

R1-050603

RAN1 Ad Hoc on LTE

Sophia Antipolis, France

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Agenda item: 4.2

E-UTRA Downlink OFDM Numerology

Texas Instruments

Outline

- Options for E-UTRA downlink OFDM parameters:
 - 5 options
- E-UTRA downlink OFDM pilot for 1-antenna transmission:
 - Time-frequency pattern
 - Overhead
 - Frequency \rightarrow Time versus Time \rightarrow Frequency interpolation
 - Throughput performance

E-UTRA Downlink OFDM Parameters

Considerations for Downlink Numerology

- **TTI length:** between 0.5 and 0.667 ms to meet latency requirements
- **Sampling rate:** small rational fraction (a/b with both a and b small numbers) times 3.84 MHz for ease of PLL implementation.
- **Cyclic prefix:**
 - Unicast: 5 μ s and overhead should be kept to at most 10% [1,2]
 - Broadcast: 12 to 20 μ s and overhead should be kept to at most 20% (except in extraordinary situations such as with repeaters without transmission control)
- **Subcarrier spacing:** between 11 and 15 kHz to trade off phase noise and Doppler ITI impact on performance versus cyclic prefix overhead [1,3]
 - Subcarrier spacings smaller than 11 kHz may have too much loss with Doppler ITI
 - Subcarrier spacings larger than 15 kHz have larger overheads for cyclic prefix

[1] R1-050386, NTT DoCoMo, Ericsson, Fujitsu, Mitsubishi Electric, NEC, Nortel, Panasonic, Texas Instruments, "Views on OFDM Parameter Set for Evolved UTRA Downlink ", Athens, Greece, May 9-13, 2005.

[2] R1-050520, Motorola, "EUTRA Downlink Numerology", Athens, Greece, May 9-13, 2005.

[3] R1-050387, Texas Instruments, "E-UTRA Downlink Multiple Access Study", Athens, Greece, May 9-13, 2005.

Downlink Numerology Options (5 MHz Channel)

Option Number	1	2	3	4	5
Sampling Frequency (MHz)	4.48 7/6*3.84	4.48 7/6*3.84	4.8 5/4*3.84	6.528 17/10*3.84	6.72 7/4*3.84
FFT Size	256	256	512	512	512
Subcarrier Spacing	17.5 kHz	17.5 kHz	9.375 kHz	12.75 kHz	13.125 kHz
TTI Length – Unicast	0.5 ms	0.625 ms	0.667 ms	0.667 ms	0.667 ms
# Symbols/ TTI for Unicast	8	10	6	8	8
Prefix Size for Unicast	5.357 μ s 24 samp 8.6%	5.357 μ s 24 samp 8.6%	4.444 μ s 21.3 samp 4.0%	4.902 μ s 32 samp 5.9%	7.143 μ s 48 samp 8.6%
TTI Length – Broadcast	1.0 ms	1.25 ms	1.33 ms	1.33 ms	1.33 ms
# Symbols/ TTI for Broadcast	14	18	10	14	14
Prefix Size for Broadcast	14.286 μ s 64 samp 20.0%	12.302 μ s 55.1 samp 17.7%	26.667 μ s 128 samp 20.0%	16.807 μ s 109.7smp 17.6%	19.048 μ s 128 samp 20.0%
Number of Used Sub-carriers *	256	256	480	353	343
Number of Pilot Subcarriers/Symbol**	16	16	30	22	22
Number of Data Sub-carriers	239	239	449	330	320

* Assumes 90% bandwidth occupancy. Number includes DC subcarrier.

** Assumes two transmit antennas at Node B. Pilot numbers given for unicast.

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Example: Downlink Numerology Expanded (Option 2)

TTI length = 0.625 ms for unicast and 1.25ms for broadcast

Number of symbols per TTI = 10 for unicast and 18 for broadcast

Subcarrier spacing = 17.5 kHz, Useful Symbol Duration = 57.143 μ s

Unicast: Guard time = 5.357 μ s, Overhead = 8.57%

Broadcast: Guard Time = 12.302 μ s, Overhead=17.71%

System Bandwidth (MHz)	20	15	10	5	2.5	1.25
Sampling Frequency (MHz)	17.92 (14/3*3.84)	17.92 (14/3*3.84)	8.96 (7/3*3.84)	4.48 (7/6*3.84)	2.24 (7/12*3.84)	1.12 (7/32*3.84)
FFT Size	1024	1024	512	256	128	64
Prefix Size for Unicast	96	96	48	24	12	6
Prefix Size for Broadcast	220.44	220.44	110.22	55.11	27.56	13.78
Number of Used Sub-carriers *	1024	768	512	256	128	64
Number of Pilot Subcarriers/Symbol**	64	48	32	16	8	4
Number of Data Sub-carriers	959	719	479	239	119	59

* Includes DC subcarrier.

** Assumes two transmit antennas at Node B. Pilot numbers given for unicast.

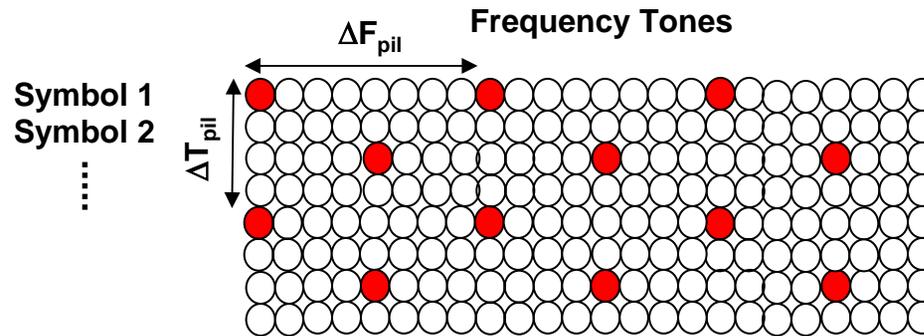
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E-UTRA Downlink OFDM Pilot for 1- antenna Transmission

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OFDM Pilot Structure

- Scattered common pilot with checkerboard pattern
- Assume 1 transmit antenna
- Parameters:
 - Spacing in frequency domain : ΔF_{pil} (tones)
 - Spacing in time domain : ΔT_{pil} (OFDM symbols)
 - Power boost relative to data : P_{pil}



- Total overhead = $2 \times \frac{1}{\Delta F_{pil}} \times \frac{1}{\Delta T_{pil}} \times P_{pil}$
- With 2 TX antennas, the overhead becomes 2x if the same power boost factor is used ₈

Coherence Time and Bandwidth

Coherence time and bandwidth are used to provide a guideline for pilot frequency & time spacing

Coherence Time:

At 2.6 GHz, 350-kmph $\rightarrow f_D = 843$ Hz

$$50\% \text{ correlation coherence time [4]} \sim \frac{0.423}{f_D} = 500\mu\text{s}$$

Coherence Bandwidth: Longest rms delay spread [2,5] $D_S = 3 \mu\text{s}$

$$50\% \text{ correlation coherence BW [4]} \sim \frac{1}{5D_S} = 67 \text{ kHz}$$

Rms delay spread for TU channel is $1.07 \mu\text{s}$ for a coherence bandwidth of 187 kHz

[2] R1-050520, Motorola, "EUTRA Downlink Numerology", Athens, Greece, May 9-13, 2005.

[4] Rappaport, Wireless Communications, Prentice Hall, 1996.

[5] R1-050384, Nokia, "Downlink multiple access parameterisation", Athens, Greece, May 9-13, 2005.

Examples of Pilot Configurations

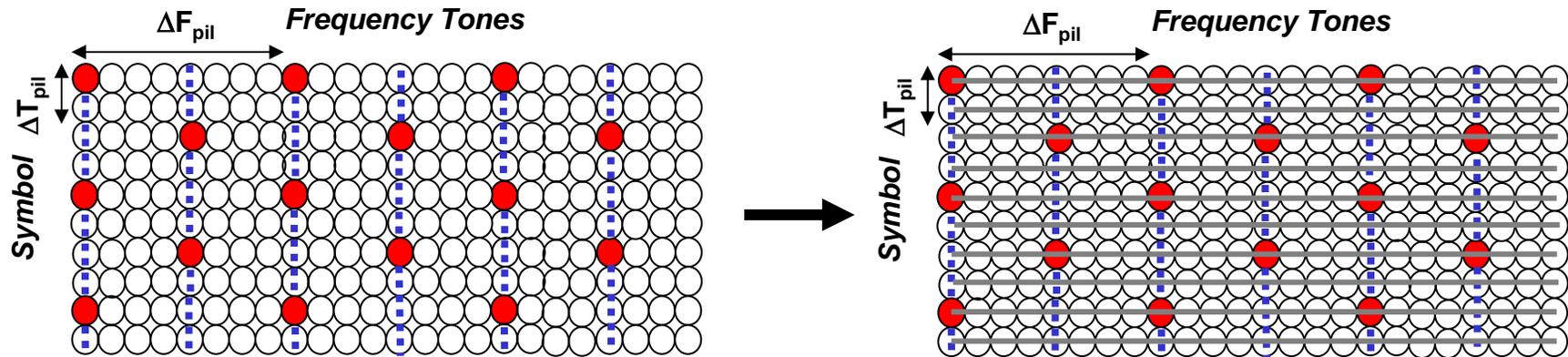
- As an example with Option 2
 - TTI length = 0.625ms
 - Sampling rate = $(7/6) \times 3.84$ MHz = 4.48 MHz (for 5 MHz BW)
 - Inter-carrier spacing = 17.5 kHz
 - 256-pt FFT, 10 OFDM symbols per TTI
 - Cyclic prefix length = 24 samples (5.357 μ s)
 - 50% coherence time (350kmph @2.6GHz) ~ 8 symbols
 - 50% coherence BW (TU channel) ~ 11 tones
- TU channel, UE speed \leq 350 kmph
- 1-antenna transmitter
- 2 pilot power overhead values: 6.25% and 10%.
- 4 examples:

Pattern	ΔF_{pil} (tones)	ΔT_{pil} (OFDM symbols)	P_{pil} for 6.25% overhead	P_{pil} for 10% overhead
1	8	4	0 dB	2.04 dB
2	4	8	0 dB	2.04 dB
3	16	4	3 dB	5.04 dB
4	8	8	3 dB	5.04 dB

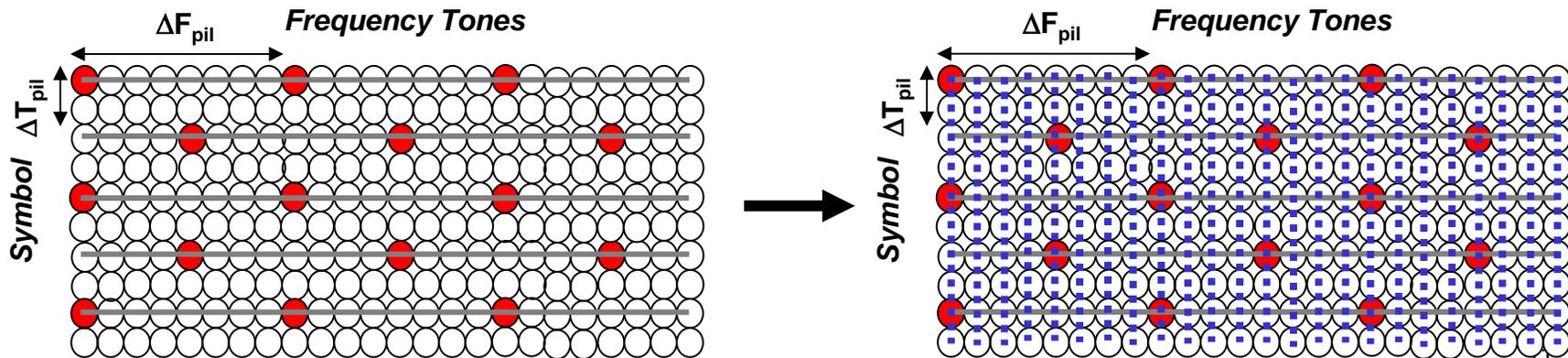
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Channel Estimation Methods

- Choice I: *Time* interpolation followed by *frequency* interpolation (T→F)



- Choice II: *Frequency* interpolation followed by *time* interpolation (F→T)



Throughput Definition

- Use throughput to compare different pilot configurations:

$$TP(G) = R \times (1 - FER(G))$$

$$R = \frac{M \times (N_U - N_{pil})}{T_{TTI} \times BW}$$

$$G = \left(1 + O_{TOT} - \frac{N_{pil}}{N_U} \right) \times SNR$$

G = geometry, SNR = average received symbol SNR

O_{TOT} = total pilot overhead (0.0625 or 0.1)

M = no. data bits per symbol

N_U = no. useful tones per TTI

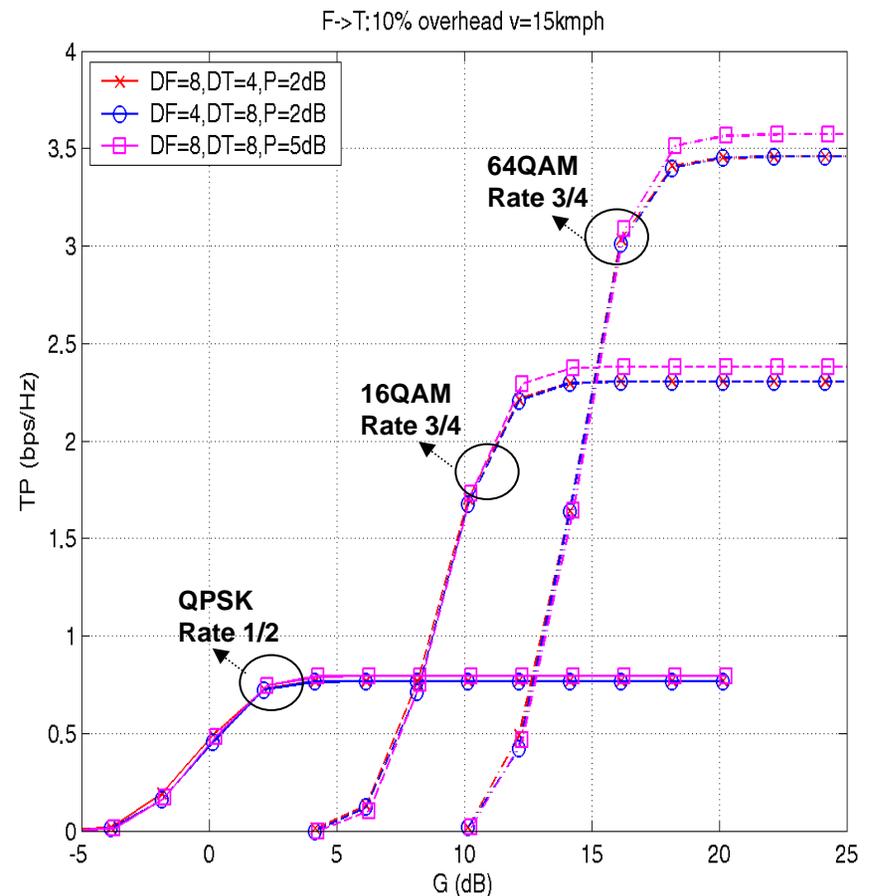
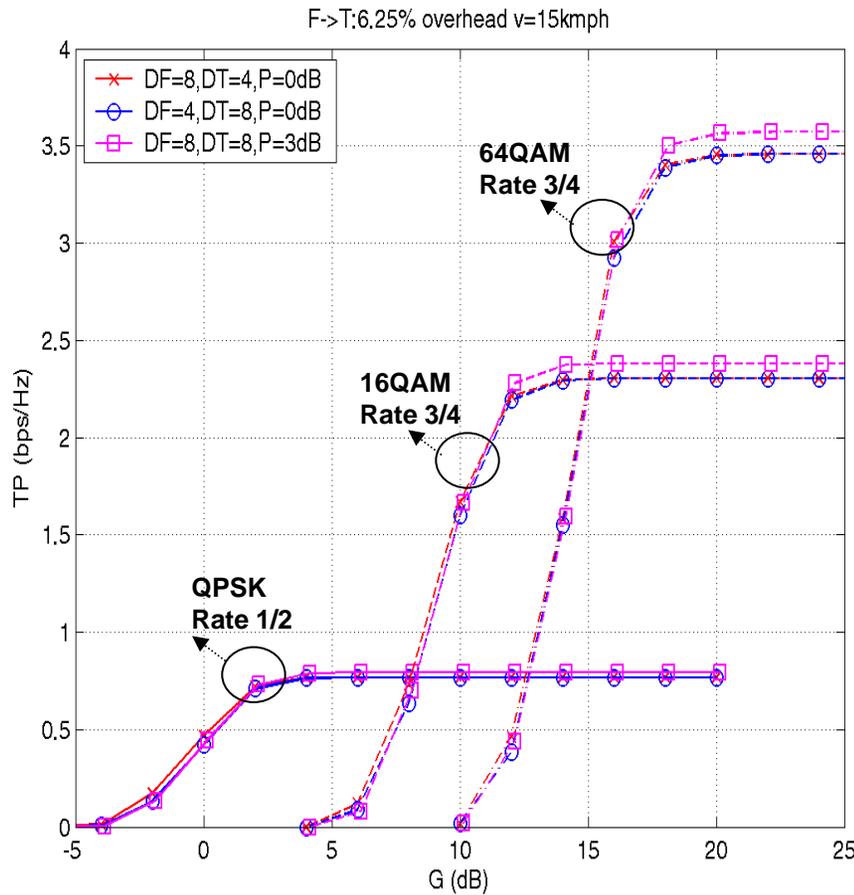
N_{pil} = no. pilot tones per TTI

T_{TTI} = TTI length

BW = bandwidth (5 MHz)

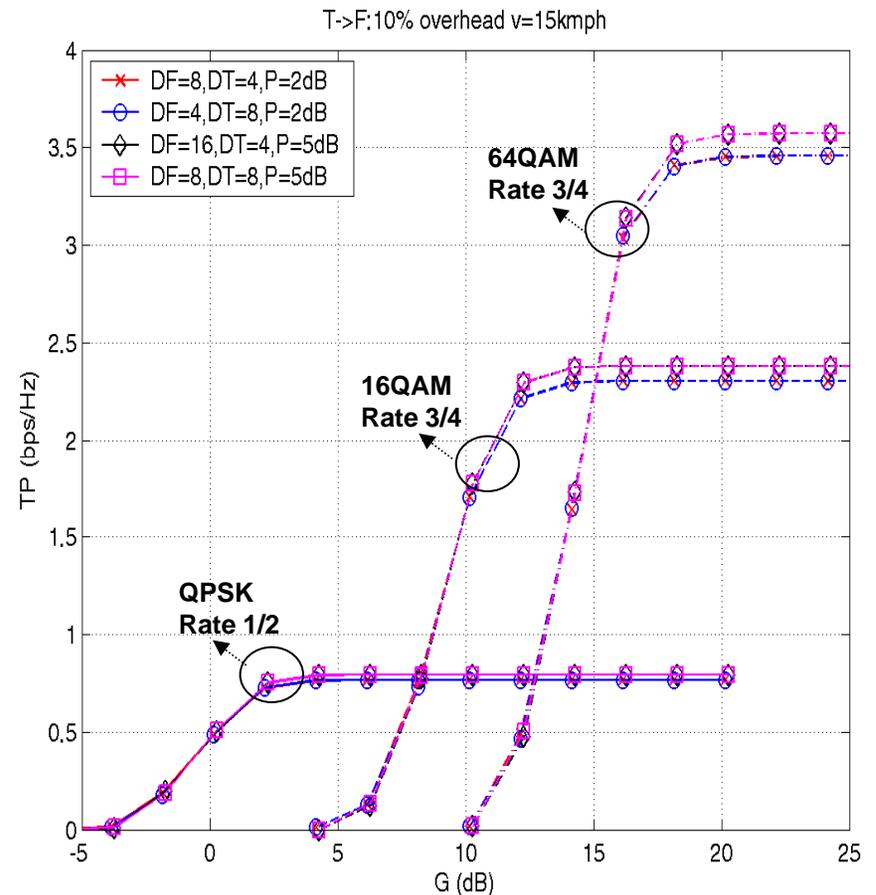
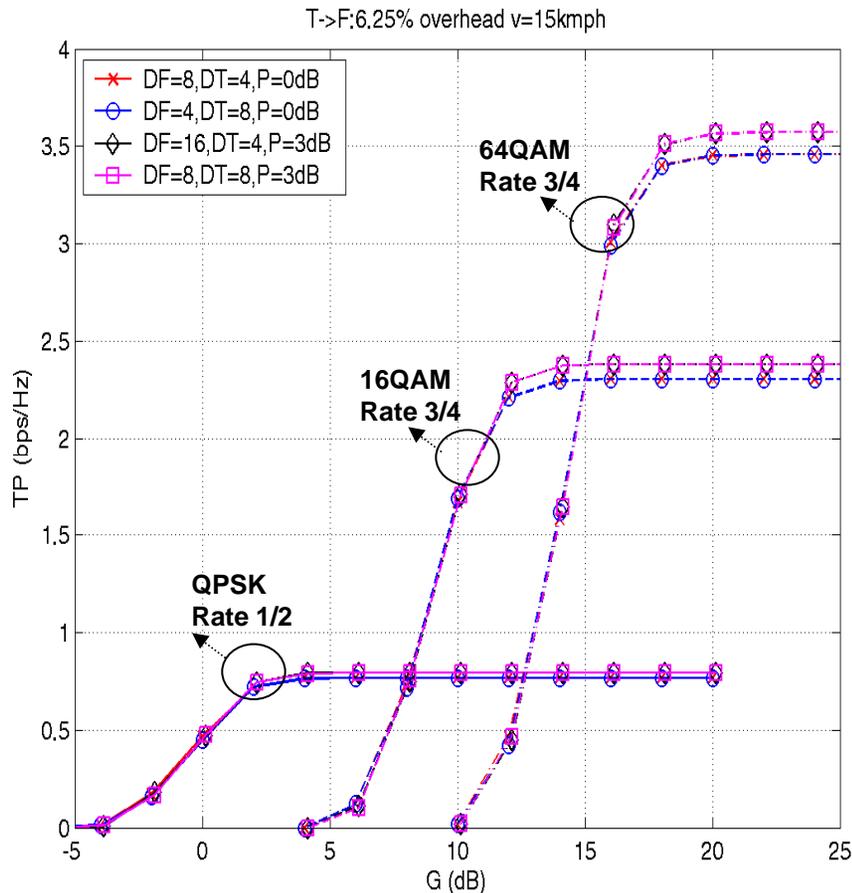
- Throughput reflects trade-off between link level performance and rate loss due to pilot₁₂ overhead

Results: 15kmph (F→T channel estimation)



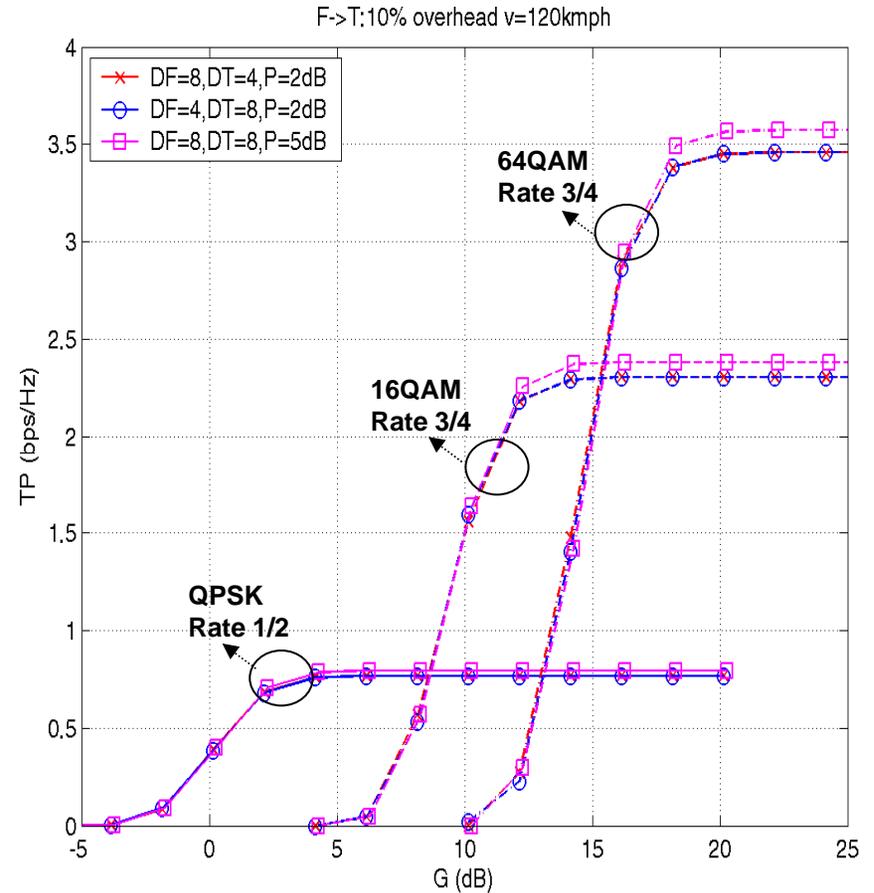
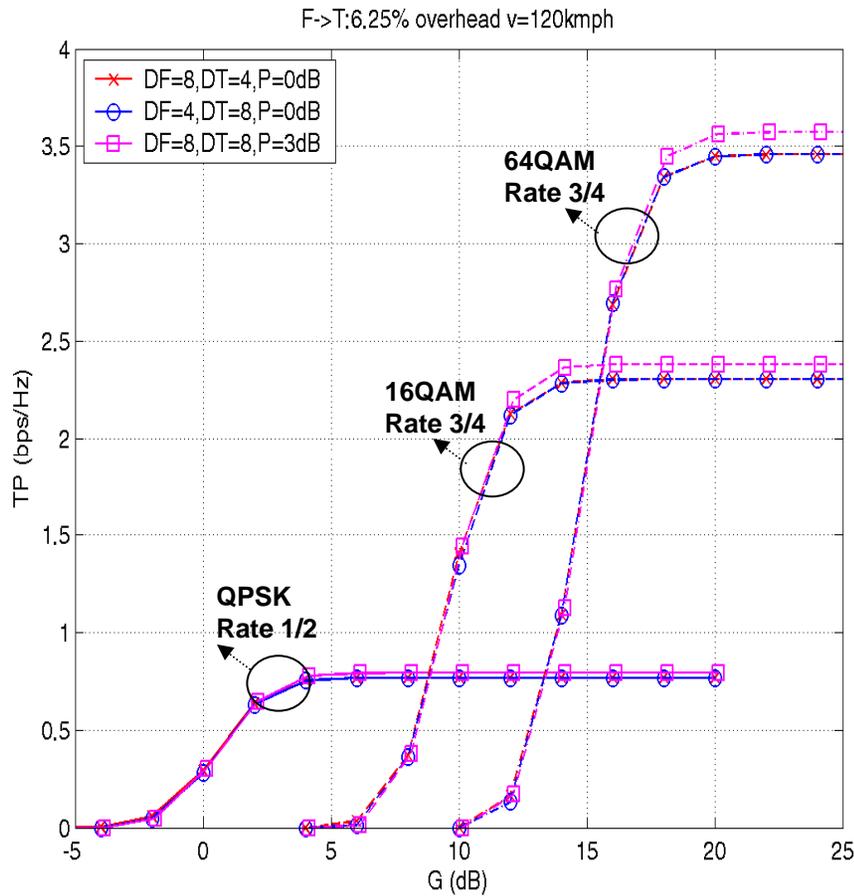
- With F→T channel estimation DF=16,DT=4 pattern exceeds 50% coherence BW. Hence F→T channel estimation results in very poor performance (results not shown) for DF=16,DT=4
- Except for DF=16, different patterns yield almost the same performance in moderate geometry region.
- Peak rate is higher for DF=DT=8

Results: 15kmph (T→F channel estimation)



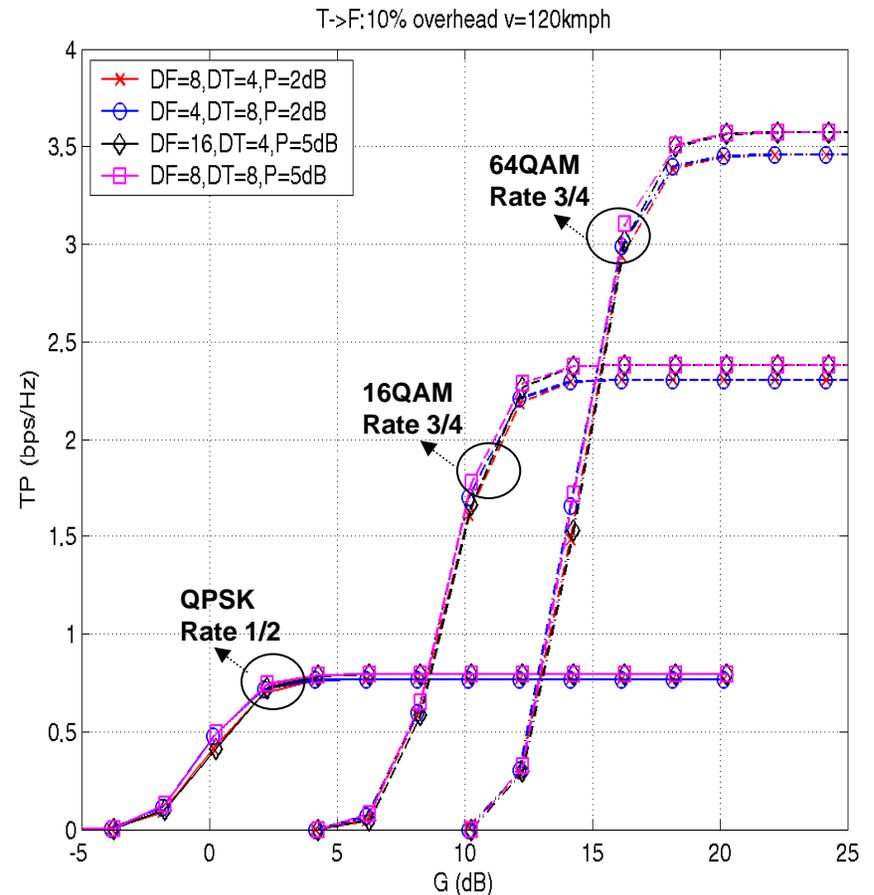
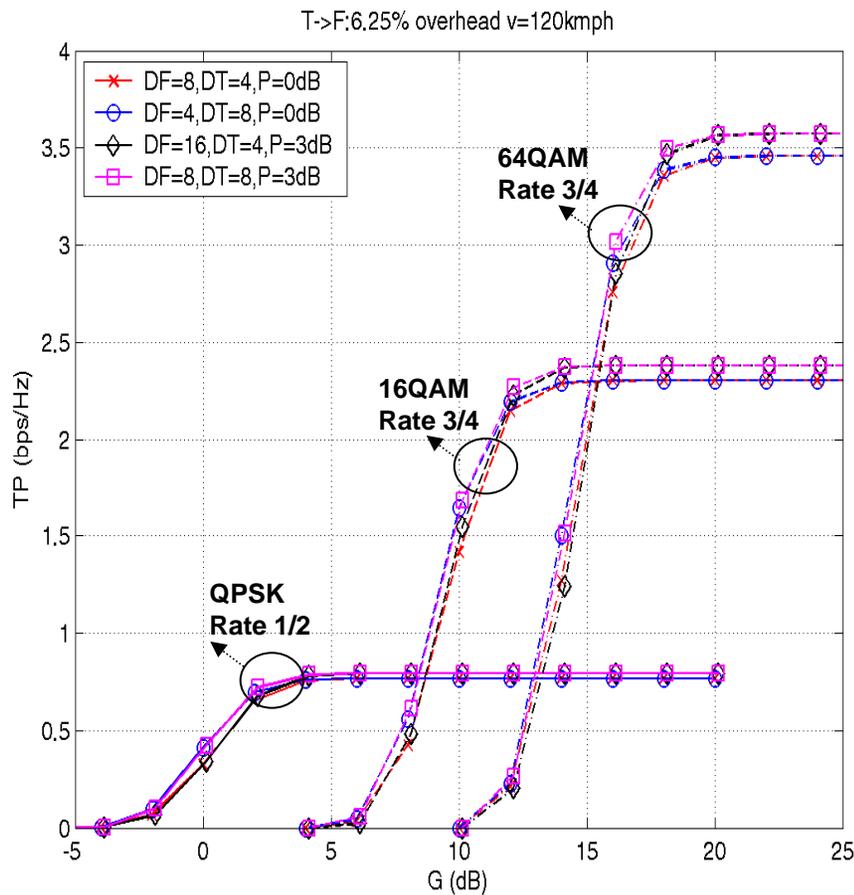
- With T→F channel estimation, the effective frequency spacing after time interpolation is $DF/2$. Hence T→F channel estimation yields satisfactory for $DF=16,DT=4$.

Results: 120kmph (F→T channel estimation)



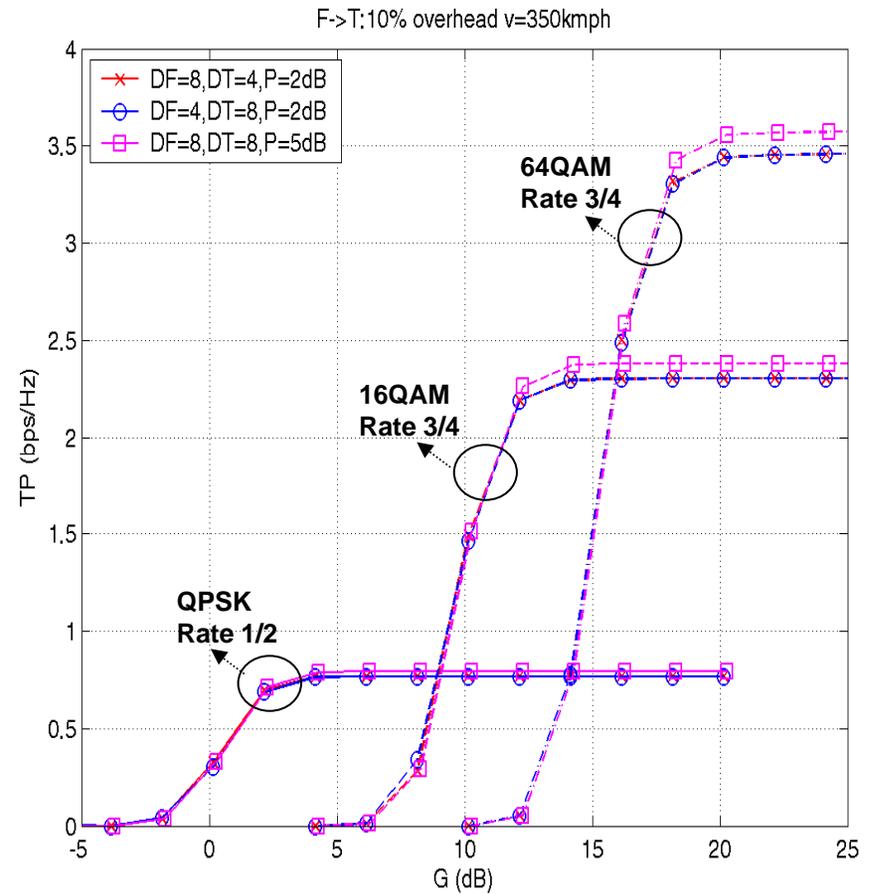
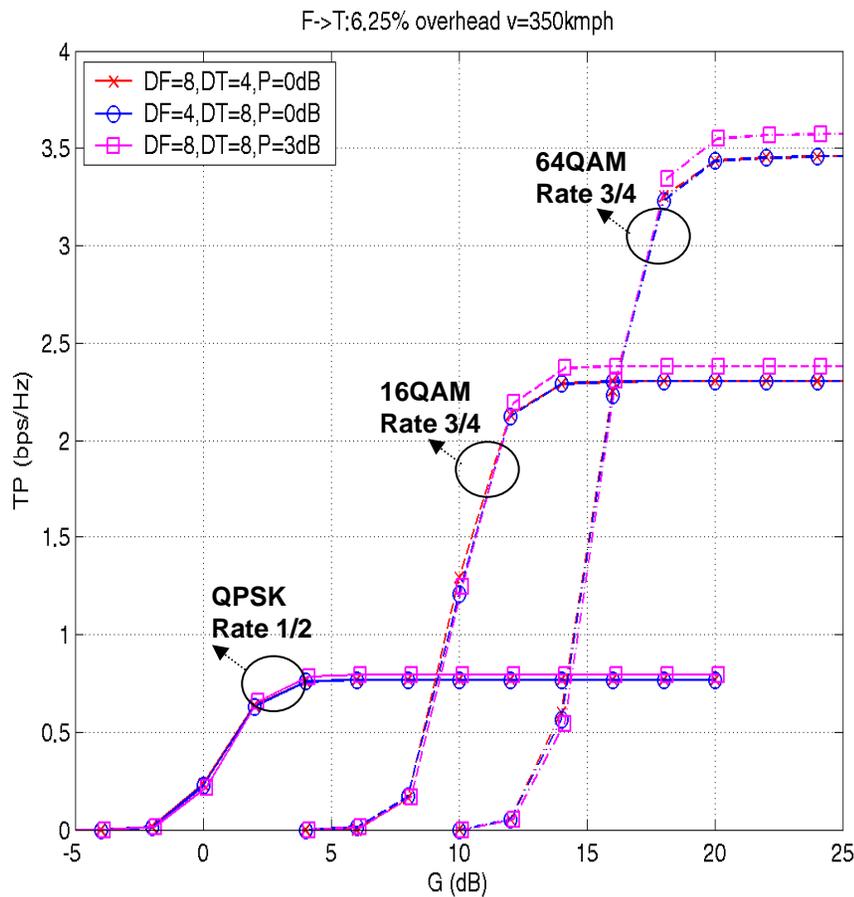
- Same trend as for v=15kmph

Results: 120kmph (T→F channel estimation)



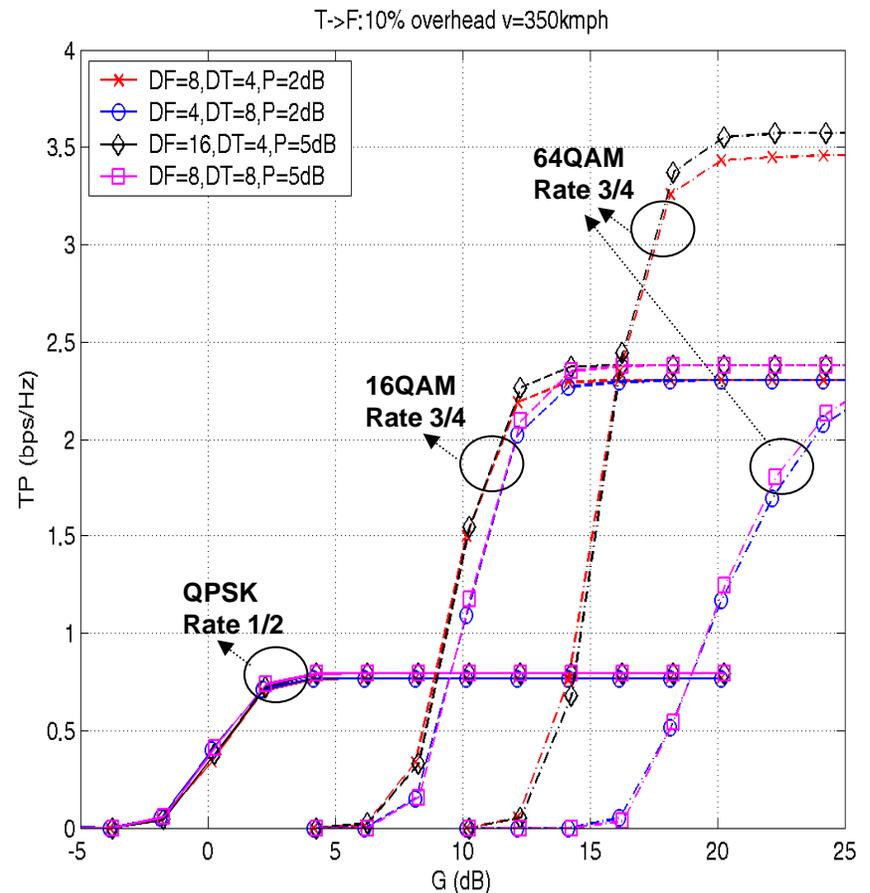
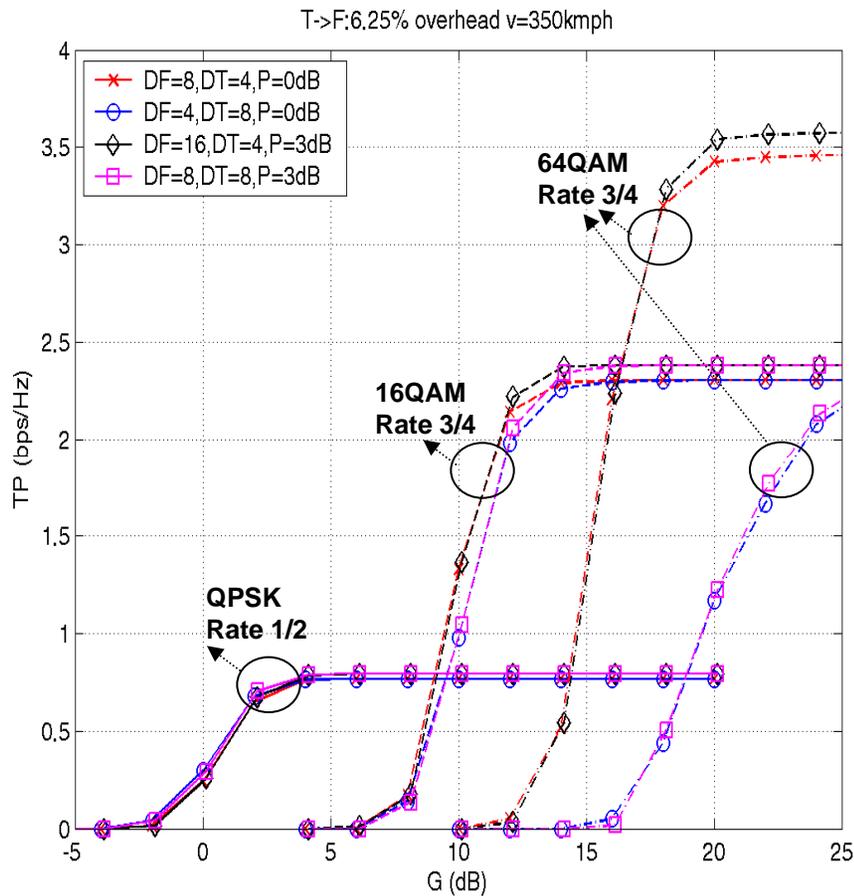
- Same trend as for v=15kmph

Results: 350kmph (F→T channel estimation)



- Same trend as for 15, 120 kmph
- Note that with F→T channel estimation, the effective time spacing after frequency interpolation is $DT/2$. Hence F→T channel estimation yields satisfactory performance for $DT=8$.

Results: 350kmph (T→F channel estimation)



- With T→F channel estimation, DT=8 is very close to 50% coherence time at 350kmph. Hence significant performance degradation is observed especially for 64QAM.

Summary of Results: QPSK rate 1/2

- Throughput (bps/Hz):

Red: best pilot patterns for each scenario

		G = 0 dB		G = 5 dB	
		TOH = 6.25%	TOH = 10%	TOH = 6.25%	TOH = 10%
$\Delta F=8, \Delta T=4$	V=15kmph	0.47	0.47	0.77	0.77
	V=120kmph	0.33	0.39	0.76	0.76
	V=350kmph	0.24	0.32	0.76	0.77
$\Delta F=4, \Delta T=8$	V=15kmph	0.45	0.46	0.77	0.77
	V=120kmph	0.41	0.45	0.76	0.77
	V=350kmph	0.30	0.37	0.77	0.77
$\Delta F=16, \Delta T=4$	V=15kmph	0.45 (T→F)	0.46 (T→F)	0.79 (T→F)	0.79 (T→F)
	V=120kmph	0.32 (T→F)	0.37 (T→F)	0.79 (T→F)	0.79 (T→F)
	V=350kmph	0.24 (T→F)	0.33 (T→F)	0.79 (T→F)	0.79 (T→F)
$\Delta F=8, \Delta T=8$	V=15kmph	0.45	0.46	0.79	0.79
	V=120kmph	0.40	0.44	0.79	0.79
	V=350kmph	0.28	0.36	0.79	0.79

- The performance of T→F and F→T are very close except indicated otherwise (in bracket)

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Summary of Results: 16QAM rate 3/4

- Throughput (bps/Hz):

Red: best pilot patterns for each scenario

		G = 10 dB		G = 15 dB	
		TOH = 6.25%	TOH =10%	TOH = 6.25%	TOH =10%
$\Delta F=8, \Delta T=4$	V=15kmph	1.67	1.63	2.30	2.30
	V=120kmph	1.42	1.53	2.29	2.30
	V=350kmph	1.33	1.41	2.30	2.30
$\Delta F=4, \Delta T=8$	V=15kmph	1.69	1.63	2.30	2.30
	V=120kmph	1.64	1.61	2.30	2.30
	V=350kmph	1.21 (F→T)	1.37 (F→T)	2.30 (F→T)	2.30 (F→T)
$\Delta F=16, \Delta T=4$	V=15kmph	1.64 (T→F)	1.63 (T→F)	2.38 (T→F)	2.38 (T→F)
	V=120kmph	1.47 (T→F)	1.51 (T→F)	2.37 (T→F)	2.38 (T→F)
	V=350kmph	1.28 (T→F)	1.37 (T→F)	2.38 (T→F)	2.38 (T→F)
$\Delta F=8, \Delta T=8$	V=15kmph	1.64	1.63	2.38	2.38
	V=120kmph	1.61	1.61	2.38	2.38
	V=350kmph	1.17 (F→T)	1.33 (F→T)	2.38 (F→T)	2.38 (F→T)

- The performance of T→F and F→T are very close except indicated otherwise (in bracket)

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Summary of Results: 64QAM rate 3/4

- Throughput (bps/Hz):

Red: best pilot patterns for each scenario

		G = 15 dB		G = 20 dB	
		TOH = 6.25%	TOH = 10%	TOH = 6.25%	TOH = 10%
$\Delta F=8, \Delta T=4$	V=15kmph	2.29	2.23	3.45	3.45
	V=120kmph	2.01	2.09	3.45	3.45
	V=350kmph	1.43	1.50	3.43	3.43
$\Delta F=4, \Delta T=8$	V=15kmph	2.30	2.24	3.45	3.45
	V=120kmph	2.20	2.21	3.45	3.45
	V=350kmph	1.40 (F→T)	1.49 (F→T)	3.43 (F→T)	3.43 (F→T)
$\Delta F=16, \Delta T=4$	V=15kmph	2.27 (T→F)	2.23 (T→F)	3.56 (T→F)	3.56 (T→F)
	V=120kmph	1.94 (T→F)	2.06 (T→F)	3.56 (T→F)	3.56 (T→F)
	V=350kmph	1.28 (T→F)	1.31 (T→F)	3.52 (T→F)	3.52 (T→F)
$\Delta F=8, \Delta T=8$	V=15kmph	2.27	2.23	3.56	3.56
	V=120kmph	2.17	2.21	3.56	3.56
	V=350kmph	1.31 (F→T)	1.43 (F→T)	3.54 (F→T)	3.54 (F→T)

- The performance of T→F and F→T are very close except indicated otherwise (in bracket)

Conclusions

- Increasing pilot power boost (from 6.25% to 10% in total overhead) is beneficial only in moderate geometry region and high mobility scenarios:
- Comparison among 4 different pilot patterns:
 - Low to moderate geometries: higher pilot density is better (better interpolation). $\Delta F=4$, $\Delta T=8$ gives best performance.
 - High geometries: lower pilot density is better (higher peak rate). $\Delta F=8$, $\Delta T=8$ gives the best performance.
- $\Delta F=8$, $\Delta T=8$ with 3dB boost (6.25% total power overhead) seems to be an overall better choice.