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

Submission Title: [CSM Issues in FH Networks]
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Re: [802.15.4g Comment Resolution for LB59]
Abstract: []

Purpose: [CSM related Comments Resolution for LB59]

Outline

- This document explores the CSM performance issues in FH networks that will be operating at data rates higher than 50 kbps
  - Center frequencies alignment
  - CSM channel utilization

- This document suggests the following
  - to align center frequencies of 200 kHz-spacing channels with those of 400 kHz-spacing channels
  - to exchange CSM messages (EB/EBR) only on 200 kHz-spacing channels whose center frequencies coincide with ones of 400 kHz-spacing channels (the so-called “odd 200 kHz-spacing channels”)

Topics

1. Use cases for a 4g MR-FSK hopping network
   - w/ speed up => network is operating at data rates higher than 50 kbps
   - w/o speed up => network is operating at 50 kbps

2. FH network operating at high data rates:
   - the need for alignment of center frequencies of 200 kHz- and 400 kHz-spacing channels, when FH network w/ speed up
   - CSM channel utilization for FH network w/ and w/o speed up: performance comparison for the “best case”
     - Upper bound on the probability of successfully exchanging EB/EBR
     - Lower bound on average waiting time for successfully exchanging EB/EBR

Use cases for 4g MR-FSK hopping networks

Uses cases for a MR-FSK FH network

- Use cases
  1. FH network w/ speed up
     - network is operating at data rates higher than 50 kbps => 400 kHz channel spacing
     - network can use all or a set of standard defined 400 kHz-spacing channels
     - CSM is used to exchange EB/EBR with any unassociated device => 200 kHz channel spacing
  2. FH network w/o speed up
     - network is operating at 50 kbps => 200 kHz channel spacing
     - network can use all or a set of standard defined 200 kHz-spacing channels
     - CSM is used to exchange EB/EBR with any unassociated device => 200 kHz channel spacing

- Result
  1. FH network w/ speed up
     - the need to deal with two modes of operation, i.e., mandatory and optional modes
     - the need to define a common set of channels to be used for CSM message exchanges
  2. FH network w/o speed up
     - the need to define a common set of channels to be used for CSM message exchanges

Center Frequencies Alignment

(for FH networks w/ speed up)

Center frequencies alignment

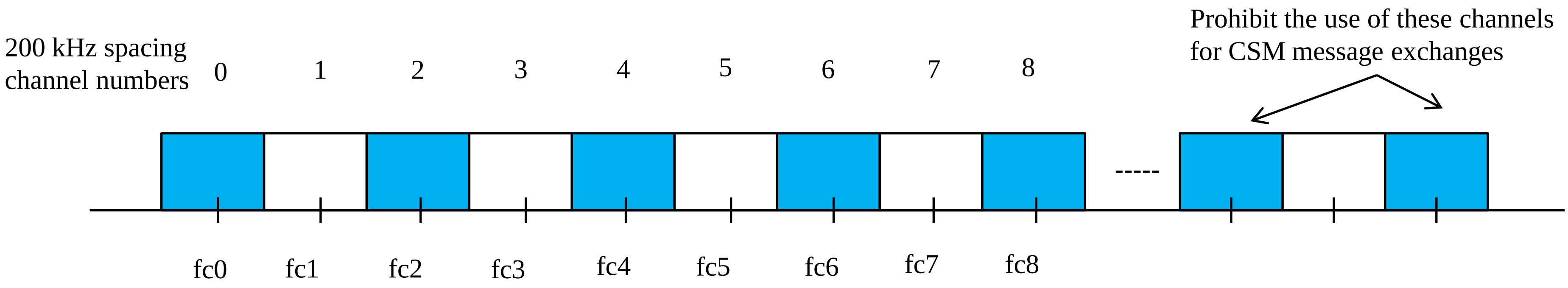
- Assume
  - 200 kHz- and 400 kHz-spacing channels not aligned (w/r/t center frequencies)
  - FH network operating at high data rates => 400 kHz channel spacing
  - Unassociated devices attempting to exchanges EB/EBR with a FH network use the CSM => 200 kHz channel spacing

- Result
  - FH network must interleave its mode of operation over two channel plans with different center frequencies (and channel spacing)
  - time multiplexing is required to accommodate the two modes of operation => poor performance
  - poorer performance if the FH network and the device do not use a common set of channels

Center frequencies alignment (cont'd)

- Solution:
  - require alignment of the 200 kHz-spacing channels with the 400 kHz-spacing channels (w/r/t center frequencies)
  - require from unassociated devices to use only those 200 kHz-spacing channels that align with the 400 kHz-spacing channels, when exchanging CSM messages
  - require from FH network and unassociated devices to use a common set of channels to exchange CSM messages

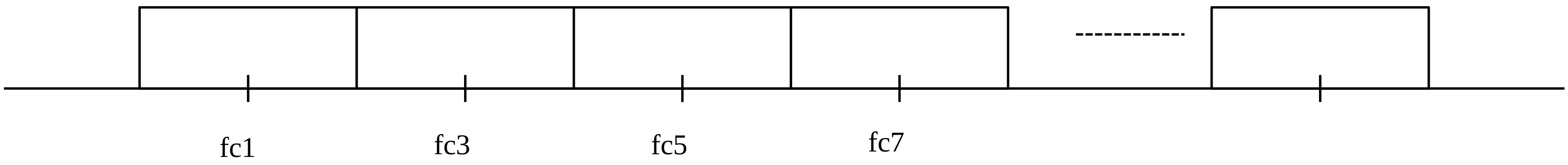
MR-FSK channel plan for a given band



Channel plan for MR-FSK mandatory mode @ 200 kHz channel spacing

Channel plan for MR-FSK optional modes @ 400 kHz channel spacing

Center frequencies of 400 kHz-spacing channels correspond to center frequencies of the odd 200 kHz-spacing channel numbers



Notes:

1. A PHY capable to communicate on every 200 kHz spacing channel number (0, 1, 2, 3, 4, 5, ….) can also communicate only on odd channel numbers (1, 3, 5, …).
2. This does not add any additional requirements to the existing PHY.

CSM channel utilization: Performance comparison

(for FH networks w/ speed up)

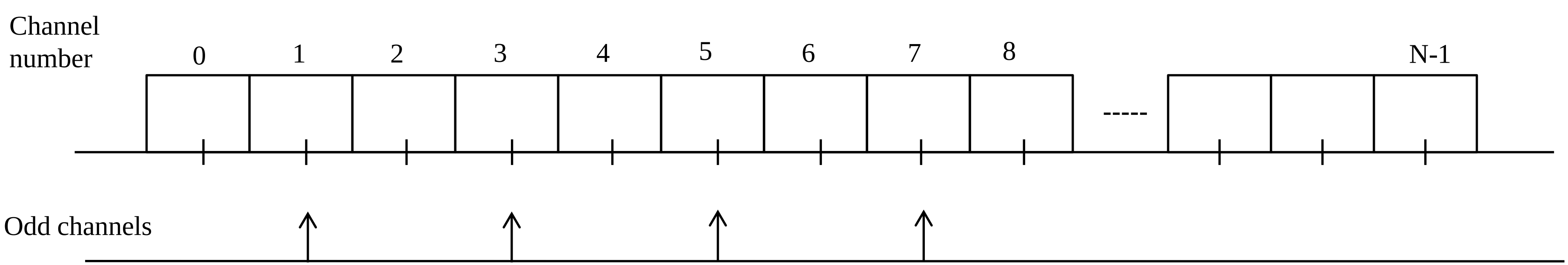
Performance comparison
Probability of successfully exchanging EB/EBR

- Assumptions
  - FHSS system running @ 200kHz channel spacing
  - # of channels = N ; (N > 1)
  - Tx and Rx synchronized ; no interferences and collisions
  - Tx and Rx use the same set of channels
  - Hopping sequences used by Tx and Rx are statistically independent

- Performance parameter: probability of Tx and Rx hopping on the same channel (see Annex A)

I. Tx random on all 200 kHz-spacing channels and Rx random on all 200 kHz-spacing channels
   - P = 1/N

II. Tx random on odd 200 kHz-spacing channels and Rx random on all 200 kHz-spacing channels
   - P = 1/N



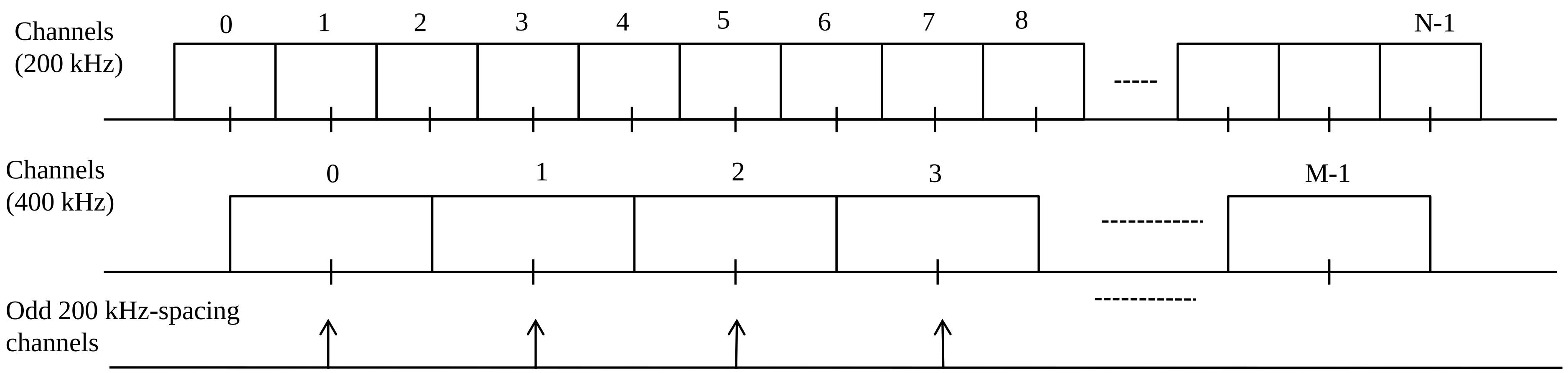
Performance comparison
Probability of successfully exchanging EB/EBR

- Assume
  - FHSS system running at 400kHz channel spacing
  - # of 200 kHz spacing channels = N ; (N > 1)
  - # of 400 kHz spacing channels = M ; (M > 1, M < N); center frequencies aligned with those of 200 kHz-spacing channels => 400 kHz-spacing channels represent a set of 200 kHz-spacing channels
  - Tx and Rx hopping sequences are statistically independent
  - Tx and Rx synchronized ; no interferences and collisions

- Performance parameter: probability of Tx and Rx hopping on the same channel (see Annex A)

  III. Tx random on all 200 kHz-spacing channels and Rx random on all 400 kHz-spacing channels
  - P = 1/(2M)

  IV. Tx random on odd 200 kHz spacing channels and Rx random on all 400 kHz-spacing channels
  - P = 1/M



Performance comparison
Average waiting time for successfully exchanging EB/EBR

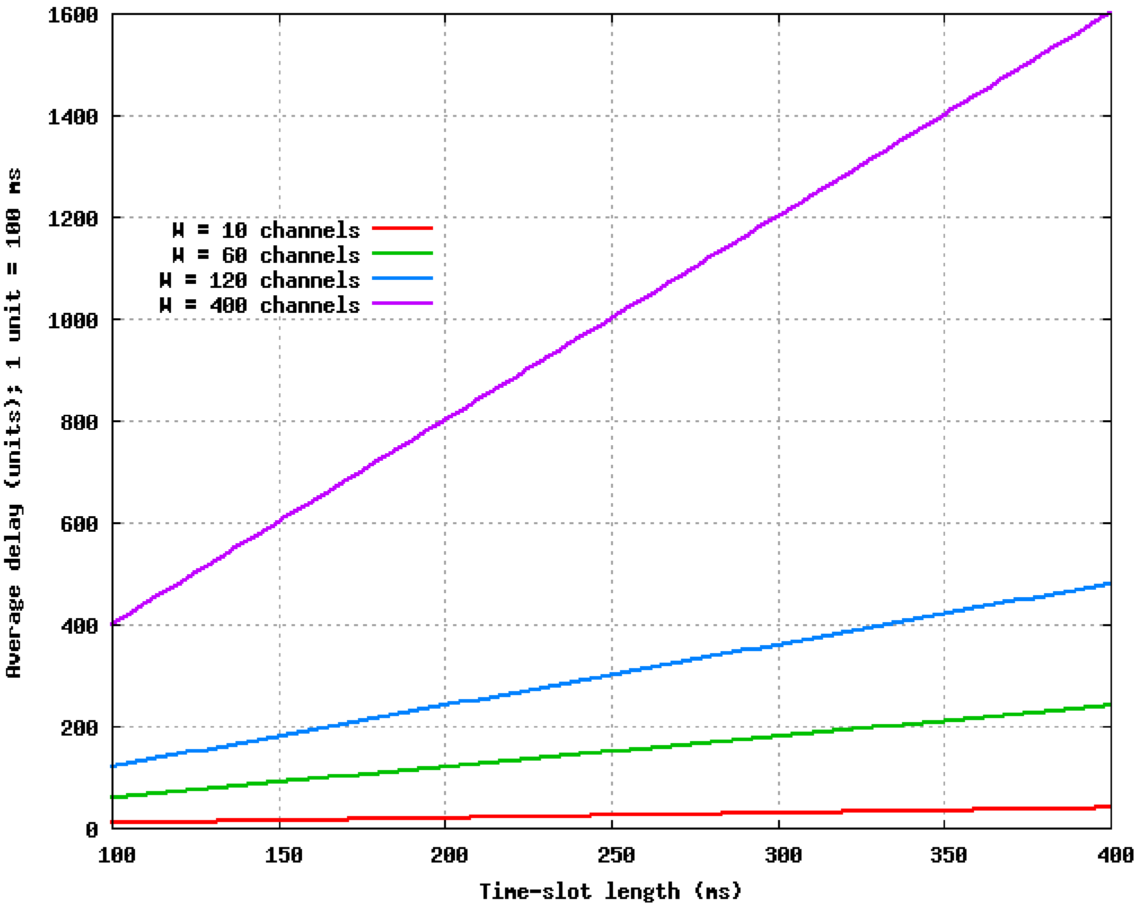
- Assumptions for the “best case”
  - A common set of W channels is used by Tx and Rx
  - A time slot with a length of T (sec)
  - Tx and Rx are synchronized; no interferences and collisions
  - Tx and Rx hopping sequences are statistically independent

- Average delay (D) for Tx and Rx hopping into the same channel (see Annex B)
  - $D = W \times T$ (sec)

Performance comparison
Average waiting time for successfully exchanging EB/EBR

- Smaller the number of channels *W* used to exchange CSM messages smaller the delay

- Notice that the case where Tx and Rx use a set of different channels can lead to (much) higher delays



Conclusions

1. It is inefficient for MR-FSK FH system operating at optional modes to exchange information with a device using CSM, if the center frequencies of the channels they use do not coincide.

2. MR-FSK FH system operating at mandatory mode and utilizing only the odd 200 kHz-spacing channels for CSM message exchanges does not show performance degradation.

3. Unassociated device trying to exchange CSM messages with a MR-FSK FH system operating at optional modes sees its performance increased when utilizing only the odd 200 kHz-spacing channels (comparing to the case when it utilizes all 200 kHz-spacing channels).

4. A MR-FSK FH system and an unassociated device not using a common set of channels to exchange CSM messages => very poor performance.

Annex A
Probability of successfully exchanging EB/EBR

- Consider
  - hopping sequence A = {a(i); $0 \le i \le N-1$} for 200 kHz channel spacing
  - hopping sequence B = {b(j); $0 \le j \le M-1$} for 400 kHz channel spacing
  - hopping sequences A and B are statistically independent
  - without losing generality, we can consider N is an integer multiple of 2 => M = N/2

- Probability for the case

I. See Slide 11 for assumptions

P = Prob{a(i) = b(j); (∀) i ≠ j} = N/(NxN) = 1/N

II. See slide 11 for assumptions

P = Prob{a(i) = b(j); (∀) i ≠ j} = (N/2)/[N x (N/2)] = 1/N

III. See slide 12 for assumptions

P = Prob{a(i) = b(j); (∀) i ≠ j} = M/(M x N) = 1/(2M)

IV. See slide 12 for assumptions

P = Pob{a(i) = b(j); (∀) i ≠ j} = M /[M x (N/2)] = 1/M

Annex B
Average waiting time for successfully exchanging EB/EBR

Lets call $p = 1/W$ (1)

$D = p \cdot T + (1-p) \cdot p \cdot 2 \cdot T + (1-p)^2 \cdot p \cdot 3 \cdot T + \ldots \Rightarrow D = p \cdot T \cdot [1 + 2 \cdot (1-p) + 3 \cdot (1-p)^2 + \ldots] = p \cdot T \cdot S(p)$, (2)

where $S(p) = 1 + 2 \cdot (1-p) + 3 \cdot (1-p)^2 + \ldots$

Lets call $a = 1-p \quad \Rightarrow \quad S(p) = S_1(a) \quad \Rightarrow \quad S_1(a) = 1 + 2a + 3a^2 + \ldots$

It is easy to show that $S_1(a) = 1/(1-a)^2 \quad \Rightarrow \quad S(p) = 1/p^2$ (3)

(1) + (2) + (3) $\Rightarrow$ $\mathbf{D} = T/p = \mathbf{T \cdot W}$