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

Submission Title: [CSM Issues in FH Networks]
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Source: [Daniel Popa, Gilles Picard, Hartman Van Wyk]
Company [ITRON],
Address [France],
E-Mail:[{daniel.popa, hartman.vanwyk}@itron.com]

Re: [802.15.4g Comment Resolution for LB59]
Abstract: []

Purpose: [CSM related Comments Resolution for LB59]

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Outline

- This document explores the CSM performance issues in FH networks
  - 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

Topics

- The need for alignment of center frequencies of 200 kHz- and 400 kHz-spacing channels
- CSM channel utilization: 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

Center Frequencies Alignment

Issue of center frequencies alignment

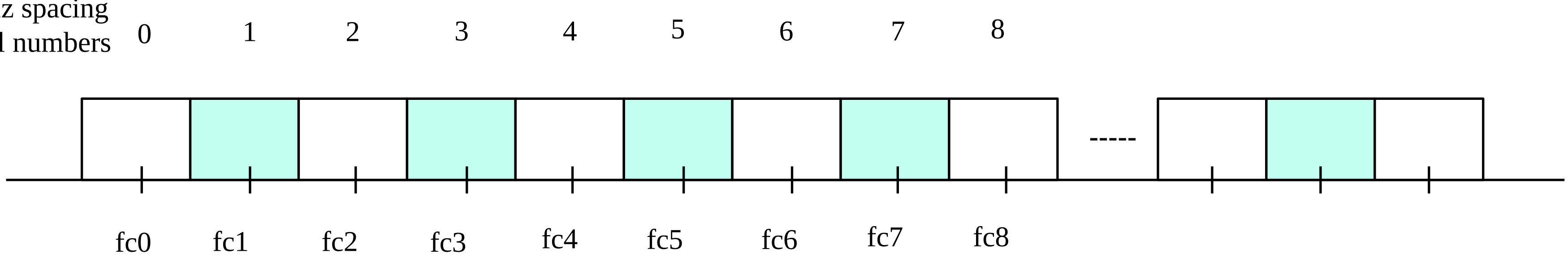
- Assume
  - 200 kHz- and 400 kHz-spacing channels not aligned (w/r/t center frequencies)
  - FH network operating at high data rates => 400 kHz channel spacing
  - A device attempting to exchanges EB/EBR with a FH network uses the mandatory mode => 200 kHz channel spacing
- Result:
  - network must interleave its mode of operation over two channel plans with different center frequencies (and channel spacing)
  - time multiplexing is required to accommodate the two mode of operation => poor performance

Center frequencies alignment issue (cont’d)

- Solution:
  – Require the alignment of the 200 kHz-spacing channels center frequencies with those of the 400 kHz-spacing channels

MR-FSK channel plan for a given band

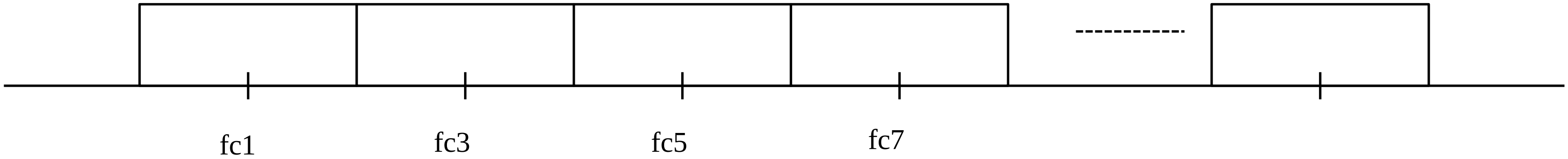
200 kHz spacing
channel numbers



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 200 kHz spacing odd 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

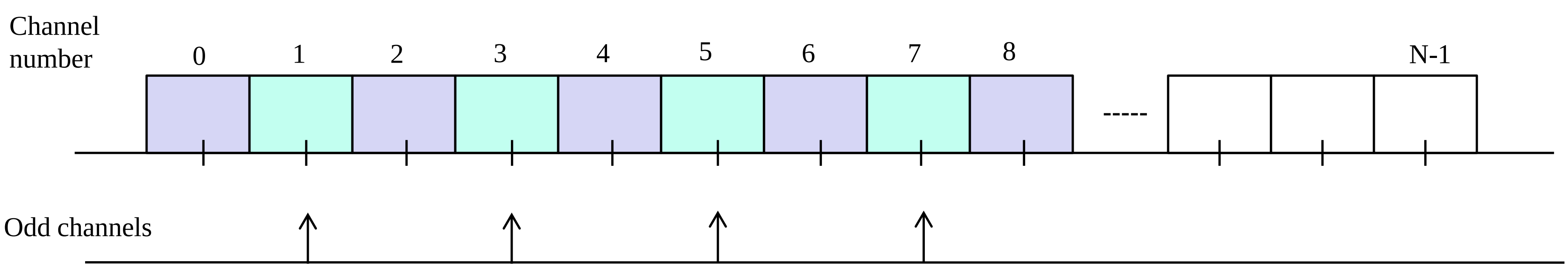
Performance comparison
Probability of successfully exchanging EB/EBR

- Assumptions
  - FHSS system running @ 200kHz channel spacing
  - # of 200 kHz spacing channels = N ; (N > 1)
  - Tx and Rx synchronized ; no interferences and collisions

- 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

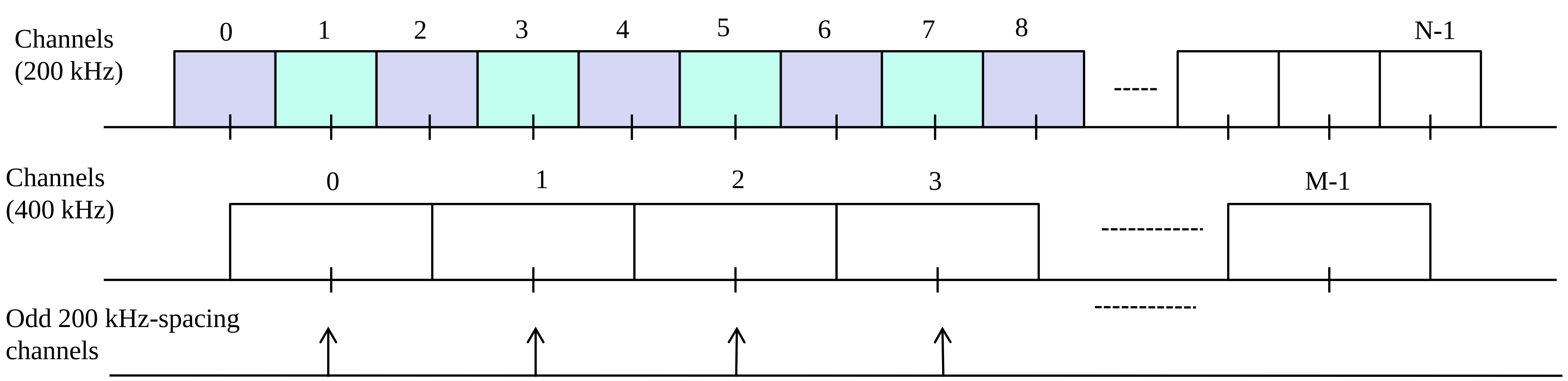


Performance comparison
Probability of successfully exchanging EB/EBR

- Assume
  - FHSS system running at 400kHz channel spacing
  - # of 400 kHz spacing channels = M ; (M > 1); center frequencies aligned with those of 200 kHz-spacing channels
  - # of 200 kHz spacing channels = N ; (N > 1, N > M)
  - the hopping sequences of length M and N 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

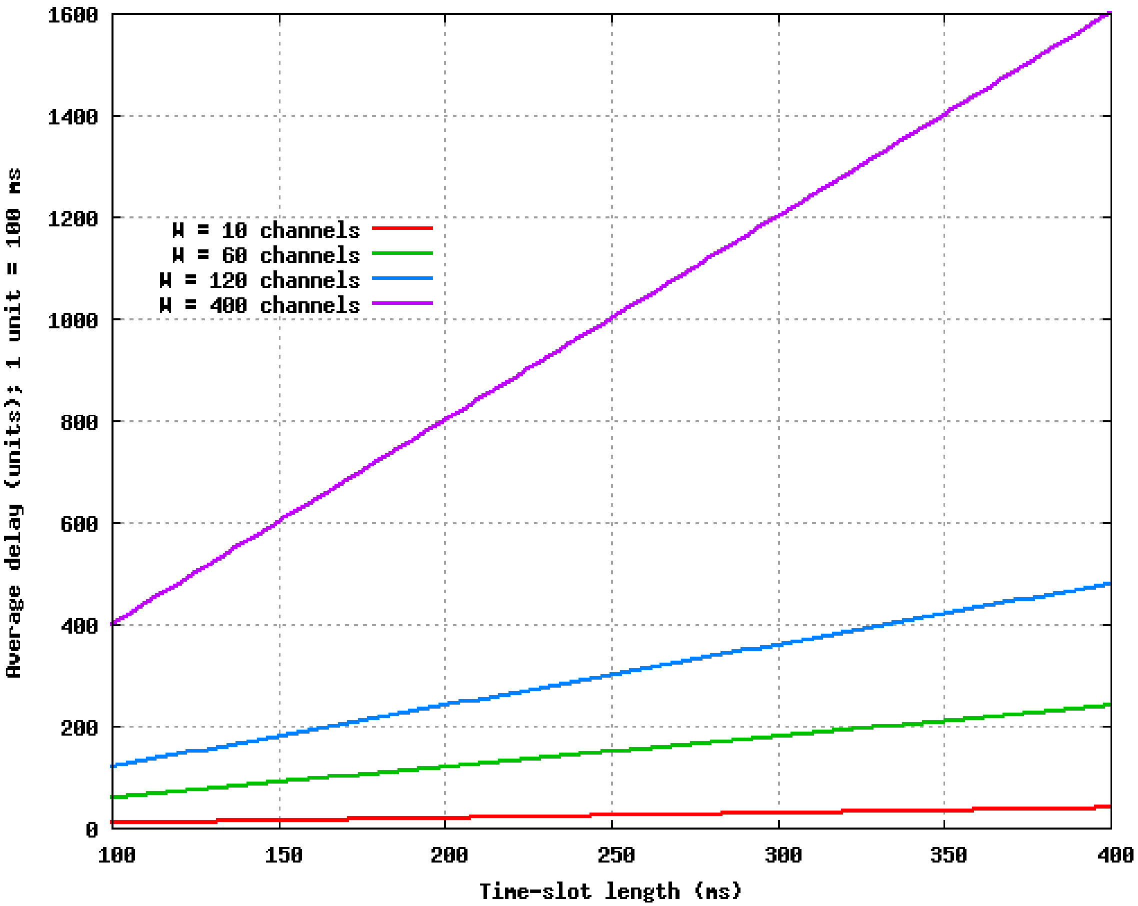


Performance comparison
Average waiting time for successfully exchanging EB/EBR

- Assumptions for the “best case”
  - A set of W channels 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

Conclusions

1. It is inefficient for an 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. A 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. A MR-FSK FH system operating at optional modes and utilizing only the odd 200 kHz-spacing channels for CSM message exchanges sees its performance increased, compared to the case when utilizing all 200 kHz-spacing channels for CSM message exchanges.

Annex A
Probability of successfully exchanging EB/EBR

- Consider
  - hopping sequence A = {a(i); $0 \leq i \leq N-1$} for 200 kHz channel spacing
  - hopping sequence B = {b(j); $0 \leq j \leq M-1$} 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 9 for assumptions

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

II. See slide 9 for assumptions

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

III. See slide 10 for assumptions

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

IV. See slide 10 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) $\Rightarrow$ $\mathbf{D} = T/p = \mathbf{T \cdot W}$