IEEE P802.15

Wireless Personal Area Networks

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Source	Henk de Ruijter Voice: +14087021235 E-mail: hendricus.deruijter@silabs.com
Re:	RS-GFSK PHY Informative Annex
Abstract	This document describes the use and benefits of the RS-GFSK PHY as specified by TG 802.15.4q.
Purpose	To provide information on the use and benefits of the RS-GFSK PHY
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RS-GFSK PHY Informative Annex

Introduction

The RS-GFSK PHY (RS stands for Rate Switch) was designed with energy efficiency as priority. There are several essentials specified by the RS-GFSK PHY that may significantly prolong the battery life time:

- **Rate Switch**
- **Options for higher data rate**
- **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.

1. 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.

A Link Margin Information Element is specified that provides feedback on the available Link Margin at the receiver side. This Link Margin Information Element may be transmitted as part of an Enhanced Acknowledgement. Nodes communicating with sufficient link budget may enable 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.

2. 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.

3. Overhead Reduction

The RS-GFSK PHY is energy efficient as it allows for shorter preambles and PHY header resulting in a higher energy efficiency compared to MSK, SUN FSK and LECIM FSK PHYs. As an example, consider transmission of 4 data Bytes, followed by a short ack. In SUN FSK this will take 23 Bytes (PANID and short addresses) for the data transfer and 13 Bytes for the short ack. Using the RS-GFSK PHY both data transfer and short ACK are reduced by 3 Bytes = 20% saving.

4. Asymmetric Link Networks

The RS-GFSK PHY supports the formation of Asymmetric Link Networks (ALN) which has great benefits in terms of energy savings in all end nodes of a star network by alleviating their transmit and receive requirements.

An ALN can be formed in a star network topology. In an ALN the central coordinator device employs a higher receive sensitive and transmit power compared to the other devices in the network. A coordinator, usually a mains powered device, may leverage its excess in sensitivity and transmit power to alleviate these requirements in the other devices of the network. Lowering the requirements for transmit power and receive sensitivity help to prolong battery life. 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.

The Modulation and Coding Schemes as made available by the RS-GFSK PHY are designed to leverage the concept of ALN. E.g the GMSK modulation in combination with FEC allows for high receive sensitivity whereas the GFSK modulation allows for low power and low cost implementations with moderate receive sensitivity.

As an example the coordinator device may use a coherent receiver optimized for MCS-6 (500 kbps at modulation index 0.5) with FEC decoding capability to boost its receive sensitivity by up to 8 dB (see document 15-14-0072-00-004q-Joint RS-GFSK PHY layer proposal). To reduce energy consumption, the other devices may be equipped with a non-coherent FSK receiver optimized for MCS-4 (500 kbps at modulation index 0.76) without FEC decoding capability but with FEC encoding capability. 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. This helps to balance the link budget between uplink and downlink.

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 the 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/N0 @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 absence of FEC by an increased transmit power.

5. Transmit Power Control

The RS-GFSK PHY facilitates transmit power control by introducing the RS-GFSK Link Margin Information Element. This Information Element provides feedback on the available Link Margin at the receiver side. This Link Margin Information Element may be transmitted as part of an Enhanced Acknowledgement.

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 RS-GFSK Link Margin Information Element in its enhanced acknowledgement. When device-B receives the RS-GFSK Link Margin Information Element 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.

An additional advantage of transmit power control is that a reduction in transmit output power will reduce the probability of destructive interference resulting in fewer collisions and retransmissions.

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

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

6. 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.