Project: IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)

Submission Title: [Comment Resolution for CID 150: DF00 Beamforming Performance Evaluation]
Date Submitted: [Spt. 10, 2008]
Source: [Junyi Wang, Zhou Lan, Chang woo Pyo, Chin-Sean Sum, Tuncer Baykas, Azizur Rahman, Ryuhei Funada, Fumihide Kojima, Hiroshi Harada, Shuzo Kato, Su-Khiong Yong*, Huai Rong Shao*, Jisung Oh*, Ismail Lakkis+]
Company [National Institute of Information and Communications Technology (NICT), Tensorcom, Samsung]
Address[1][3-4 Hikari-no-oka, Yokosuka-shi, Kanagawa 239-0847, Japan;
416 Maetan-3Dong Yeongtong-Gu Suwon-shi Kyunggi-Do 443-742, Korea*;
10875 Rancho Bernardo Rd, #108, San Diego, CA 92127+]
Voice[1]:[+81-46-847-5074] , FAX[1]: [+81-46-847-5440]
E-Mail[junyi.wang@nict.go.jp]
Re: []
Abstract: [Comment Resolution for CID 150: DF00 Beamforming Performance Evaluation]
Purpose: [To be considered in TG3C baseline document.]

Comment Resolution for CID 150: DF00 Beamforming Performance Evaluation

NICT

High level summary

- The document present beamforming performance in the sense of PHY layer simulation and MAC layer set-up time calculation. Both of them show that proposed beamforming procedure is feasible for implementation.
- The document also provides a resolution to command 150 shown as follows
  - Command: Beamforming protocol has not been tested
  - Suggested from owner: provide simulations on why and how the beamforming can provide High rate transmission and articulate the delay associated to beamforming

Contents

- The PHY layer beamforming performance is evaluated assuming phase shifter is not ideal, but with some phase errors.
- The MAC layer set-up time is calculated for one-to-one communication link.

PHY layer beamforming performance

- Performances of gain loss, defined as gain degradation at the direction of maximum gain, is evaluated by assuming the phase shifter has phase errors.
- The gain loss is calculated by comparing gain difference between two cases with/without phase error.
- The phase error is modeled as uniform distribution with 0 mean and standard variance following either of following two cases:
  - Case 1: The Gaussian noise is independent of absolute phase shift. The phase error of each phase shifter is independent of each other with the same standard variance.
  - Case 2: The Gaussian noise depends on absolute phases, with standard variance proportional to the absolute phase.

Case 2 is considered due to the measured phase error at 60GHz shown as follows

TABLE I
MEASURED PHASE ERROR OF THE TWO-BIT PHASE SHIFTER AT 60 GHz

Phase state	0°	45°	90°	135°
Measured phase shift	0°	41.5°	84.3°	128.7°
Phase error	0°	3.5°	5.7°	6.3°

TABLE II
MEASURED PHASE ERROR OF THE THREE-BIT PHASE SHIFTER AT 60 GHz

Phase state	0°	45°	90°	135°	180°	225°	270°	315°
Measured phase shift	0°	39.9°	81.1°	120.1°	143.0°	180.0°	222.1°	265.5°
Phase error	0°	5.1°	8.9°	14.9°	37.0°	45.0°	47.9°	49.5°

J.Park, H. Kim, W.Choi, Y. Kwon, Y. Kim, “V-Band Reflection-Type Phase Shifters Using Micromachined CPW Coupler and RF Switches. ”, IEEE Journal of Mricroelectromechanical Systems, Vol. 11, No. 6, pp.808-814

Conclusions from PHY layer beamforming simulations

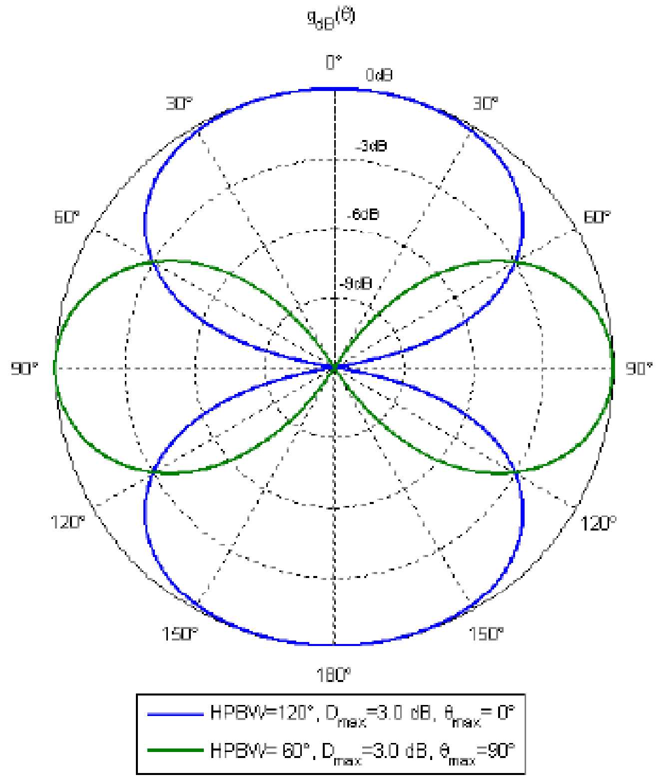
- The designed codebook is robust to the phase error.
- The gain variation is lower than 1dB with 90% outrate probability when standard variance of phase error is 0.5 [28.6 degree] for each of phase shifters.
- The larger the phase error, the larger the gain degradation when phase error of each phase shifter has the same distribution with the same standard variance.
- When standard variance of phase error is proportional to absolute phase shift, the gain degradation is in general lower than the case with standard variance =0.5 although the phase error for 270 in this example is 1 .

Beamforming with codebook of 2 antenna elements

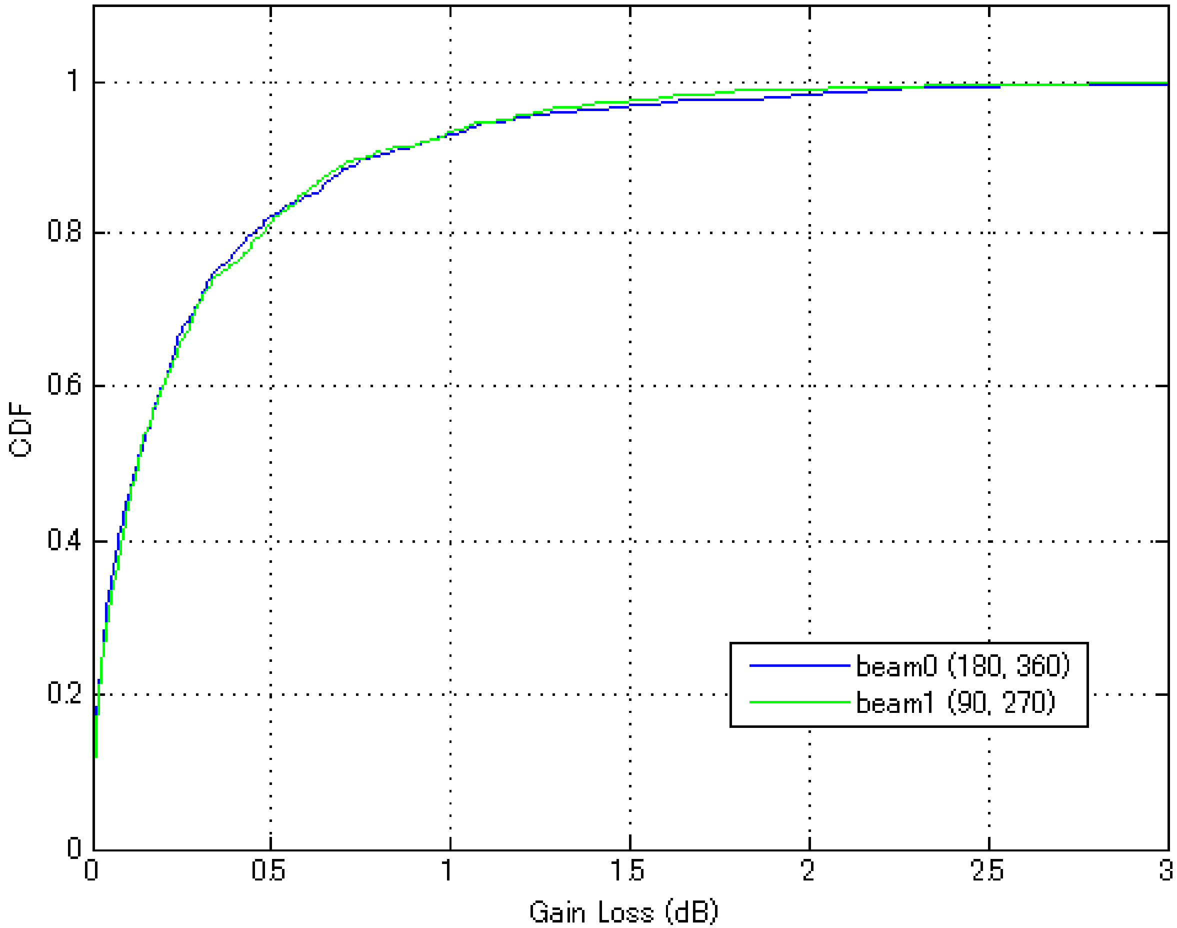
- Codebook ID: 0000
- Two elements separated by $\lambda/2$;
- Codebook = two orthogonal beamformer (combiner) vectors given by the columns of matrix $\mathbf{W}$;

$$\mathbf{W} = \begin{bmatrix} +1 & +1 \\ -1 & +1 \end{bmatrix}$$

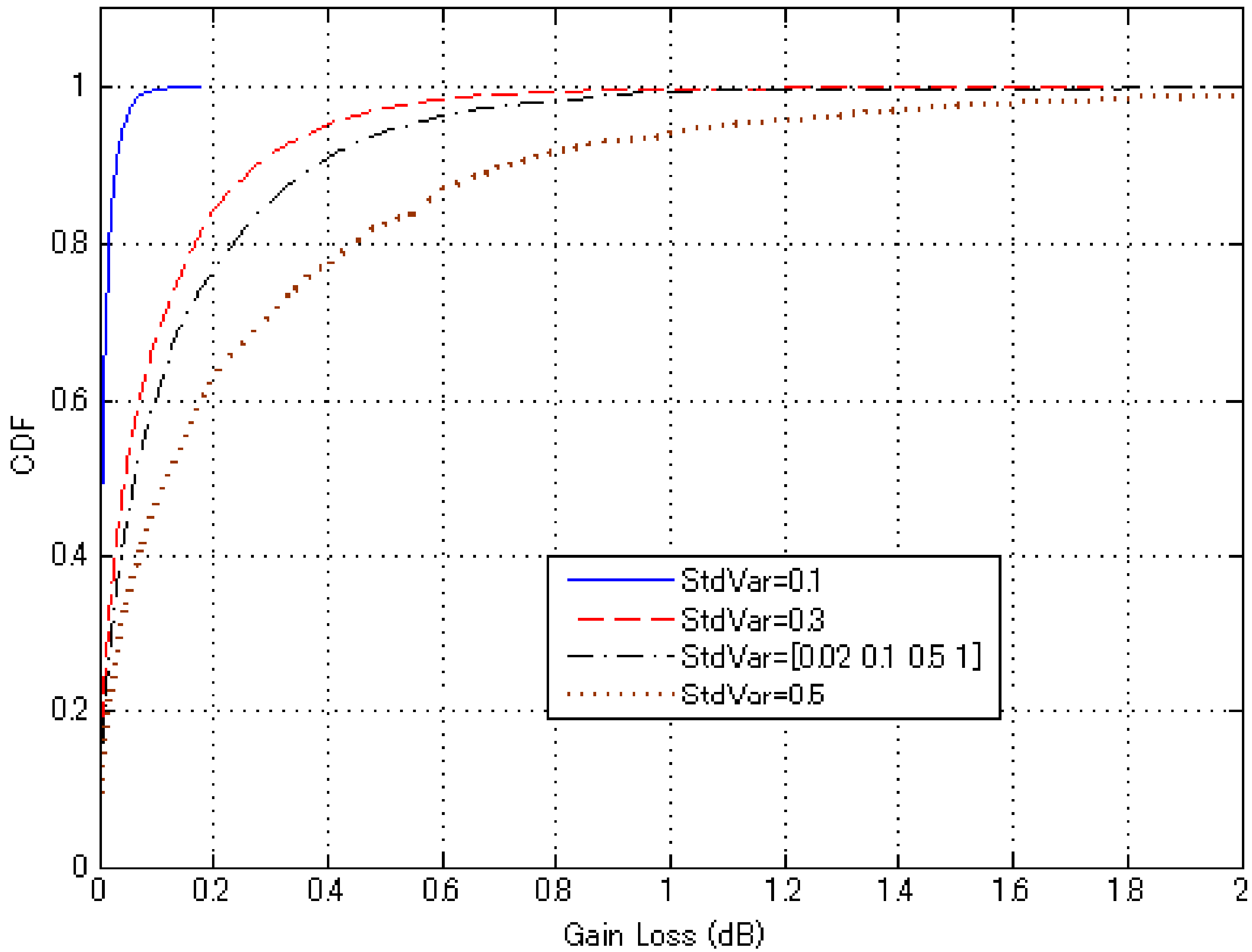
Codebook vector ID	θ_{max}	$HPBW_{\theta}$	D_{max}
0	0°	120°	3.01 dB
1	90°	60°	3.01 dB



Gain loss with phase error (Standard variance = 0.5 [28.6 degree])



Gain loss due to phase error with different standard variance

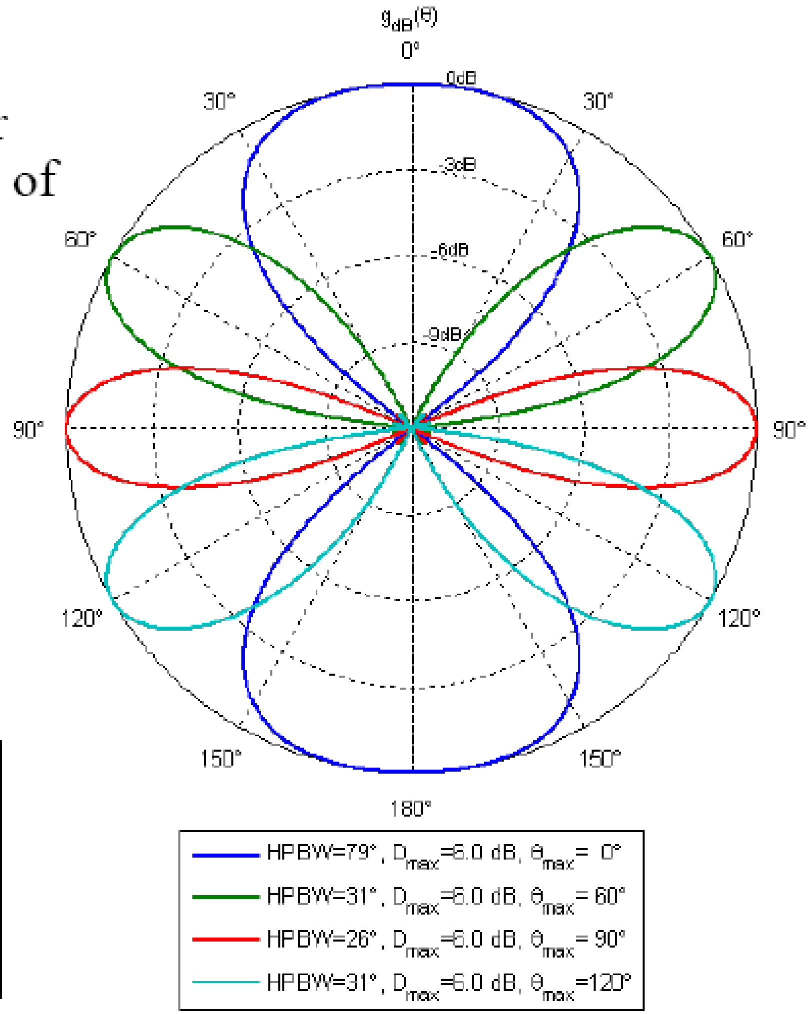


Beamforming with codebook of 4 antenna elements

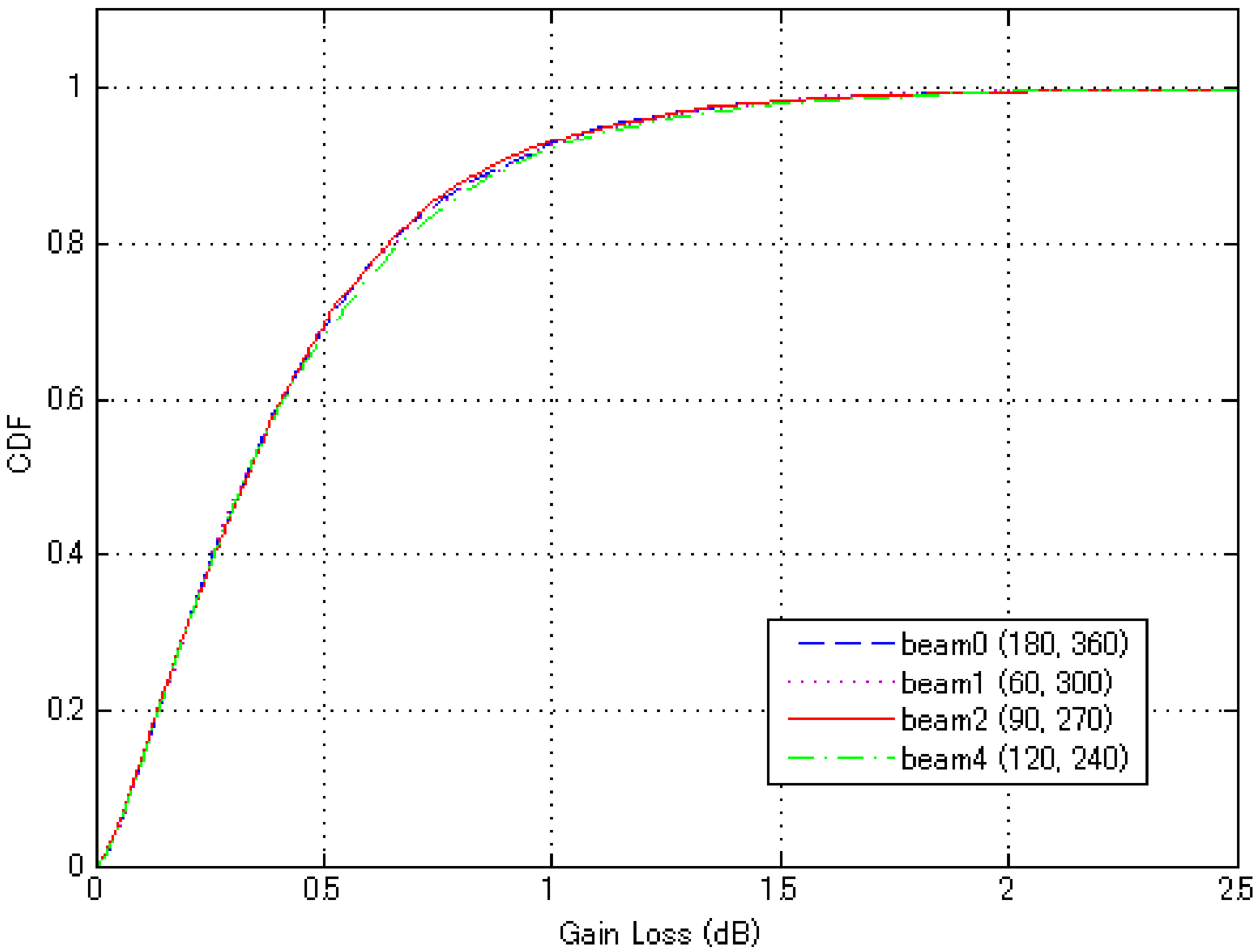
- Codebook ID: 0011
- Four elements separated by $\lambda/2$;
- Codebook = four orthogonal beamformer (combiner) vectors given by the columns of matrix **W**;

$$\mathbf{W} = \begin{bmatrix} +1 & +1 & +1 & +1 \\ -1 & -j & +1 & +j \\ +1 & -1 & +1 & -1 \\ -1 & +j & +1 & -j \end{bmatrix}$$

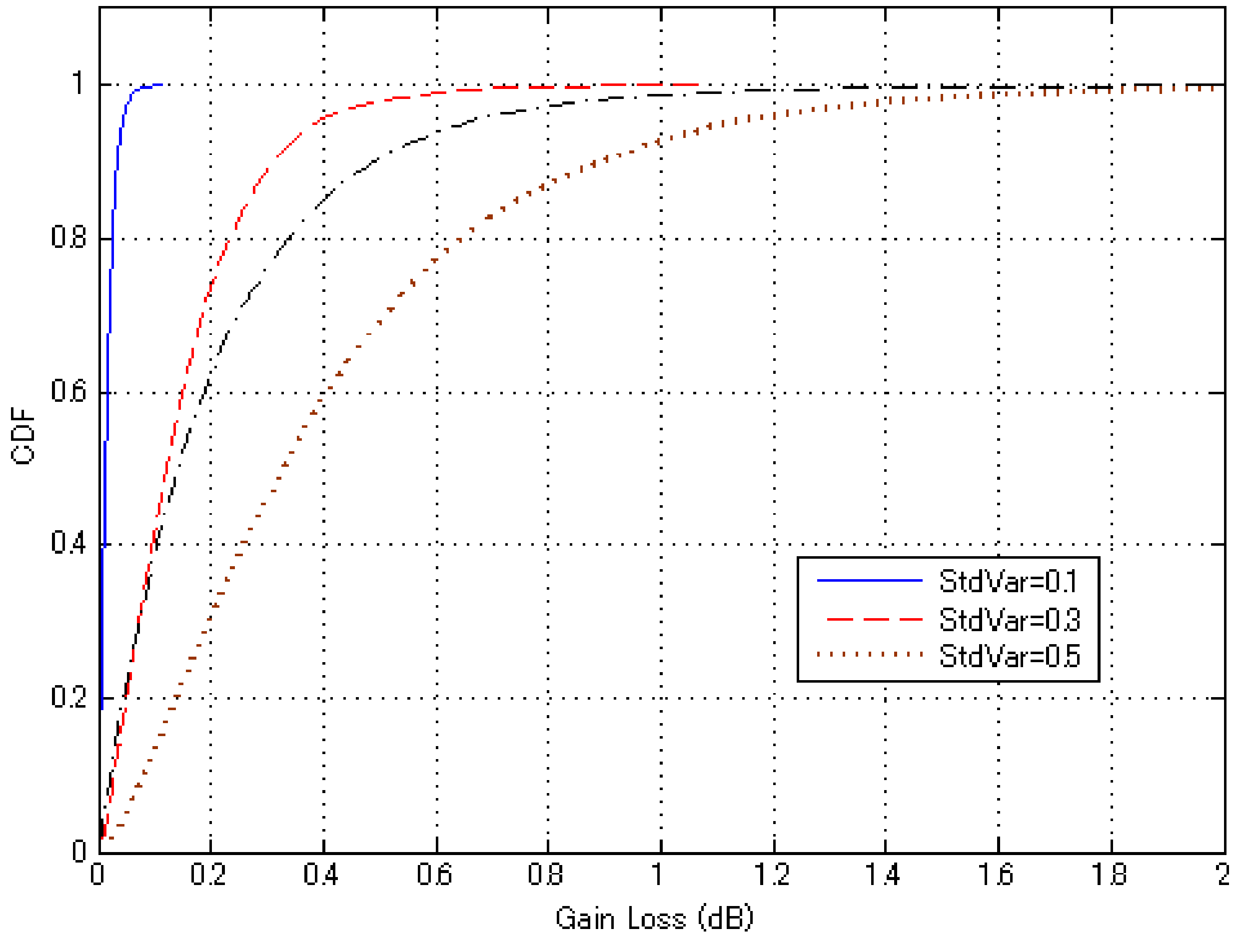
Codebook vector ID	θ_{max}	$HPBW_{\theta}$	D_{max}
0	0°	79°	6.02 dB
1	60°	31°	6.02 dB
2	90°	26°	6.02 dB
3	120°	31°	6.02 dB



Gain loss with phase error (Standard variance = 0.5 [28.6 degree])



Gain loss due to phase error with different standard variance

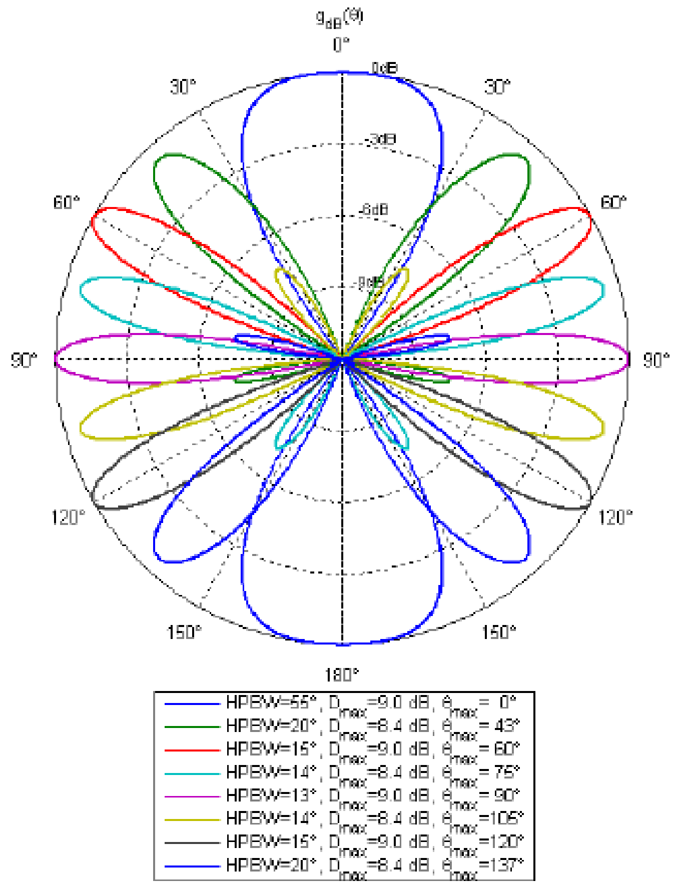


Beamforming with codebook of 8 antenna elements

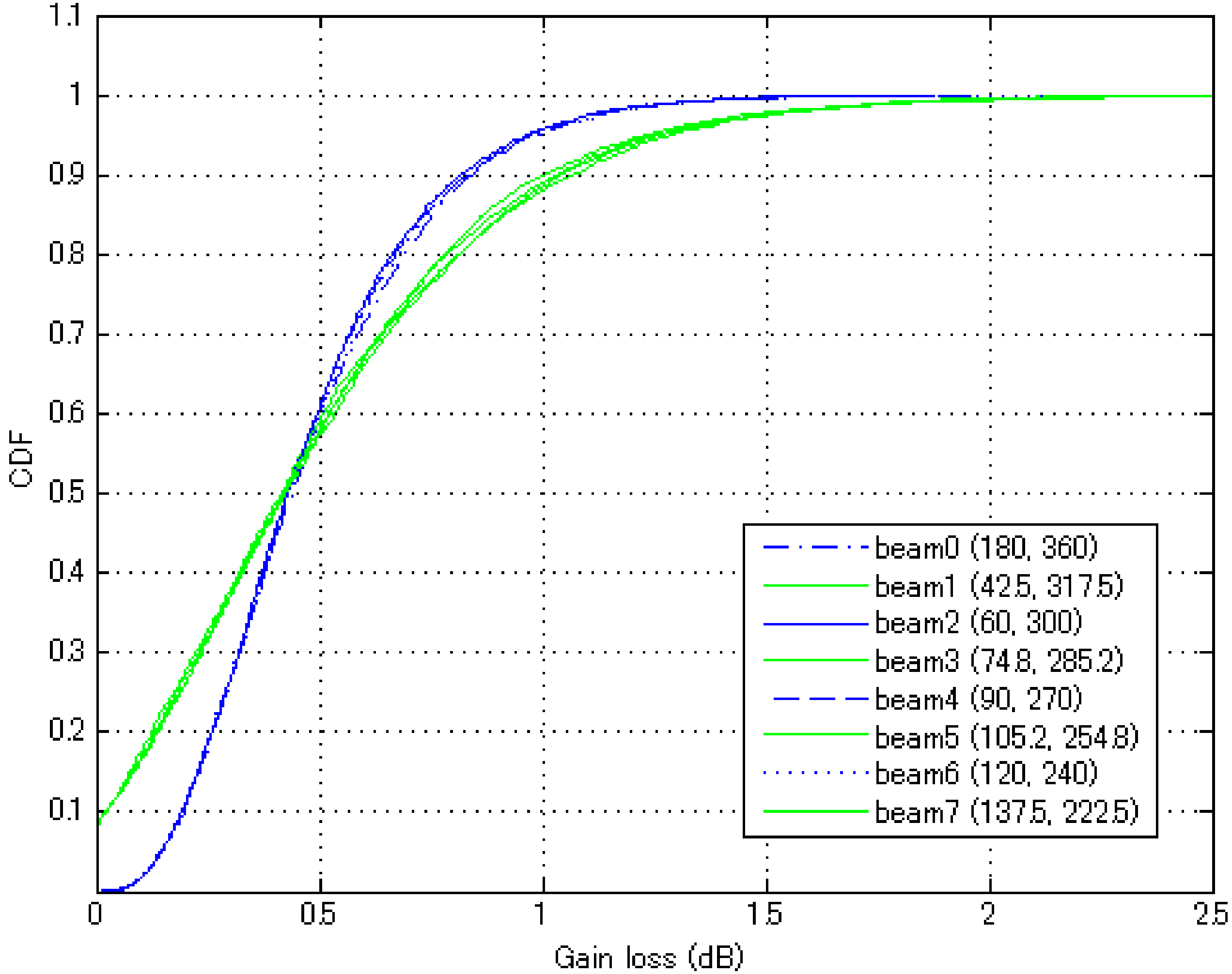
- Codebook ID: 1011
- Eight elements separated by $\lambda/2$;
- Codebook = 8 orthogonal beamformer (combiner) vectors given by the columns of **W**

$$\mathbf{W} = \begin{bmatrix} +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 \\ -1 & -j & -j & -j & +1 & +j & +j & +j \\ +1 & +j & -1 & -j & +1 & +j & -1 & -j \\ -1 & +1 & +j & -1 & +1 & -1 & -j & +1 \\ +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 \\ -1 & +j & -j & +j & +1 & -j & +j & -j \\ +1 & -j & -1 & +j & +1 & -j & -1 & +j \\ -1 & -1 & +j & +1 & +1 & +1 & -j & -1 \end{bmatrix}$$

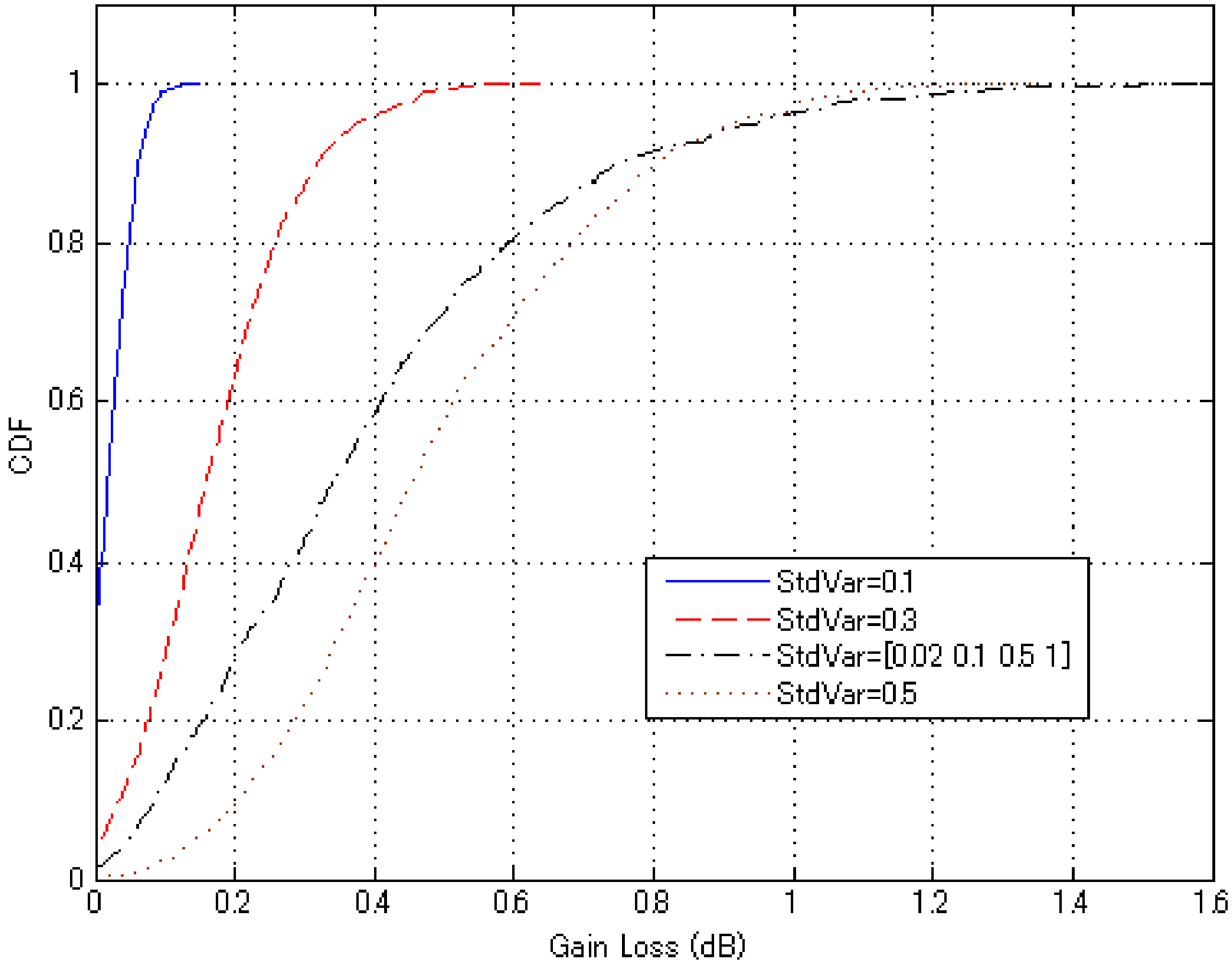
Codebook vector ID	θ_{max}	$HPBW_\theta$	D_{max}
0	0°	55.2°	9.03 dB
1	42.5°	19.6°	8.38 dB
2	60.0°	15.1°	9.03 dB
3	74.8°	13.5°	8.38 dB
4	90.0°	13.1°	9.03 dB
5	105.2°	13.5°	8.38 dB
6	120.0°	15.1°	9.03 dB
7	137.5°	19.6°	8.38 dB



Gain loss with phase error (Standard variance = 0.5 [28.6 degree])



Gain loss due to phase error with different standard variance



Beamforming set-up time calculations

Assumptions

- The command mode is used for beamforming set-up
- There are no transmission errors and no retransmissions.
- System is AAS (Asymmetric Antenna System) or SAS (Symmetric Antenna System)

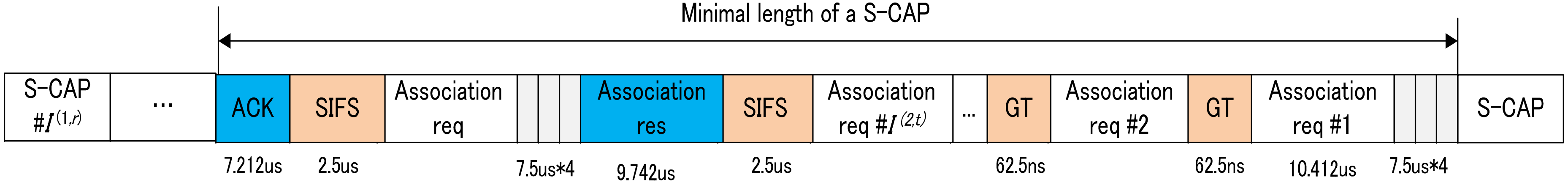
Contents

- The beamforming set-up time is short enough for implementation.
- Association with directional antenna can be completed around 500us (AAS,maximum 4 Quasi-omni).
- Sector level training can be completed within 210us (AAS,maximum 4 sectors)
- Beam level training can be completed within 550us (AAS,maximum 8 beams)
- DEV-DEV communication link can therefore be established around 1.26ms

Time duration for each part of superframe

(1) PHY preamble (long)	3.259us
(2) Channel estimation sequence	0.593us
(3) Training sequence (1)+(2)	3.852us
(4) PHY header (10 octets)	1.581us
(5) MAC header (15 octets)	2.372us
(6) SIFS	2.5us
(7) Guard time between 2 cycles	62.5ns
(8) Feedback IE (32 bits)	0.632us
(9) Mapping IE (40 bits)	0.791us

Association with directional antenna

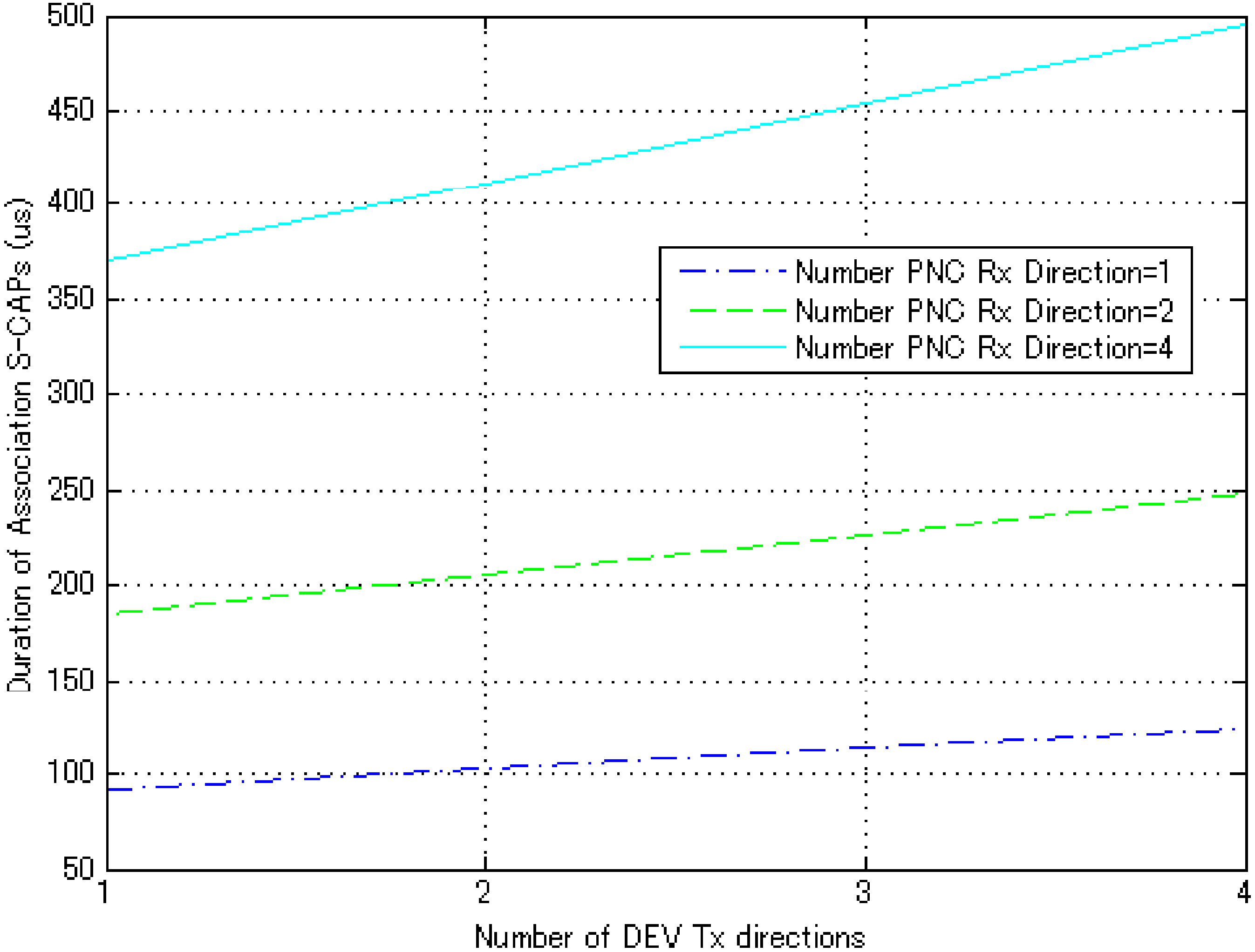


Duration = (2*Backoff+(Assoc.Req+GT)*DEV_TX_NUM+Assoc.Res+2*SIFS+ACK)*PNC_RX_NUM

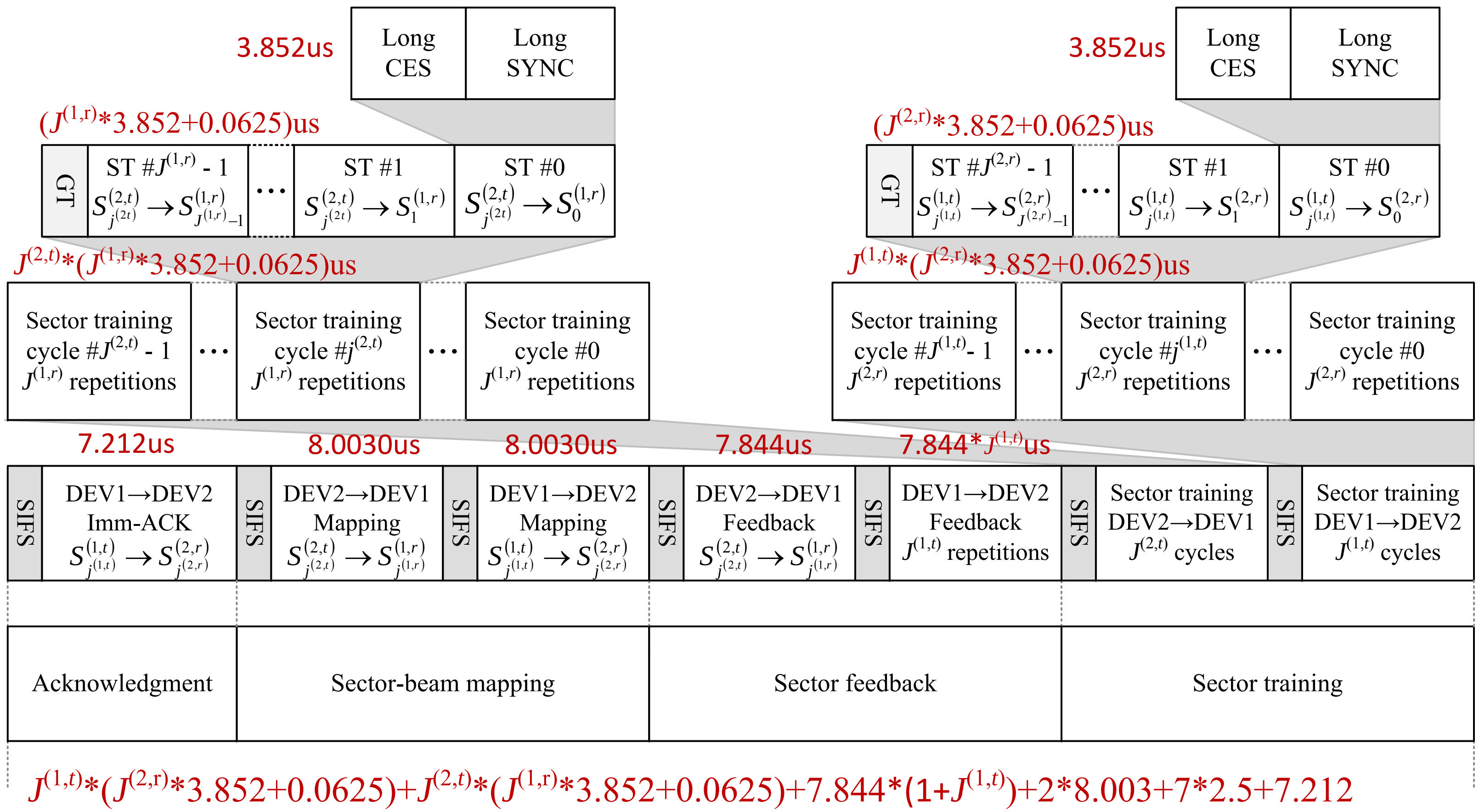
Procedure

1. Scanning in order to receive any of beacon from PNC
2. Sensing channel inside S-CAP (DEV)
3. Sending Association.req from each of transmission direction of DEV
4. Waiting for Response
5. Responding from PNC (obtaining DEV ID from PNC)
6. Sensing channel inside S-CAP (DEV)
7. Sending Association.req with obtained DEV ID
8. Waiting for ACK
9. Obtain ACK from PNC, association successful

Numerical example for directional association (starting from receiving one of directional beacons）



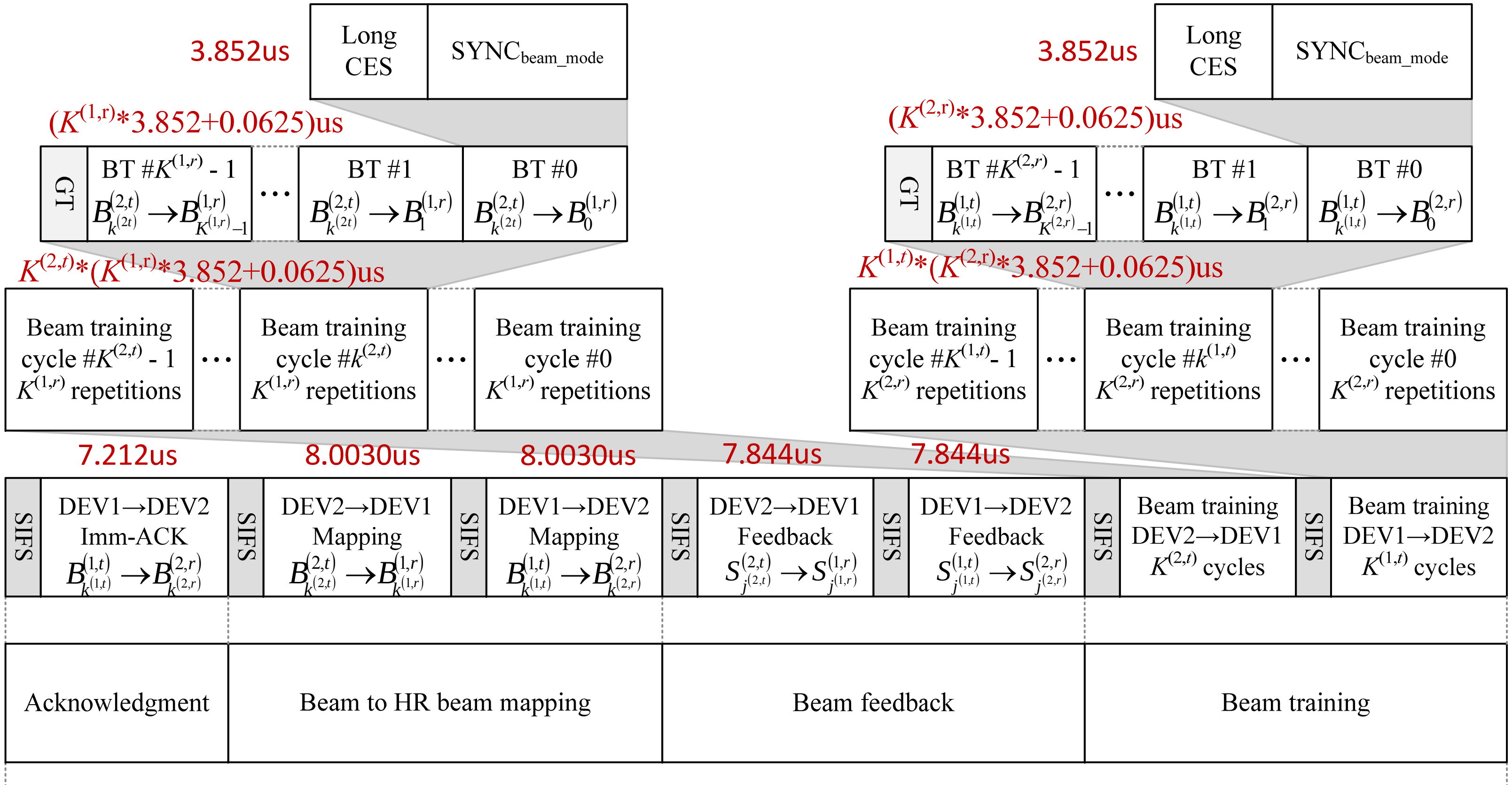
Set-up time for AAS sector level



Maximum duration is 203.7us (maxmum 4 sectors for both Tx and Rx of DEV1 and DEV2

DEV1 (J(1,t) transmit sectors, J(1,r) receive sectors)
DEV2 (J(2,t) transmit sectors, J(2,r) receive sectors)

Set-up time for AAS beam level training



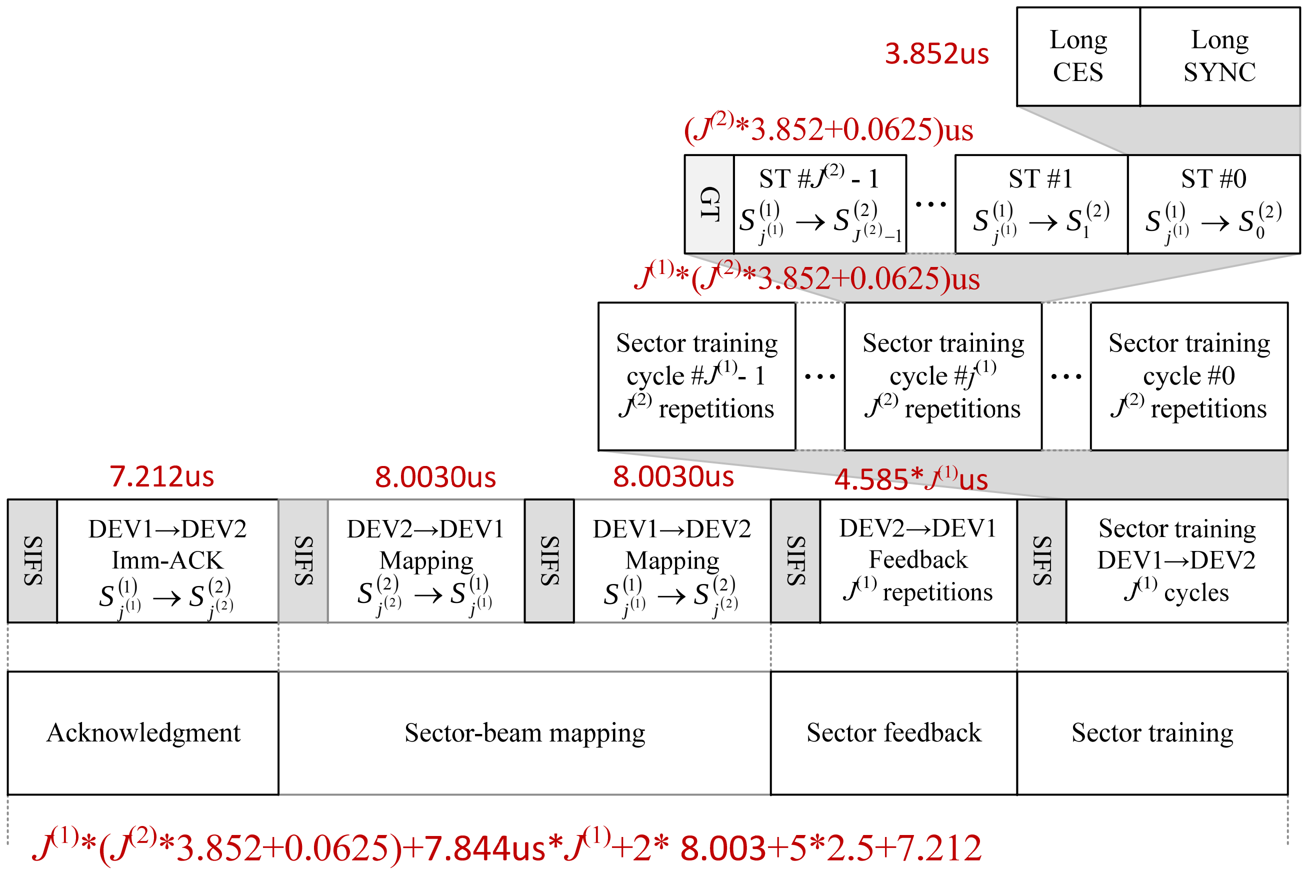
$K^{(1,t)}*(K^{(2,r)}*3.852+0.0625)+K^{(2,t)}*(K^{(1,r)}*3.852+0.0625)+7.844us*2+2*8.003+7*2.5+7.212$

Maximum duration is 550.46us (maximum 8 beams per sector for both Tx and Rx of DEV1 and DEV2)

DEV1 ($K^{(1,t)}$ transmit beams, $K^{(1,r)}$ receive beams)

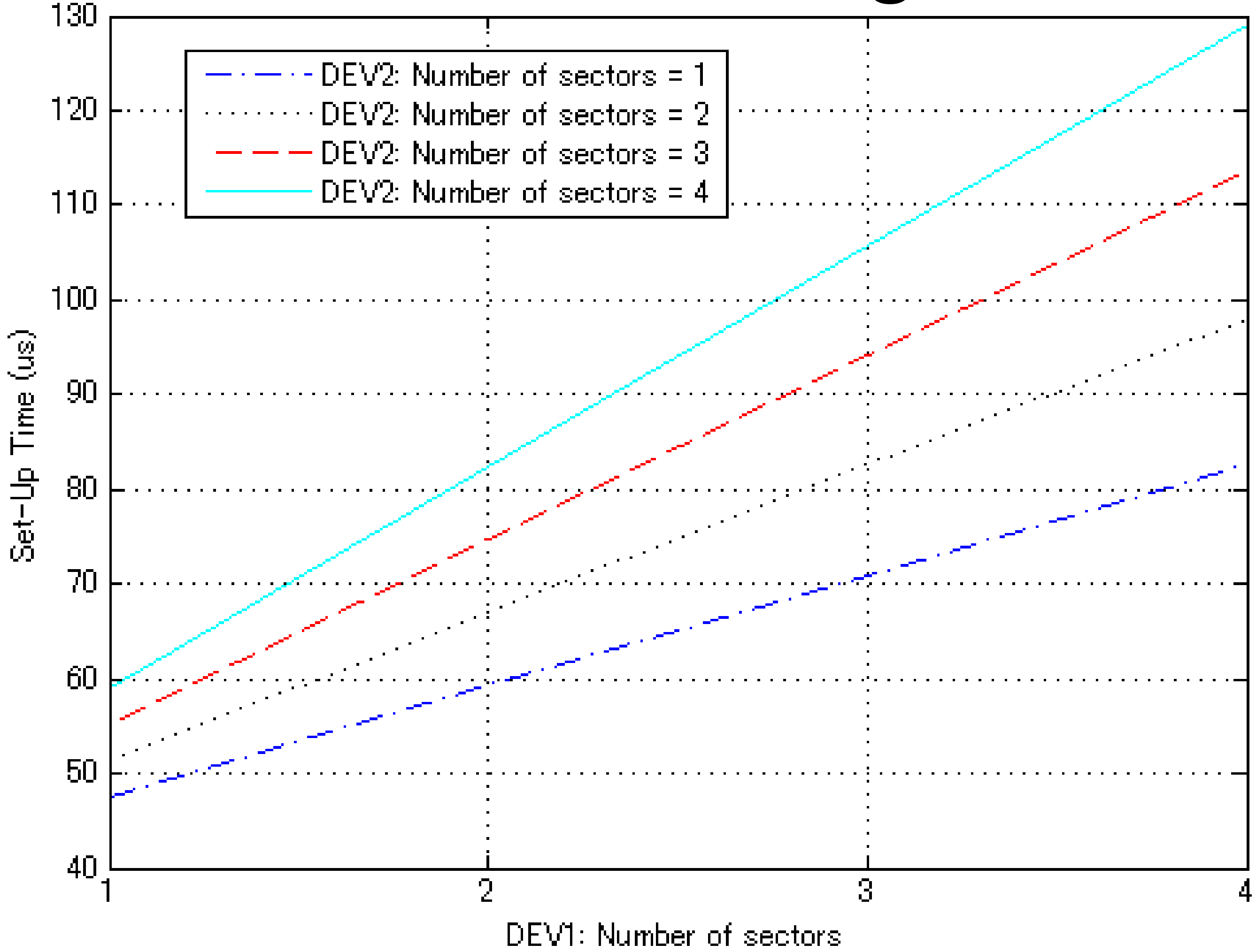
DEV2 ($K^{(2,t)}$ transmit beams, $K^{(2,r)}$ receive beams)

Set-up time for SAS sector level training

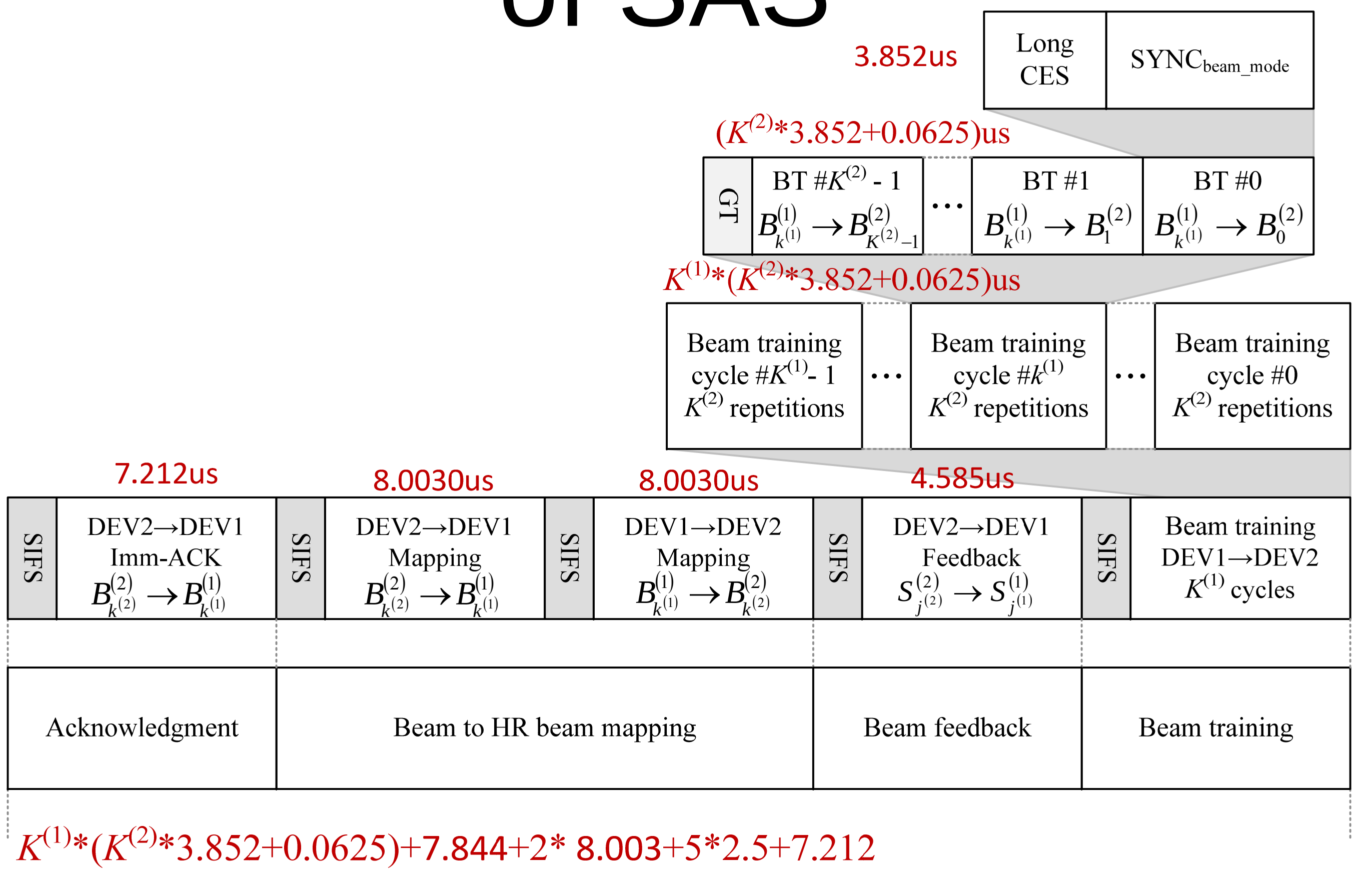


DEV1 ($J^{(1)}$ sectors) and DEV2 ($J^{(2)}$ sectors)

Numerical example for SAS sector level training



Set-up time for beam level training of SAS



DEV1 ($K^{(1)}$ beams) and DEV2 ($K^{(2)}$ beams)

Numerical example for SAS beam level training