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

Submission Title: [Analysis and Comments on SFD proposals for 802.15.4g]
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Abstract: [Comments on SFD values for 802.15.4g standard]

SFD Proposal in Docs. 15-10-0126-00 and 15-10-0126-01 (1/2)

- Doc. IEEE 15-10-0126-00 (we call Doc.00 in this presentation) proposed plan D SFD based on Hamming Distance property.
- Doc. IEEE 15-10-0126-01 (we call Doc.01 in this presentation) raised a FA probability computation method and claimed that it is better than RMS analysis. An even position detection method is also suggested.
- In Doc. 00, Hamming distance properties are listed for all the four plans in five cases:
  - Preamble+SFD1 <-> SFD1
  - -(Preamble+SFD1) <-> SFD1
  - Preamble+SFD2 <-> SFD1
  - -(Preamble+SFD2) <-> SFD1
  - Preamble+SFD4d <-> SFD1

  and vise versa (swapping SFD1 and SFD2).

SFD Proposal in Docs. 15-10-0126-00 and 15-10-0126-01 (2/2)

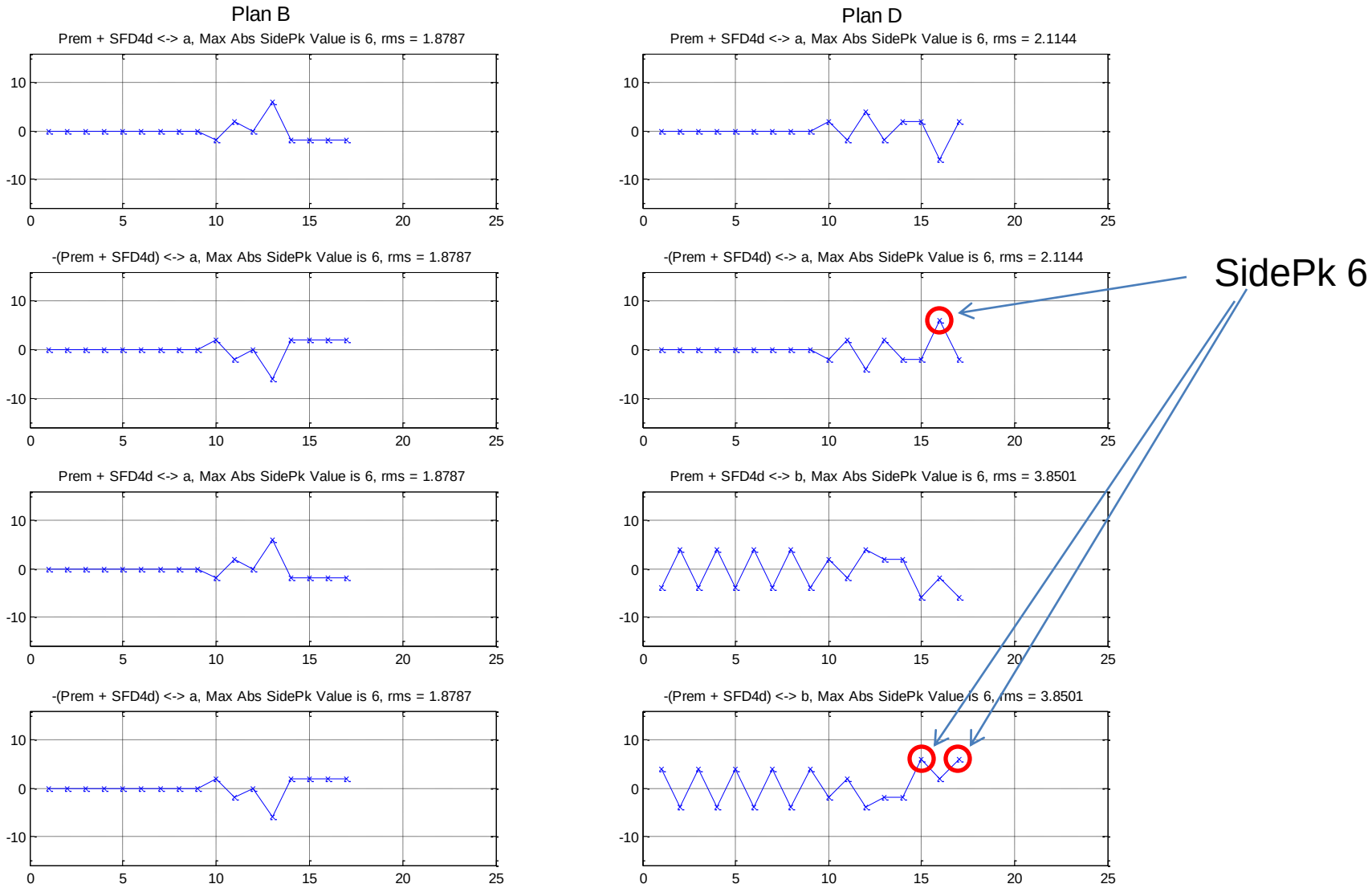
- In Doc. 01, even positions Hamming distance are compared for all the four plans in the same five cases.

Missing parts in doc. 00 and doc. 01:

1. SFD4d Image case is never considered in docs. 00 and 01, i.e.,
   -(Pream+SFD4d) <-> SFD1, or
   -(Pream+SFD4d) <-> SFD2
2. The FA probability computation is not verified in any simulations
3. MD analysis

Comments on Plan D Proposal

- The Plan D is proposed by only considering an unique receiving technique by proposers and optimized only for the receiving technique. The proposal did not take any general receiving technique into account. We must not specify any receiving technique to select SFD value because the choice of receiving technique rests with the implementers.
- The FA computation in Doc. 01 only considers one correlation value. The data only shows sidepeak 4 is better than sidepeak 6. We also agree with the point.
- In the SFD image test for "Preamble + SFD4d", we observe that image case of plan D also have sidepeak 6 (one 6 in SFD1 and two 6s in SFD2 image cases, or in Hamming Distance H_d, one H_d=5 in SFD1 and two H_d=5 in SFD2, see next two slides)
- The even position in image test could miss detect the SFD.



Sidepeak 6 is equivalent to Hamming Distance 5.

Hamming Distance Comparison Between Plans B and D

Plan B, SFD1	8	8	8	8	8	8	8	8	8	9	7	8	5	9	9	9	9
	8	8	8	8	8	8	8	8	8	7	9	8	11	7	7	7	7 (Image)
Plan B, SFD2	8	8	8	8	8	8	8	8	8	9	7	8	5	9	9	9	9
	8	8	8	8	8	8	8	8	8	7	9	8	11	7	7	7	7 (Image)
Plan D, SFD1	8	8	8	8	8	8	8	8	8	7	9	6	9	7	7	11	7
	8	8	8	8	8	8	8	8	8	9	7	10	7	9	9	5	9 (Image)
Plan D, SFD2	10	6	10	6	10	6	10	6	10	7	9	6	7	7	11	9	11
	6	10	6	10	6	10	6	10	6	9	7	10	9	9	5	7	5(Image)

Sidepeak 6 is equivalent to Hamming Distance 5.

Results and Observation

What we have done

- Both Hamming Distance and RMS comparison for all the four plans and 6 cases including image SFD4d.
- FA/MD evaluation based on simulations by employing two kinds of thresholds:
    1. Based on correlation value
    2. Based on Hamming distance

Simulation Model based on Correlation Values

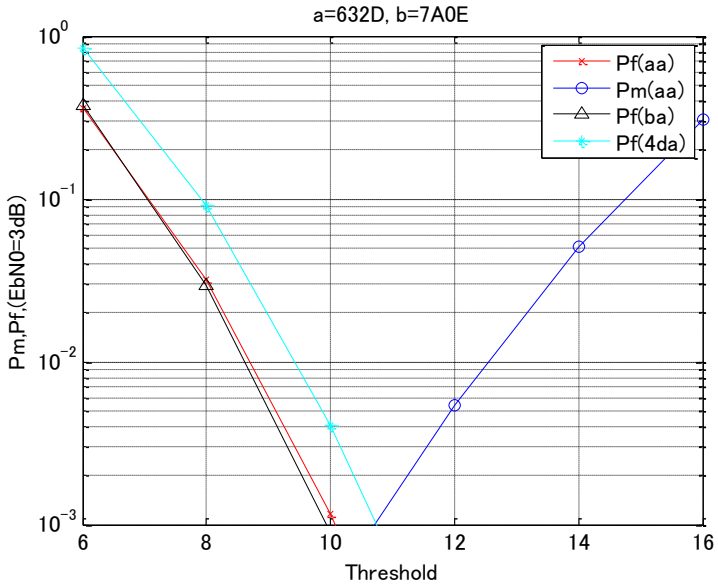
Assumption:

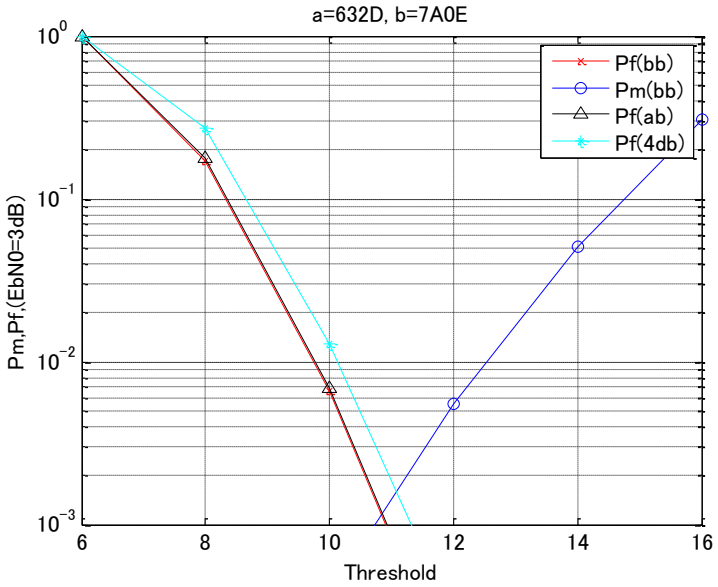
- False alarm occurs on period between the point where preamble is detected and synchronization point.

  In simulation, the period is set to (24+16 or 8)bits and (40+16 or 8) bits respectively with two preamble sizes.

- Image can be identified when correlator output is less than the negative of the selected threshold values.

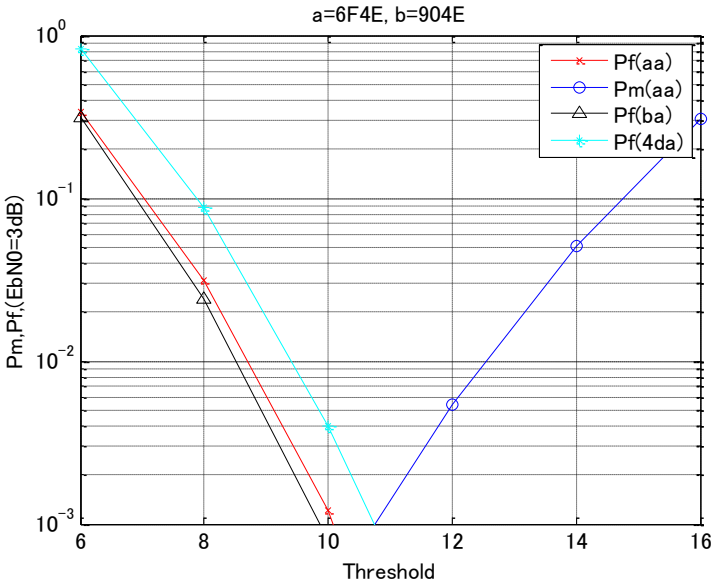
MD and FA probabilities of plan D (a=0x632D, b=0x7A0E) on 24-bit preamble+16-bit SFD or 8-bit TG4g SFD

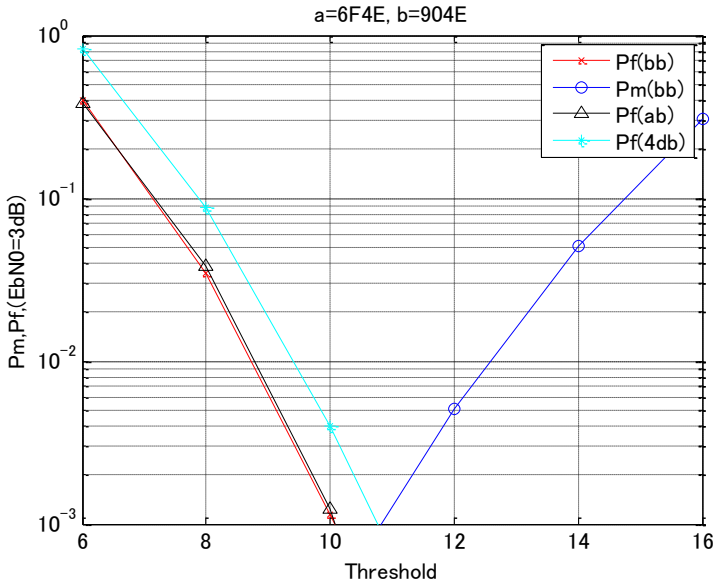




The average RMS value for Plan D SFD1 (0x632D) is 2.0701, for SFD2 (0x7A0E) is 3.5317. The obtained BER shows that Plan D SFD2 has much worse performance of about 0.01 error rate.

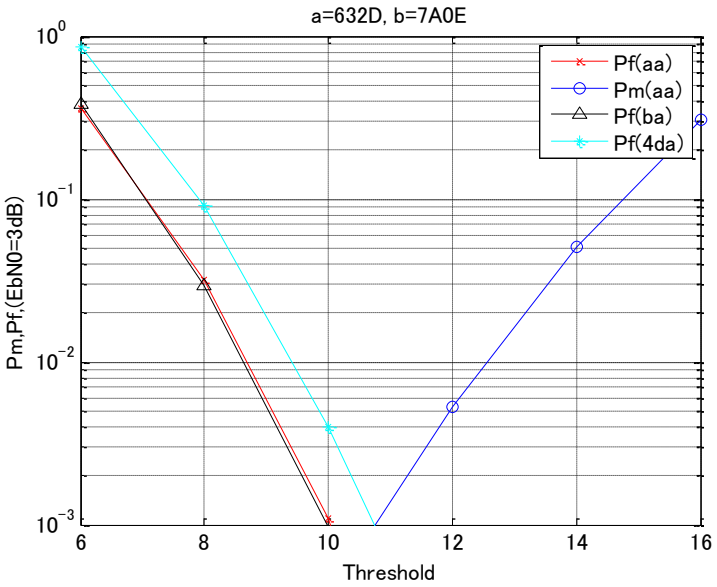
MD and FA probabilities of plan B (a=0x6F4E, b=0x904E) on 24-bit preamble+16-bit SFD or 8-bit TG4g SFD

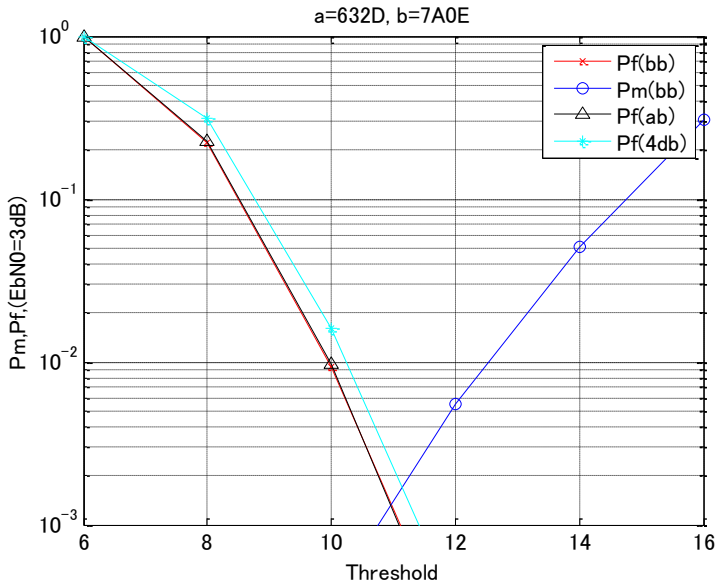




The average RMS value for Plan B SFD1 (0x6F4E) is 2.0035, for SFD2 (0x904E) is 2.1932. Plan B achieves better than plan D

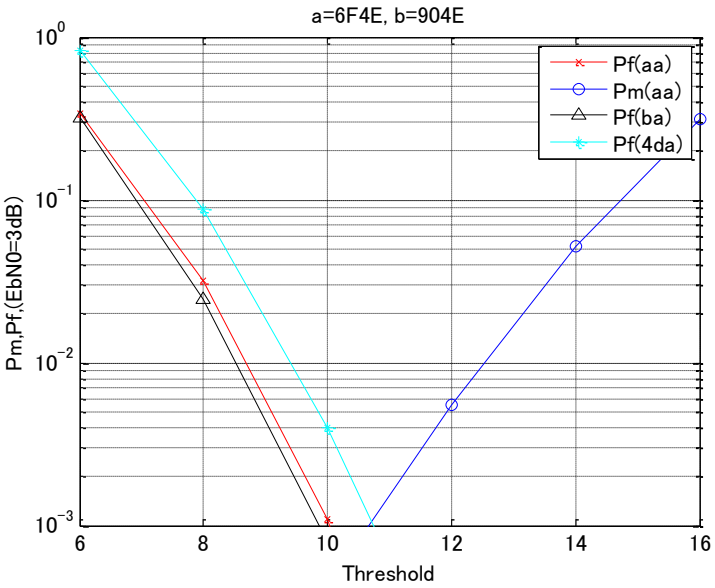
MD and FA probabilities of plan D (a=0x632D, b=0x7A0E) on 40-bit preamble+16-bit SFD or 8-bit TG4g SFD

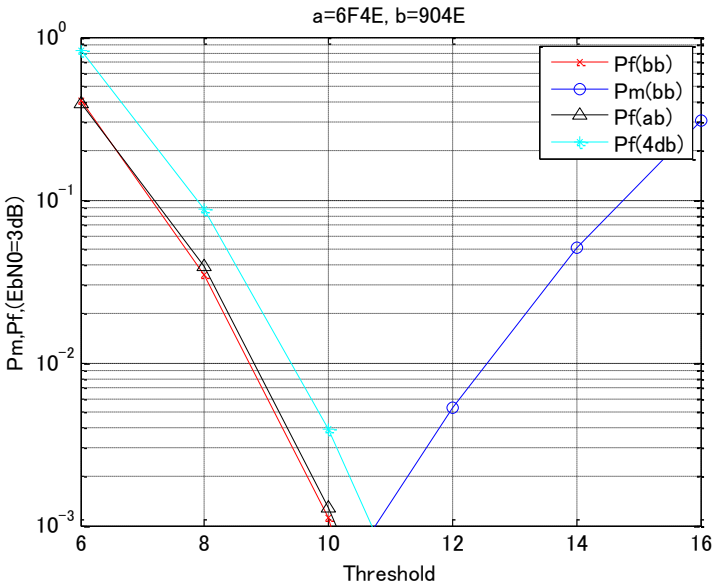




Simulations have also been conducted for '40-bit preamble+SFD'.
Plan D SFD2 has even worse performance when long preambles are used due to its worse correlation property with preamble (A series of sidelobes with values 4 and -4).

MD and FA probabilities of plan B (a=0x6F4E, b=0x904E) on 40-bit preamble+16-bit SFD or 8-bit TG4g SFD





Plan B SFD1 and SFD 2 can maintain a good performance even when the preambles length is increased from 24 bits to 40 bits.

RMS of SidePk Values

	Plan A		Plan B		Plan C		Plan D	
	a=SFD1	a=SFD2	a=SFD1	a=SFD2	a=SFD1	a=SFD2	a=SFD1	a=SFD2
Prem+a ⇔ a	1.6833	1.0801	2.1985	2.1985	2.0817	2.3094	2.1602	3.4400
Prem+b ⇔ a	2.1213	2.8577	1.8708	2.3452	2.0000	2.6458	1.9579	3.4641
Prem+sfd4d ⇔ a	2.1144	1.2834	1.8787	1.8787	1.8787	2.2752	2.1144	3.8501
-(Prem+a) ⇔ a	1.6833	1.0801	2.1985	2.1985	2.0817	2.3094	2.1602	3.4400
-(Prem+b) ⇔ a	2.1213	2.8577	1.8708	2.3452	2.0000	2.6458	1.9579	3.4641
Average RMS	1.9447	1.8318	2.0035	2.1932	2.0084	2.4371	2.0701	3.5317

Results and Observation

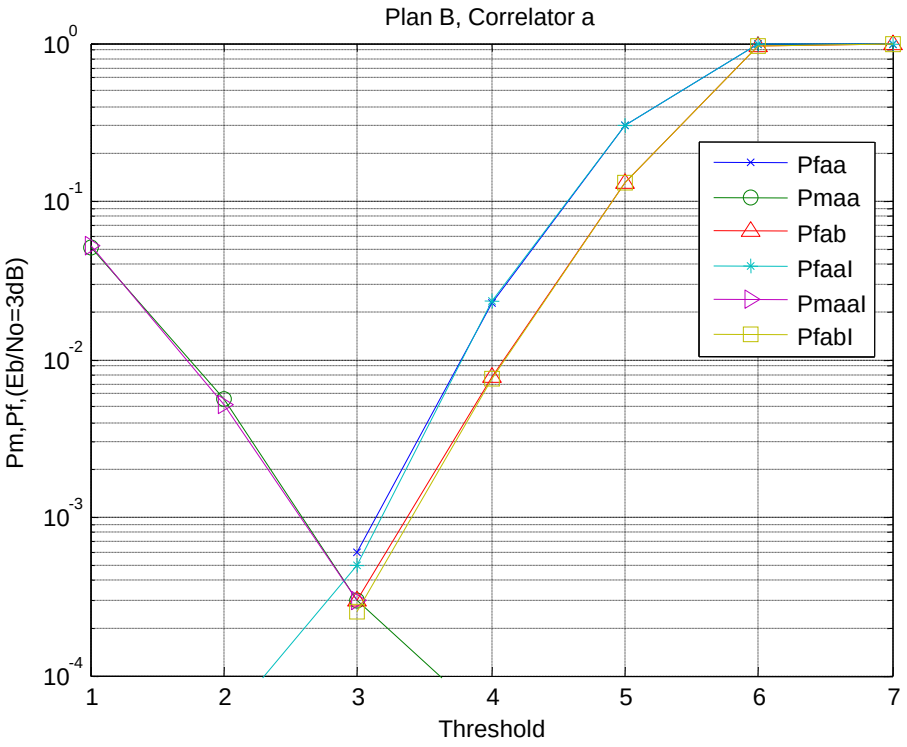
- Plan B has better detection performance than plan D based on our simulations
- Especially for longer preamble packets, plan D has worse false alarm probability than plan B due to worse correlation property against preamble. This is one of the prioritized selection criteria of SFD. (Refer to the last Slide)
- Plan B is better in TG4g frame format that supports variable length of preamble.

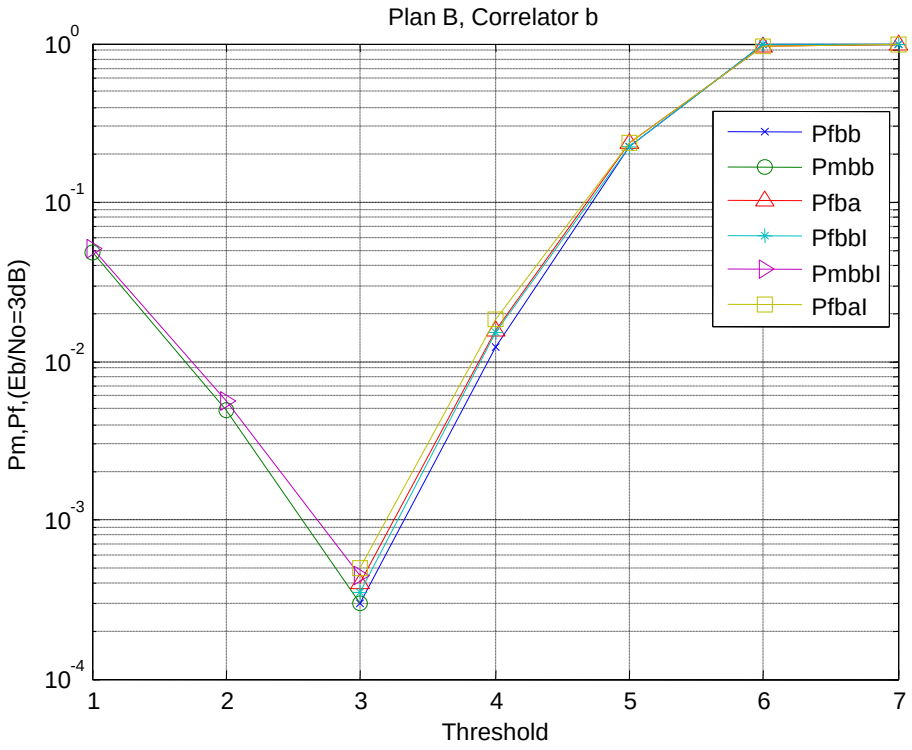
Simulation Model based on Hamming Distance

Assumption:

- Threshold is set based on Hamming distance H_d (Correlation value = $16 – 2*H_d$)
- False alarm occurs on period between the point where preamble is detected and synchronization point.
- Image can be identified when $(16 – H_d)$ is less than the selected thresholds.

FA/MD Test based on H_d

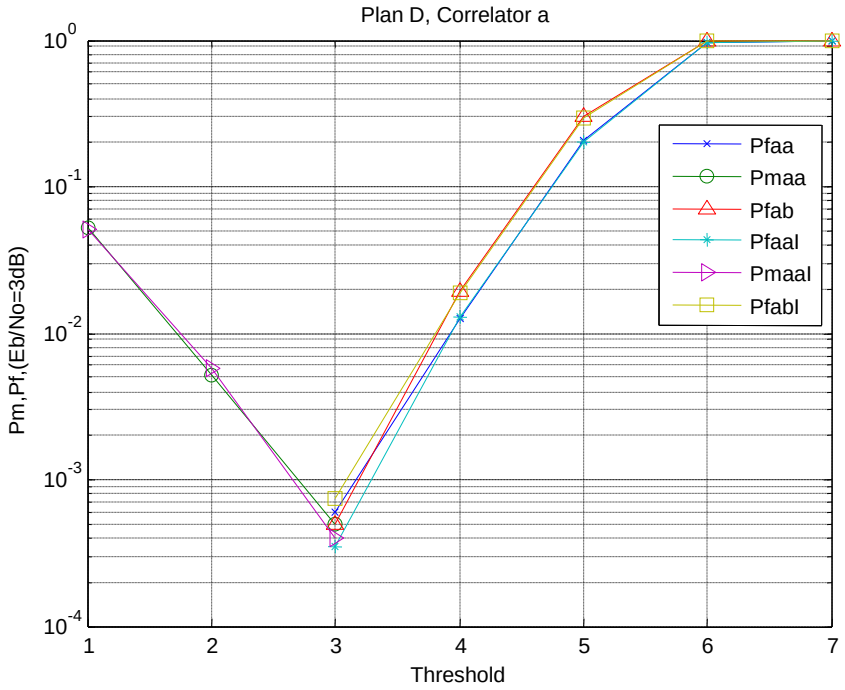


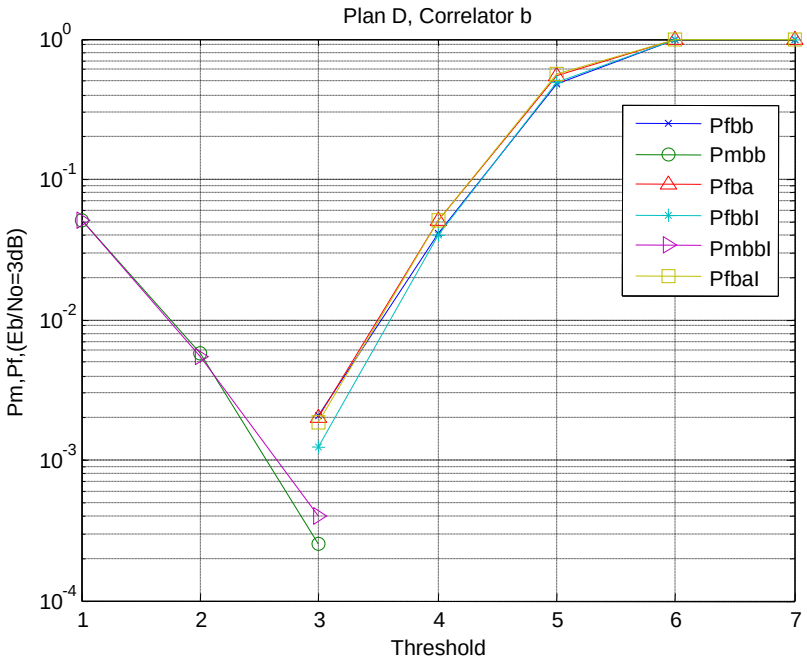


Threshold value is varied from 1 to 7

Threshold=3 is equivalent to correlation value 10.

FA/MD Test based on H_d

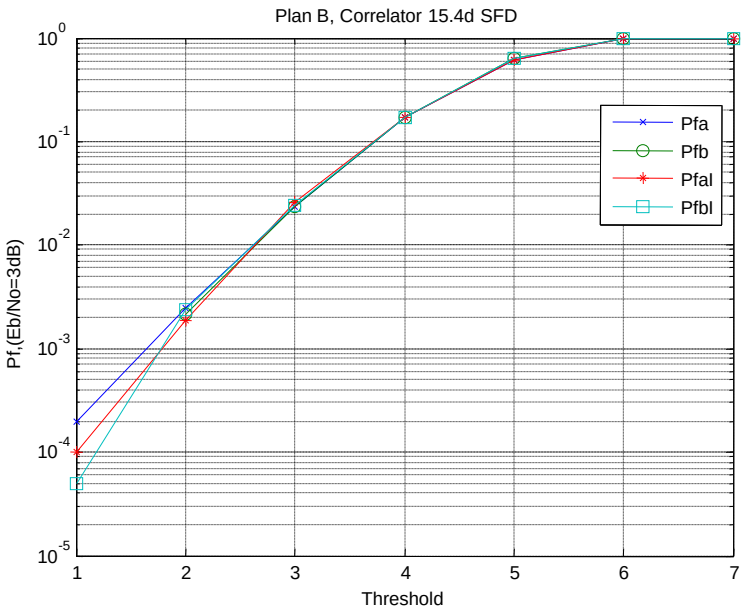


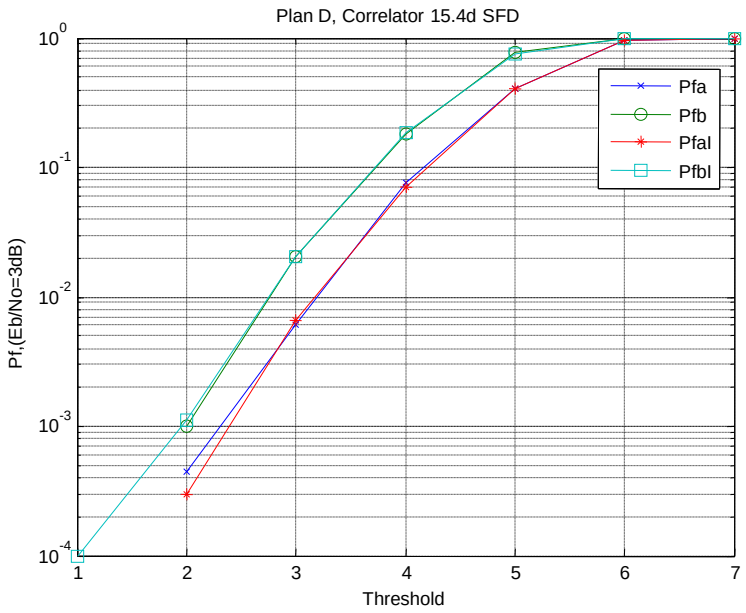


Threshold value is varied from 1 to 7, Threshold = 3 is equivalent to correlation value 10. Similar to the case using correlation values as threshold, Plan D SFD2 has worse performance because of its generally high sidelobe values or high average RMS values even though the maximum sidepeak of Plan D is as low as 4.

FA/MD Test based on H_d

"Preamble + SFD4d" and "-(Preamble + SFD4d)"





The obtained results again verify that RMS analysis matches with the FA/MD simulation results. Plan D SFD2 gives worse FA performance due to the worse correlation property.

RMS of Hamming Distances

	Plan B		Plan D	
	a=SFD1	a=SFD2	a=SFD1	a=SFD2
Prem+a ⇔ a	1.0992	1.0992	1.0801	1.72
Prem+b ⇔ a	0.9354	1.1726	0.9789	1.7321
Prem+sfd4d ⇔ a	0.9393	0.9393	1.0572	1.9251
-(Prem+a) ⇔ a	1.0992	1.0992	1.0801	1.72
-(Prem+b) ⇔ a	0.9354	1.1726	0.9789	1.7321
-(Prem+sfd4d) ⇔ a	0.9393	0.9393	1.0572	1.9251

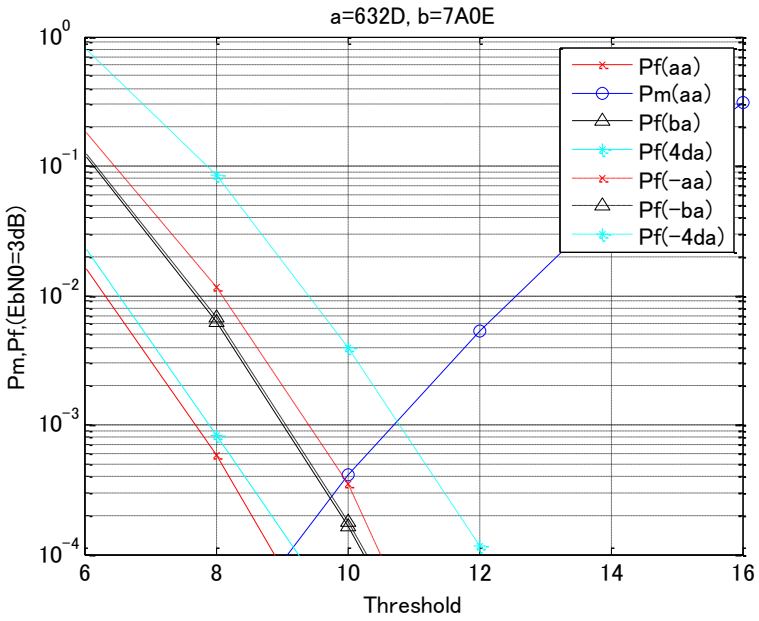
The table compares RMS values of (H_d-8) for Plans B and D in all the 6 cases. H_d = 8 is the ideal value of Hamming distance as it corresponds to correlator value 16-2*8=0. In this case, both normal detection and image detection have the best performance as no sidelobes at all.

Conclusion

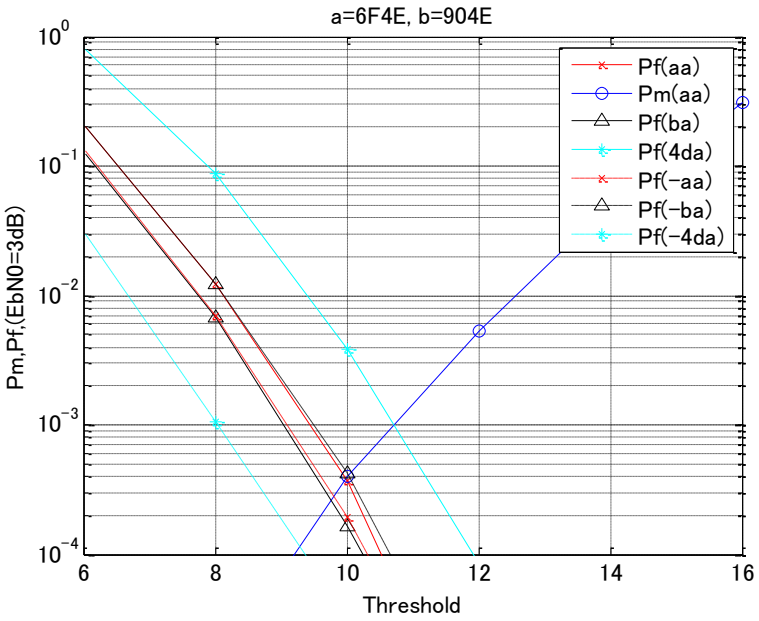
- FA and MD simulation results match the RMS analysis quite well. Plan B offers better FA/MD performance than plan D. SFD2 in plan D has worse performance due to the high RMS values and a series of sidelobes with values 4 and -4 when correlate with preamble even there is no sidepeak value 6.
- FA computation method in Doc. 15-10-0126-01 only focuses on one correlation point instead of considering overall side lobe values (all number of shifts positions).
- Hence, RMS analysis provides a more comprehensive insight to the SFD performance than the FA computation method in Doc. 15-10-0126-01.
- Plan B is better than plan D.
- The Plan D is proposed by only considering an unique receiving technique by proposers and optimized only for the receiving technique. The proposal did not take any general receiving techniques into account. We must not specify a special receiving technique to select SFD value because the choice of receiving technique rests with the implementers.

Appendix

MD and FA probabilities of “a” sequence of plan B (a=0x6F4E, b=0x904E) and plan D (a=0x632D, b=0x7A0E) on 40-bit preamble+16-bit SFD or 8-bit TG4g SFD



Plan D



Plan B

The simulation if based on even position detection method. The obtained results show that even using the receiving technique in Docs. 15-10-0126-00 and 15-10-0126-01, Plan D is not better than Plan B when the case image ‘preamble+SFD4d’ is taken into consideration.

SFD Selection Criteria

The criteria for the selection of 2 SFD's is given in 15-10-0051-01-004g-fsk-sub-group-resolution-update.pdf

Process to select the SFD values:

1. Will be selected based on the following prioritized criteria:
   a. Autocorrelation and cross correlation to the other pattern
   b. Good image rejection (low correlation against the image)
   c. Correlation relative to the preamble (low side lobes against the preamble)

2. The following prioritized differentiators will be used to select SFD values if multiple solutions are found with identical performance. Supporting data for item 2a shall be provided by all proposals.
   a. The selected code should have good orthogonality against the existing 802.15.4d SFD. (Co-existence with 802.15.4d is imperative)

3. Timeline:
   a. Harada-san: proposals provided within one month (no later than 2/22 midnight PST) and exchanged among subgroup participants. Proposals will be emailed to Harada-san and copied to all members of the SFD subgroup. Harada-san will send an email to all SFD participants.
   b. There will be a conference call the week of 2/22 to review the proposals. Harada-san will schedule the conference call for 2/25 (we propose using the normal 4g call time)