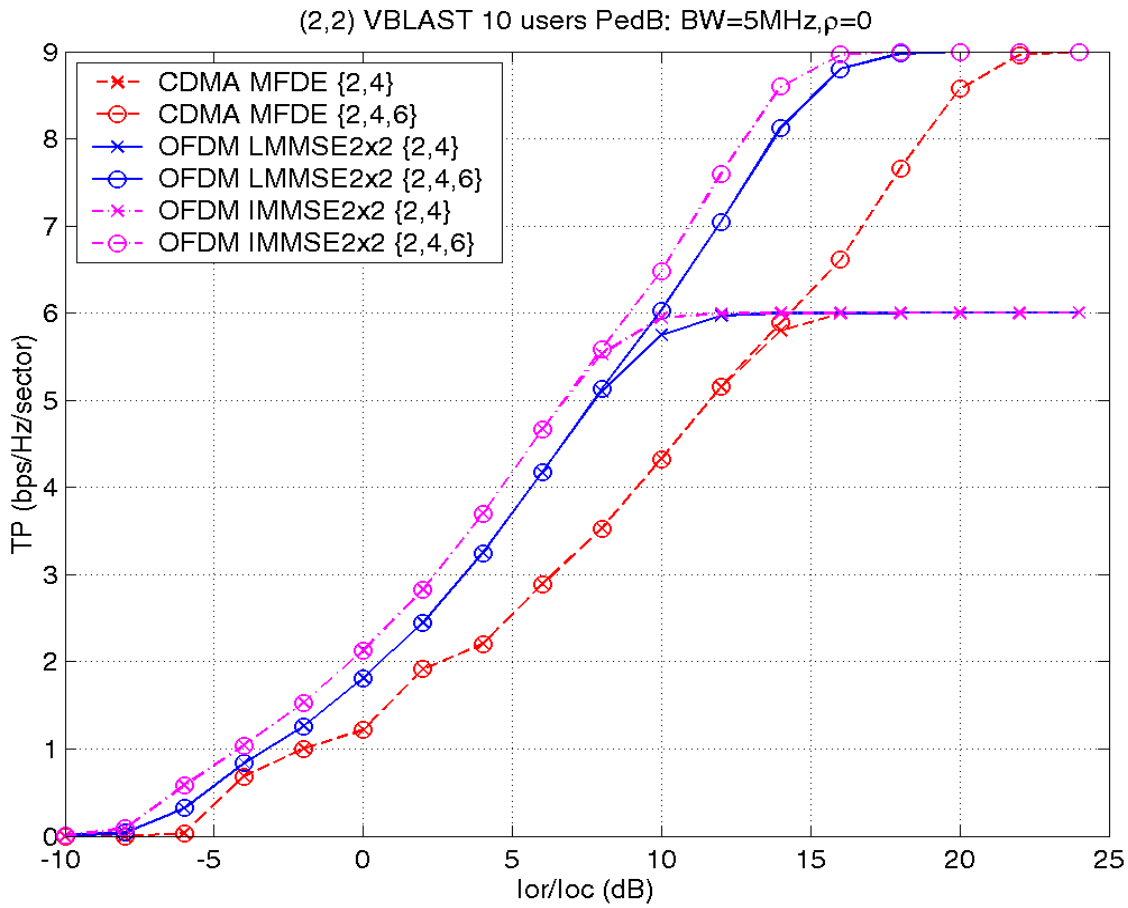
OFDM vs. CDMA: 1x1 Results



2=QPSK
4=16QAM
6=64QAM

- OFDM gain over CDMA: 20-50% throughput gain depending on geometry

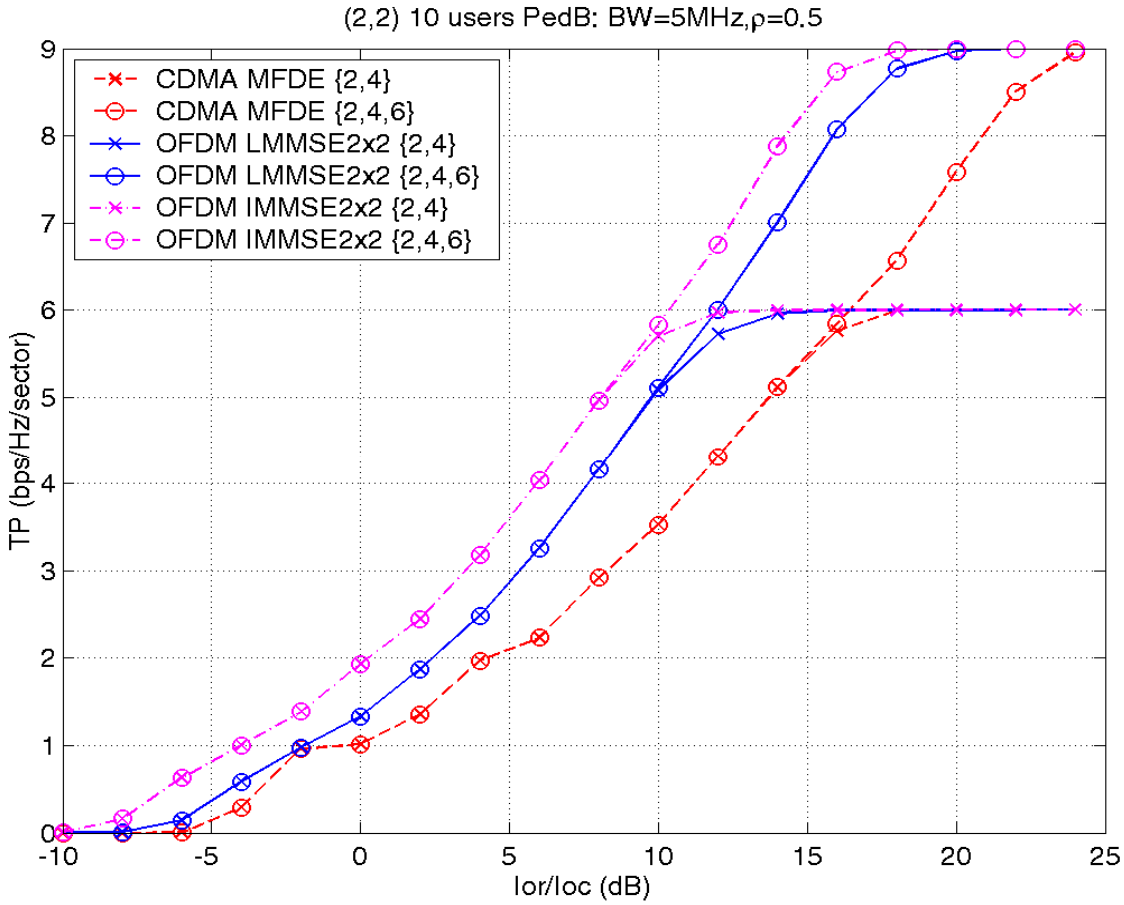
2x2 MIMO: OFDM vs. CDMA Spatial Corr=0



2=QPSK
4=16QAM
6=64QAM

- OFDM gain over CDMA: 20-50% throughput gain depending on geometry
- IMMSE gain over LMMSE is small for OFDM

2x2 MIMO: OFDM vs. CDMA Spatial Corr=0.5



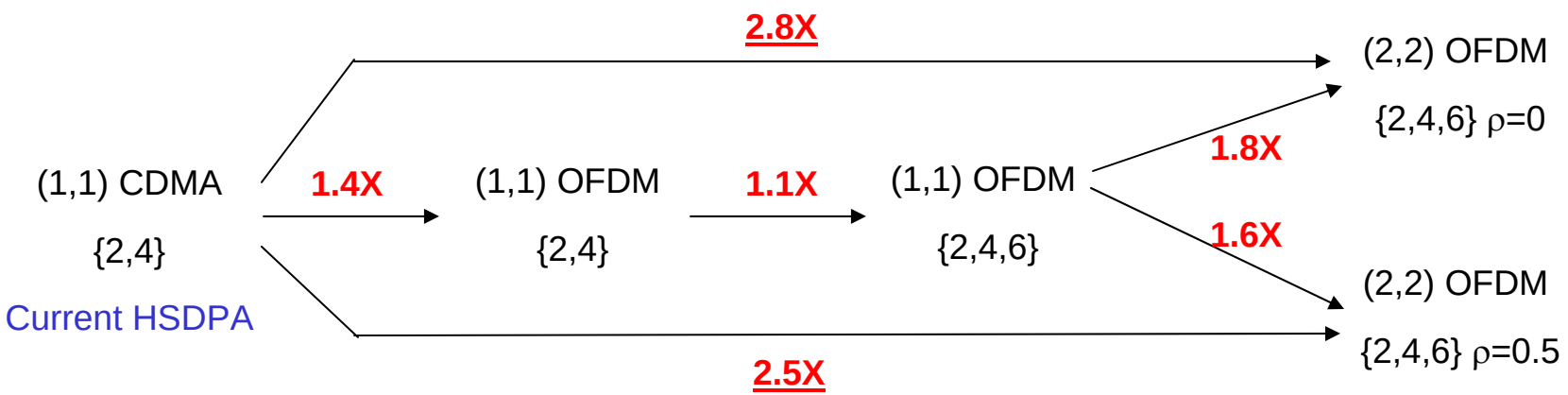
2=QPSK
4=16QAM
6=64QAM

- OFDM gain over CDMA: 20-50% throughput gain depending on geometry
- Gain of IMMSE over LMMSE for OFDM is more noticeable

Spectral Efficiency Comparison of OFDM vs. CDMA (bps/Hz/*cell*)

	(1,1)	(2,2) ρ=0		(2,2) ρ=0.5	
CDMA {2,4}	1.4	2.4		2	
CDMA {2,4,6}	1.4	2.5		2	
OFDM {2,4}	1.9	3.1	3.4	2.6	3.2
OFDM {2,4,6}	2.1	3.4	3.8	2.8	3.4
		LMMSE	IMMSE	LMMSE	IMMSE

Relative Spectral Efficiencies

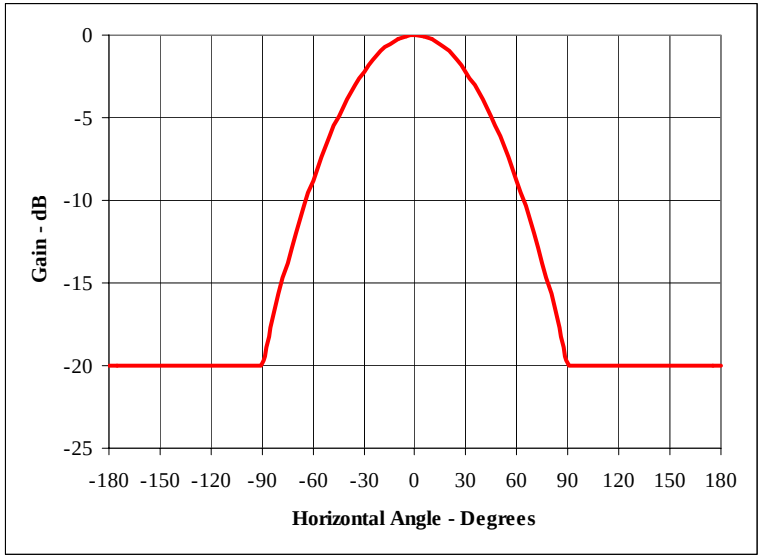


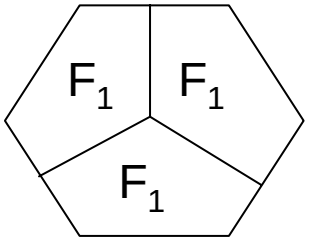
Conclusions: OFDM vs. CDMA

- OFDM provides significant (~ 50%) gain over CDMA for downlink:
  - Single-antenna
  - MIMO

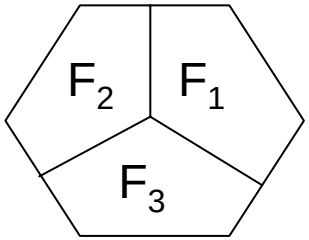
Frequency Reuse (1:1 vs. 1:3) and Higher Order Modulations (QPSK, 16-QAM, 64-QAM, 256-QAM)

Sectorization and Frequency Reuse (1)

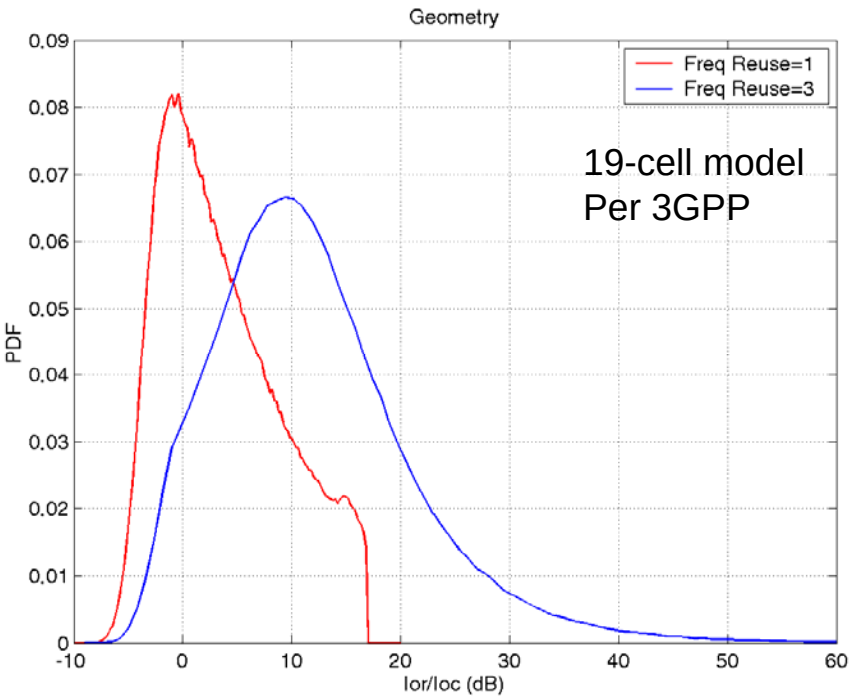




1:1



1:3



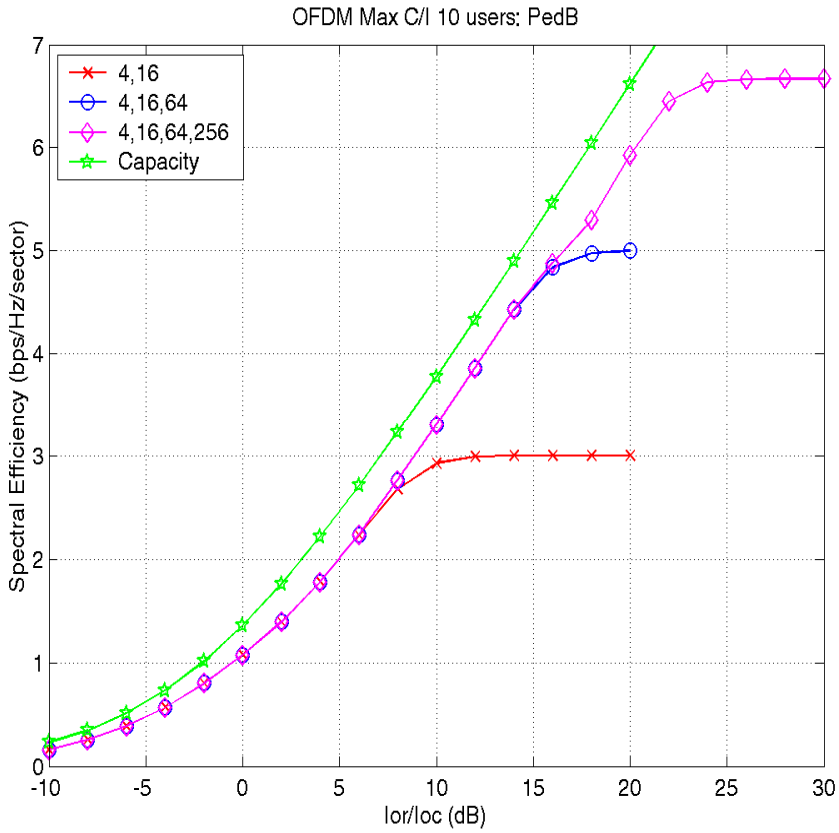
- FR 1:1
  - 17dB geometry ceiling: 20dB interference from 2 intra-cell sectors
  - Limit gain of advanced schemes
  - Limit achievable spectral efficiency
- FR 1:3
  - 10dB higher geometry mode, longer tail

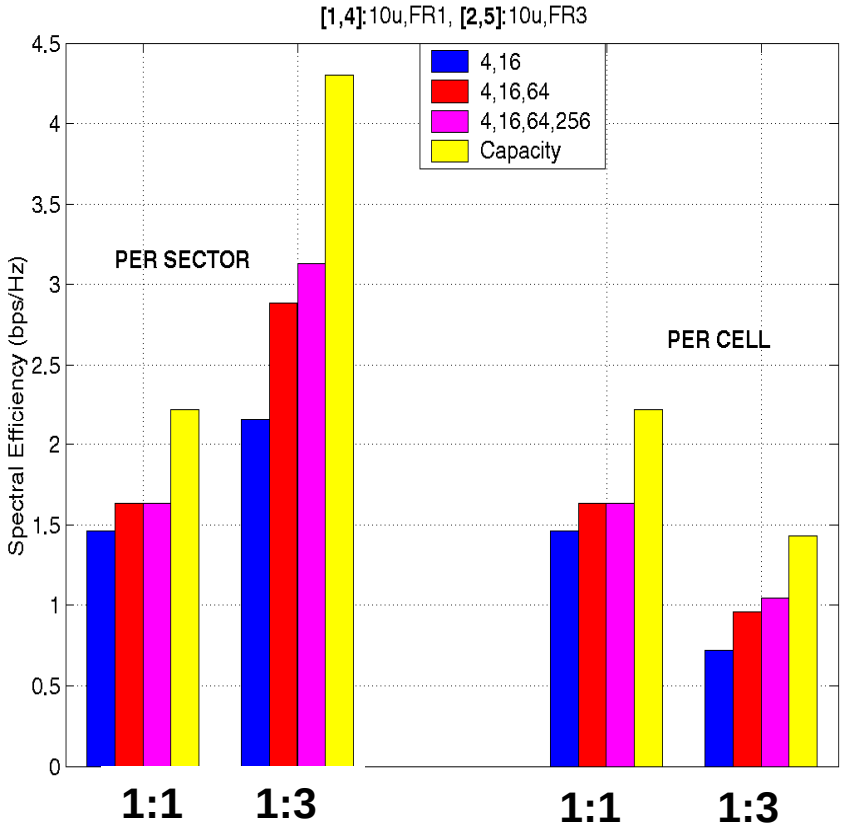
Sectorization and Frequency Reuse (2)

- FR 1:1 vs. FR 1:3
  - — FR 1:3 can achieve higher spectral efficiency per sector.
  - — Triple bandwidth usage per cell in FR 1:3
  - → FR 1:3 can achieve higher spectral efficiency per cell only if spectral efficiency per sector gain is > 3x

- Geometry distribution for FR 1:1 can be improved by:
  - — Lowering the side lobe gain of sectorization array (e.g 30dB)
  - — Improved array response

Higher Order Modulation & Frequency Reuse





- Gain by adding 64QAM: ~15% for reuse 1:1, ~25% for reuse 1:3
- 256QAM does not seem to provide significant gain
- FR 1:3 has 30-50% lower spectral efficiency per cell compared to FR 1:1

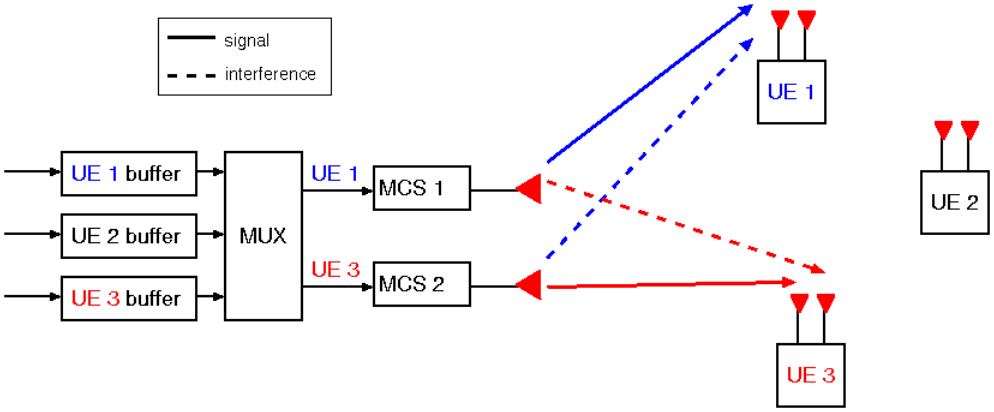
Conclusions: Higher Order Modulation & Frequency Reuse

- 256-QAM need not be supported for E-UTRA downlink
- Frequency reuse of 1:1 provides higher average service throughput

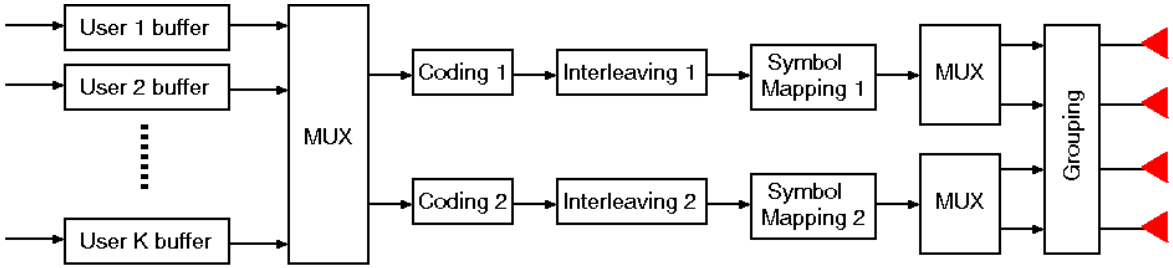
MIMO OFDM

Multiuser (MU) MIMO

- User multiplexing across antennas: 2X2 MU PARC



- 4x4 per group rate control (PGRC):
  - Only 2 MCS chains: greatly reduced signaling complexity compared to 4x4 PARC



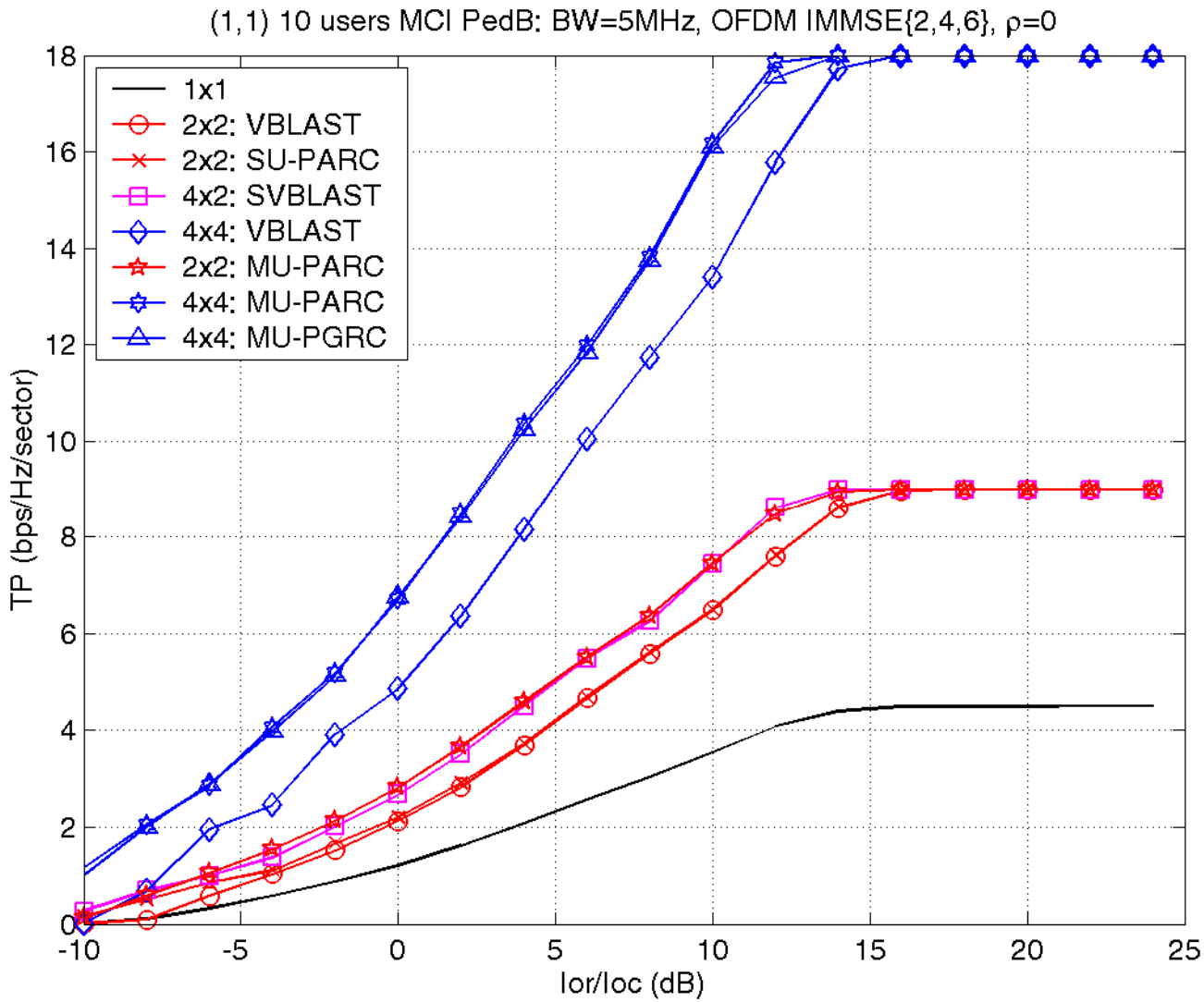
4x4 PGRC

  - Optimum grouping rule (minimum BER):
    - Group 1: the best 2 antennas
    - Group 2: the worst 2 antennas
    - 3 grouping possibilities: (1,2)(3,4) ; (1,3)(2,4) ; (1,4)(2,3)

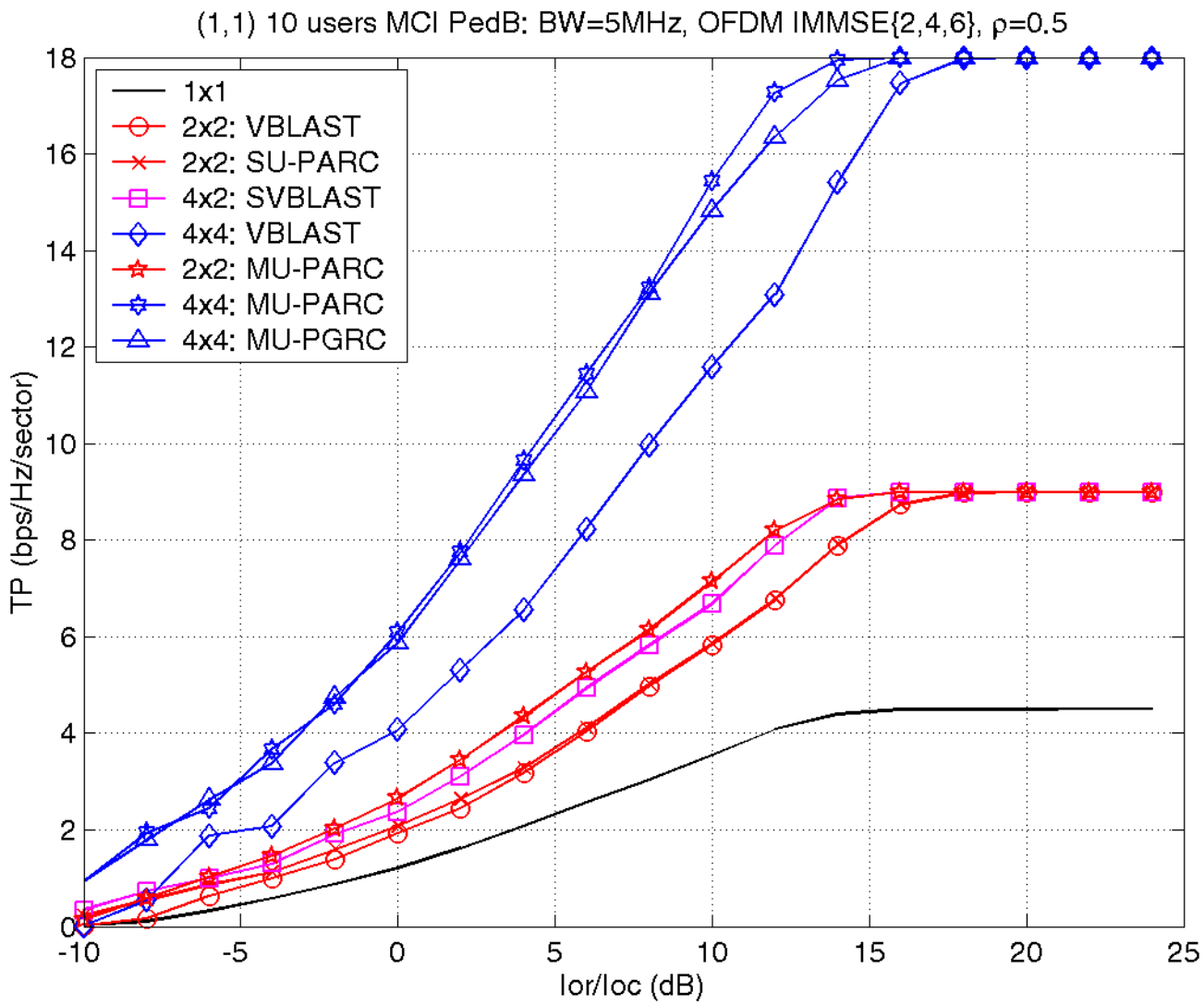
Comparison: MIMO-OFDM schemes

- 2x2:
  - V-BLAST
  - Single user PARC
  - Multiuser PARC
- 4x2:
  - Selective (2 out of 4 TX antennas) VBLAST
- 4x4:
  - V-BLAST
  - Single user PARC
  - Multiuser PARC
  - Multiuser PGRC
- Iterative MMSE receiver

MIMO OFDM: ρ=0


(1,1) 10 users MCI PedB: BW=5MHz, OFDM IMMSE{2,4,6}, ρ=0
1x1
2x2: VBLAST
2x2: SU-PARC
4x2: SVBLAST
4x4: VBLAST
2x2: MU-PARC
4x4: MU-PARC
4x4: MU-PGRC
TP (bps/Hz/sector)
Ior/Ioc (dB)
0
2
4
6
8
10
12
14
16
18
-10
-5
0
5
10
15
20
25

MIMO OFDM: ρ=0.5



Spectral Efficiency Comparison (bps/Hz/*cell*)

- Rel 6 HSDPA:
  - 1x1 CDMA {2,4}
  - Simulation result: SE = **1.4** bps/Hz/cell (assumes infinite queue traffic)

OFDM {2,4,6} configuration	SE (bps/Hz/cell)		Gain over Rel 6 HSDPA	
	ρ=0	ρ=0.5	ρ=0	ρ=0.5
1x1	2.2		1.5X	
2x2 VBLAST	3.8	3.4	2.7X	2.4X
2x2 SU-PARC	3.8	3.5	2.7X	2.5X
2x2 MU-PARC	4.8	4.6	**3.2X**	**3.1X**
4x2 SVBLAST	4.4	4.0	3.1X	2.9X
4x4 VBLAST	8.2	6.9	5.9X	4.9X
4x4 MU-PARC	9.9	9.4	7.1X	6.7X
4x4 MU-PGRC	9.9	9.1	**7.1X**	**6.5X**

- SU-PARC gives small gain over regular VBLAST for 2x2
- 2x2 → 4x2: no dramatic gain. 4x2 → 4x4: more than 2X gain
- 4x4 MU-PARC vs. MU-PGRC: 0-3% difference in SE
- SU MIMO → MU MIMO: 18-33% gain in SE

Link-level Study of Inter-tone Spacing

Link Level Study of Inter-tone Spacing

- Inter-tone interference (ITI) for high mobility (up to 350 kmph)
  - Effect is manifested in data tones & channel estimation quality
- Questions:
  1. Can 64QAM be supported at high mobility ?
     - Regular packet data transmission (before HARQ): target FER ~ 10%
     - Real-time services and MBMS : lower target FER
  2. How much is the degradation due to ITI?
  3. What is a good choice of inter-tone spacing?

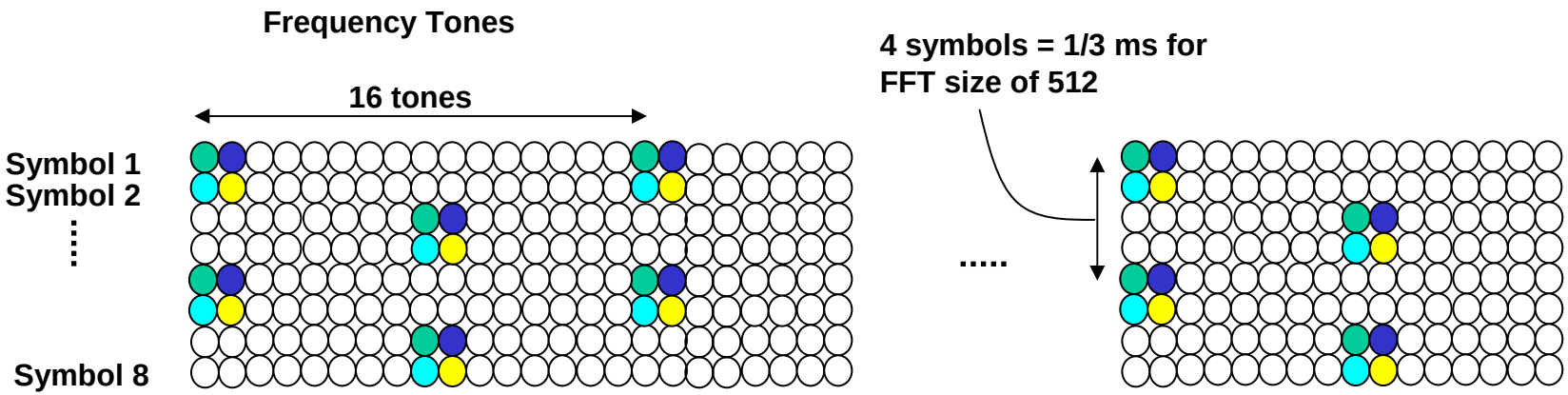
Simulation Assumptions

- 1 transmit, 2 receive antennas
- Guard interval = 7.143 us (= 48 samples)
- BW = 5 MHz, sampling rate = 1.75x3.84 MHz → $\Delta F = \frac{6.72\,MHz}{N_{FFT}}$

N_{FFT}	ΔF (kHz)	GI Overhead
1024	6.5625	4.5%
512	**13.125**	**8.6%**
256	26.25	15.8%

- MCS (Turbo code, interleaver size depends only on MCS, not on inter-tone spacing):
  - QPSK rate ½ ; 16QAM rate ½, ¾ ; 64QAM rate ¾
- Speed: 3, 30, 120, 350 kmph. ITU PedB channel.
- Average FER vs. (long term) symbol SNR
- Both noise-free channel estimation and actual channel estimation using scattered pilots with a spacing of 4 symbols between pilot symbols on the same tone (1/3 ms for FFT size of 512).

Pilot Symbol Assumptions



Data

Scattered Pilot for Antennas 1,2,3 & 4

For the pilot tone locations, only one antenna transmits a pilot symbol for the particular tone and the other antennas are nulled.

- means that only antenna 1 transmits a pilot symbol
- means that all antennas transmit data

The overhead for pilots for 4 transmit antennas is 12.5% of the OFDM tones

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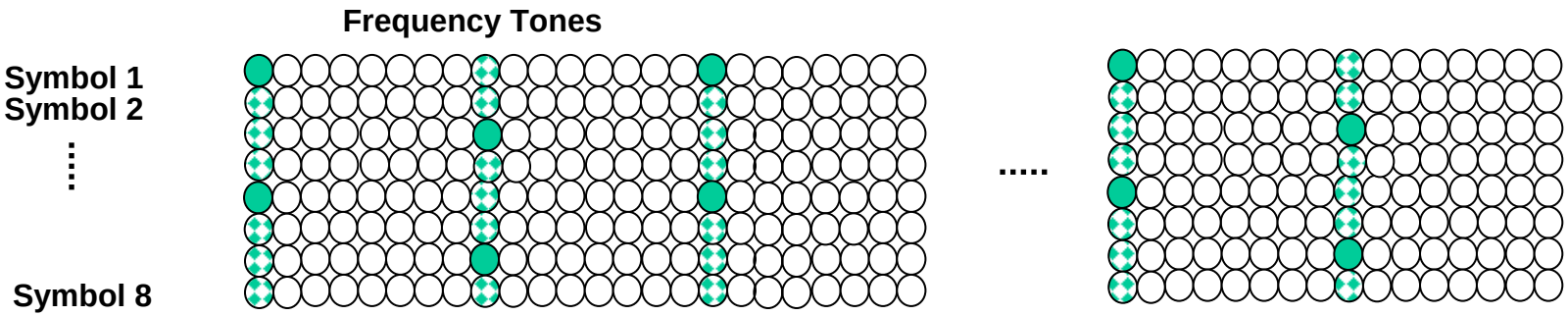
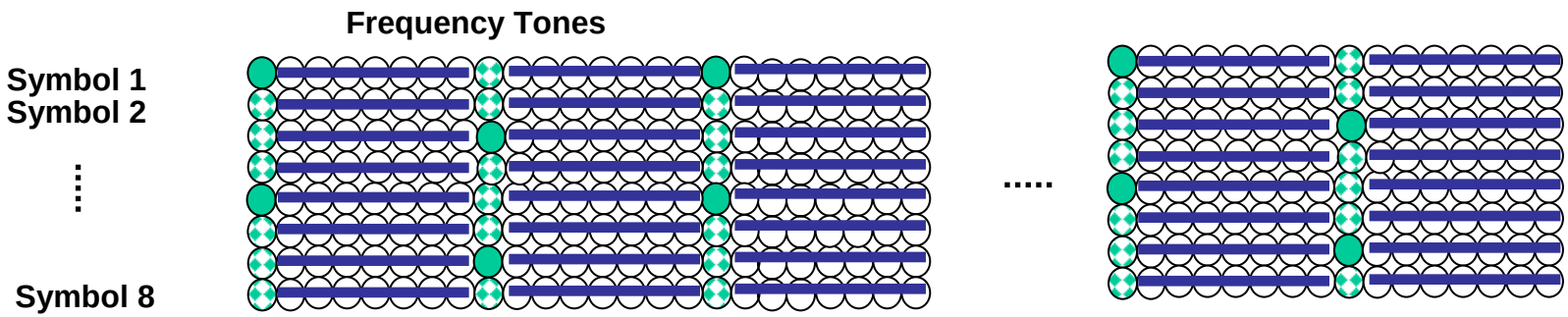
Channel Estimation Method

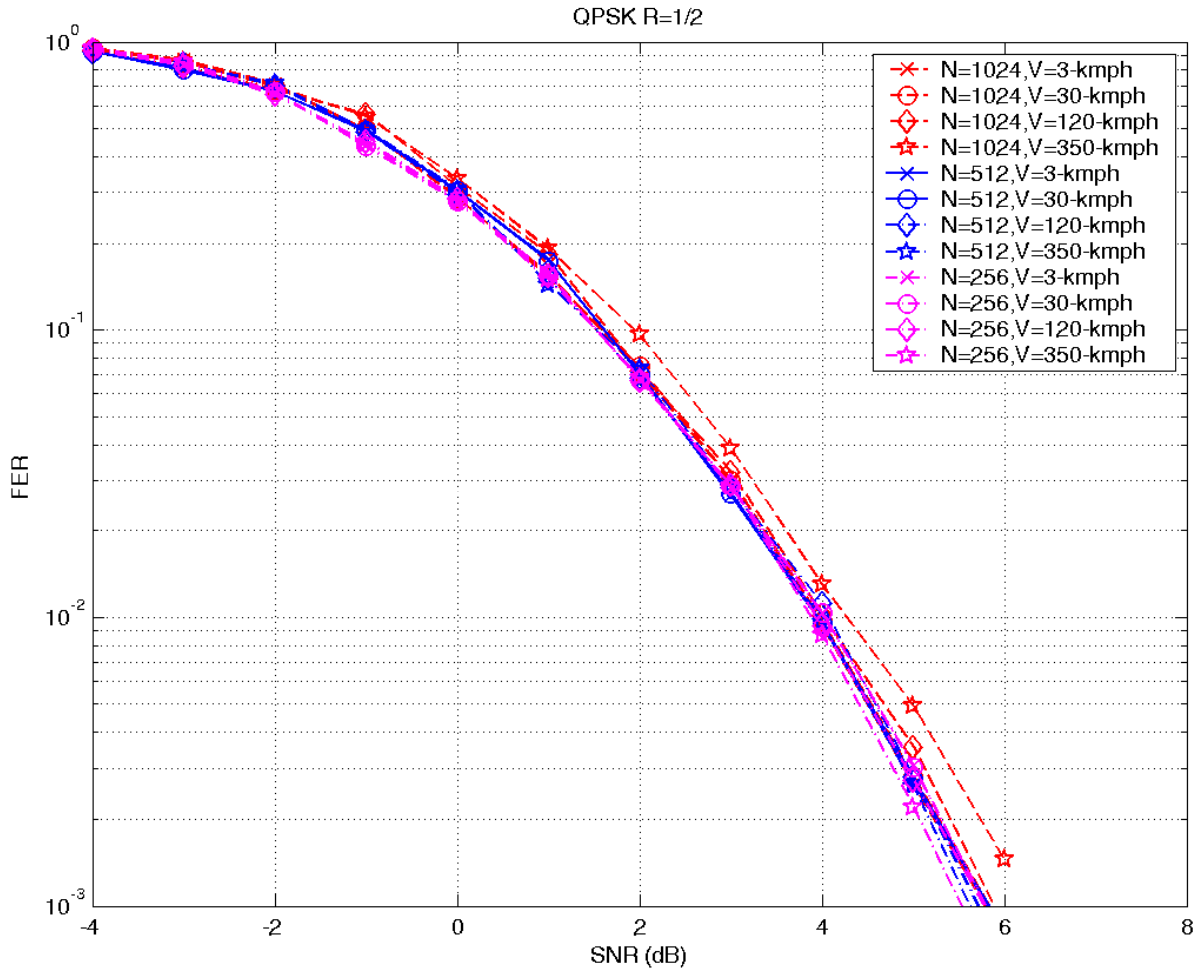
Time interpolation between symbols fills in the gaps between pilot tones so the frequency spacing becomes 8 tones.



Frequency interpolation gives channel estimates for all tones.

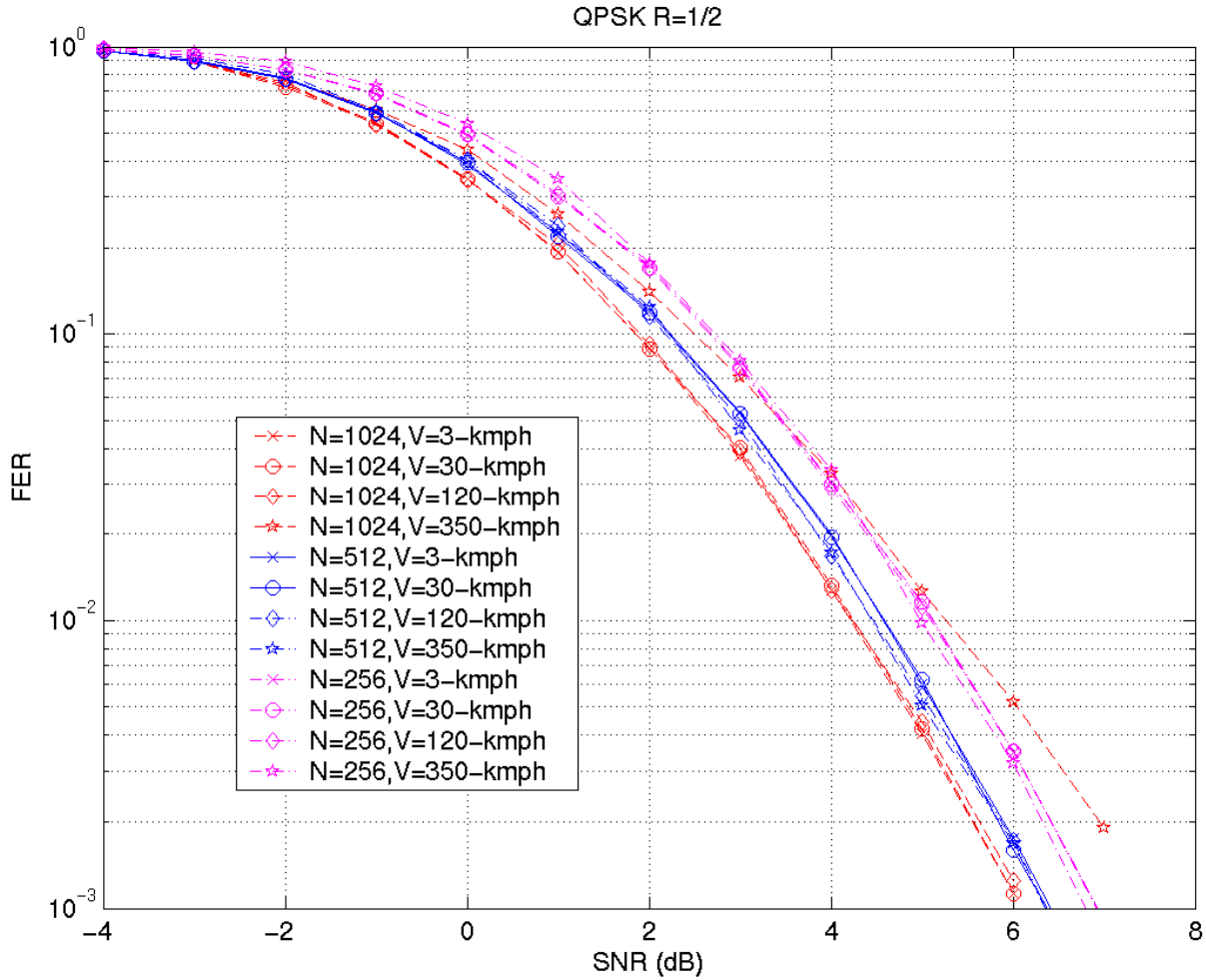


QPSK rate 1/2 (Noise-Free Channel Estimation)



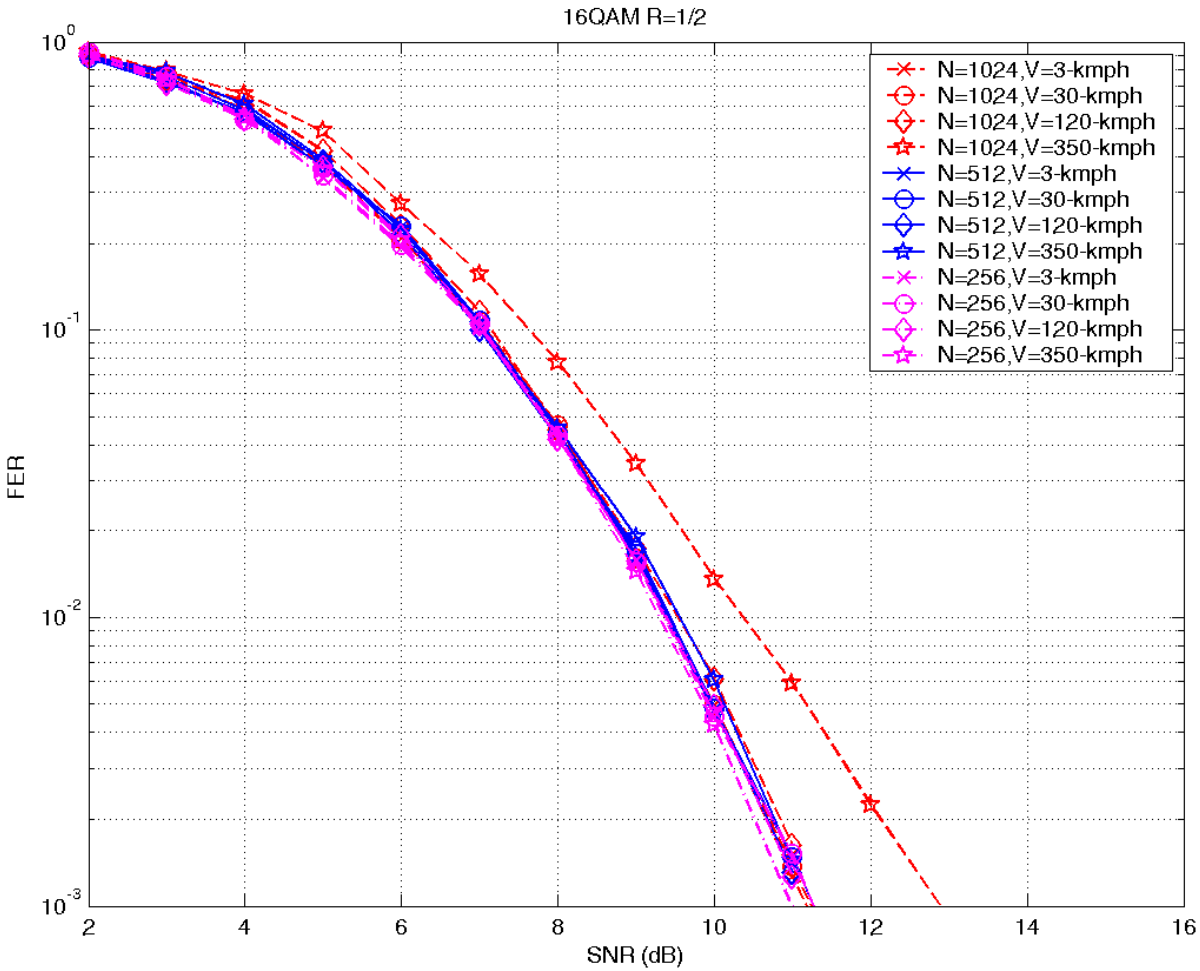
- All intertone spacings perform equally well for 120 kmph and below.
- For 350 kmph, N=1024 is worse than others.

QPSK rate 1/2 (Actual Channel Estimation)



- Similar trends as noise-free channel estimation results
- The spread in results for N=256, 512, and 1024 is due to different symbol lengths, so more pilot averaging for N=1024

16QAM rate 1/2 (Noise-Free Channel Estimation)



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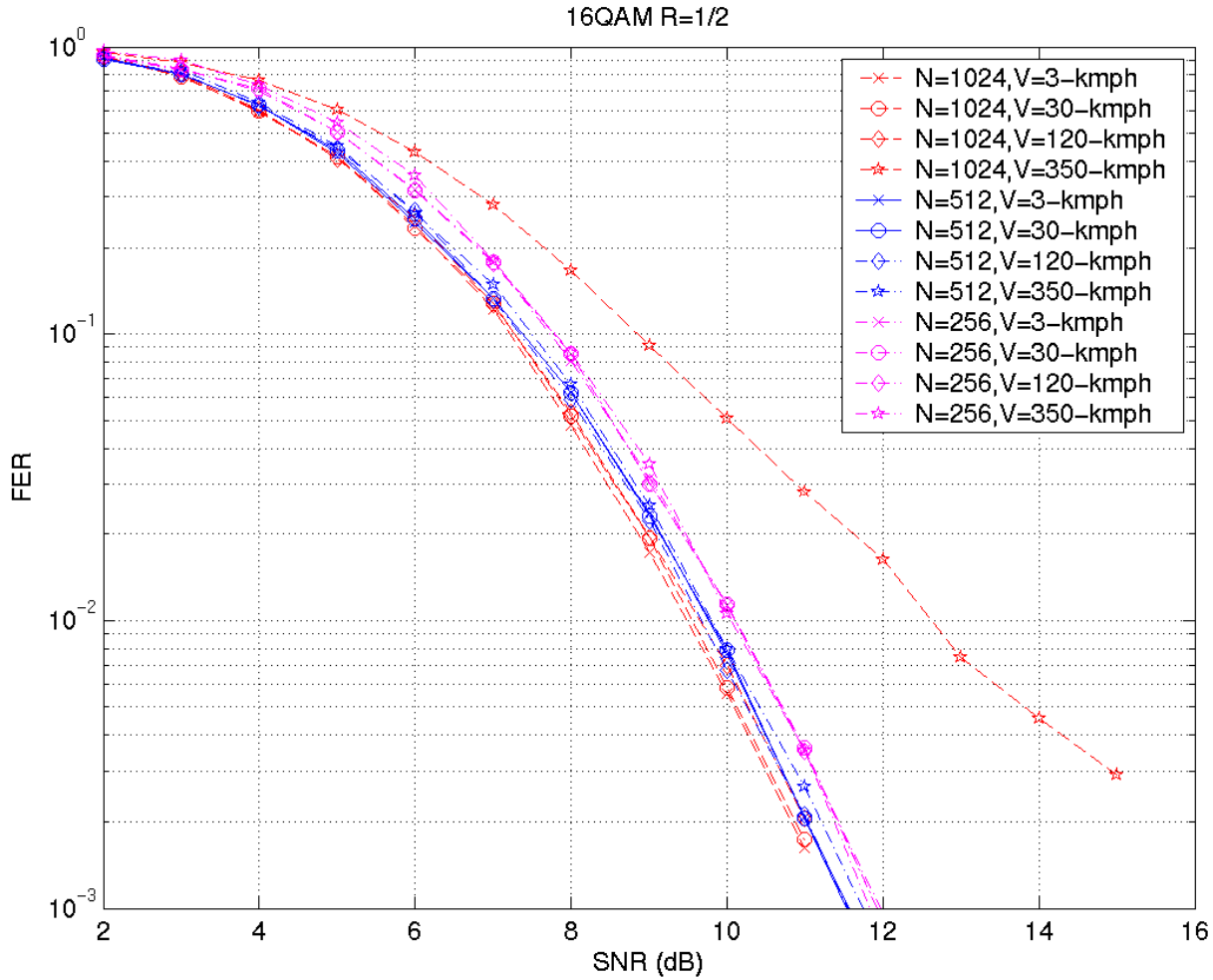
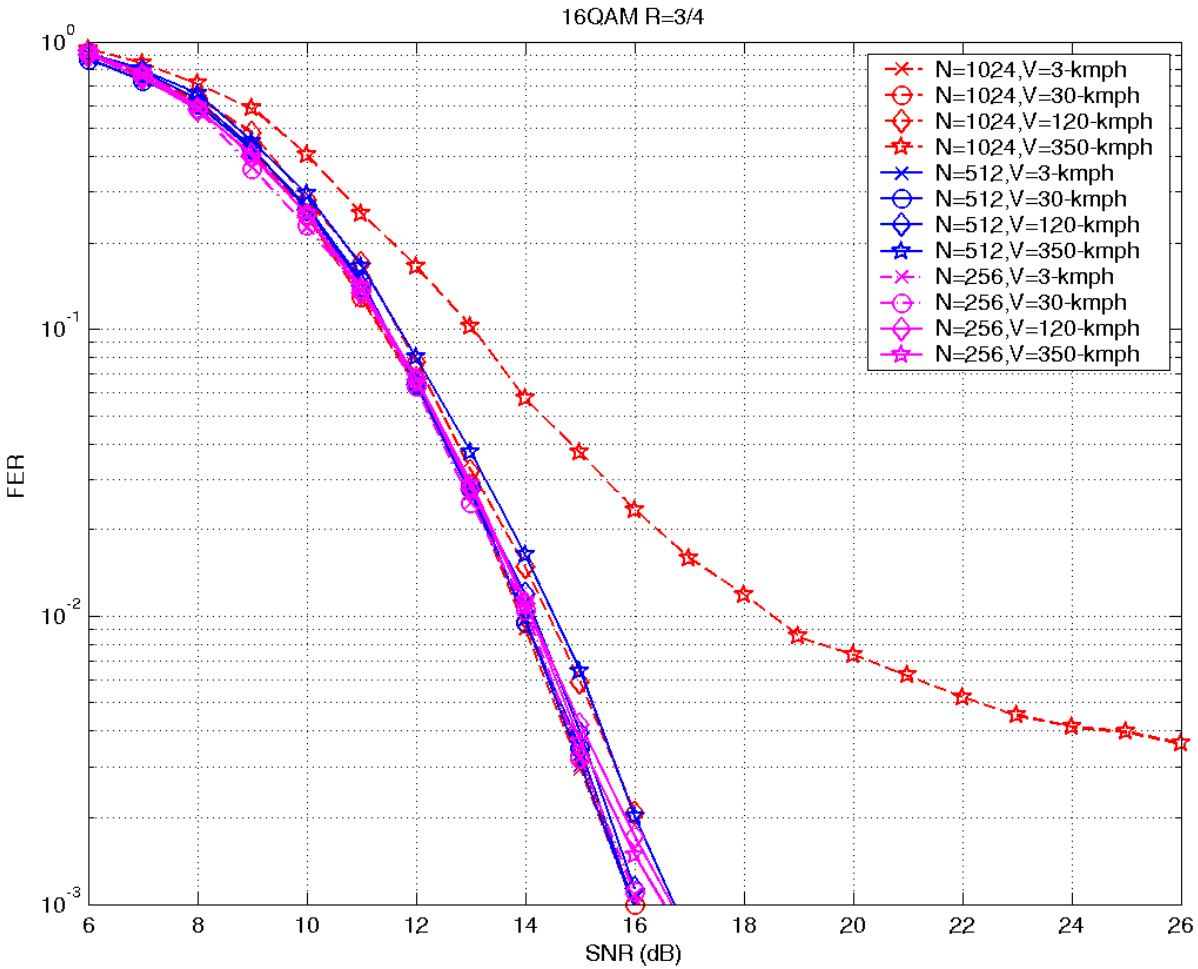
16QAM rate 1/2 (Actual Channel Estimation)



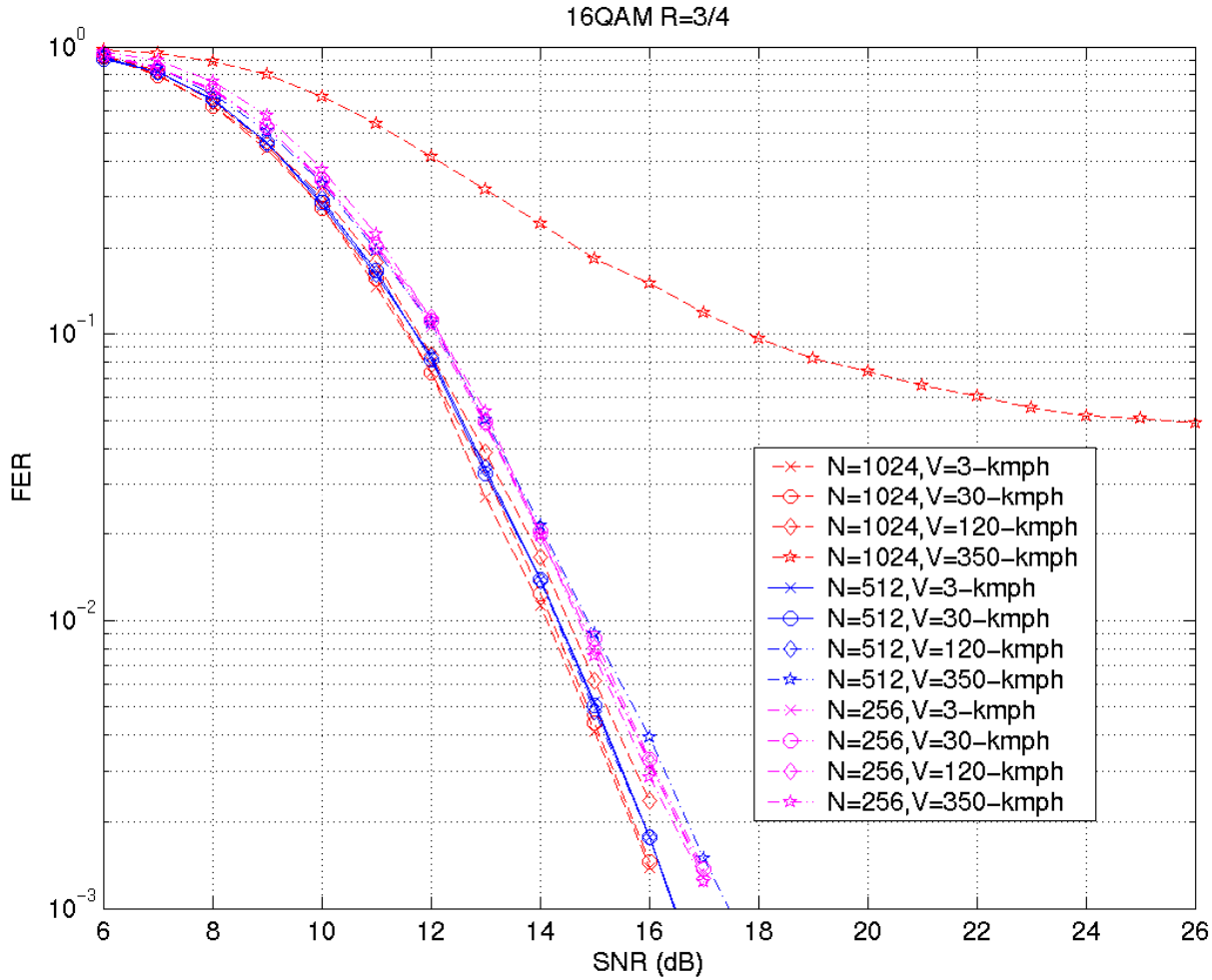
- Similar trends as noise-free channel estimation results
- For 350 kmph, N=1024: the 2 pilot symbol averaging in time does not work well due to small coherence time.

16QAM rate 3/4 (Noise-Free Channel Estimation)



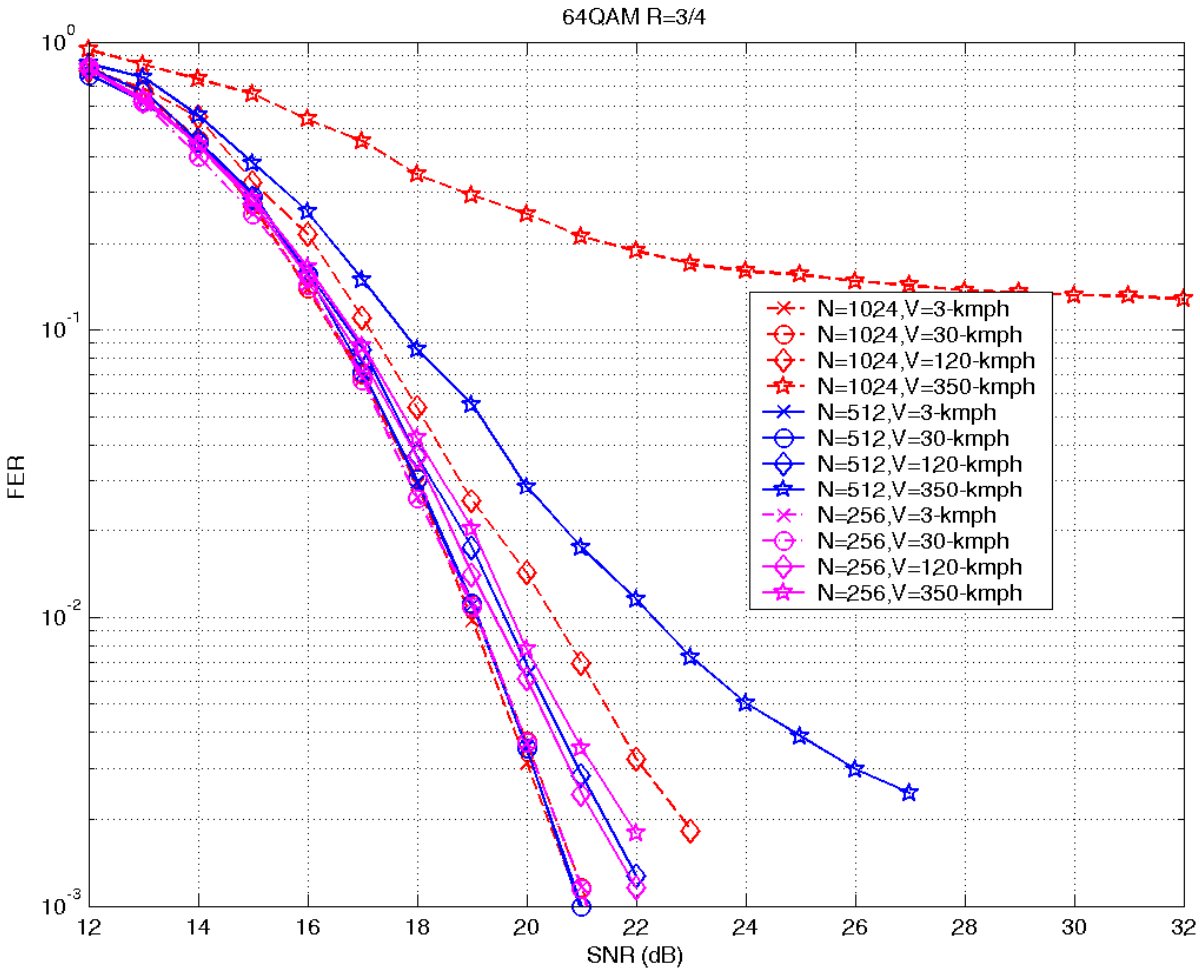
- All intertone spacings perform similarly for 120 kmph and below.
- 3dB degradation for N=1024 at 350-kmph (at 10% FER), with error floor > 1% FER

16QAM rate 3/4 (Actual Channel Estimation)



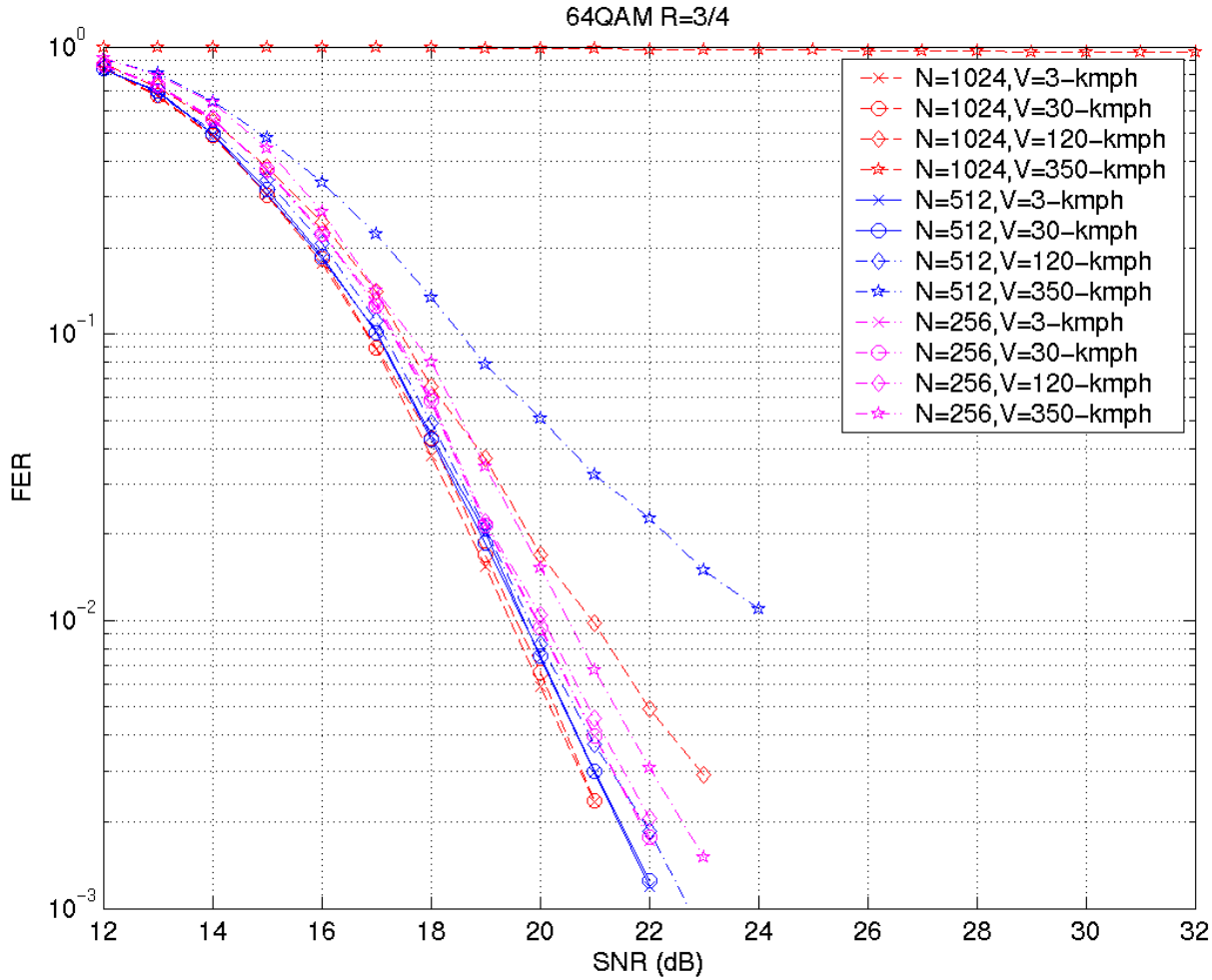
- Similar trends as noise-free channel estimation results
- For 350 kmph, N=1024: the 2 pilot symbol averaging in time does not work well due to small coherence time.

64QAM rate 3/4 (Noise-Free Channel Estimation)



- N=1024: Error floor > 10% FER at 300-kmph. 1dB degradation at 120-kmph
- N=512: Error floor slightly lower than 1% FER + 2dB degradation at 350-kmph

64QAM rate 3/4 (Actual Channel Estimation)



- Similar trends as noise-free channel estimation results
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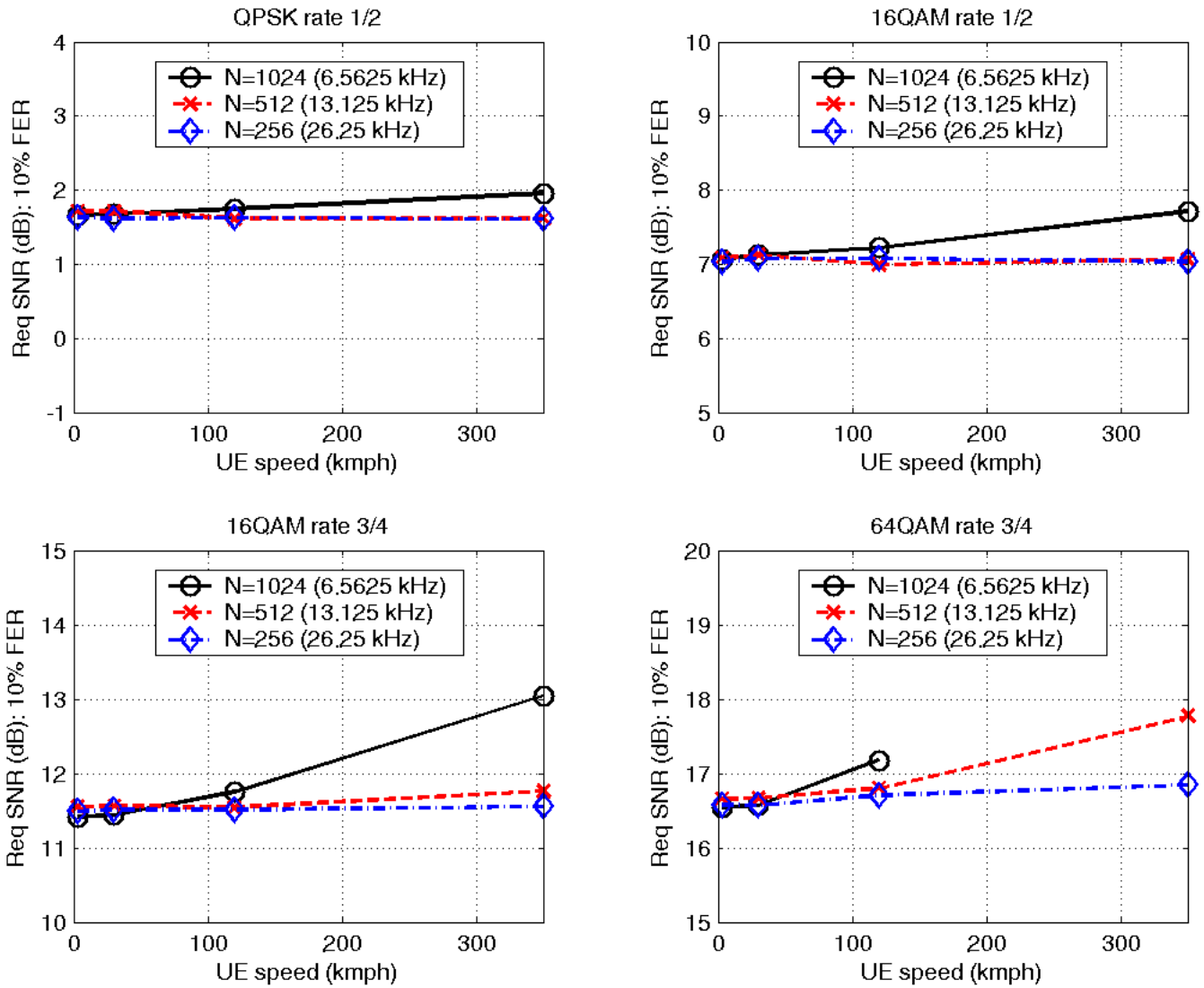
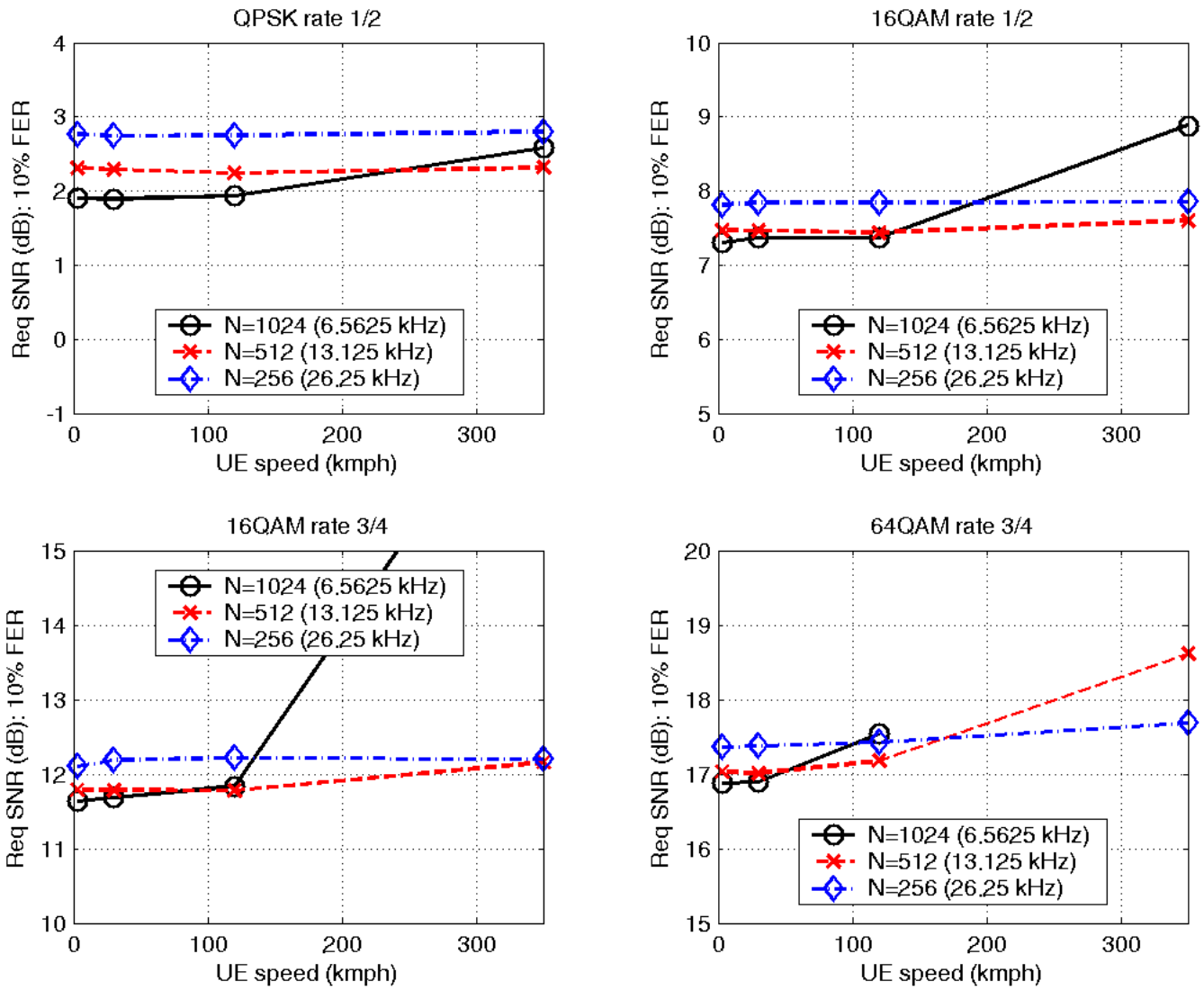
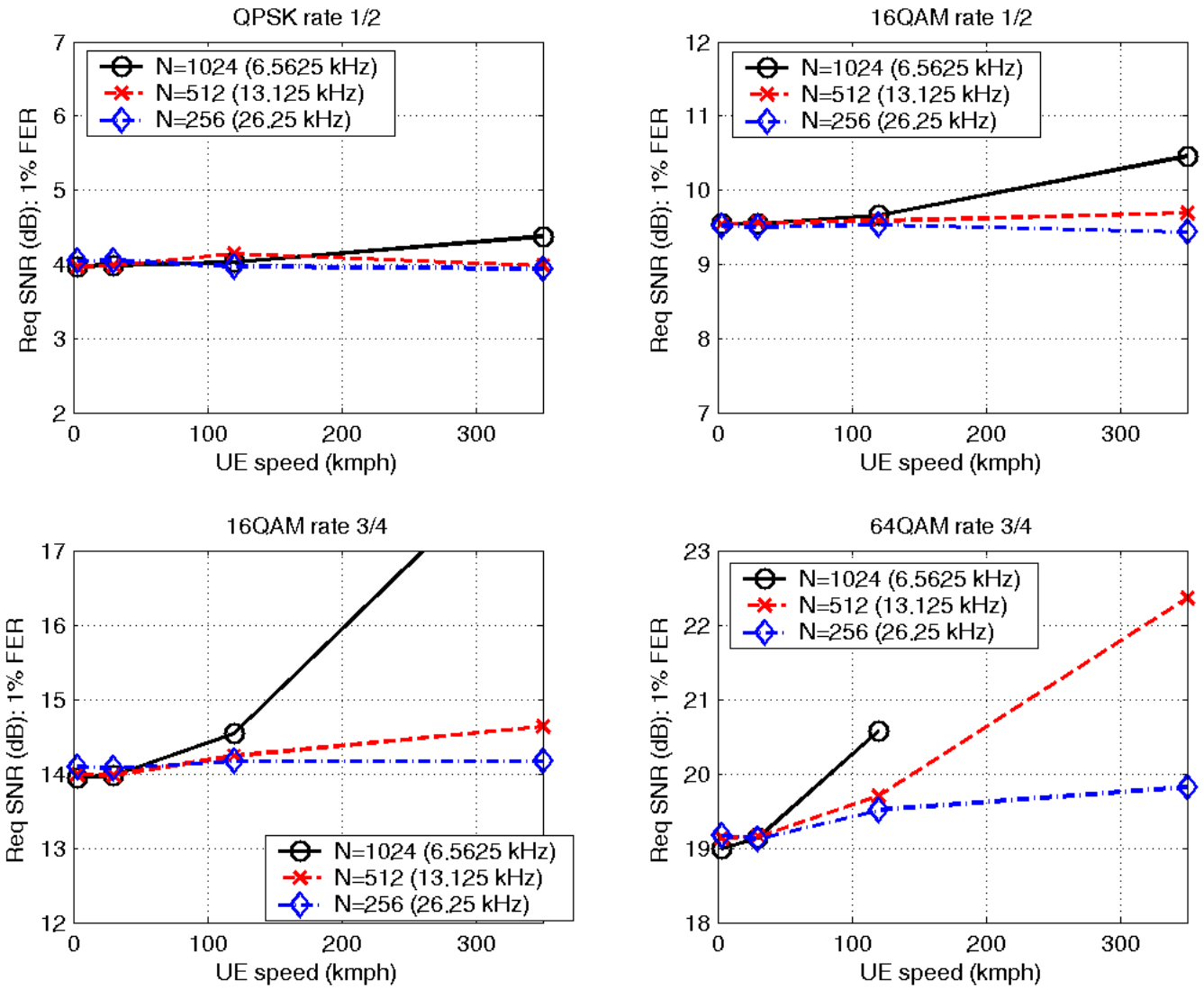
Required SNR for 10% FER (Noise-Free Channel Estimation)



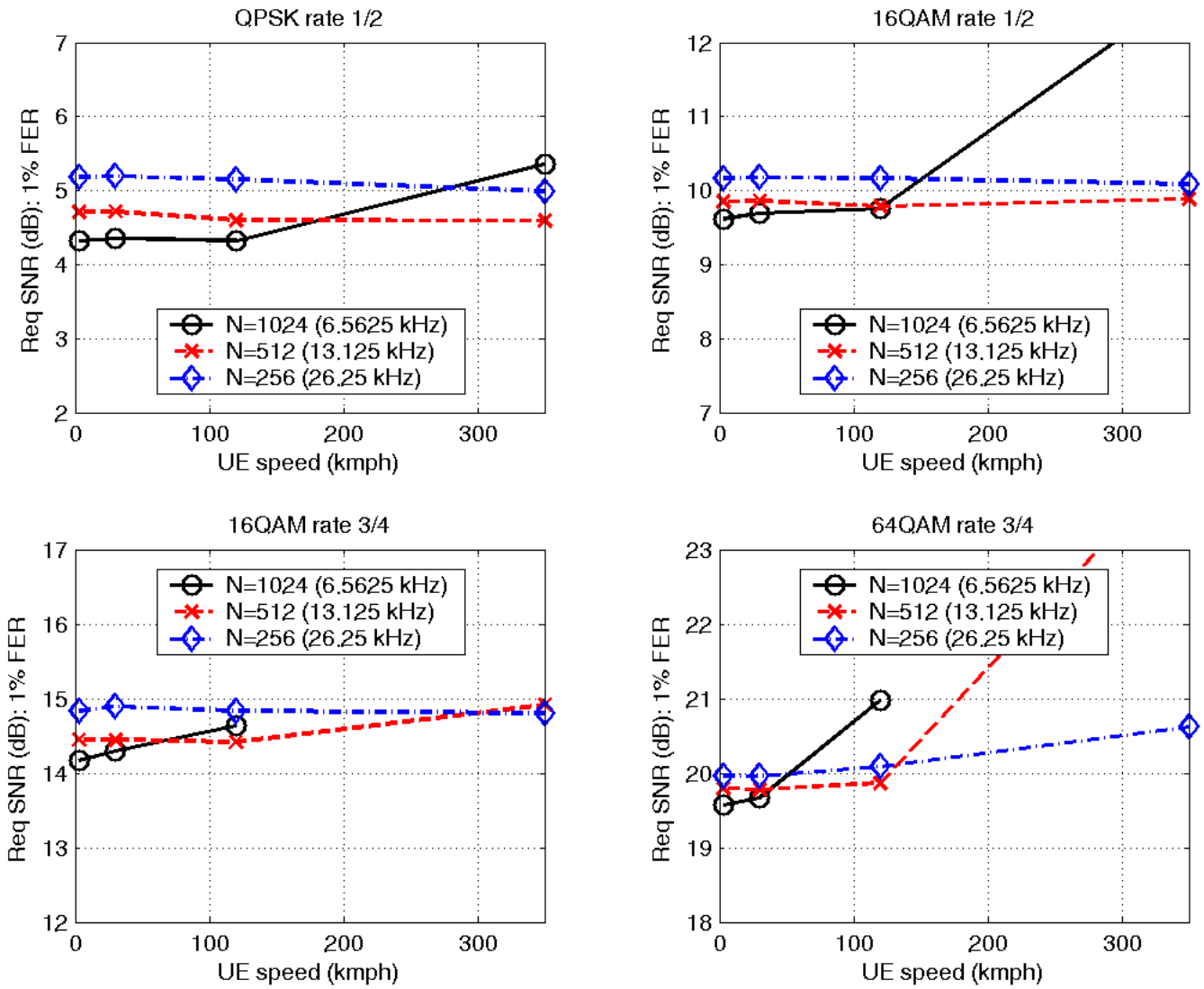
Required SNR for 10% FER (Actual Channel Estimation)



Required SNR for 1% FER (Noise-Free Channel Estimation)



Required SNR for 1% FER (Actual Channel Estimation)



Results with Noise-Free Channel Estimation: Summary

- Regular best effort packet data services (FER ~ 10%):

	N=1024, 6.375kHz	**N=512, 12.75kHz**	**N=256, 25.5kHz**
64QAM at 350kmph	Not supportable	1.5 dB loss	0.3dB loss
64QAM at 120kmph	1.5 dB loss	No loss	No loss
16QAM rate ¾ at 350kmph	2 dB loss	No loss	No loss
Other scenarios	<= 1dB loss	No loss	No loss
Rate penalty due to CP	Small	Moderate	Large

- High QoS services, e.g. MBMS (FER ~ 1%):

	N=1024, 6.375kHz	**N=512, 12.75kHz**	**N=256, 25.5kHz**
64QAM at 350kmph	Not supportable	3.5 dB loss	0.5dB loss
64QAM at 120kmph	1 dB loss	1.5 dB loss	No loss
16QAM rate ¾ at 350kmph	4.5 dB loss	0.5 dB loss	No loss
Other scenarios	<= 2dB loss	No loss	No loss
Rate penalty due to CP	Moderate	Large	Very large

- From the above results, **N=512 (12.5kHz spacing)** seems to be the best choice:
  - Balance between performance at high mobility & CP overhead penalty

Results with Actual Channel Estimation: Summary

- Regular best effort packet data services (FER ~ 10%):

	N=1024, 6.375kHz	**N=512, 12.75kHz**	**N=256, 25.5kHz**
64QAM at 350kmph	Not supportable	1.5 dB loss	0.3dB loss
64QAM at 120kmph	1.5 dB loss	No loss	No loss
16QAM rate ¾ at 350kmph	6 dB loss	No loss	No loss
Other scenarios	<= 2dB loss	No loss	No loss
Rate penalty due to CP	Small	Moderate	Large

- High QoS services, e.g. MBMS (FER ~ 1%):

	N=1024, 6.375kHz	**N=512, 12.75kHz**	**N=256, 25.5kHz**
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16QAM rate ¾ at 350kmph	Not supportable	0.5 dB loss	No loss
Other scenarios	<= 3dB loss	No loss	No loss
Rate penalty due to CP	Moderate	Large	Very large

- From the above results, **N=512 (12.5kHz spacing)** seems to be the best choice:
  - Balance between performance at high mobility & CP overhead penalty

Conclusions: Inter-tone Spacing

- For inter-tone spacing, a spacing of between 11 and 15 kHz seems to be the best choice:
  - Balance between performance at high mobility & CP overhead penalty