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

**Submission Title:** Thoughts on a 2Mbps PHY for 802.15.4

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**Abstract:** Some PHY design considerations are presented.

**Purpose:** Creation of a 2Mb/s PHY

# Outline:

- Scope
- PHY design considerations
- Device Types and recommended PHY capabilities
- Two directions
- Abbreviations

# Scope:

From the TG4t PAR, the scope of the project is as follows:

*This amendment defines a physical layer for IEEE Std. 802.15.4 current revision, capable of supporting 2 Mb/s data rates, utilizing the 2400 - 2483.5 MHz band, having backwards-compatibility to, and the same occupied bandwidth as, the present 2450 MHz O-QPSK physical layer, and capable of simple implementation. Target range should be at least 10 meters. This amendment defines modifications to the Medium Access Control (MAC) layer needed to support this new physical layer.*

# PHY design considerations:

- Modulation bandwidth.
- Overhead of Synchronization Header and PHY header.
- PHY agnostic receiver vs PHY switching protocol.
- Industry adoption

# Modulation bandwidth:

- **TG4t PAR states:**

*"…. capable of supporting 2 Mb/s data rates, utilizing the 2400 - 2483.5 MHz band, having backwards-compatibility to, and the same occupied bandwidth as, the present 2450 MHz O-QPSK physical layer…"*

- Easy to obtain by removing spreading
- Chip rate of O-QPSK PHY is 2 Mc/s
- After removing spreading, every chip becomes a data bit
- Modulation options (with constant envelop):
  - O-QPSK half sine shaped
  - MSK
  - GMSK

# Overhead of Synchronization Header and PHY header:

- Payload efficiency

$$\eta_{PSDU} = \frac{T_{payload}}{T_{total}}$$

- $T_{total}$ = total transmit on time
- $T_{payload}$ = time of payload transmission

# PHY agnostic receiver vs PHY switching protocol:

- PHY switching protocol requires energy → adds to overhead
- A PHY agnostic receiver adapts its receiver to either the legacy PHY or the new 2Mb/s PHY
  - No need to negotiate the PHY.
  - Receiver is capable of receiving both PHY’s without prior knowledge on which PHY is being transmitted.

# Industry adoption:

- Strive for compatibility with existing SoC's
  - Minimum modification effort
  - Short design cycle
- Ultra low BOM for end node devices (RFDs)
  - Low cost sensor nodes
  - Integration into smart phones

# Device Types and recommended PHY capabilities:

- FFD (e.g. a coordinator) → capable of both O-QPSK PHY and 2Mb/s PHY
- FFD receiver should be PHY agnostic, meaning the FFD receiver is capable of receiving both PHY's without prior knowledge on which PHY is being transmitted.
  - May be supported by a Link Margin IE similar to the RS-GFSK PHY
- RFD (e.g. a sensor node)→ may support O-QPSK PHY or 2Mb/s PHY or both
  - Single PHY RFD helps to keep the cost down
  - When both PHY are implemented the RFD receiver should be PHY agnostic

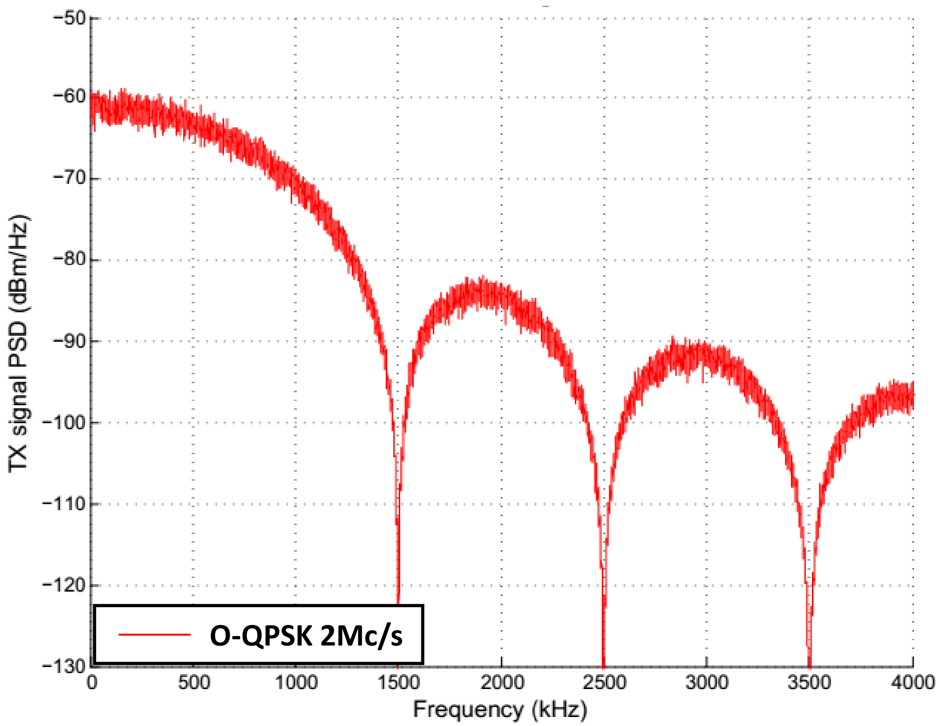
# Direction-1 → GMSK based PHY:

- 2Mb/s PHY is using GMSK modulation with BT = 0.5
- Preamble = 16 ~ 64 bit (e.g. 4x “01010101)
- SFD = 16 ~ 32 bit
- PHR = 8 bits, same as O-QPSK PHY

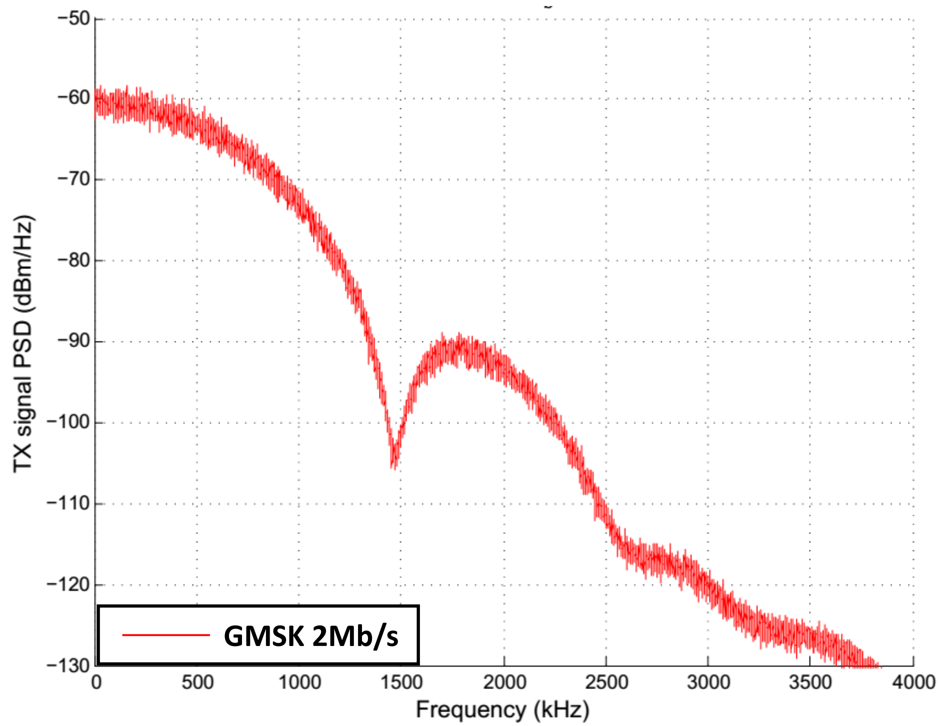
- GMSK suitable for low cost and power efficient implementation.
- RFD may be implemented on Bluetooth 5.0 SoCs.
  - Provide a path to roll 15.4 into smart phones and wearables
  - Accelerates adoption by the momentum in BLE SoC development

# PSD of proposed GMSK PHY compared with O-QPSK PHY:

## Q-QPSK half-sine shaped




## GMSK with BT = 0.5



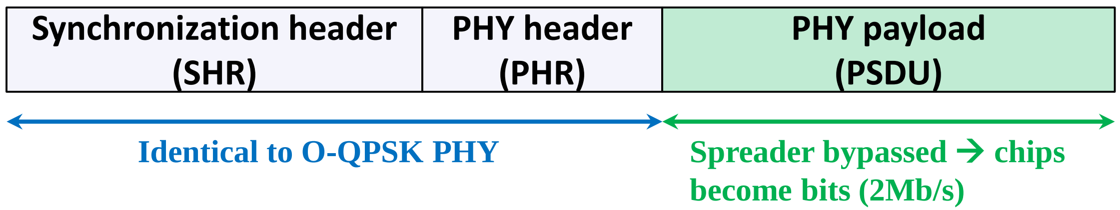

Reduced out of band emission

# Direction-2 → O-QPSK based:

- Modulation: O-QPSK
- SHR identical to existing O-QPSK PHY
- PHR = same as O-QPSK PHY → use reserved bit to signal:
  - Bit 7 = 0 → PHY payload transmitted with spreading according to O-QPSK PHY
  - Bit 7 = 1 → PHY payload transmitted with spreading is bypassed

# Direction-2 (continued):

## Example:




## PROs:

- O-PSK receiver HW can be used to synchronize the receiver on a 2Mb/s frame

## CONs:

- Duration of SHR is long → Poor PHY payload efficiency.
  - SHR duration is 10 x 32 x 0.5us = **160 us**
  - PHR + PSDU duration with maximum frame length is 128 x 8 x 0.5us = 512 us
  - PHR + PSDU duration of acknowledgement frame is 24 us
- Not energy efficient when short PHY payloads are transmitted.
- Not compatible with BLE SoCs

# Comparison:

| | GMSK based (direction-1) | O-QPSK based (direction-2) |
|---|---|---|
| Modulation bandwidth | +++ | ++ |
| Payload efficiency | ++ | - |
| Industry adoption | +++ | + |

# Summary:

- PHY agnostic receiver is recommended
- Link Margin IE to support PHY selection
- Two PHY are proposed:
  - GMSK based
    - Provides a path to roll 15.4 into smart phones and wearables
    - Accelerates adoption by the momentum in BLE SoC development
    - High payload efficiency
    - Supports low energy and cost effective single mode end devices
  - O-QPSK based
    - Reuse of SHR
    - Low payload efficiency
    - Not compatible with BLE SoCs

# Abbreviations:

| | |
|---|---|
| BLE | Bluetooth Low Energy |
| BOM | Bill of Materials |
| FCS | Frame Check Sequence |
| FFD | Full Functional Device |
| GMSK | Gaussian Minimum Shift Keying |
| O-QPSK | Offset Quadrature Phase Shift Keying |
| PHR | PHY header |
| PPDU | PHY Protocol Data Unit |
| PSD | Power Spectral Density |
| PSDU | PHY Service Data Unit |
| RDF | Reduced Functional Device |
| SFD | Synchronization Frame Delimiter |
| SHR | Synchronization header |