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

Submission Title: [Pairing BAN healthcare applications to wireless technologies]

Date Submitted: [November, 2006]

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Abstract: [This document is to discuss the reference wireless technologies, such as IEEE802.15.4b and IEEE802.15.4a-CSS, for BAN healthcare applications.]

Purpose: [potential technologies for BAN healthcare application.]

Pairing BAN healthcare applications to wireless technologies

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Motivations

- Do we need a new PHY/MAC for BAN?
  - We should know the performance of existing IEEE wireless technologies for BAN healthcare applications
  - Do they work? In which case they do not work? Where is the performance bottleneck?
- IEEE wireless technologies
  - 15.4b, 15.4a-CSS
- Example BAN healthcare applications
  - 20 leads ECG

Typical data rates in healthcare

- EEG
  - 192kbps (6kbps/channel, 32 channels)
- ECG
  - compressed ECG, 48kbps
  - Raw ECG, 72kbps (20 leads, 300Hz sample, 12-bits ADC)
- EMG
  - 1.488Mbps (8kHz sample, 16 bits, 12 channels)

Typical data rates healthcare (cont.)

- Capsule endoscope
  - Still image (410K pixels, color, 30 images/s)
- Blood analysis
  - 8kbps
- Supervisor and control
  - 4kbps
- Alarm and status
  - BP, Oxygen saturation
  - 0.5kbps

Features of healthcare traffics

- Real time low data rate
  - Multiple channels/leads (>10)
  - EEG, EMG, ECG and blood analysis
- Best-effort low data rate
  - Supervisor and control
- Real time high data rate
  - A few channels (<5)
  - EEG, endoscope image

Scalability analysis

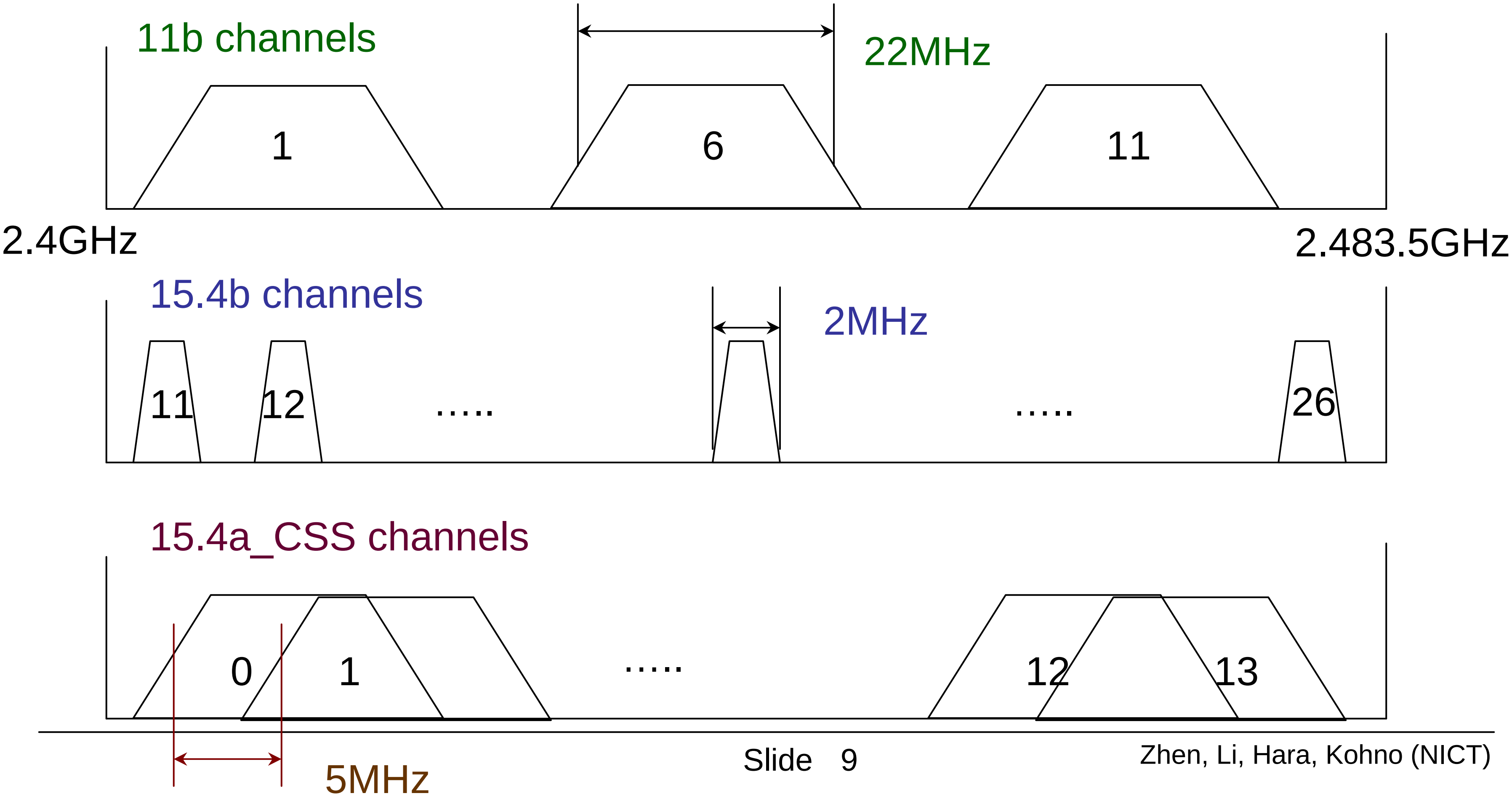
- 16 leads ECG, 32 channels ECG, 12 channels EMG
  - The 802.15.4 only has 7 guaranteed slots in slotted structure
  - No guaranteed slots in un-slotted mode
  - Even the total slots (16) are usually not enough
- ECG application works in unslotted superframe structure
- There are at most 7 slaves in a Bluetooth piconet

IEEE WPAN technologies

- 802.15.4b @ 2.4GHz ISM band
  - 250Kbps, CSMA/CA,
  - 256 devices per piconet
  - Slotted and unslotted structures
  - Optional Acknowledgement
- 802.15.4a CSS
  - 1Mbps, ALOHA
- WLAN, e.g. 802.11b, is an interference source because of its pervasive applications
  - Interference from 802.11b is like AWGN
- Bluetooth is not considered since the major Bluetooth applications are associated with cellular phones

Channel plans

- There are four 15.4b channels are in the guard bands between 11b channels



Some equations

Path loss

$$\begin{cases} d = 10^{\frac{(p_t - p_r - 40.2)}{20}} & for \quad d < 8m \\ d = 8 * 10^{\frac{(p_t - p_r - 58.5)}{33}} & for \quad d > 8m \end{cases}$$

BER of 15.4b

$$BER = \frac{8}{15} * \frac{1}{16} * \sum_{k=2}^{16} -1^{k} \binom{16}{k} e^{20SNR(1/k-1)}$$

BER of 15.4a-CSS

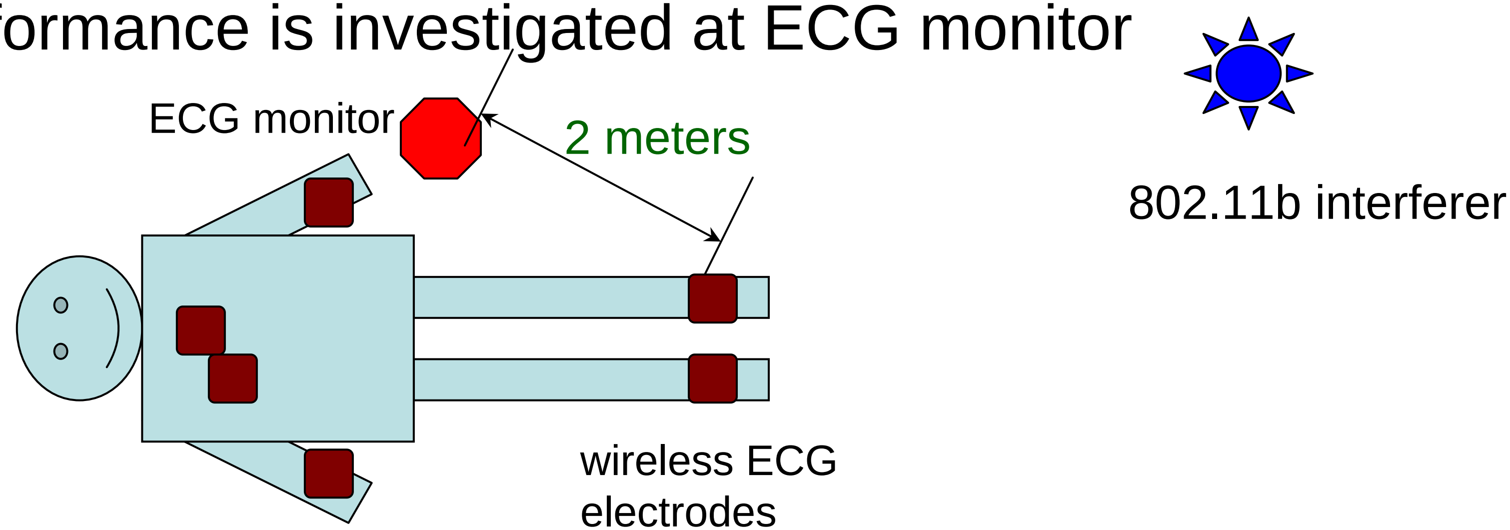
$$BER = [(M-1) * Q(\sqrt{SNR_0 * \log_2(M-2)}) + Q(\sqrt{SNR_0 * 2\log_2(M)})]/2$$

$$SNR_0 = SNR * 14 * 1.667$$

M=8 for 1Mbps

Simulation environment

- ECG data @ 72kbps
  - 20 leads, 300Hz sample, 12-bits ADC
- Wireless ECG electrodes are equipped with 15.4b/15.4a-CSS technologies
- 11b acts as background interference source
  - Duty cycle
- Performance is investigated at ECG monitor



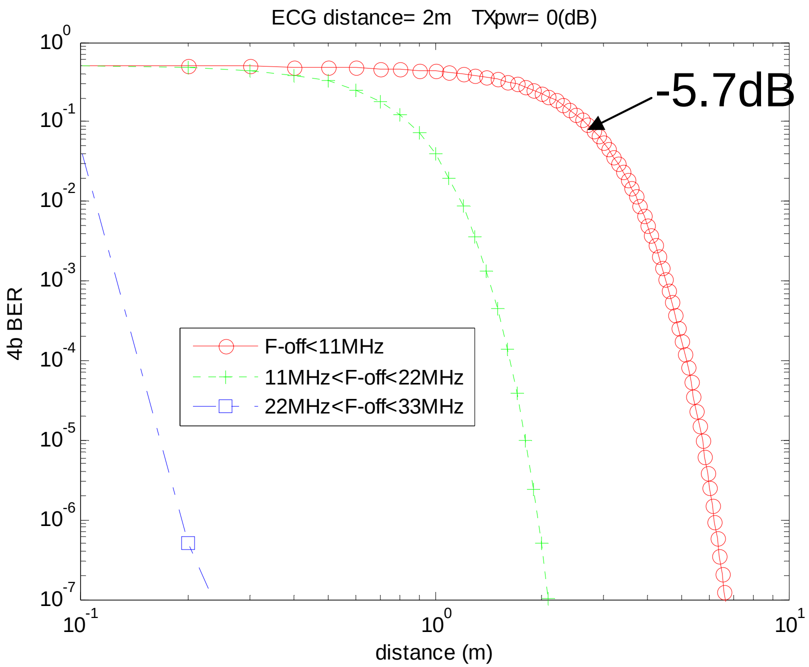
Nodes

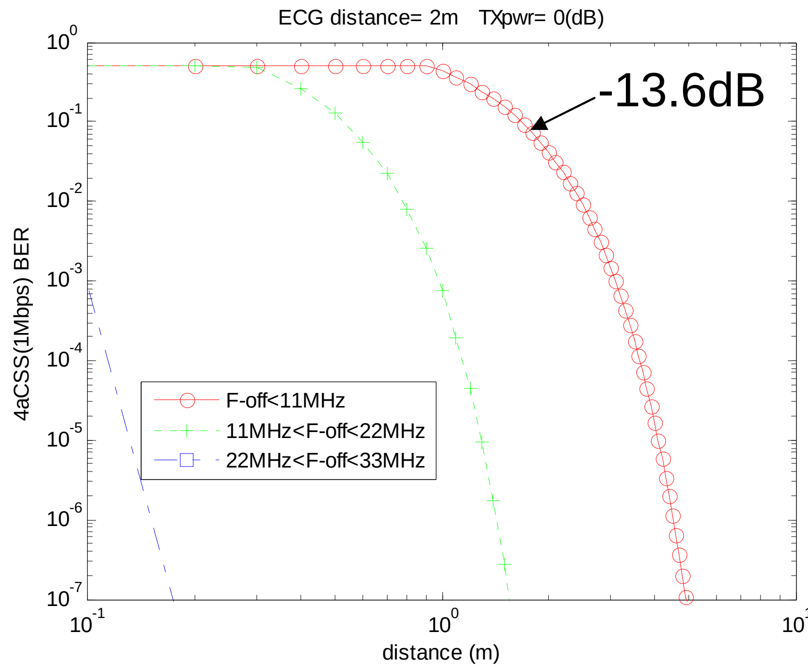
- 802.15.4a_CSS/4b ECG sensor
  - Tx power: 0dBm
  - Communication distance: 2m
  - Packet size: 36 bytes payload
- 802.11b interferer
  - Tx power: 18dBm
  - Offset attenuation: (<4MHz, 0dB), (6Mhz, -10dB), (9MHz, -30dB), (15MHz, -50dB)

Channel access

- 15.4a_CSS ECG sensors
  - ALOHH
- 11b interferer and 15.4b ECG sensors
  - CSMA-CA
- 15.4b can sense the activities of 11b by CCA when ED is over -79dBm
  - 11b signal is much strong
- 11b cannot sense the 15.4b signals

Bit error rate



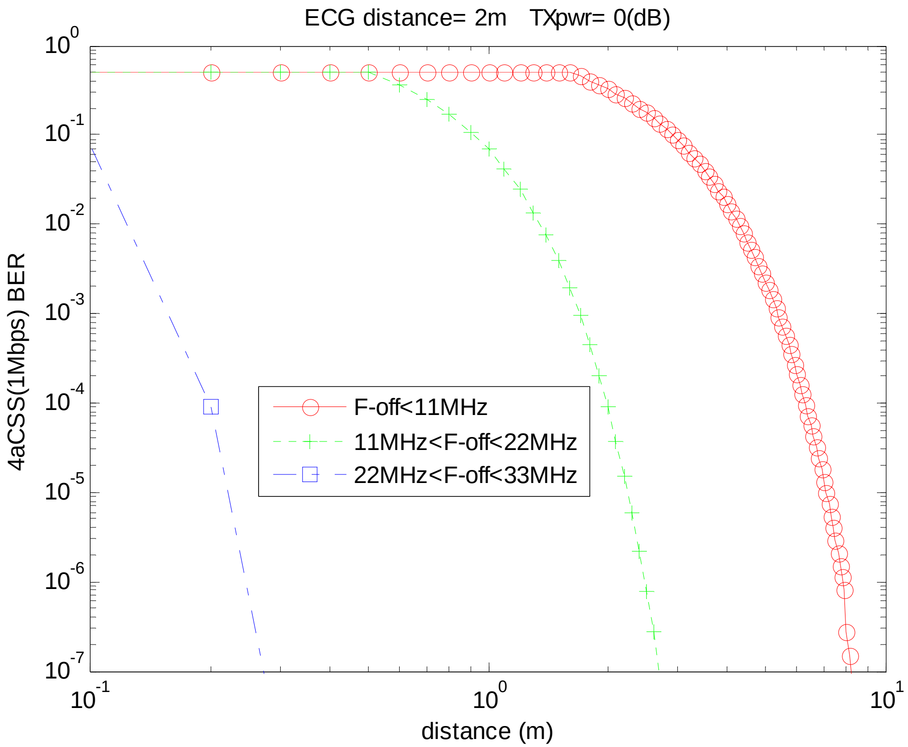


5MHz channel overlap

15.4b

15.4a CSS

Bit error rate (cont.)

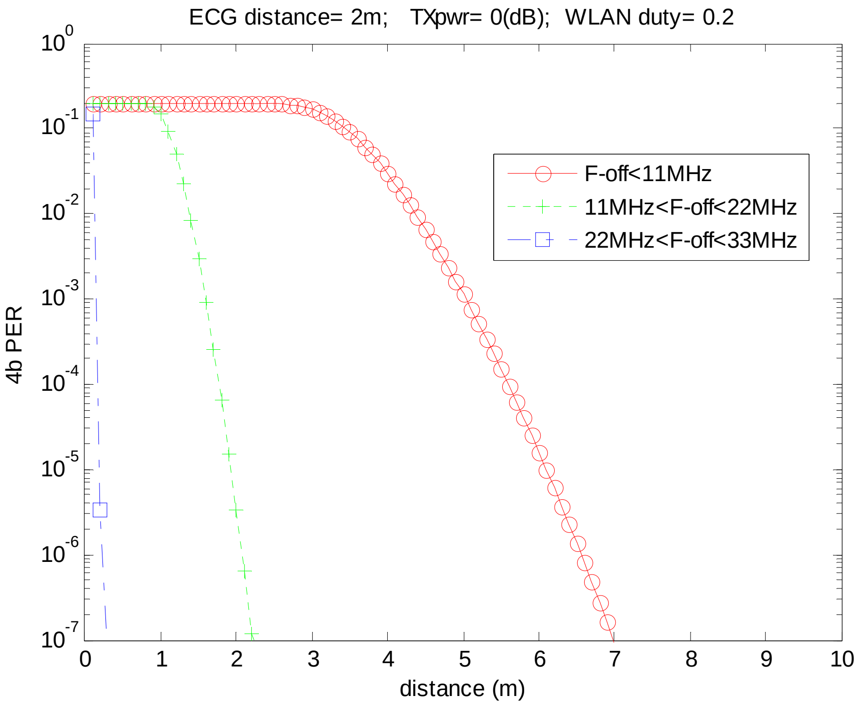


15MHz channel overlap

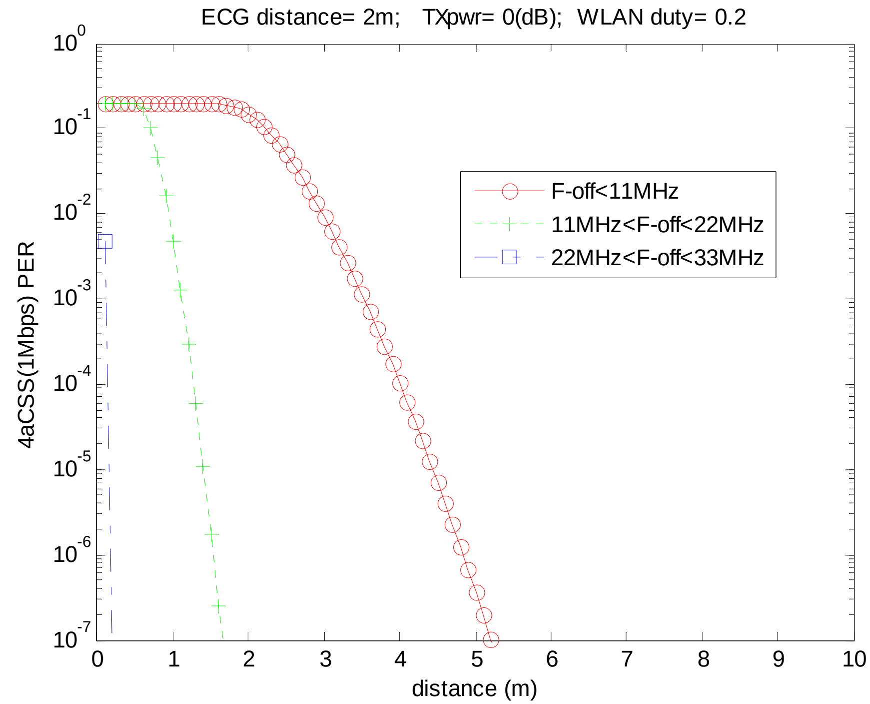
15.4a CSS

Frame error rate

20% duty cycle of WLAN 11b interferer



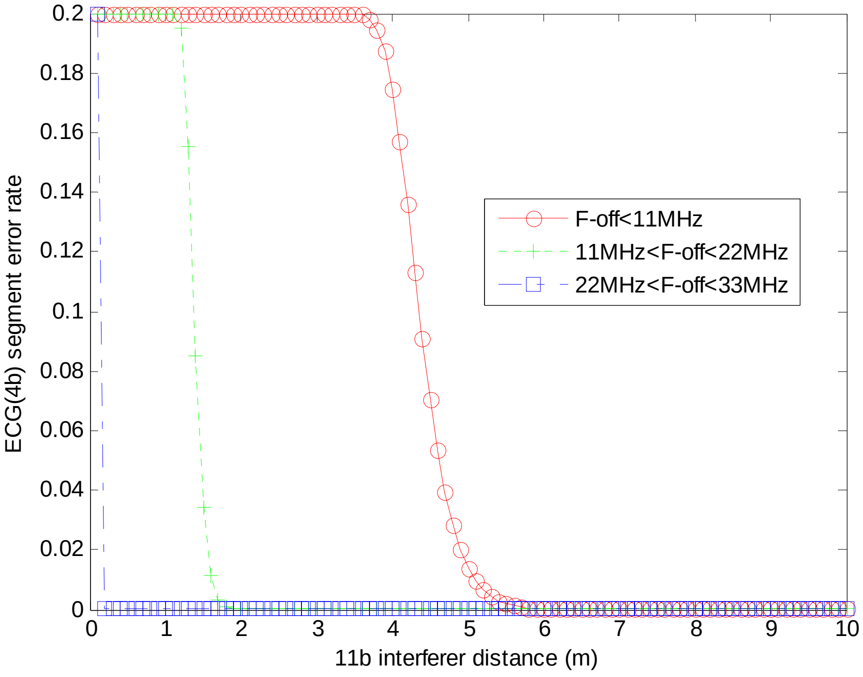
15.4b

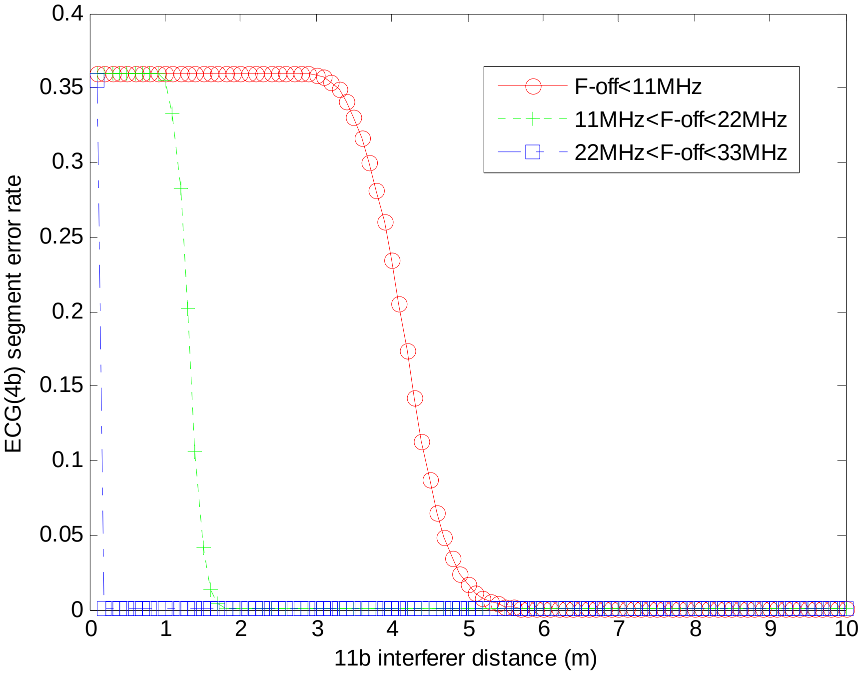


15.4a CSS

4b is more robust than 4a-CSS (low data rate)

ACK (4b)



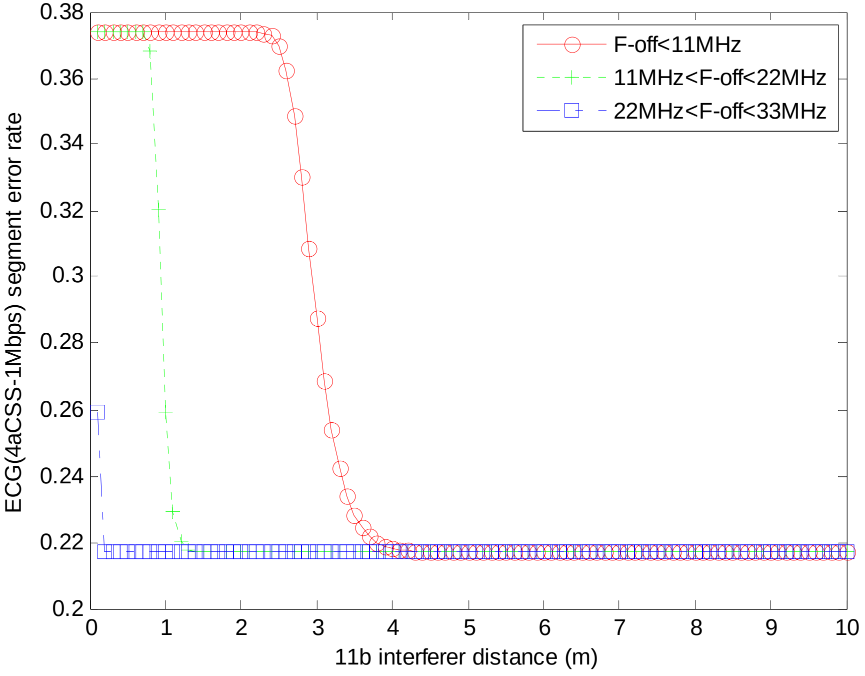


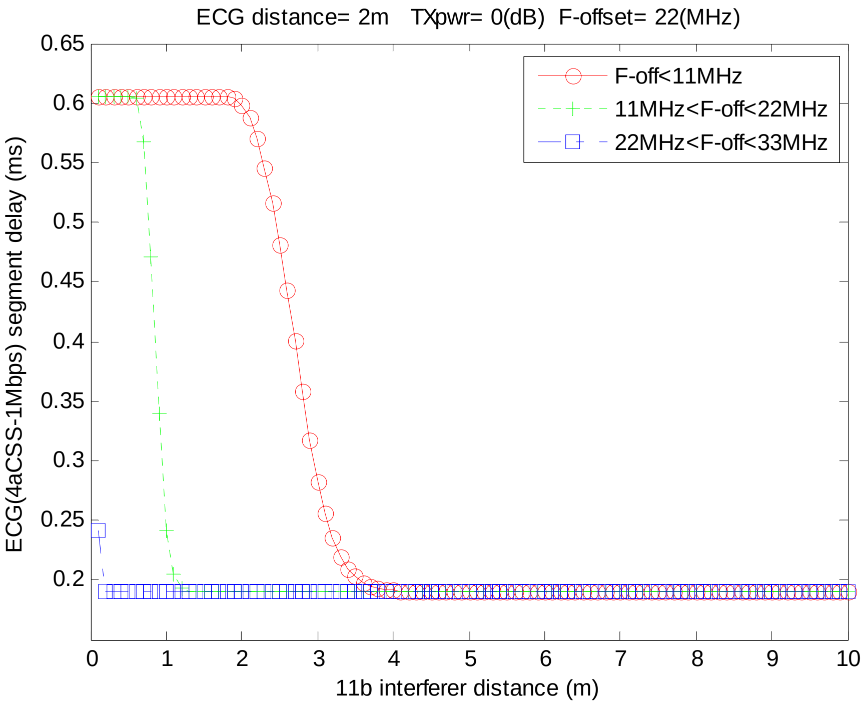
ACK off

ACK on

ACK increase packet error probability since ACK has no carrier sense

ACK (4a-CSS)





ACK off

ACK on

Additional packet error due to noise and ALOHA collision

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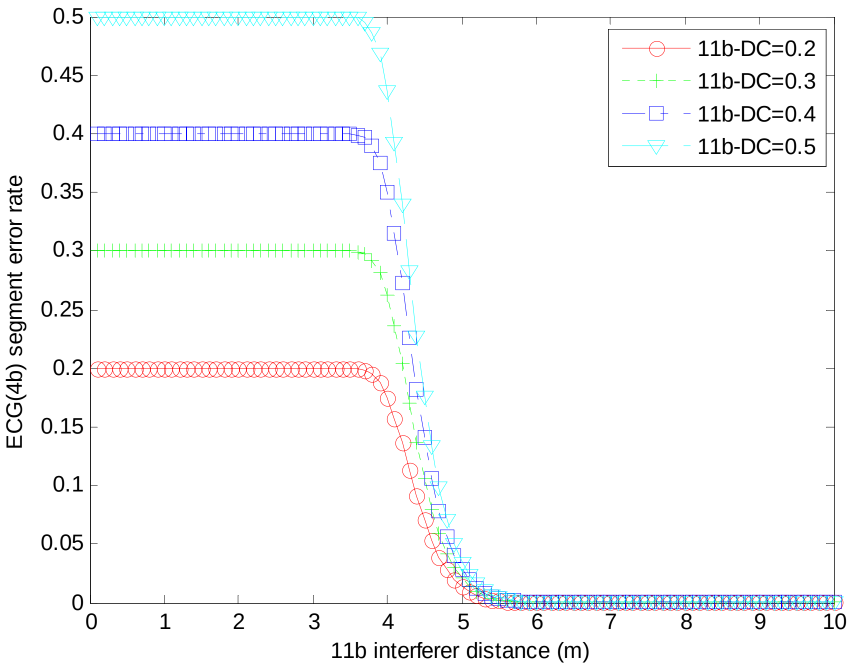
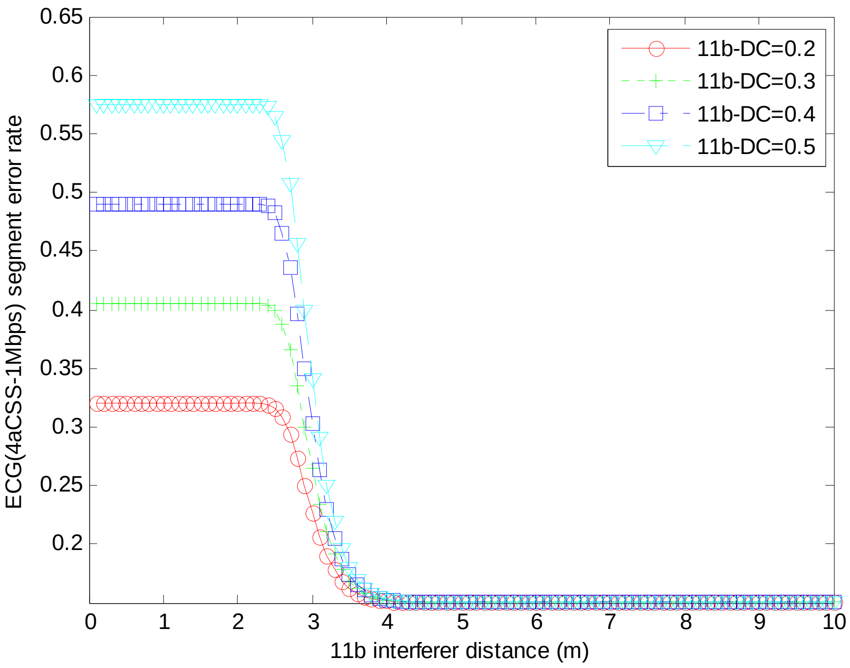
Interferer duty cycle

Co-channel interference, 16 wireless ECG electrodes, ACK off



4b

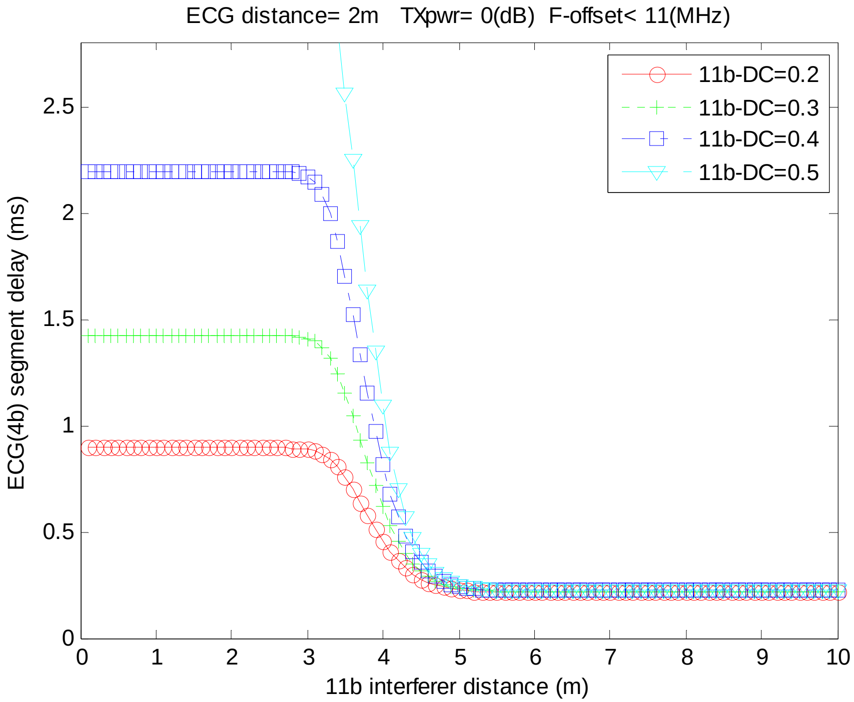


4a-CSS

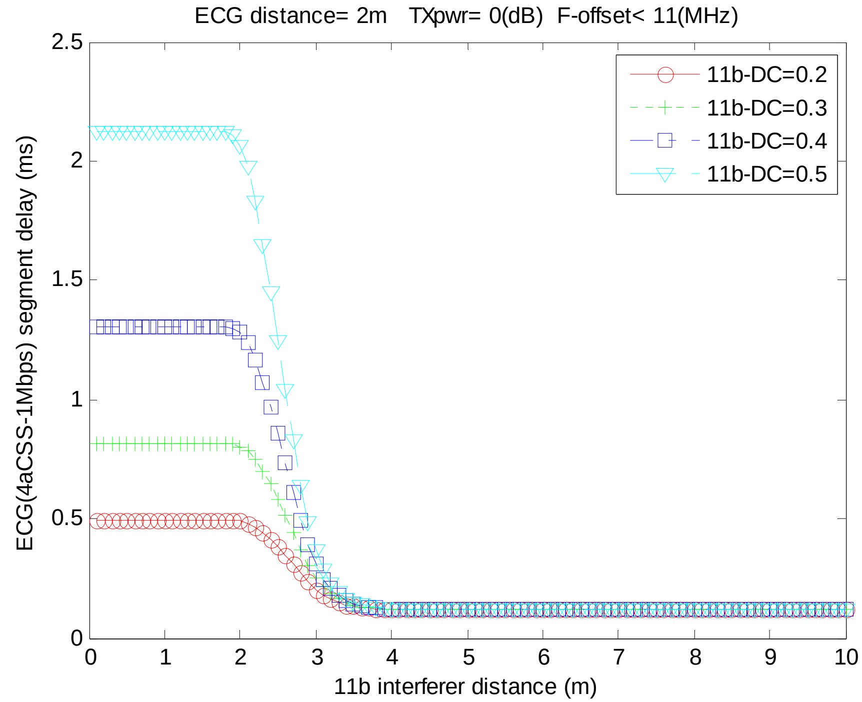
More 11b duty cycle, more packet loss

ECG frame delay

Co-channel interference, 16 wireless ECG electrodes, ACK on



4b

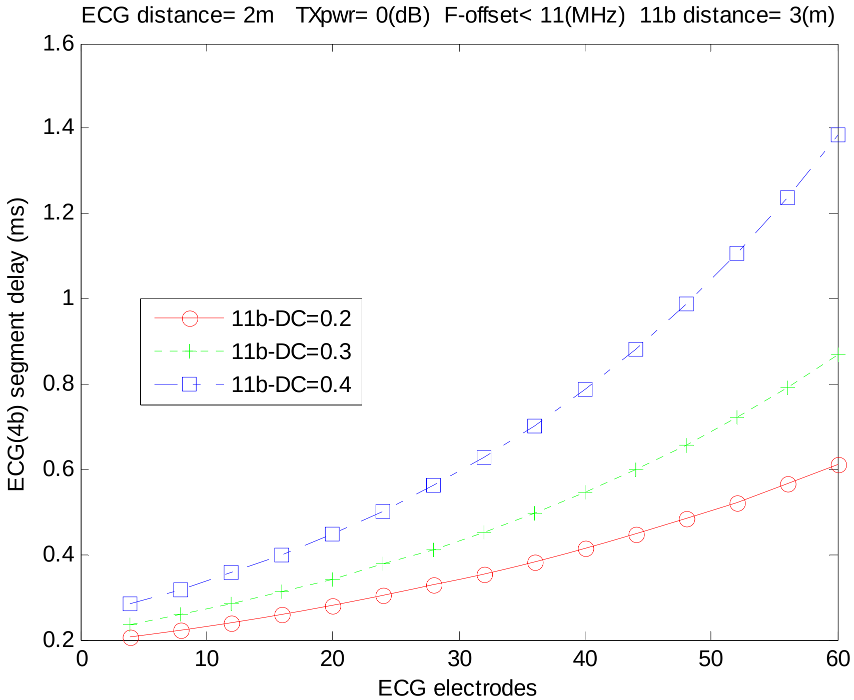


4a-CSS

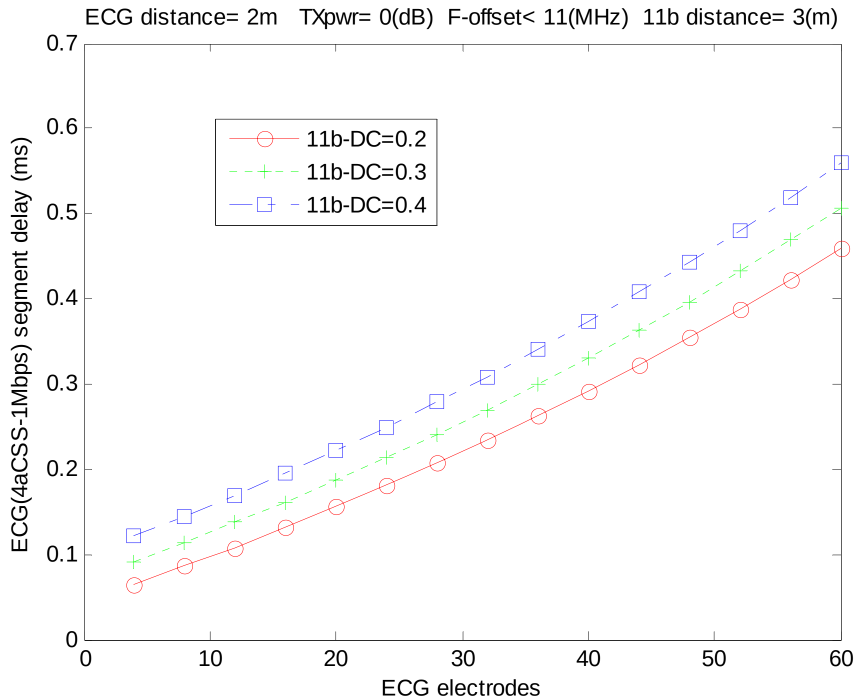
4b cannot work when 11b duty cycle is 0.5

ECG electrodes

ACK off, co-channel interference, 11b duty cycle= 0.4



4b

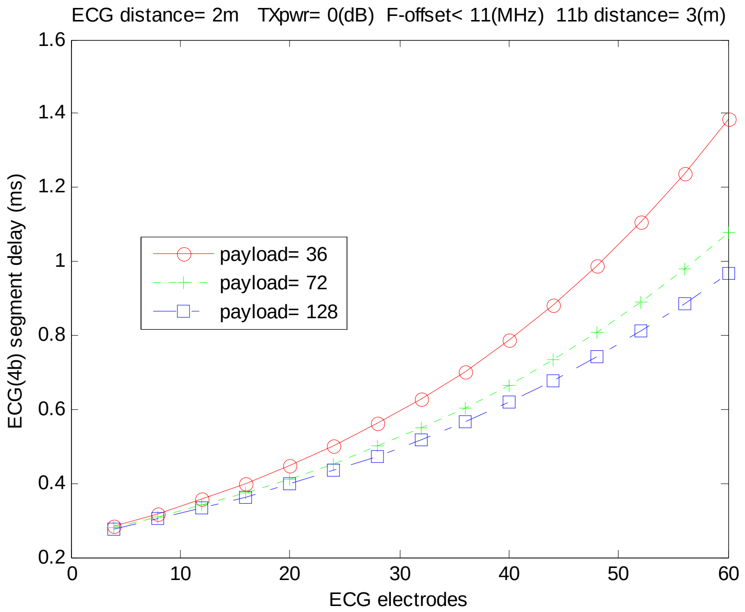


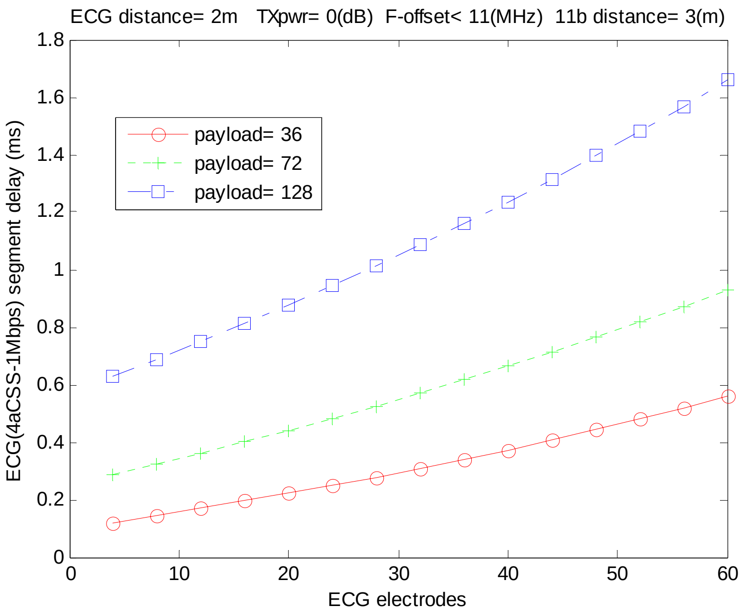
4a-CSS

Bigger packet size is only better for 15.4b

ECG packet size

ACK off, co-channel interference, 11b duty cycle= 0.4





4b

4a-CSS

Bigger packet size is only better for 15.4b

Interference summary

- Distance and frequency band separations between interferer and victims are important
  - Co-channel interferer: (<5m and <7m)
  - Adjacent channel interferer: (<1.5m and <2m)
- Duty cycle of 11b interference is an key point
  - Packet loss results from both MAC error and interference
- Performance of 15.4a_CSS depends on how much channel overlap
  - The more the channel overlap, the more the noise
- ACK increases error probability
  - ACK has no carrier sense
  - ACK increase traffic load
  - ACK can save battery power when network load is light

Conclusions

- Scalability issue
  - 15.4b and 15.4a-CSS have major constraints in term of supporting multiple real time healthcare sensor (>30)
- MAC flexibility issue
  - Combination of a few high rate traffic and large low rate traffic
- Interference issue
  - Frame error rate may be pretty high
    - >0.5 or more in some cases
    - ACK increases frame error
  - Frame delay may be un-tolerable