**IEEE P802.15**

**Wireless Personal Area Networks**

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| Re: | [IEEE P802.15.4w Low Power Wide Area Call for Proposals, IEEE 802.15-18-0147-01-004w] |
| Abstract | [Proposal from Fraunhofer IIS for 802.15.4w.] |
| Purpose | [Proposed PHY layer extension for a more interference robust transmission based on the existing LECIM PHY.] |
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Fraunhofer IIS 802.15.4w proposal

# Changes to LECIM FSK PHY Section

All changes are in reference to the current 802.15.4-2015 document [1].

## 24.1 General

### Add

For fragmented transmission, the default length of the Preamble shall be 0.

## 24.2.1.1 Preamble field format

### Change

Adjust phyLecimFskPreambleLength in 11.3 to allow shorter preambles down to 0.

## 24.2.1.2 SFD field format

### Add

For fragmented transmission, the SFD shall be 4 bits of the end of a preamble octet, followed by 12 synchronization bits as shown in Figure 1:

|  |  |  |
| --- | --- | --- |
|  | preamble-tail | synchronization bits |
| Bit map | 0101  | 1011 1010 1010 |

Figure 1 SHR for fragmented transmission

## 24.3 Modulation and coding for LECIM FSK PHY

### Add

For fragmented transmission, the modulation index shall be 0.5 for all symbol rates. GFSK with a BT of 1.0 shall be used.

The symbol rate shall be a power-of-two multiple of 2380.37109375 symbols/s. The PIB attribute phyLecimFskFragmentedSymbolMultiple controls the power-of-two multiple.

For fragmented transmission the channel spacing shall be an integer multiple of the symbol rate. The minimal channel spacing may be chosen as permitted by local regulations.

## 24.3.1 Reference Modulator

### Merge



Figure 2 Reference modulator with new sub-packet fragmentation.

When sub-packet fragmentation is used, the fragmentation shall be done on the FEC code word. Data whitening, precoding and interleaving shall be used in conjunction with sub-packet fragmentation.

## 24.3.4 FEC

### Add

Add phyLecimFskFecMode in 11.3 to allow additional rate 1/3 convolutional code and LDPC code.

Create new subsections for every FEC code that can be used:

* 24.3.4.1 Rate 1/2 Convolutional Code
* 24.3.4.2 Rate 1/3 Convolutional Code
* 24.3.4.3 Rate 1/4 LDPC code

### Change

The use of FEC is controlled by the PIB attributes phyLecimFecEnabled and phyLecimFskFecMode as defined in 11.3.

## 24.3.4.1 Rate 1/2 Convolutional Code

### Add

Copy description of existing rate 1/2 convolutional code into this new subsection.

Note: Potentially change padding and termination or move to own subsection as termination of PHR introduces overhead especially for lower data rates.

## 24.3.4.2 Rate 1/3 Convolutional Code

### Add

When the corresponding mode is selected in phyLecimFskFecMode and phyLecimFecEnabled is TRUE, FEC shall employ rate 1/3 convolutional coding with constraint length K=7 using the following generator polynomials:

$$G\_{0}\left(x\right)=1+x^{2}+x^{3}+x^{5}+x^{6}$$

$$G\_{1}\left(x\right)=1+x+x^{2}+x^{4}+x^{6}$$

$$G\_{2}\left(x\right)=1+x+x^{2}+x^{3}+x^{4}+x^{6}$$

The encoder is shown in Figure 3, where ⊕ denotes modulo-2 addition.



Figure 3 Rate 1/3 convolutional encoder

The initial encoder state at k=0 shall be all 0.

The corresponding output sequence of code-bits, z, shall be generated as follows:

$z=\left\{…a\_{k}^{0}, a\_{k}^{1}, a\_{k}^{2},a\_{k+1}^{0},a\_{k+1}^{1}, a\_{k+1, }^{2} a\_{k+2}^{0},a\_{k+2}^{1},a\_{k+2}^{2}…\right\}=\{z\_{0},z\_{1},z\_{2},…,z\_{N\_{FEC}-1}\}$,

where $N\_{FEC}$ denotes the length of the bit sequence after the FEC encoding.

## 24.3.a Sub-packet fragmentation and interleaving

### Add

When the attribute phyLecimFskCodewordFragmentation is enabled, the interleaver and fragmentation change depending on the utilized FEC, configured by phyLecimFskFecMode. An overview of the number of sub-packets the encoded code word is fragmented into is given in Table 1.

Table 1 Number of sub-packets dependent on FEC mode

|  |  |
| --- | --- |
| phyLecimFskFecMode | Number of sub-packets $N\_{Sp}$ |
| 0 (1/2 Convolutional Code) | 12 |
| 1 (1/3 Convolutional Code) | 18 |
| 2 (1/4 LDPC) | 23 |

The FEC coded bits shall be interleaved over the available sub-packets as follows:

The sequence of FEC encoded bits

$$z=\{z\_{0},z\_{1},z\_{2},…,z\_{N\_{FEC}-1}\}$$

is mapped over the $N\_{SP}$ sub-packets by writing them linearly into the sub-packets.

For a symbol $z\_{n}$ the subpacket index $l$ and the position $i$ within the subpacket payload are given by:

$$l\left(z\_{n}\right)=n modulo N\_{SP} $$

$$i\left(z\_{n}\right)=\left⌊n/N\_{SP}\right⌋$$

where $i=0$ denotes the first bit after the SHR.

The payload of each sub-packet $s\_{l}$ with $l=0, 1, …, N\_{SP}-1$ is then individually muxed with the generated SHR as shown in Figure 4 to yield one sub-packet.

|  |  |
| --- | --- |
| SHR | Sub-packet payload $s\_{l}$ |

Figure 4 Sub-packet format

## 24.3.b Sub-packet transmit time and channel selection

Transmitter and receiver need to be aware of the exact channel and time a transmission takes place.

## 24.3.b.1 Uncoordinated ALOHA access

Time Frequency patterns for uncoordinated transmission depend on the number of sub-packets used for transmission. Time reference point is the transmission start of the SHR. The time interval between two sub-packet time references is given in Table 4 in symbol durations.

The respective channels are listed in Table 3, with the lowest defined channel as channel 0 and correspondingly higher channels with higher indices.

The pattern p shall be chosen based on the CRC32 calculated over the whole PHR+PSDU to generate a pseudo random number $R$ as shown in Figure 5.



Figure 5 Generation of pseudo random number R

$$p\left(R\right)=R modulo P$$

where $P$ represents the number of available patterns.

The listed patterns define time and channel for up to $L$ sub-packets. If less than L sub-packets are to be transmitted, a consecutive sub-set of the required number of sub-packets $L'$ shall be chosen. The index of the first sub-packet $l\_{0}$ of the sub-set is derived from $P$ by:

$$l\_{0}=R modulo (L-L^{'}+1)$$

Other time/frequency hopping schemes can be used based on implementation needs.

Table 3 Example of 8 channel patterns p for transmission of sub-packet $l$ on channel $C(l)$

|  |  |
| --- | --- |
| lp | $$C(l)$$ |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 1 | 5 | 21 | 13 | 6 | 22 | 14 | 1 | 17 | 9 | 0 | 16 | 8 |
| 2 | 4 | 20 | 12 | 1 | 17 | 9 | 0 | 16 | 8 | 6 | 22 | 14 |
| 3 | 4 | 20 | 12 | 3 | 19 | 11 | 6 | 22 | 14 | 7 | 23 | 15 |
| 4 | 6 | 22 | 14 | 2 | 18 | 10 | 7 | 23 | 15 | 0 | 16 | 8 |
| 5 | 7 | 23 | 15 | 4 | 20 | 12 | 3 | 19 | 11 | 2 | 18 | 10 |
| 6 | 3 | 19 | 11 | 6 | 22 | 14 | 2 | 18 | 10 | 0 | 16 | 8 |
| 7 | 3 | 19 | 11 | 1 | 17 | 9 | 5 | 21 | 13 | 7 | 23 | 15 |
| 8 | 0 | 16 | 8 | 6 | 22 | 14 | 3 | 19 | 11 | 2 | 18 | 10 |
| lp | $$C(l)$$ |
| 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| 1 | 7 | 23 | 15 | 4 | 20 | 12 | 3 | 19 | 11 | 2 | 18 | 10 |
| 2 | 7 | 23 | 15 | 2 | 18 | 10 | 5 | 21 | 13 | 3 | 19 | 11 |
| 3 | 0 | 16 | 8 | 5 | 21 | 13 | 2 | 18 | 10 | 1 | 17 | 9 |
| 4 | 1 | 17 | 9 | 4 | 20 | 12 | 5 | 21 | 13 | 3 | 19 | 11 |
| 5 | 6 | 22 | 14 | 0 | 16 | 8 | 1 | 17 | 9 | 5 | 21 | 13 |
| 6 | 7 | 23 | 15 | 1 | 17 | 9 | 4 | 20 | 12 | 5 | 21 | 13 |
| 7 | 0 | 16 | 8 | 2 | 18 | 10 | 6 | 22 | 14 | 4 | 20 | 12 |
| 8 | 4 | 20 | 12 | 7 | 23 | 15 | 5 | 21 | 13 | 1 | 17 | 9 |

Table 4 Example of 8 time gap patterns between $(l-1)$-th and $l$-th sub-packet in symbols

|  |  |
| --- | --- |
| lp | $$T(l)$$ |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 330 | 387 | 388 | 330 | 387 | 354 | 330 | 387 | 356 | 330 | 387 | 432 |
| 2 | 330 | 387 | 435 | 330 | 387 | 409 | 330 | 387 | 398 | 330 | 387 | 370 |
| 3 | 330 | 387 | 356 | 330 | 387 | 439 | 330 | 387 | 413 | 330 | 387 | 352 |
| 4 | 330 | 387 | 352 | 330 | 387 | 382 | 330 | 387 | 381 | 330 | 387 | 365 |
| 5 | 330 | 387 | 380 | 330 | 387 | 634 | 330 | 387 | 360 | 330 | 387 | 393 |
| 6 | 330 | 387 | 364 | 330 | 387 | 375 | 330 | 387 | 474 | 330 | 387 | 355 |
| 7 | 330 | 387 | 472 | 330 | 387 | 546 | 330 | 387 | 501 | 330 | 387 | 356 |
| 8 | 330 | 387 | 391 | 330 | 387 | 468 | 330 | 387 | 512 | 330 | 387 | 543 |
| lp | $$T(l)$$ |
| 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |  |
| 1 | 330 | 387 | 352 | 330 | 387 | 467 | 330 | 387 | 620 | 330 | 387 |  |
| 2 | 330 | 387 | 361 | 330 | 387 | 472 | 330 | 387 | 522 | 330 | 387 |  |
| 3 | 330 | 387 | 485 | 330 | 387 | 397 | 330 | 387 | 444 | 330 | 387 |  |
| 4 | 330 | 387 | 595 | 330 | 387 | 604 | 330 | 387 | 352 | 330 | 387 |  |
| 5 | 330 | 387 | 352 | 330 | 387 | 373 | 330 | 387 | 490 | 330 | 387 |  |
| 6 | 330 | 387 | 478 | 330 | 387 | 464 | 330 | 387 | 513 | 330 | 387 |  |
| 7 | 330 | 387 | 359 | 330 | 387 | 359 | 330 | 387 | 364 | 330 | 387 |  |
| 8 | 330 | 387 | 354 | 330 | 387 | 391 | 330 | 387 | 368 | 330 | 387 |  |

## 24.3.b.2 PAN Coordinator controlled access with time slotting

In a PAN network with PAN coordinator, the PAN coordinator opens its active listening slots at given time slots after the beacon on different frequencies as shown in Figure 5.



Figure 6 PAN specific hopping pattern example with activity rate of 1/3 (A=3)

The transmission is split into a total of $C$ channels, set in phyLecimFskFragmentPshpChannels. The radio burst itself can have a bandwidth narrower than the channel bandwidth due to regulatory restrictions. To make best use of the frequency range a channel is therefore sub-divided into $W$ sub-channels as shown in Figure 7. The number can be set via phyLecimFskFragmentPshpSubChannels.

Each sub-channel can be as wide as the spectral envelope of the transmission. (With GFSK this is typically the symbol rate in Hz). For high performance SDR receivers it is possible to receive multiple sub-channels simultaneously. The number of stacked sub-channels $N$ is set in phyLecimFskFragmentPshpStackedSubChannels



Figure 7 Sub-channelization within a channel

To achieve a decoupling of different PANs, each listening hopping sequence of the PAN coordinator, the PAN specific hopping pattern (PSHP) is derived from the PAN ID and a counter as shown in Figure 7. The counter shall be increased by one every time a beacon is transmitted.



Figure 8 Derivation of PAN Specific Hopping Pattern parameters from PAN-ID and counter

The PAN-ID and the counter are combined to form a 32bit number: the two MSB are given by the PAN-ID and the two LSB by the counter. On this number then a 32bit CRC is performed to derive a pseudo random number $r$. From this number three variables are then derived, with the most significant bit represented by bit index 31 and the least significant bit given by index 0:

* timeslot activation $t$, given by is the most significant bit of $r$ hence $r[31]$
* sub-channel mapping $v$, given by bits 29 to 15, hence $r[29:15]$
* channel mapping $m$, given by bits 14 to 0, hence$ \left[14:0\right]$

These variables are then used to calculate the actual channel index $c(n)$, the subchannel offset $w(n)$ as well as the PAN slot activation $a(n)$.

As not every slot will be used in the transmission, the PAN slot activation determines if a slot can actually be used for transmission or not ($a=1\rightarrow $ slot is active and can be used, $a=0\rightarrow $ 0 slot is inactive and no transmission may take place in this slot). The activation parameter $A$ can be set by phyLecimFskPanActivation as given in Table 5.

Table 5 phyLecimFskPanActivation options

|  |  |  |  |
| --- | --- | --- | --- |
| A | Activity Ratio | Initial $a\left(n\right)=0 ∀ n$ | Interpretation |
|  | 1.0 | $$a\left(n\right)=1 ∀ n$$ | Every timeslot is used, no gap between active time slots |
| 1 | 1/2 | $$a\left(n\right)=1 ∀ n\in \{0,2,4,6…\}$$ | Time slots with even indices are used for transmission, leaving a gap of 1 slot between active slots |
| 2 | 1/2 | $$a\left(n\right)=1 ∀ n\in \{1,3,5,7…\}$$ | Time slots with odd indices are used for transmission, leaving a gap of 1 slot between active slots |
| 3 | 1/3 | $$a\left(n\right)=1 ∀ n\in \{0,3,6,9…\}$$ | Every third time slot is used in a periodic manner, starting with slot 0, leaving a gap of 2 inactive slots between active slots |
| 4 | 1/3 | $$a\left(3k+t\* \left(3k\right)\right)=1$$$$k=\left⌊n/3\right⌋$$ | Chooses active slots randomly based on $t$ while maintaining a minimal gap of 1 inactive slot between two active ones |

For each timeslot $n$ the lowest potential active sub-channel stack $s(n)$ is given by:

$$s\left(n\right)=W\*c\left(n\right)+w\left(n\right)+d\left(n\right), s\in \{0,1…\left(C\*W-1\right)\}$$

## 24.3.c Precoding

For each input bit $i[k]$ the output bit $o[k]$ is given by $o\left[k\right]=i\left[k-1\right] XOR i[k]$, with the initial state $i\left[-1\right]=0$.

## 24.3.d Initial Synchronization

### Asynchronous registration

In systems with a powerful base station, which allows continuous detection in the complete band, a connection request can be sent by the node to join the network and the appropriate answer with the necessary synchronization information to join the network is transmitted to the node in a predefined time after the uplink. The time between uplink and downlink is chosen based on the system requirements.

### Beacon detection

To allow easy synchronization of nodes with a beacon based system as described in 24.3.b a cluster of additional synchronization sub-packets shall be transmitted a predefined time before each beacon.

The payload of the cluster is the FEC encoded and interleaved PAN-ID combined with the counter as shown in Figure 9.

|  |  |
| --- | --- |
| PAN-ID | counter |

Figure 9 Payload of synchronization cluster

The time frequency pattern of the cluster as well as the time to the actual beacon shall be chosen according to implementation and regulatory requirements. The minimal cluster size shall be three.

The cluster transmission shall start with an offset of 0 on the lowest channel and the offset shall be increased by the cluster size after every beacon. Once the highest channel has been used, the offset shall be reset to 0.

# References

|  |  |
| --- | --- |
| [1]  | LAN/MAN Standards Committee, *IEEE Standard for Low-Rate,* IEEE Std 802.15.4-2015, 2015.  |
| [2]  | R. Heile, *P802.15.4w PAR,* IEEE P802.15-18-0050-03-0000.  |
| [3]  | J. Robert, *TG 802.15.4w LPWA Agenda July 2018 Plenary,* IEEE P802. 15-18-0319-04-004w.  |
| [4]  | J. Robert, *802.15.4w Technical Guidance Document,* IEEE P802.15-18-0161-00-004w.  |
| [5]  | J. Robert, *Draft IG LPWA Report,* IEEE P802.15-17-0528-01-lpwa.  |
| [6]  | J. Robert, *IEEE P802.15.4w Low Power Wide Area Call for Proposals,* IEEE P802-15-18-0147-01-004w.  |