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

Submission Title: Ultra-Low Power Medical BAN PHY Proposal
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Re: Call for Proposals

Abstract: Sub-GHz ULP PHY for Medical BAN applications

Purpose: Zarlink's response to 802.15.6 Call for Proposals

Ultra-Low Power Medical BAN PHY proposal

Zarlink’s proposal for 802.15.6 BAN

Outline

- Goal
- Frequency band
- Channel plan
- Modulation
- Data rate
- Conducted power and sensitivity
- FEC, CRC and packet structure
- Simulation results
- Power consumption
- Size

Goal

- Meet medical applications needs
  - Up to few kbit/s per channel
- With the lowest power possible
  - In transmit: helps higher data rate sensor nodes
  - In receive: allow power efficient PNC

Frequency band (1)

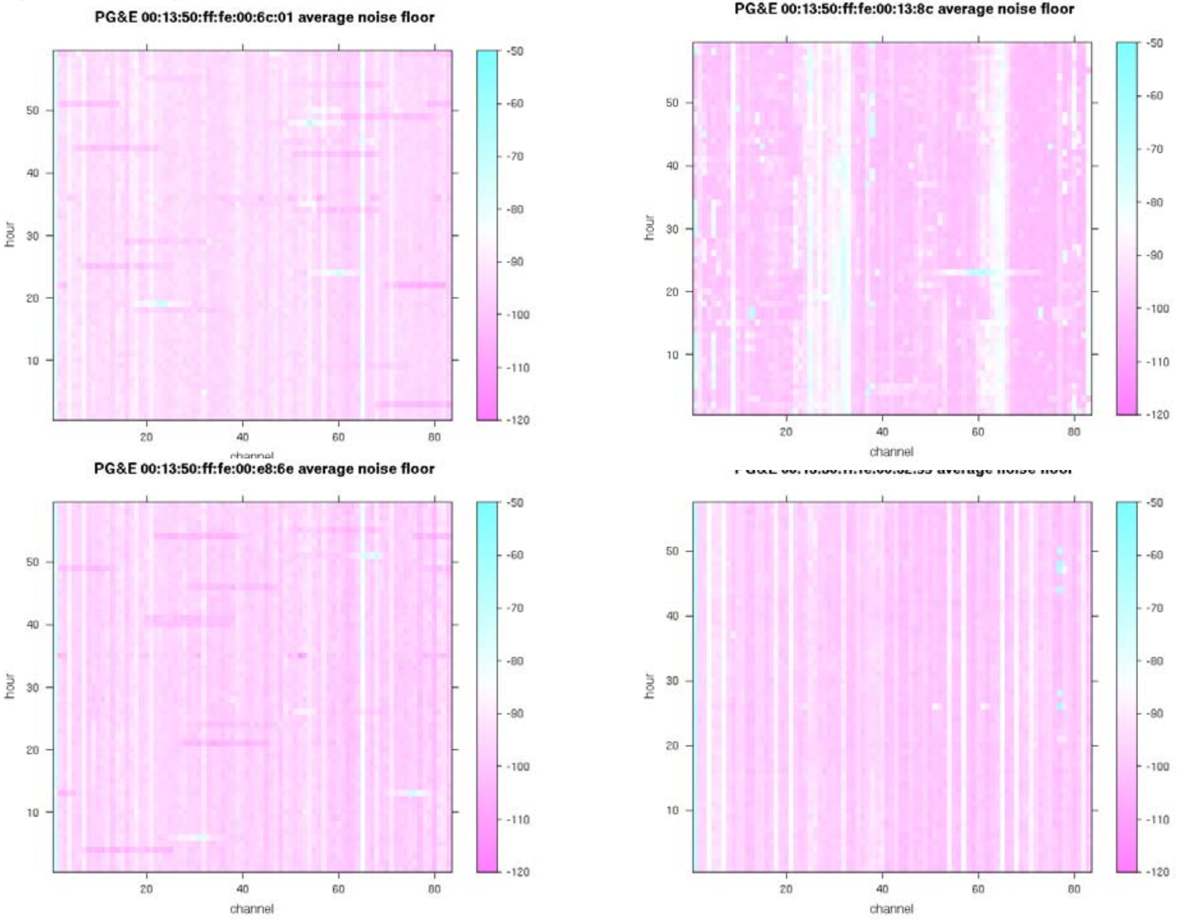
- 2.4 GHz ISM is not a viable option for reliable ULP communication
  - Too crowded
  - Wideband and high power transmitters (802.11)
    - Getting even worse with 11n
  - Others typically use gaps
    - But need high Tx power to go through
    - “Who shouts the loudest wins”
  - Outage of ULP transceivers could be very high

Frequency band (2)

- Overall, sub-GHz is a better choice
  - 900 MHz ISM band used to be crowded as well
  - But many high volume applications are moving to 2.4GHz or above
    - Example: cordless phones
  - High power users are typically narrow band
    - Leaves a lot of gaps
  - Better path loss, i.e. lower Tx power
  - Better behavior close to the body

Frequency band (3)

- Spectrum sharing rules established by the FCC in the early 1990’s still work well



  - Graphics show signal occupancy across 26MHz (902-928MHz).
  - Each sweep takes about 300ms and each channel gets 60 averaged ‘reads’.
  - These data were taken in a ‘small city’ environment – trolley cars, four lane streets, etc.
  - Occupied channels are blue. Empty channels are red/pink trending toward white
  - None of these plots show substantial traffic, interference, or noise.

Source:
15-09-0073-01-004g-tutorial-summary-jan-2009.ppt

Channel plan

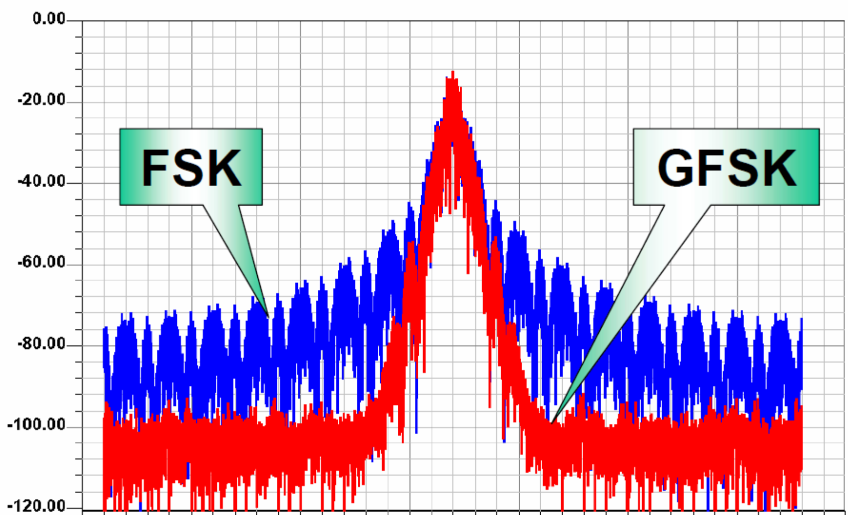
- Bands:

– US: ISM 902 – 928 MHz	No channelization
– EU: 868 MHz	Various: up to 600kHz
– Japan: 950 MHz	n x 200 kHz [1≤n ≤ 3]

- Default channel BW: 300 kHz
  - Over 80 channels in US
- Can be reduced to 200 kHz
  - To increase number of channels in EU and Japan
  - At cost of lower data rate
- Or increased to 500kHz for higher data rate
  - Only when needed
  - when conditions allow (available spectrum, link margin)

Modulation

- Gaussian Mean Shift Keying (GMSK)
- MSK is a special case of FSK
  - Modulation depth = 0.5
  - Constant envelope modulation
  - Better performance than FSK (similar to O-QPSK)
  - Simple differential demodulation (no Trellis-based detection required)
- Gaussian
  - Better spectrum utilization
  - Optimizes data rate in limited BW conditions
- Proven solution



Data Rate

- Data rate function of channel BW
- Default: 180 kbps

Ch BW (kHz)	Data rate (kbps)	Implementation
200	120	Mandatory
300	180	Mandatory
500	300	Optional

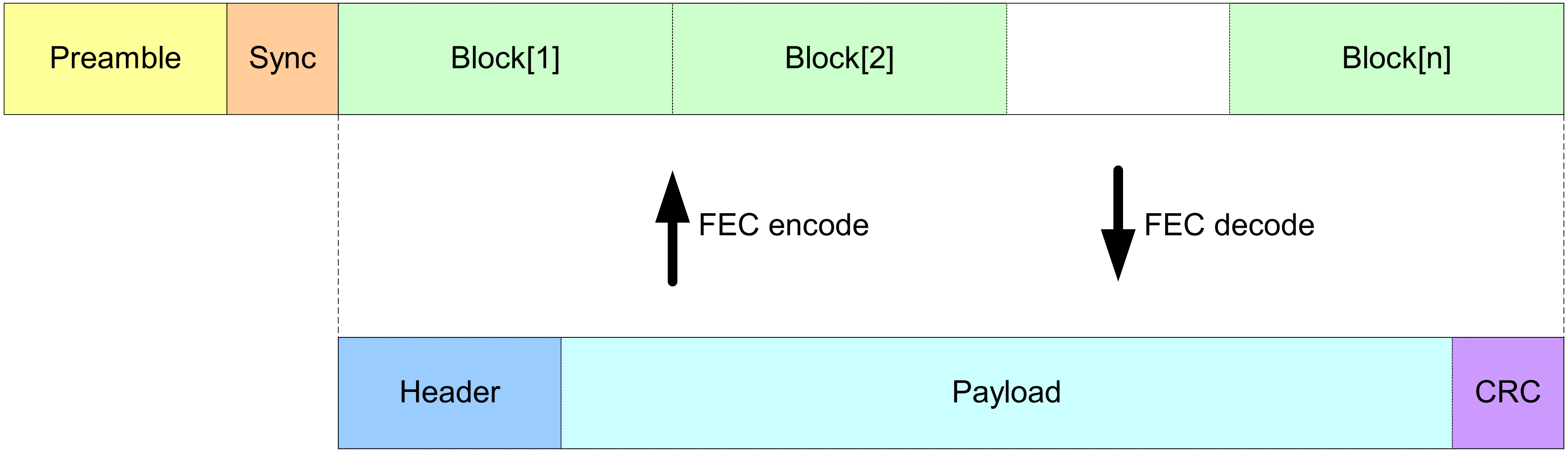
Tx power and sensitivity

- Tx power
  - Programmable between -30dBm and 0dBm
  - Default: -10dBm
  - Leverage sub-GHz advantage for low power
  - Meet SAR requirements
    - Most stringent is 1.6mW; Tx power < 1mW
- Sensitivity
  - Receiver alone: -96 dBm
  - FEC for 256 bytes packets adds ~2dB gain (at edge of sensitivity)
  - Overall: -98 dBm

FEC and CRC

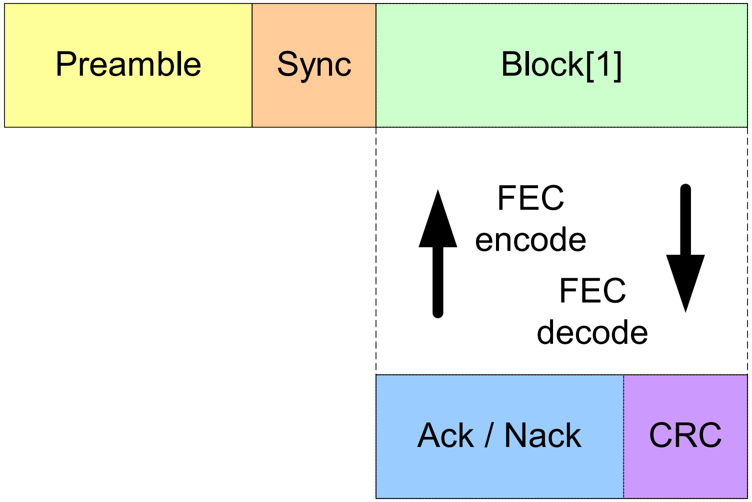
- FEC
  - RS[31;25] code
  - Blocks of 155 bits
  - 125 bits payload per block
  - Can detect up to 6 symbol errors
  - Can correct up to 3 symbol errors
- 16-bit CRC at packet level
- Power and size efficient

Data packet



- For payload of 256 bytes: 18 RS blocks

Ack/Nack packet



- Limited to 1 RS block to minimize air time

Simulation methodology

- CM3
  - Compared models A, B and C
  - Used model C because most pessimistic
- CM4
  - Used worst case, i.e. NLOS
- Used walking scenario: worst case fading
- Run model 1000 times and calculated path loss such that 95% of points are lower
  - Slightly pessimistic vs full receiver simulation
- Conservative approach overall

Simulation Results (1)

- CM3: on-body to on-body

Tx Power	-10 dBm	Assumes typ pwr; can be raised up to 0dBm
Tx Antenna Gain	-5 dBi	Electrically small loop
Radiated Power	-15 dBm	
PL	56 dB	Total PL+fading: 76 dB
Fading Margin	19.5 dB	
RX antenna Gain	-5 dBi	Electrically small loop
RX Power	-96 dBm	
RX Sensitivity	-98 dBm	
Margin	3 dB	

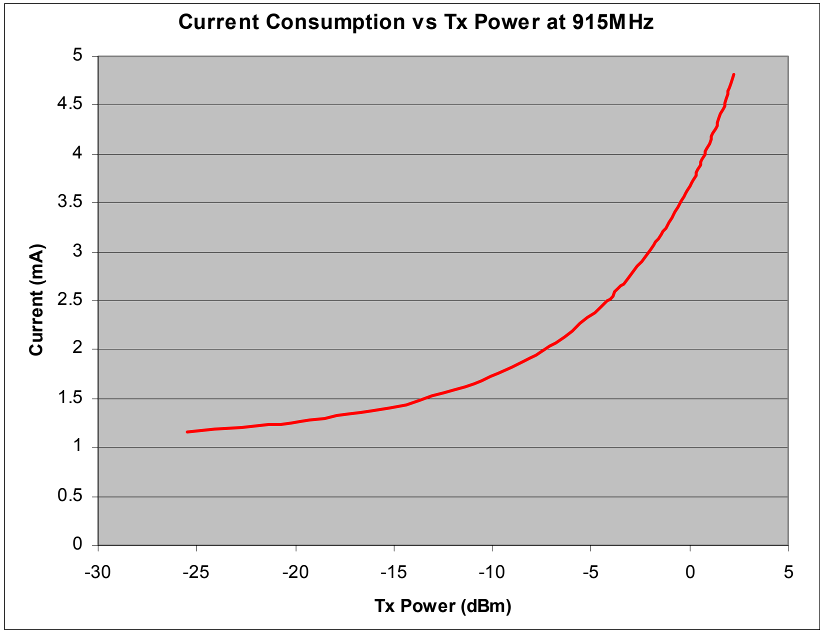
- With model A distance need >3m for 76dB PL
- With model B, PL saturates at 74dB (incl fading) for distance > 0.5m

Simulation Results (2)

- CM4: on-body to away-from-body

Tx Power	-10 dBm	
Tx Antenna Gain	-5 dBi	Electrically small loop (on-body side)
Radiated Power	-15 dBm	
Distance	3 m	
PL @ Distance	62 dB	
Fading Margin	6 dB	
RX antenna Gain	0 dBi	External side
RX Power	-83 dBm	
RX Sensitivity	-98 dBm	
Margin	15 dB	

Transmitter power consumption



- For 186 kbps, current silicon consumes
  - Less than 2mW for -10dBm
  - Less than 5mW for 0dBm
- Modifications required will only add < 500uW
- Link budget shows that -10dBm is sufficient in most cases
- BAN Tx peak power: 2.5mW
- Energy efficiency: 14nJ/bit

Receiver power consumption

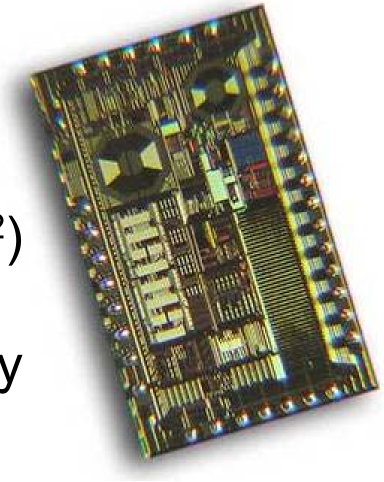
- Existing implementation consumes
  - Less than 2mW
  - For -94 dB sensitivity (w/o FEC) at 186 kbps
- Modifications required will only add between 0.5mW and 1mW
- BAN Rx peak power: 2.5 - 3 mW
- Energy efficiency: 14 - 17 nJ/bit

- *Enables small or longer lasting PNC or higher MAC performance (e.g. latency)*

Total power consumption

- The MAC for such an ULP radio
  - should not consume more than 1 mW
  - Most likely less than 0.5 mW
- The overall peak power should be
  - Less than 3 mW in Tx
  - Less than 3 - 3.5 mW in Rx
- Can easily be powered from the smallest batteries
  - E.g. CR1025, CR1216, zinc-air (HA), thin-film
  - Energy is in the order of 100 – 150 mWh
  - Would still be able to power an ECG for few days, 24h/day
- Enables very small size wireless sensors
  - Because battery is traditionally the main size constraint

Size considerations



- Transceiver IC
  - Current silicon is area is < 6 mm^2 (TxRx: 2.5 mm^2)
  - Modifications would add 10% - 20%
  - Could be smaller by going down process geometry
- Externals
  - Currently only crystal and 1 resistor
  - Matching network is additional but not necessary
  - No change
- Antenna
  - Small loop is the best choice for body proximity
    - Prototype: 25 x 10 mm, -5dBi, almost no detuning near body
  - External devices can have a more efficient antenna
- Battery
  - Smallest usable batteries are < 0.25 cm^3
  - About the same order of magnitude as other components

Proven solution

- Proposal based on a proven design
- That is now in full production
- Used essentially in medical applications

Conclusions

- Simple Ultra-Low Power radio
- Sub-GHz
  - Better choice for ULP medical BAN
- GMSK modulation
  - Proven, power and spectral efficient
- Allow sufficient data rate for medical applications
- Can still work under conservative CM3 and CM4 conditions
- While consuming less than 3mW peak
  - Proven by existing transceiver IC
- Enables very small wireless BAN sensors