FORWARD ERROR CORRECTION IN IEEE 802.15.4a STANDARD

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Abstract: This proposed paper is a preliminary study which deals with forward error correction issue in the IEEE 802.15.4a standard. Nowadays, this standard is at the beginning of deployment and it can be considered as technology that represents the next evolution of wireless personal area networks. Even it was officially standardized in 2007, there is deployment of such compliant devices only at the prototype level. Opportunities arising by these facts influence the researchers to face new challenges about evaluation of its parameters in details and finding the optimal approaches or features, which can be used in sophisticated way of using such technology. This work deals with forward error correction features included in standard and estimates the influence of standardized parameters. It discusses the whole FEC process in a detailed way.

Keywords: IEEE 802.15.4a, FEC, Convolution code, Reed-Solomon code

1 INTRODUCTION

Wireless sensor networks (WSNs) based on the IEEE 802.15.4 standard are still modern topic, every time finding a new area of utilization. In global meaning, they are networks of specific character and usability. WSNs take important place at information systems, because they directly enhance establishment and the opportunities provided by the internet of things, which are basically small devices like sensors and actuators. Most networks based on the 802.15.4 standard have restrictive power consumption requirements. Because of this requirement, the hardware implements microprocessors with low computational power. As low price as possible is another important property of such networks, respectively devices. This standard defines the PHY (PHYsical layer) and MAC (Medium Access Control) layer, but it does not define any specifications for upper layers, which depends on the used application. On the other hand, the standard IEEE 802.15.4a is amendment to the original 802.15.4 standard. It enhances the wireless communication medium to the UWB (Ultra Wide Band) frequencies, another modulation methods and techniques for accessing the wireless medium.

The data reliability in automation systems requires high efficient approach with respect to the throughput and needed wireless medium resources. FEC (Forward Error Correction) features in WSN are restricted by the resources of the low computational performance devices. Because of that, there is an effort for estimation of the characteristic of mentioned FEC. Globally, the FEC decoding at transmitter and correction of the errors is much more computational power consuming than the whole encoding process.

2 IEEE 802.15.4a

The IEEE 802.15.4*a* (IEEE Std 802.15.4*a* – 2007) developed by the IEEE 802.15 Low Rate Alternative PHY Task Group (TG4a working group) whose details can be found in [3] is an amendment to the original IEEE 802.15.4 (IEEE Std 802.15.4 – 2006) standard. The main interest of this Low-rate WPAN standard is to provide ranging capability and communication with high aggregate throughput, ultra low power consumption, scalability to data rates with robust performance and longer ranges than existing 802.15.4. The following Figure 1 represents the development kit implementing the 802.15.4*a* compliant prototype radio chip from DecaWave Company [2].

Figure 1: DecaWave ScenSor DW1000 development board

2.1 PHYSICAL AND DATA LINK LAYER OVERVIEW

The IEEE 802.15.4*a* specifies alternate physical layers (PHYs) which are UWB-PHY (Ultra-Wide Band) using DSSS (Direct-Sequence Spread Spectrum) at frequencies in low band $3.1-5$ GHz, high band $6-10.6$ GHz, sub-gigahertz $250-750$ MHz and using the CSS (Chirp Spread Spectrum) in 2.4 GHz frequency band. DSSS is spectral efficient, supports precision ranging and is robust at low transmit powers. Three different UWB bands provide ability to operate in different regions of the world. On the other hand, the CSS supports communication to devices moving with high speed and at longer ranges. The channel plan for the CSS frequency band is identical to the 802.11 with non-overlapping and partially overlapping channels to enhance the coexistence between wireless systems.

The IEEE 802.15.4*a* adopts the new approach to the MAC (Medium Access Control) strategy with ALOHA random access. Thanks to the multi-interference robustness of the UWB, the ALOHA provide access for light and medium traffic loads without delay made by collision avoidance technique. Pure ALOHA is simple medium access control protocol, which implements idea of transmitting without sensing the medium or waiting for a specific time slot. The CSMA/CA is kept in standard due to the situations with high traffic loads and due to the chirp physical layer. CSMA/CA is technology for avoiding the collision on the shared medium that implements medium sensing and back-off timers.

3 FORWARD ERROR CORRECTION

FEC techniques are mainly used at receivers for data error correction caused by disturbances and interferences occurred on the communication medium. Data are encoded before modulation by adding the redundancy to the information. The receiver after demodulation decodes the information and by using the error correction technique it retrieves the original data. FEC techniques can be implemented as linear block codes and convolution codes. The purpose of FEC codes is to provide the flexible and robust performance under the multi-path and interference conditions. The 802.15.4*a* compliant devices need support for FEC only when transmitting frames. Decoding the data is not included in IEEE 802.15.4*a* standard. It is recommended to decode the convolution code with Viterbi decoder.

The PPDU encoding process (Physical Protocol Data Unit) defined by the IEEE 802.15.4*a*-std shown in Figure 2 is composed of steps that adds redundancy to the original data at transceiver. For the first, the original PSDU (Physical layer Service Data Unit) data with maximal length of 1016 bits (127 octets) are encoded by the Reed-Solomon code with final length of maximum 1208 bits. Then the PHR (Physical Layer Header) header is attached to the frame right after the SHR (Synchronization Header) preamble. It consists of 19 bits and contains information such as data rate, frame length, ranging extension, the header extension for future purposes, preamble duration and SECDED (Single

Error Correct, Double Error Detect) check bits. These data are necessary for decoding the PSDU part of frame at receiver.

The SECDED consists of 6 parity check bits. The purpose of these bits is to protect the PHR part of frame from errors caused by interferences, multi-path conditions and noise in channel. The SECDED bits are produced by simple Hamming block code, which can correct error in a single bit and detect two bit errors. The details on computation of SECDED bits are covered in [1]. The final step of encoding data is performing the convolution code against the PHR and PSDU part of frame.

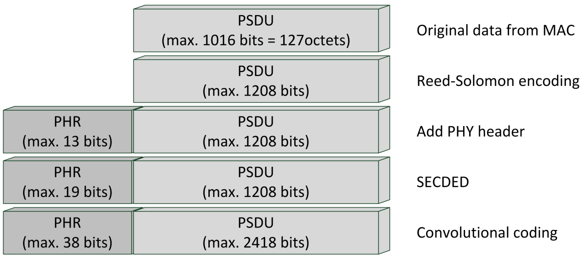

Figure 2: Encoding process of the PPDU [1]

Standard defines two available modes for forward error correction of transmitted data, options with RS (Reed-Solomon) only and combination of RS with convolution coding. FEC coder shown in Figure 3 consists of outer Reed-Solomon systematic block code and inner half-rate systematic convolution code. Inner convolution code is not enabled for all data rates.

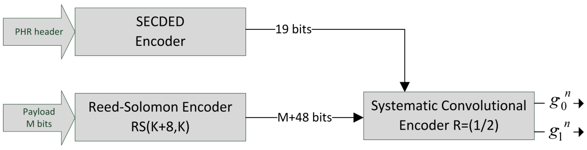

Figure 3: Block scheme of FEC encoding process [1]

There is defined "Viterbi rate" parameter that determines the rate of the convolution code applied to data bits. Value of 1 indicates no convolution coding, while value of 0.5 indicates that a rate of 1/2 is applied. Similarly the "RS rate" parameter defines code rate which is approximately 0.87 for (63, 55) RS code rate. RS coding is applied to all data bits that are transmitted. There is also "Overall FEC" rate parameter which is determined by the product of the "Viterbi" and "RS rate" parameter. Because of optional encoding ability, the overall FEC coding rate can be 0.44 or 0.87.

3.1 SYSTEMATIC REED-SOLOMON CODING

Applying the RS code on the PSDU (maximum of 1016 bits) produces the data with maximum length of 1208 bits. Implemented FEC codes are "systematic", which means that these FEC bits are redundant and receiver need not to use it for error correction at all. The systematic Reed-Solomon code $RS_6(K+8,K)$ adds the 48 FEC bits for every block of data with length of 330 bits. If the block of data is less than 330 bits, the dummy (zero) bits are appended. A block of M bits is encoded into a code word of $(M+48)$ in five steps. First, there is addition of dummy bits to the total size of 330 bits. Next, there is bit to symbol conversion, where 330 bits are converted into 55 RS symbols (*symbols of* 6 *bit size*). The third step is encoding the information bits with systematic $RS(63,55)$ code. Next, the symbol to bit conversion is performed and for the last step the firstly added dummy bits are removed and only the last $(M+48)$ bits are transmitted. So this means that final maximum length of data after RS encoding is 1208 bits, because PSDU data is segmented into three blocks of 330 bits and one with length of 26 bits, and for every block of data 48 parity bits are appended $(3 \cdot (330+48)+(26+48) = 1208$ bits).

3.2 SYSTEMATIC CONVOLUTION CODING

The PHY header before convolution encoding is composed of 19 bits and after encoding with rate of $R = 1/2$ it has 38 bits. The rate $R = 1/2$ means that for each input bit two output bits are produced. In Figure 3 the g_0^n is the original data stream bit, and the g_1^n is the parity bit. The PSDU part of frame consist of maximum 1208 bits. In addition to the previous explanation, the final length after encoding (with rate of $R = 1/2$) is 2418 bits. The two zero bits have to be appended ($(1208 \cdot 2)+2$ bits) to the PPDU for returning the convolution coder into the default zero state.

3.3 COMPARISON OF USED FEC ENCODING

The main contribution of this work is description and analysis of forward error correction implementation in IEEE 802.15.4*a* standard. Further description and possible settings of all of the parameters needed for the physical layer functionality is beyond the scope of this article. Because of that, the sample settings for nominal data rate of 850 Kb/s are used. In Figure 4, the time duration of FEC encoded data with possible combination of parameter for all allowed frame sizes $(1-127\text{B})$ is shown.

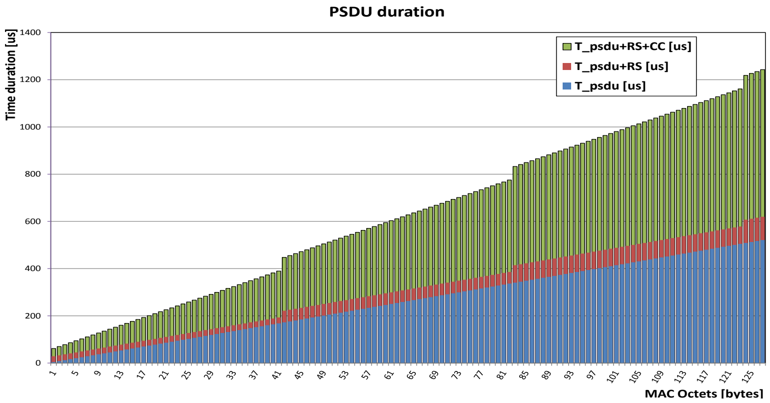

Figure 4: The PSDU duration

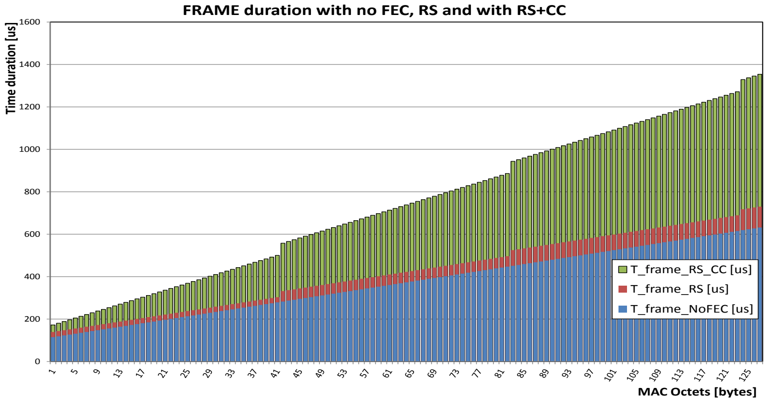

Figure 5: Frame duration

These combinations are shown only as sample illustration of the influence of FEC. The blue graph represents the pure data duration without using the FEC. Then, the red graph represents encoding with RS only and finally the green graph shows the influence of convolution encoding. There can be seen significant redundancy in data bits. The graph in Figure 4 shows the duration of only the PSDU part of frame to see the mentioned influence in more detail and the graph in Figure 5 shows the time duration of complete frame (SHR+PHR+PSDU).

4 CONCLUSION AND FUTURE WORK

Since we are living in information age, the security and authenticity of provided information is very important issue. This importance grows with needs for sensing and actuation at home and industry harsh environments. Proposed evaluation was mainly conducted for estimation of the properties of communication system based on the IEEE 802.15.4a-std. All needed parameters which are beyond the scope of article were estimated and the simple test application in table editor was created. With this application different kind of settings and its influence on the time duration, respectively throughput can be further estimated. The whole article respectively works around FEC uprise from the need to reach the detailed view of the whole implementation of this standard. This work is the preliminary study of FEC encoding and the main contribution can be seen in evaluation and analysis of FEC implementation in IEEE 802.15.4*a*-std. As was mentioned earlier, the shown devices are only at the prototype level, which means there is not yet developed any functional software network stack, that is also needed for communication. Future work will primarily focus on the implementation and evaluation of the physical and data link layer to the real devices. The entire study and developed application will be used as validation tool in implementation phase.

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