

IEEE P802.15**Wireless Personal Area Networks**

Project	IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs)	
Title	Merits of the ULP-GFSK PHY	
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Re:	Merits of ULP-GFSK	
Abstract	This document describes the merits of the ULP-GFSK PHY as specified in 802.15.4q.	
Purpose	To provide direction towards a low power PHY specification for the IEEE802.15.4 standard	
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Merits of the ULP-GFSK PHY as specified in 802.15.4q

The ULP-GFSK PHY was designed with energy efficiency as priority. There are several essentials specified by the ULP-GFSK PHY that may significantly prolong the battery life time:

- **Options for higher data rate**
- **Rate Switch**
- **Overhead Reduction**
- **Asymmetric Link Networks**
- **Transmit Power Control**
- **Wideband Digital Modulation**

This document clarifies these essentials in terms of their use and potential energy savings.

Options for higher data rate

Higher data rate capabilities in IEEE 802.15.4q reduces the active time in both transmit and receive which saves energy. The highest rate specified in the 4q draft is 1 Mbps which is 2.5 times higher than available in the SUN-FSK PHY. The added advantage is a lower interference footprint resulting in fewer collisions and retransmissions.

Rate Switch

The Rate Switch is signaled in the PHR by the Rate Switch bit. When enabled the Rate Switch is seamless between PHR in 2GFSK and PSDU in 4GFSK. The modulation indices of the 2GFSK and 4GFSK modulation types are specified such that the outer deviation is identical and hence the modulation bandwidth is close to identical. The seamlessness, simplicity and ease of implementation makes the Rate Switch feature unique. Nodes communicating with sufficient link budget can use the Rate Switch to reduce the active time in both transmitting node as well as the receiving node and save energy on both sides of the link.

Overhead Reduction

IEEE 802.15.4q is energy efficient as it utilizes shorter preambles and PHY header. Consequently, 15.4q is more energy efficient than PHY 802.15.4f, 802.15.4g and 802.15.4k. As an example: transmission of 4 data Bytes, followed by a short ack. In MR-FSK this will take 23 Bytes (PANID and short addresses) for the data transfer and 13 Bytes for the short ack. Using the ULP-GFSK PHY both data transfer and short ACK are reduced by 3 Bytes = 20% saving.

Asymmetric Link Networks

The ULP-GFSK PHY introduces the Asymmetric Link Networks (ALN) which has great potential to save energy in all end nodes of a star network by alleviating their transmit and receive requirements.

An Asymmetric Link Network (ALN) may be formed in a star network. A device being part of an ALN will have a different MCS for transmit compared to its receive MCS. The formation of an ALN may be particularly useful when the central coordinator device employs a higher receive sensitive and transmit power compared to the end node devices in the network. In an ALN the coordinator is preferably a high performance mains powered device which may leverage its excess in sensitivity and transmit power to alleviate these requirements in the end node devices. Lowering the end node requirements for transmit power and receive sensitivity helps to prolong their battery life. In addition, the slightly higher cost of the coordinator allows all the end node devices to be low cost which helps to reduce the overall cost of the network.

As an example the coordinator device may use a coherent receiver optimized for MCS-6 (500 kbps at modulation index 0.5) with FEC capability. Given a proper receiver design and using FEC combined with differential pre-coding and GMSK may improve the receive sensitivity by up to 8 dB (see document 15-14-0072-00-004q-Joint ULP-GFSK PHY layer proposal). The improved sensitivity in the coordinator allows the end nodes to operate with a lower transmit power.

To continue the example, the end node devices may be equipped with a non-coherent FSK receiver optimized for MCS-4 (500 kbps at modulation index 0.72) without FEC decoding capability but with FEC encoding capability. The higher transmit power of the coordinator permits the end devices to operate with less sensitivity which allows for a current reduction in their receiver components such as LNA and demodulator and absence of FEC decoding. The FEC encoding involves low complexity and its power consumption is insignificant. Notice in link budget calculation below how the noise figure and transmit power are relaxed in the end nodes while maintaining a balanced link budget.

Link budget example of Asymmetric Link Network			
		uplink	downlink
TX	Over-the-air data rate [kSymbols/s]	1000	500
	Distance [m]	30	30
	TX antenna gain [dBi]	-5	0
	Center frequency [MHz]	868	868
	Transmit power [dBm]	-5	+5
Channel	Path loss [dB] (PL exponent 2.7)	71	71
RX	RX antenna gain [dBi]	0	-5
	Received signal strength [dBm]	-86	-71
	Receiver noise figure [dB]	5	10
	Min. Eb/NO @1% PER [dB]	3.2	12.1
	Implementation loss [dB]	2	2
	RX sensitivity [dBm]	-103.8	-92.9
Link margin [dB]		22.8	21.9

The transmit power in uplink direction can be reduced, as differential encoding and FEC reduce the signal energy necessary for successful decoding. In downlink direction the concentrator device makes up for the missing differential encoding and FEC in the end node by an increased transmit power.

In an ALN the link budget in the uplink direction is characterized by a relatively low transmit power and high receive sensitivity while in downlink direction that is reversed so that the link budget in both directions is balanced.

Transmit Power Control

The ULP-GFSK PHY introduces Transmit Power Control (TPC). For example, when device-A receives a first data frame from device-B it may inform device-B to adjust its transmit power by including a ULP-GFSK TPC IE in its enhanced acknowledgement. When device-B receives the ULP-GFSK TPC IE it may reduce its transmit power during transmission of a second data frame to device-A. This will reduce the transmit power consumption in device-B.

To avoid lock-up the transmit power may be increased in cases where the acknowledgement is not received.

TPC is an optional feature in the ULP-GFSK PHY. The power control algorithm is not part of the ULP-GFSK PHY.

TPC will not break CSMA/CA as long as the power control is reduced as appropriate. E.g. a close-by device may blast the receiver with -40dBm. With TPC that may be reduced to -43dBm which will not break CSMA/CA but it may save energy. As an example: ~4mW power reduction would be obtained when the RF power is reduced from +5dBm to +2dBm assuming a PA efficiency of 40%. On the 15mW budget as mentioned in the PAR this is a significant saving.

Additional advantage of TPC: Nodes that are able to reduce their output power will also reduce the probability of destructive interference resulting in fewer collisions and retransmissions.

Wideband Digital Modulation

MCS-4 may be used for wideband digital modulation according to FCC part 15.247 which allows for transmit power in excess of -1.23 dBm without requiring frequency hopping. The elimination of the overhead related to frequency hopping saves energy. In addition the data rate of MCS-4 is relatively high which allows for short on-air times which saves energy as well.