

A photograph of a surfer in a black wetsuit riding a large, curling wave. The wave is a vibrant green color and is breaking over the surfer, creating a tunnel-like structure. The surfer is positioned in the lower center of the frame, riding the base of the wave. The background is a clear blue sky.

Transmit Power Back-off (PBO) for 2.5G and 5G BASE-T

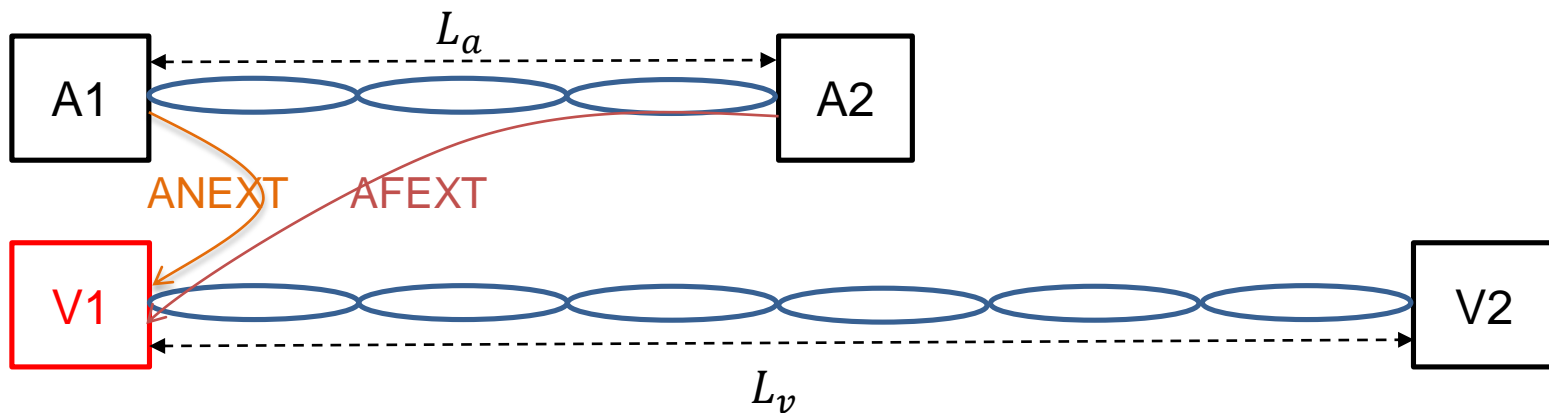
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Why Power Back-off is Needed

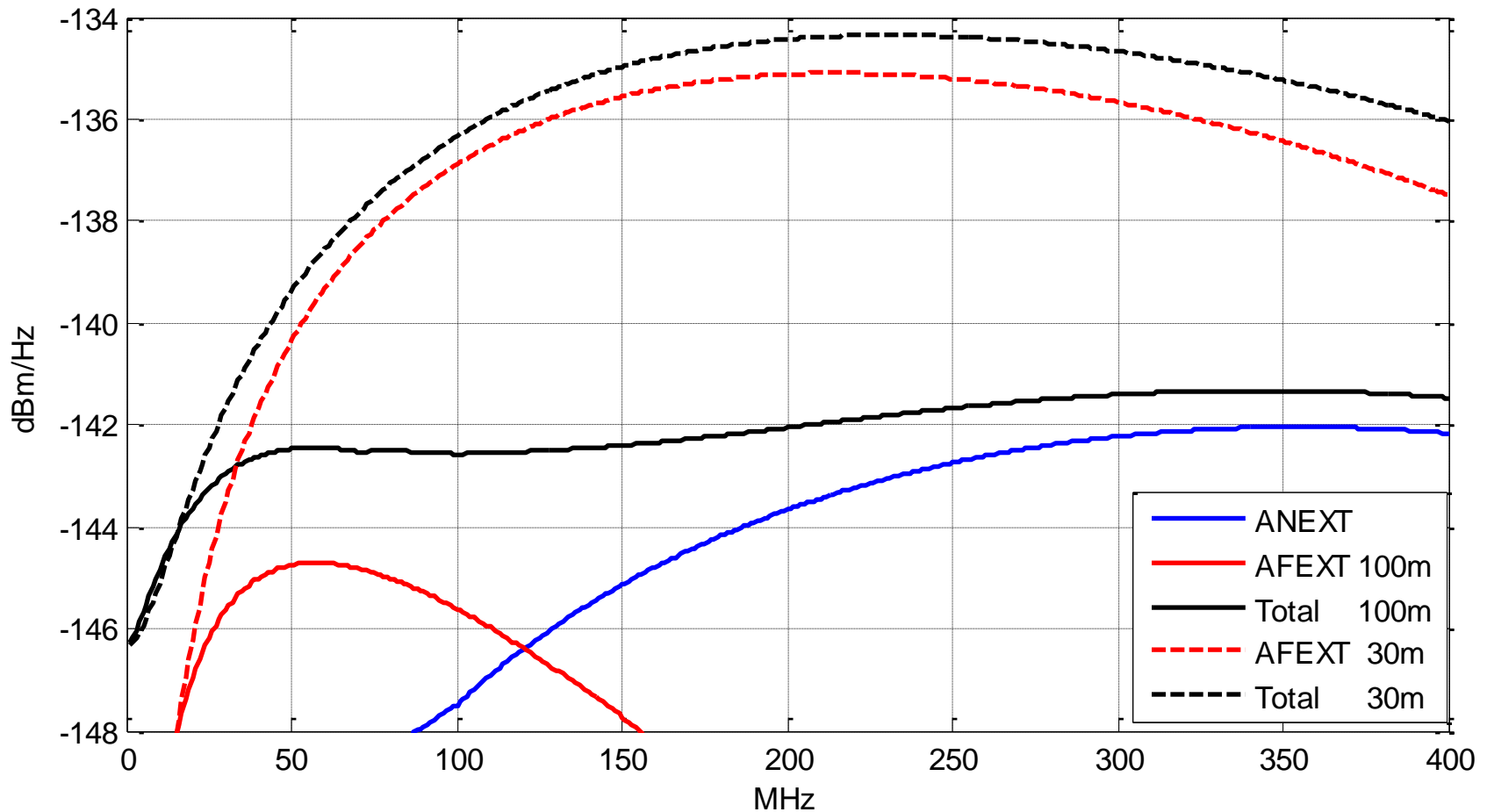
- Transmit power back-off (PBO) is a mechanism to alleviate the effect of alien crosstalk
- Alien crosstalk is stronger when a remote aggressor is on a shorter cable and closer to a victim
- PBO reduces the transmit power on short cables so that the crosstalk to adjacent links is reduced



Alien Crosstalk in BASE-T Systems

- Alien crosstalk is stronger when
 - Signaling bandwidth is wider
 - Coupling between cables is stronger
- Alien crosstalk is considered negligible in 1000BASE-T due to low bandwidth and low SNR requirements
 - Annex 40A defines a limit on ANEXT for 1000BASE-T systems
- 10GBASE-T is very sensitive to alien crosstalk because of its wider bandwidth. Coping mechanisms:
 - Use of Cat6a with lower coupling factor
 - PBO
- Alien crosstalk is an important noise source in 2.5G and more so in 5GBASE-T because
 - Cat5e/Cat6 cables have higher coupling factor
 - Signaling bandwidth is fairly wide

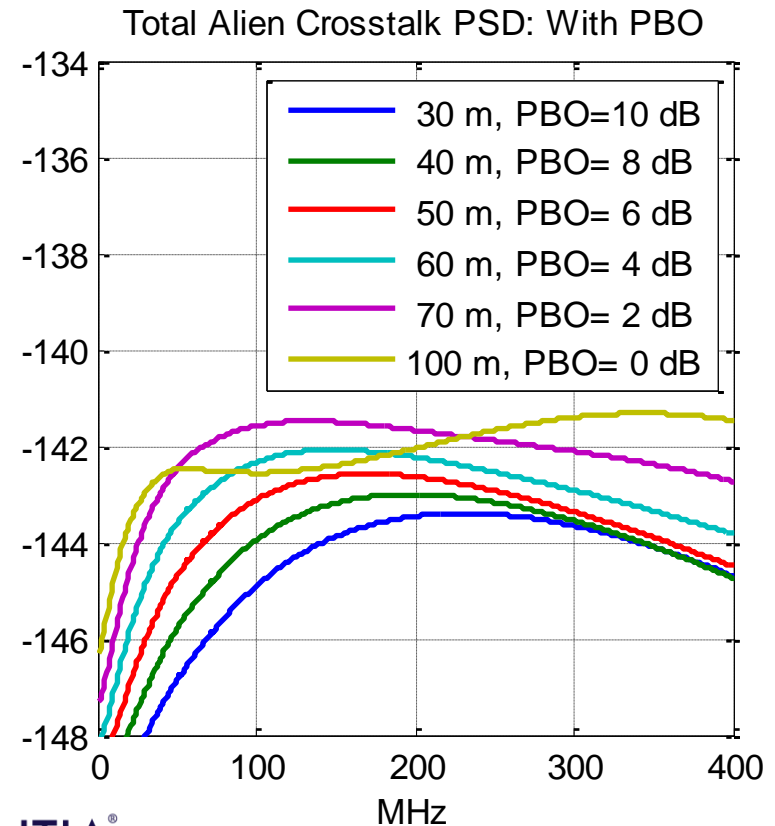
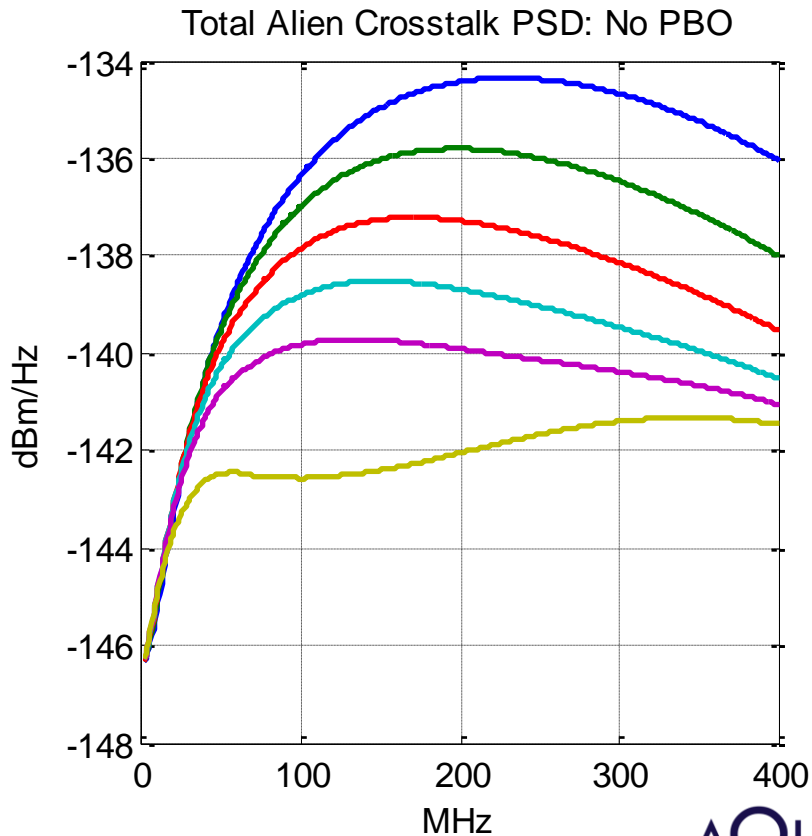
Alien Crosstalk PSD in 10GBASE-T



- ANEXT power is mostly independent of cable length
- AFEXT varies with insertion loss and coupling length

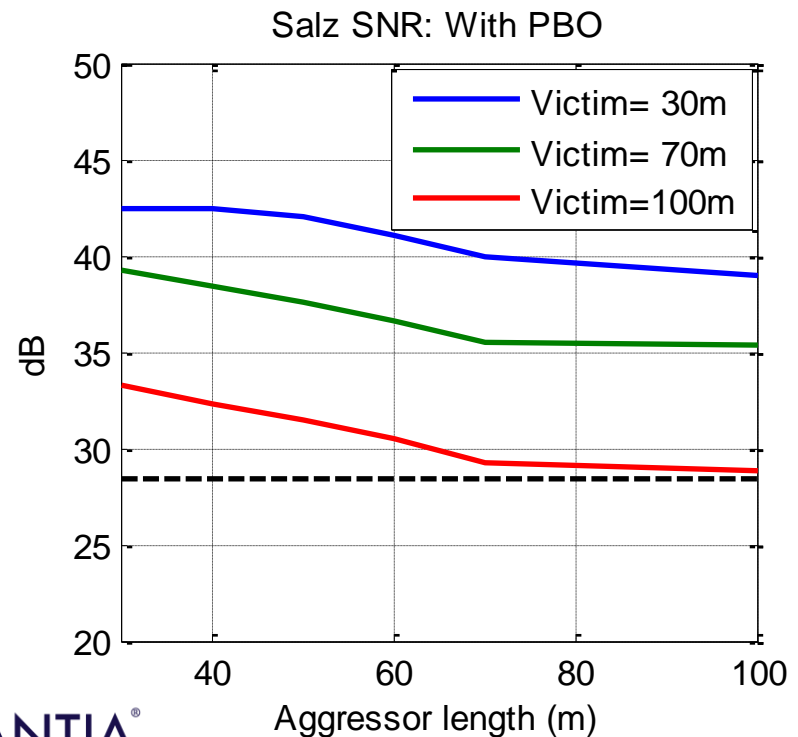
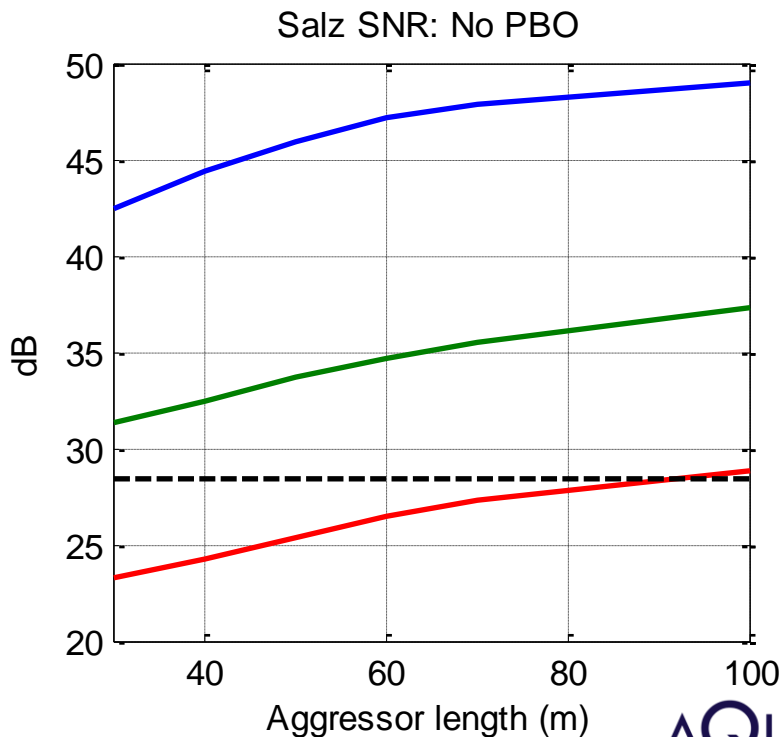
PBO in 10GBASE-T

- Alien crosstalk may be equalized across cable lengths with proper back-off of transmit power on shorter cables
- 10GBASE-T allows up to 14 dB of PBO in steps of 2 dB



PBO Selection in 10G

- Method: reduce the transmit power on shorter cables
 - so that the crosstalk on longer victim is minimized
 - while the SNR on shorter cables is not sacrificed too much
- Criterion: SNR should remain above a target for any combination of victim and aggressors cable lengths



PBO Considerations in 5G/2.5G

- There is no limit-line or model for alien crosstalk of Cat5e and Cat6 cables
- Usage model for 5G/2.5G allows mixture of victim and aggressors with potentially different rates and PSDs
- Aggressors and victim can be any combination of the following rates:
 - 1000BASE-T: BW=62.5 MHz, no PBO
 - 2.5GBASE-T: BW=100 MHz
 - 5GBASE-T: BW=200 MHz

Alien Crosstalk Models for Cat6/5e

- For this analysis, Cat6a models are extended with an additional constant offset

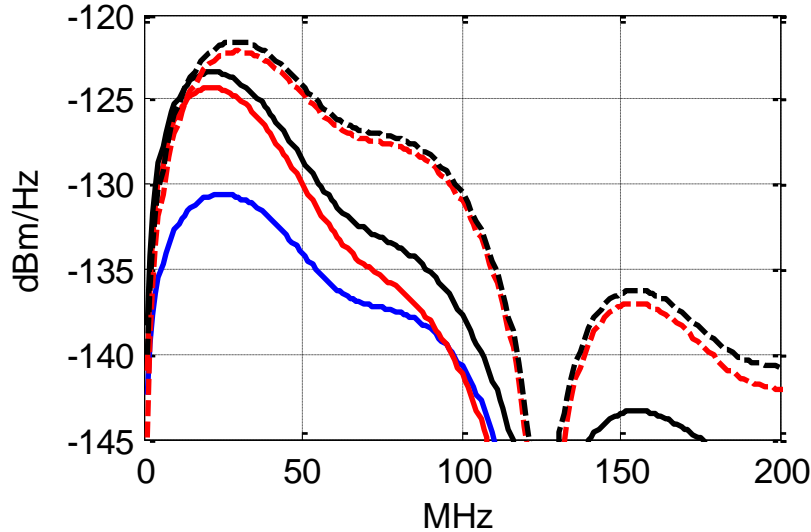
$$ANEXT_{PS} = \begin{cases} X_n - 10 \times \log(f/100) - X_o & f < 100 \text{ MHz} \\ X_n - 15 \times \log(f/100) - X_o & f \geq 100 \text{ MHz} \end{cases}$$

$$AELFEXT_{PS} = X_f - 20 \times \log(f/100) - 10 \times \log(L/100) - X_o$$

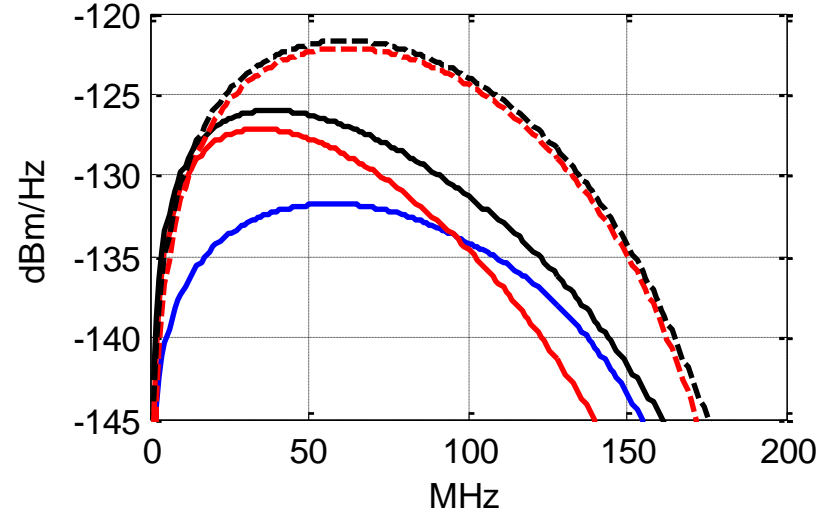
- X_f and X_n are alien crosstalk loss of Cat6a at 100 MHz
- X_o is the offset of Cat6/5e from Cat6a
 - An offset of $X_o \approx 15$ dB is used as the starting point
 - Do we need different offset for ANEXT and AFEXT?

Alien Crosstalk PSD for Various Rates

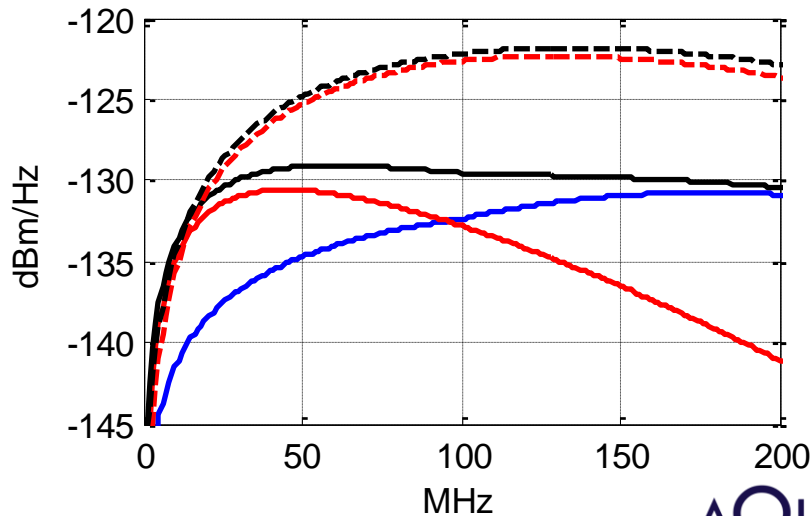
1G over Cat5e ($X_0=15$ dB)



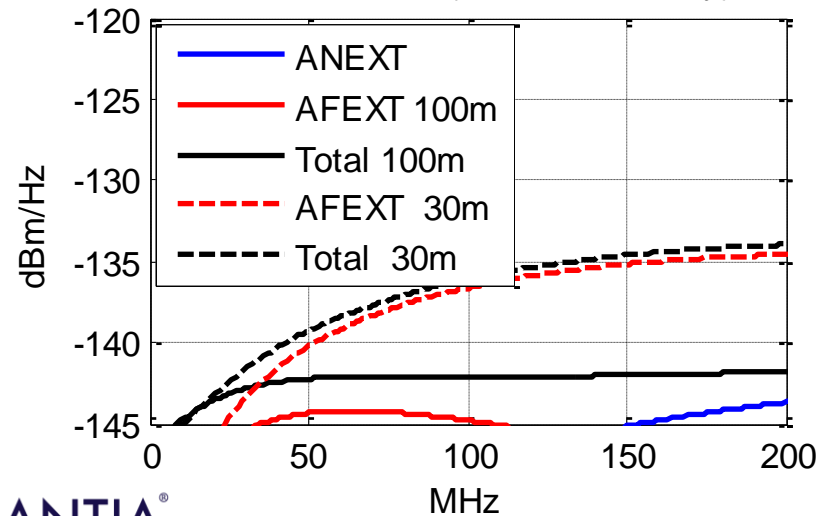
2.5G over Cat5e ($X_0=15$ dB)



5G over Cat5e ($X_0=15$ dB)



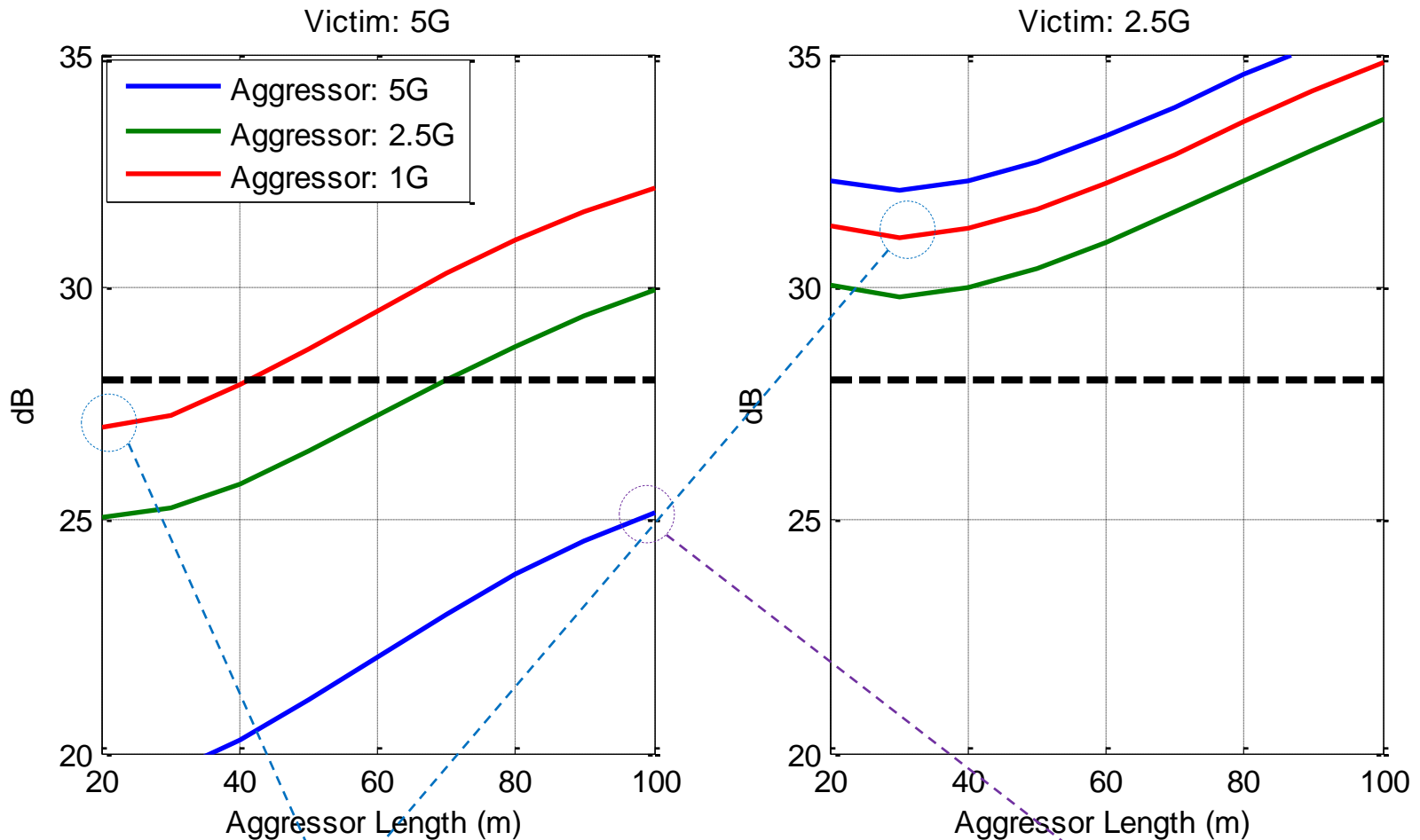
10G over Cat6a (for reference only)



SNR Analysis

- Cable: Cat5e with alien crosstalk offset of 15 dB
- Transmit power:
 - 5G/2.5G: 2 dBm
 - 1G: 3.5 dBm (no spec, based on modeling and measurement)
- Bandwidth
 - 5G: 200 MHz
 - 2.5G: 100 MHz
 - 1G: 62.5 MHz
- Background thermal noise: -150 dBm/Hz
 - Implementation-dependent noise sources are not included
- Mixed aggressor model: each of 6 aggressors contributes 1/6 to the total crosstalk power

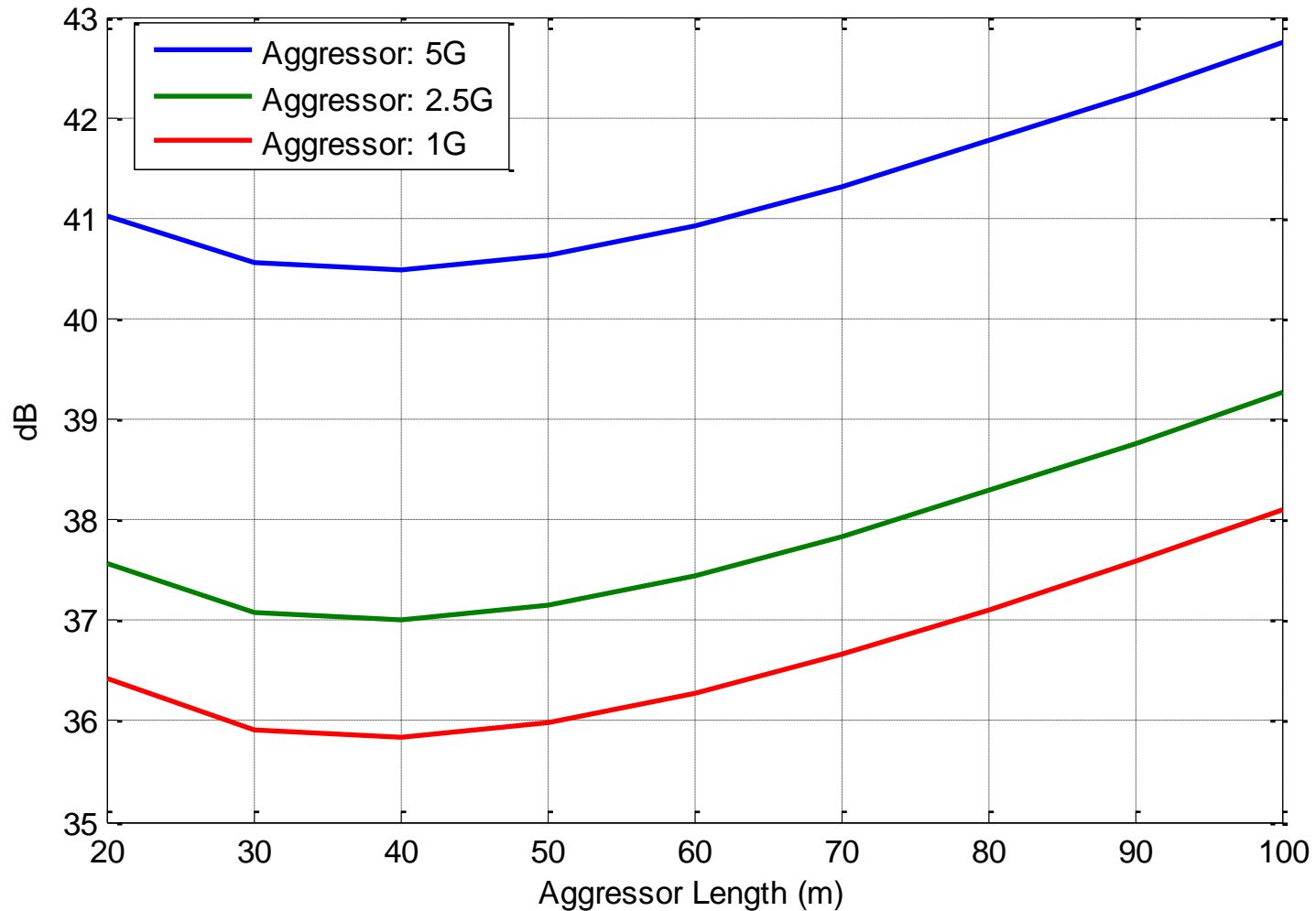
Salz SNR: 5G/2.5G over 100m – No PBO



A short 1G aggressor may be a limiting factor for 5G/2.5G

SNR too low for 5G link over 100m Cat5e with 15 dB offset

Salz SNR: 1G over 100m



- 1000BASE-T is immune to 5G and 2.5G aggressors!

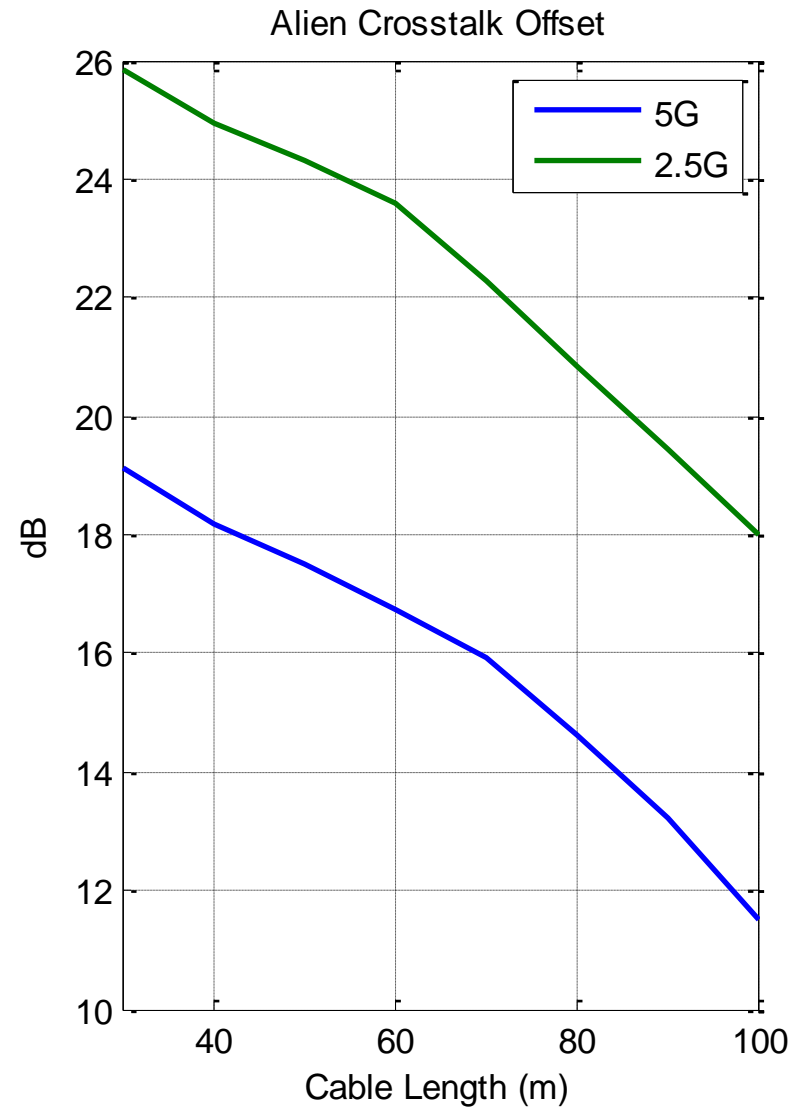
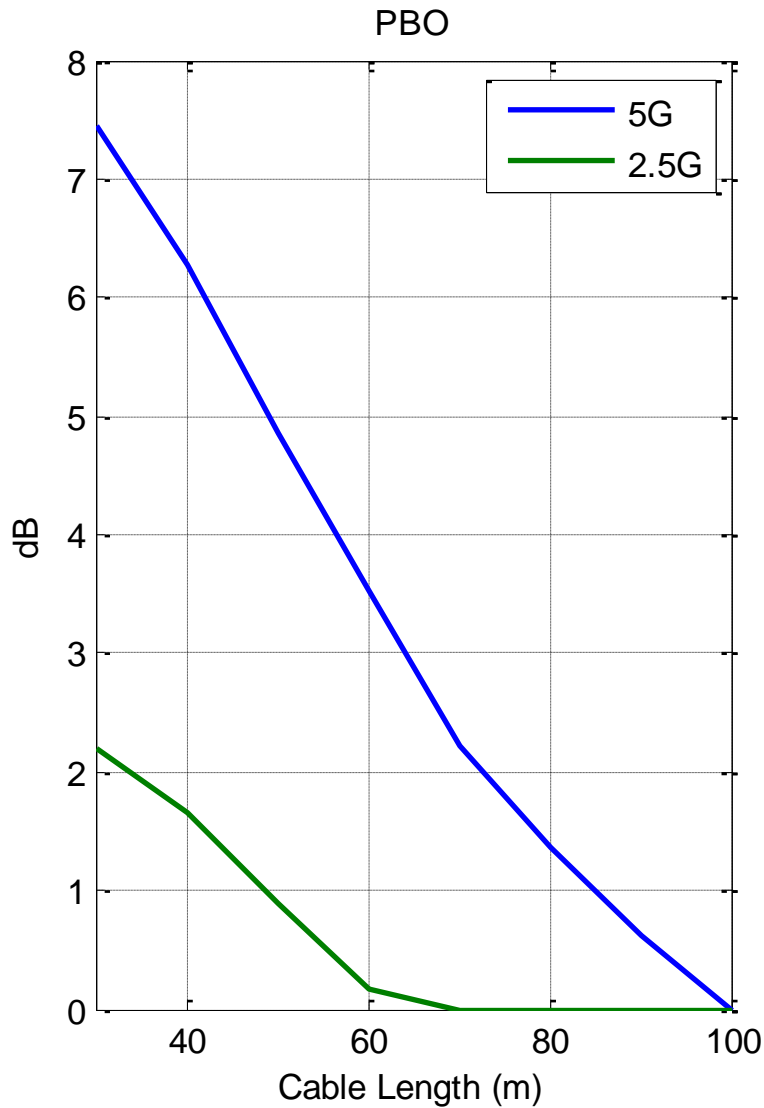
SNR, PBO and Crosstalk Offset

- Increasing the transmit power of the victim increases the SNR of the victim
- Increasing the transmit power of the aggressors reduces the SNR of the victim
- Increasing the alien crosstalk offset reduces the SNR of the victim

PBO Selection Algorithm

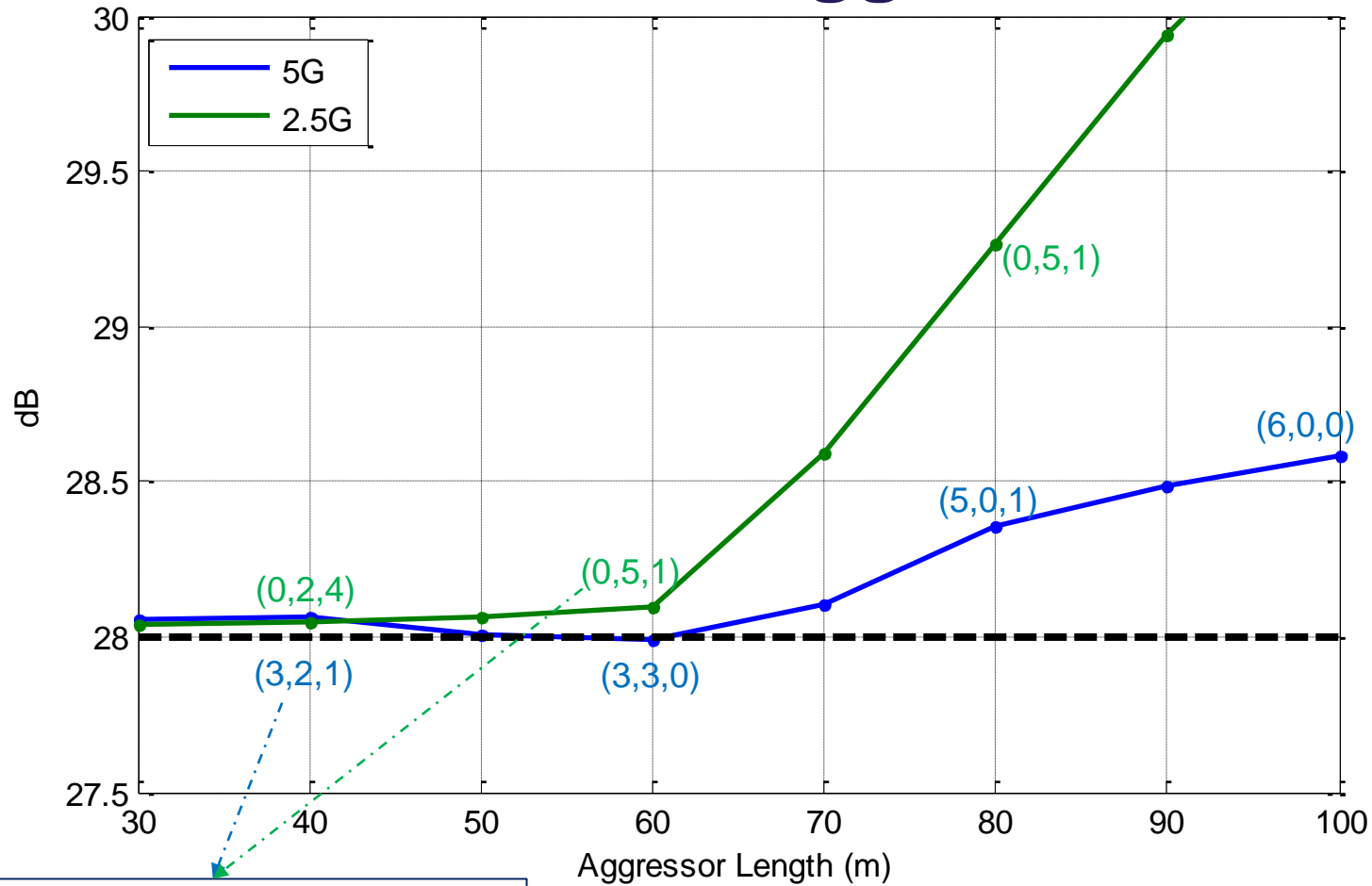
- Find the PBO and the alien crosstalk offset for each length and rate such that:
 - SNR of both victim and aggressors always remain above the target level
 - Crosstalk offset is maximized (*i.e.* widest support of cable plants in the field)
 - Maximum transmit power remains below a limit
- Other considerations:
 - Transmit power in 1G is fixed
 - Mixture of various aggressor rates

Optimal PBO and Crosstalk Offset



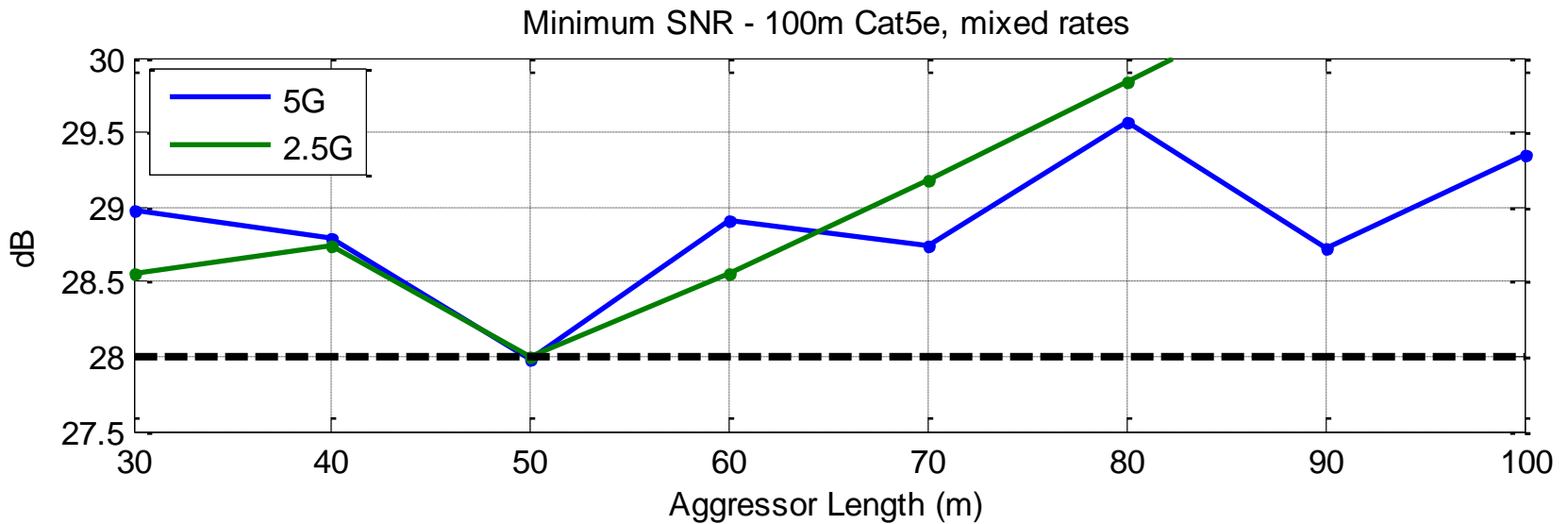
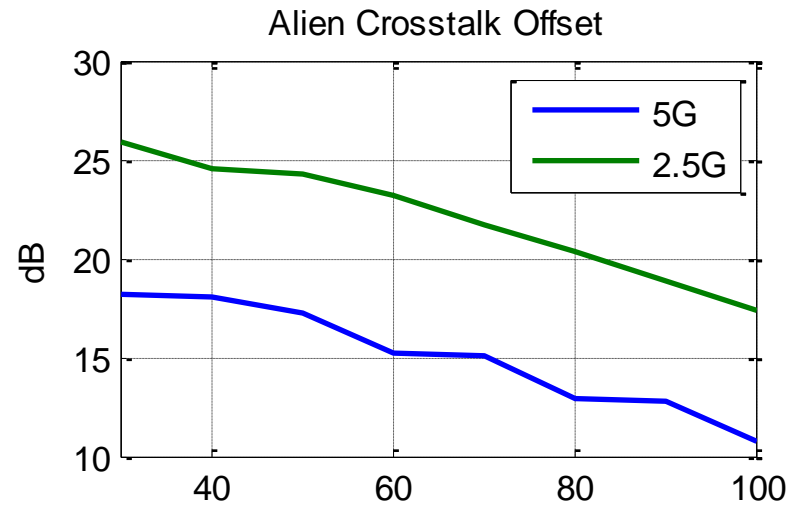
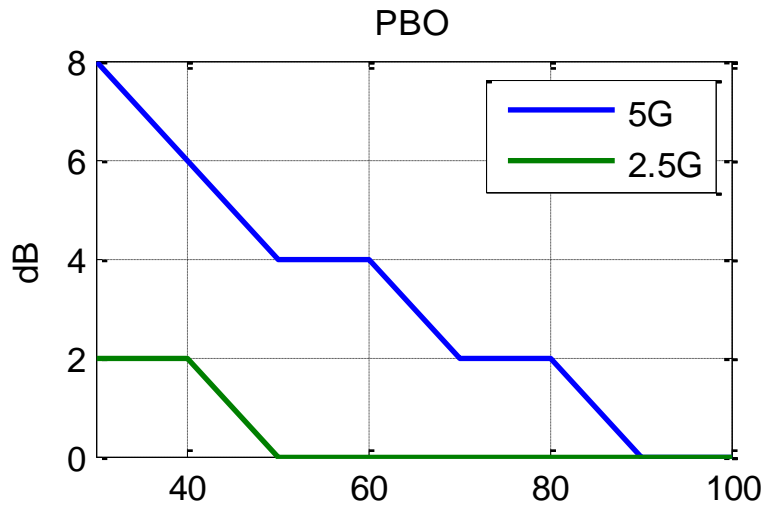
Minimum SNR

Victim: 100m Cat5e , Aggressors: Mixed



number of aggressors from each rate
(5G, 2.5G, 1G)
in a 6-around-1 bundle

PBO: 2 dB Steps

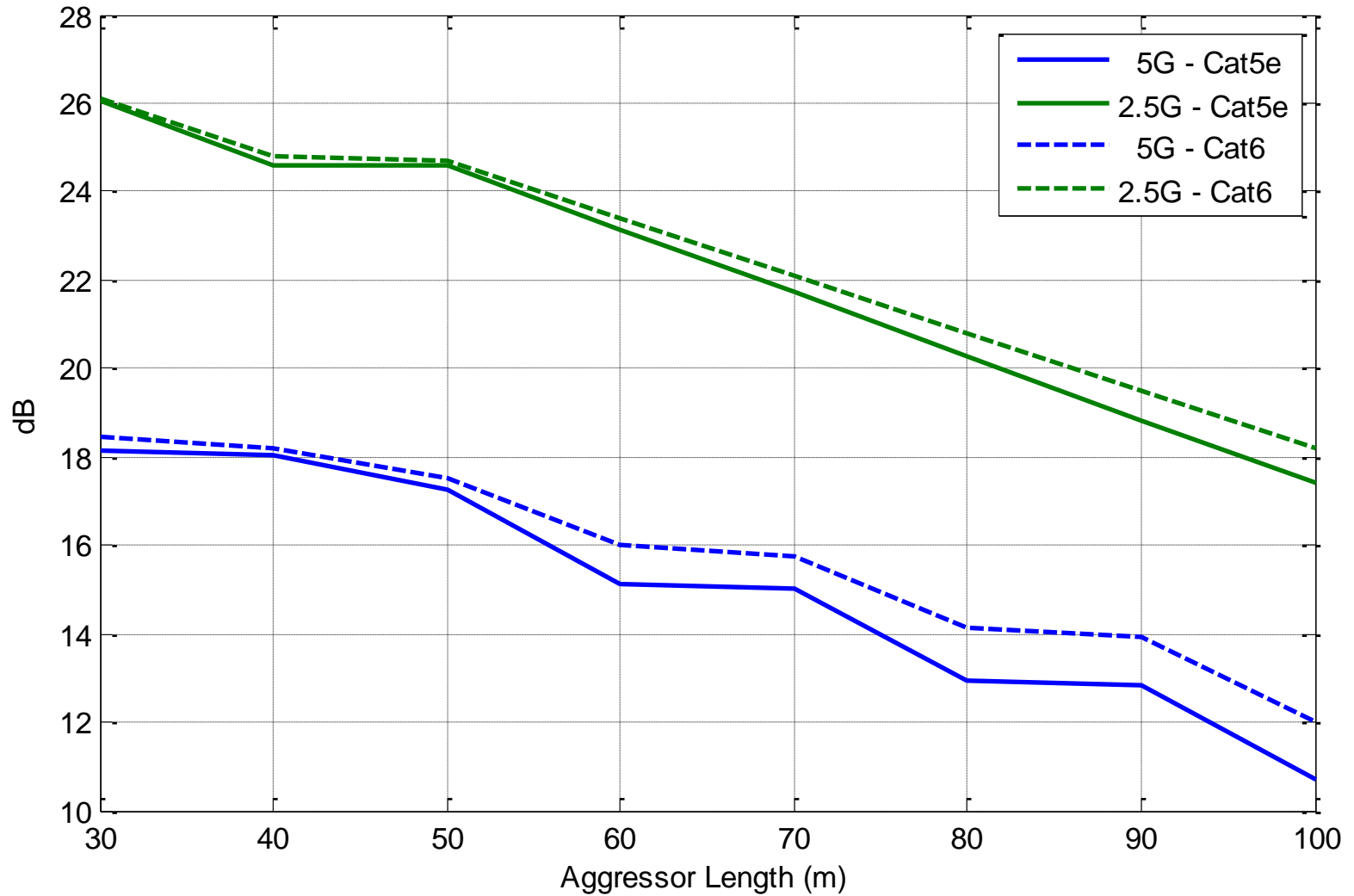


PBO Table

5G		
Receive Power (dBm)	Cable Length (m)	PBO (dB)
$-5.8 \leq P$	$L \leq 35$	8
$-7.0 \leq P < -5.8$	$35 < L \leq 45$	6
$-9.2 \leq P < -7.0$	$45 < L \leq 65$	4
$-11 \leq P < -9.2$	$65 < L \leq 85$	2
$P < -11$	$85 < L$	0

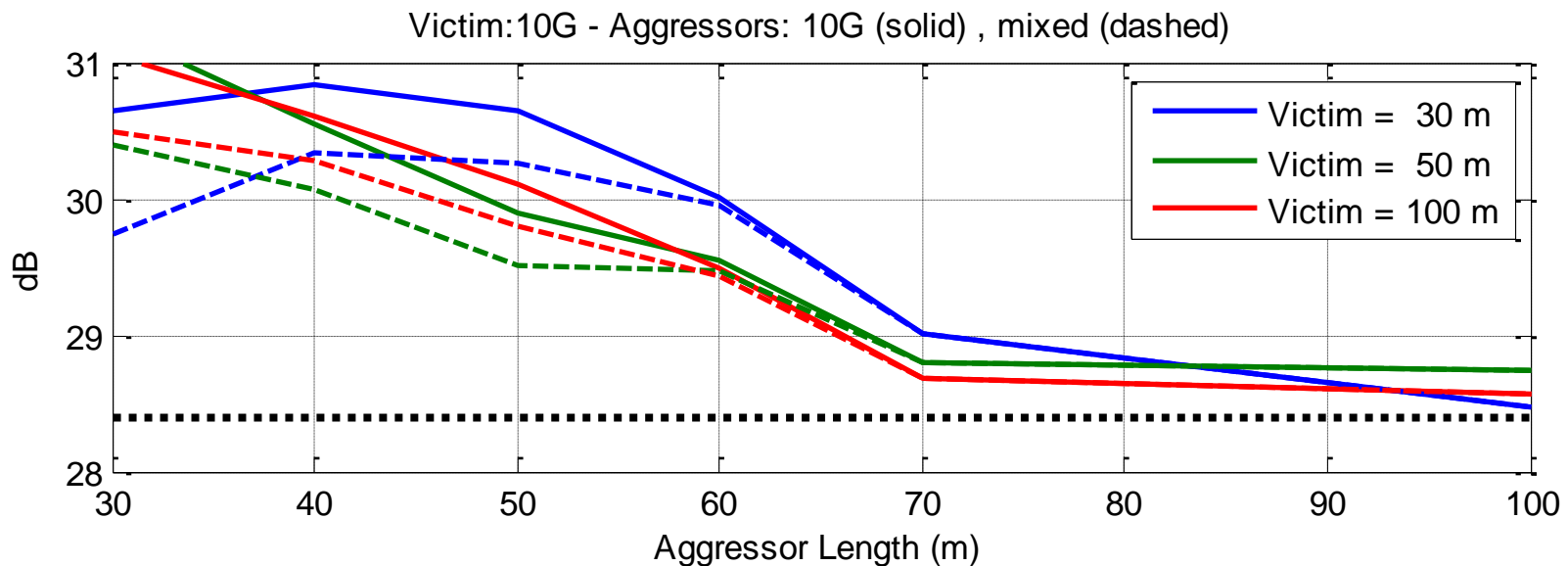
2.5G		
Receive Power (dBm)	Cable Length (m)	PBO (dB)
$-4.3 \leq P$	$L \leq 45$	2
$P < -4.3$	$45 < L$	0

Alien Crosstalk Offset Cat6 vs Cat5e



10G Victim with 5G/2.5G Aggressors

- Find the maximum offset that keeps the SNR above the target for each length of 10G victim and all lengths of 10G aggressors
- Use these offsets in the case of mixed-rate aggressors



- SNR of 10G victim does not drop below the target with mixed rate aggressors

Summary

- 5G:
 - PBO is necessary
 - A maximum of 8 dB back-off is sufficient
 - Supported alien crosstalk offset from 11 dB on long cables to more than 18 dB on short cables
- 2.5G
 - PBO is beneficial particularly for 5G operation
 - A maximum of 2 dB back-off is sufficient
 - Supported range for alien crosstalk offset is from 18 to 26 dB
- 1G is insensitive to alien crosstalk from 2.5G and 5G transceivers