Towards Data Aggregation on Multi-Sensor Low Power Wireless Transducer with ISO/IEC/IEEE 21450 Transducer Electronic Datasheets

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***Abstract*—Wireless transducer nodes often provide more than one sensor channel. The application specific requirements on these individual channels can be quite different, e.g. in terms of measurement rate and permitted latency. In order to allow for corresponding power consumption optimization for a given application, we propose an extension of the ISO/IEC/IEEE 21450 Transducer Electronic Datasheet. Based on this proposed data aggregation concept, the individual measurement rate and the permitted latency can be adjusted. In addition, potential retransmissions due to losses on the wireless communication channel can be considered. The proposed concept is showcased in an industrial condition monitoring example.**

I. Introduction

In general, a single transducer node can provide multiple sensor channels. When these devices are in measurement mode, the samples for each channel need to transmitted to a base station. For wireless sensors it is of high relevance for the power consumption how this is done. One common approach is to measure all channels at the same rate and transmit measurement results for all channels in one packet. Alternatively, several packets may be collected and transmitted jointly as this can lead to a reduction of the average power consumption due to less overhead in the wireless communication. Frequently, the required measurement rate for individual channels is different, e.g. in a transducer that can measure temperature and acceleration, the latter may require a significantly higher measurement rate.

An example for such a multi-sensor platform is shown in Figure 1. In the condition monitoring of a hydraulic crane, temperature, pressure and motion (acceleration, gear rate, etc.) need to be continuously monitored but requirements in terms of measurement rate can be quite different.

In order to allow for application specific optimization of a transducer, the way how this data aggregation is done needs to be adjustable. We propose to utilize electronic data-sheets for this purpose such that the data sink can obtain the capabilities of a device from the data sheet and customize the data aggregation approach according to the needs of the application.

Electronic Data-Sheets in our context refers to the ISO/IEC/IEEE 21450 TEDS Standard [1]. Transducer Electronic Data-Sheets are data-sheets containing meta information about a transducer consisting of multiple sensors and actuators, channel information about every sensor and actuator on the transducer, calibration information about every channel and other information. As of the 2007 version of this standard, no fields regarding data aggregation have been included. Data aggregation approaches have been suggested e.g. in [2], where multiple sensor nodes are connected to one sink via wireless connection and the data is aggregated at the sink, or in [3], where an approach is explained, which reduces the power consumption of a sensor node by applying an on/off function on the wireless interface depending on if a new sample has been generated by the sensor or not, which can also be used on sensor nodes with multiple sensors. In [4] an approach where electronic data sheets are used to decrease power consumption in a wireless node is described. In [5] a comparative overview of different data gathering and aggregation methods is shown and an analytic model to predict the energy efficiency and reliability is discussed. In [6] another study on different data aggregation techniques is conducted with the focus on energy consumption reduction for wireless sensors in disaster areas. [7] provides a comparison of different data aggregation protocols and includes more parameters with which the protocols are compared against each other.

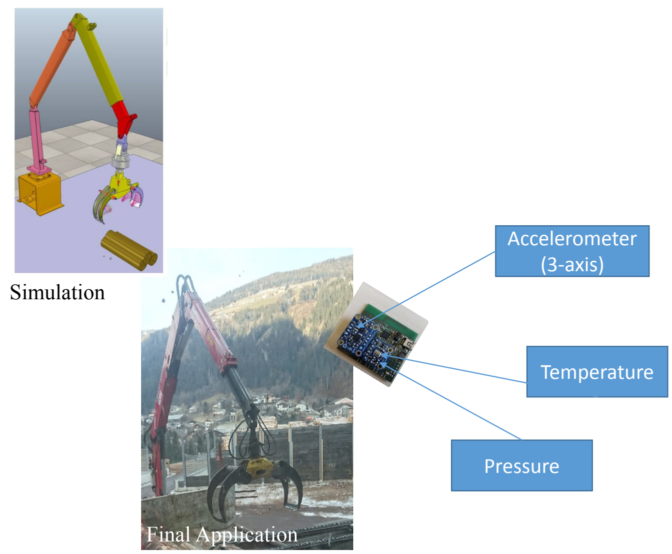

Fig. 1: Example of Multi-Sensor platform usage in condition monitoring of a forestry crane.

II. Electronic Data sheet Extension

In this work an extension for the IEEE 21450 Standard is proposed. The proposed work extends the standard data electronic data sheet (TEDS) by a section where the used data aggregation protocol and associated parameters are included. The TEDS standard includes an approach to concatenate data of multiple sensors of one transducer as described in [1], called Transducer Channel Proxy. In a Transducer Channel Proxy, sensor channels identified by their channel number can be combined. This means that commands can be send to the proxy and all sensors in the proxy are targeted by the command. For data transmission the proxy has two modes defined, which are the "block" and the "interleave" mode. In the Interleave mode, samples from the sensors are interleaved and then transmitted, while in the Block mode, samples from each sensor currently in a buffer are combined in a block and each sample block is then concatenated to all other blocks which creates a packet. This approach is intended to enable an NCAP to talk to multiple channels with one command, which targets the proxy. The proposed aggregation approached used in the extension works off a similar base principle like the 'proxy block' method, but diverges in that it is only used for the continuous data streaming mode and optimized to reduce overhead. The proposed TEDS extension is also not limited to this aggregation approach, as other types of data aggregation could also be used, like a greedy approach over multiple nodes. Here the NCAP could identify and correctly work with the incoming data stream by controlling the data aggregation part of each transducers TEDS.

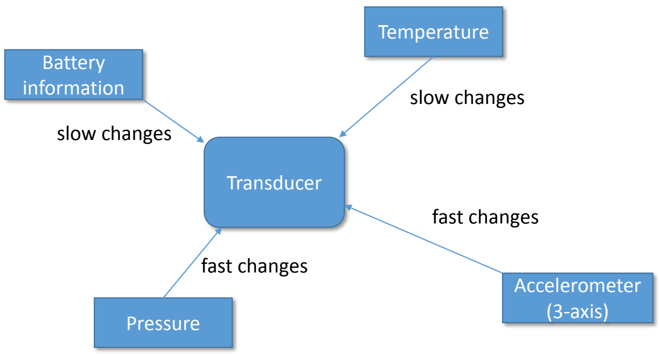

Fig. 2: Overview of transducer with multiple connected sensors which record and send their samples at different rates.

As illustrated in Figure 2, the quintessence of the extension is, that a transducer consists of multiple sensors which record and transmit data at different rates. All data measured by these sensors has to be transmitted to a base station, a so called Network Capable Application Processor (NCAP) in an energy efficient way such that the information is still synchronized. As visualized in Figure 3, the sensors record their samples with different rates and the samples are then collected by the transducer and added to a packet according to the aggregation approach described in section III. Additionally, the maximum latency in the transmission can be deducted from the samples in one packet and if a packet is dropped, a re-transmission can be done immediately. An example of a similar system implementing such a re-transmission system can be seen in [8]. If too many packets are dropped, old samples get discarded.

The introduced extension is designed to be a part of the PHY TEDS. PHY TEDS define the physical transport layer of a transducer and are best suited to also contain information about data aggregation usage for multiple sensors and the used aggregation method. This can then be used on the Network Capable Application Processor (NCAP) side to decode the incoming data stream correctly.

TABLE I: IEEE 21451 PHY TEDS Extension

Field Type	Field name	Description	Type	Number octets
129	DataAgg		-	-
130	AggMethod	Aggregation method	UInt8	1
131	TimeSynced	Samples synchronized	UInt8	1

With this information, more flexibility is added to the wireless sensor network (WSN) as different aggregation methods can be used in one sensor network and no additional configuration has to be done. The Field 129 in table I is introduced to combine all aggregation relevant fields into one section of the data sheet. The field 130 is an Integer and Enumeration from table II, which defines the aggregation method used on this transducer. Field 131 defines if the timing information between the samples can be recovered on the NCAP or not.

TABLE II: List of Aggregation Methods

Enumeration	Method name
1	No aggregation
2	Custom approach
3-255	Reserved

For the approaches defined in Table II, the first one is when no data aggregation is used. Meaning, as illustrated in Figure 4, each time a sensor generates a sample, the transducer adds the sensor id to the sample and sends it to the NCAP.

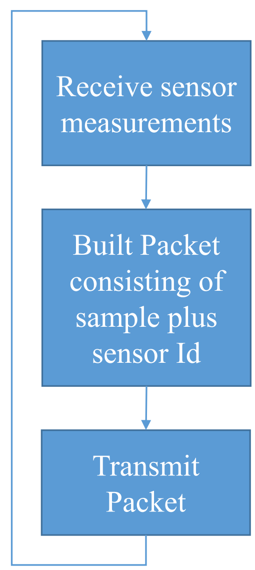

Fig. 4: Flow-graph of using no aggregation approach. Each time a sensor triggers a sample, a packet is built and send to the base station.

The next approach is a custom approach used in this work and explained in Section III. All other approaches can be defined by the manufacturers of the transducer. The reserved approaches could be approaches typically used in Wireless Sensor Networks (WSN) to aggregate data between multiple nodes in a wireless sensor network like the ones explained in [7].

III. Data aggregation approach

In this work a custom data aggregation approach has been implemented and used in an experimental setup using the extra information granted by using electronic data-sheets. Figure 5 shows a flow graph of the approach.

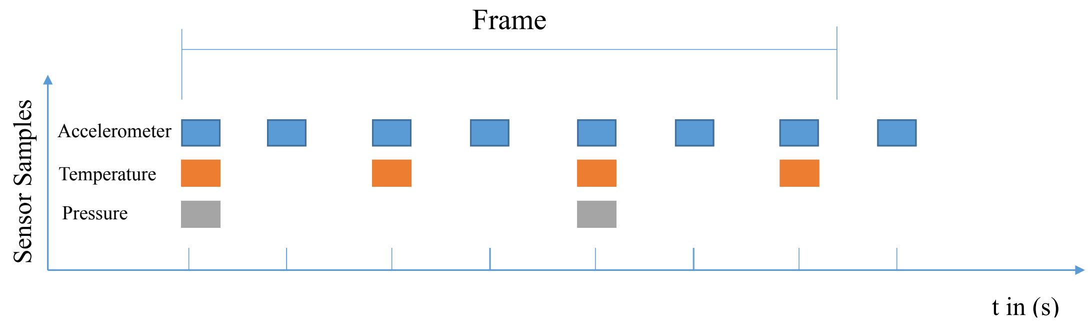

Fig. 3: Overview of the transducer input of the connected sensors over time.

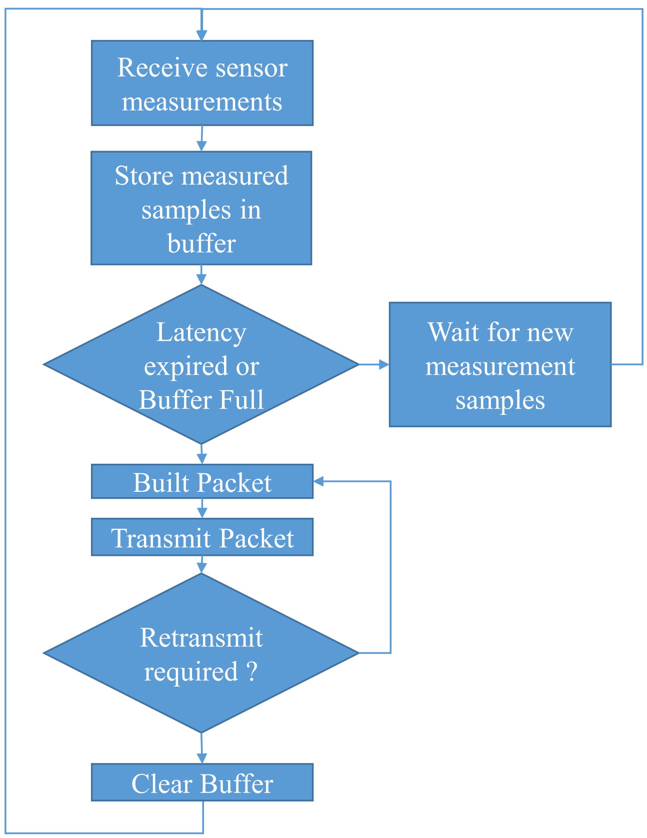

Fig. 5: Flow-graph of approach showing the inner workings of the multi-sensor node.

All sensors included in the data aggregation send their samples into a buffer. Each period of the sending rate, a packet is built from the saved samples with the format defined in Figure 6. After the packet is built, it gets transmitted over the wireless link. The packet contains a Frame Number (FN) which is needed for re-transmits and lost packets and to identify the current last received frame. Additionally, the sensor values in the packet are sorted from the first to the last sensor to enable the NCAP side to decode the packet without the need for additional information to be transmitted. In this way, the NCAP knows the currently last received frame or sample, the overall number of samples in one packet and the number of sensors of the transducer. From this information the NCAP can break down the sample part of the received packet and correctly match each sample with its corresponding sensor. The timing information of the samples can then be reconstructed by knowing the sampling rates of each sensor, which are all dependant on the base rate.

Fig. 6: Schematic illustration of one packet built by the multi-sensor node using the proposed aggregation approach.

The approach is illustrated in Figure 7, in which an example of a transducer with four sensors can be seen. The approach works by having a fixed base rate in the transducer where all measurement rates of the sensors and the transmission rate are a fraction of this base rate. The base rate and the transmission rate can be found in the PHY TEDS and the sensor rates can be found in the CHANNEL TEDS. The sensor rates and the transmission rate can additionally be altered later on by using embedded actuator channels defined in the TEDS for each sensor channel. This enables the transducer to be dynamic in its measurement cycle, which allows to change the amount of data to be transmitted in one packet and the ratio of the samples of different sensors in a packet, if the physical sensors allow for a rate change.

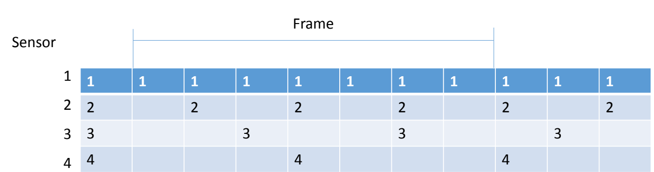

Fig. 7: Illustration of samples from all four connected sensors being stored in the buffer on the node over time. Illustrates that the sensor rates are fractions of the base rate, which allows the reconstruction of the timing information.

This approach reduces the overhead which would be produced when each sensor creates packets for its samples. Additionally the possibility of collisions and other problems is minimized by reducing the number of packets send over the wireless link.

On the NCAP side, as visualized in Figure 8, the first step when the sensor first connects is to retrieve its TEDS from the transducer. Then extract important information like transducer name, number of sensors on the transducer and the properties of each sensor. After this, the interface and data reconstruction accordingly is configured accordingly. When receiving a new packet from a transducer, the first step is to extract the number of samples and the current frame number. Using both, the sensor samples can be correctly retrieved and the timing information of the samples can be reconstructed. This is done by relying on the synchronisation between the sensor channels and the fact that their sample rates a fractions of the base rate of the sensor.

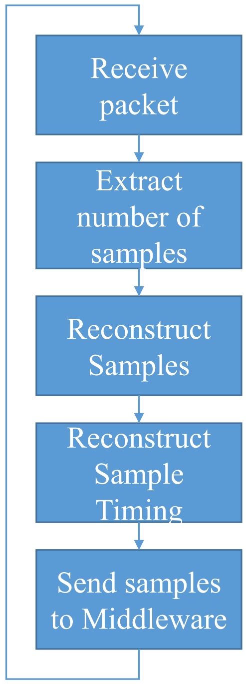

Fig. 8: Flow graph on Receiver (NCAP) side illustrating the process of receiving and parsing incoming packets from the multi-sensor node.

IV. Experimental Setup

To test the proposed TEDS extension and the aggregation approach, the approach has been implemented on a multi-sensor transducer platform. A TEDS with the extension has been created for the transducer and is used in conjunction with the NCAP software. In Figure 10, the used transducer can be seen and in Figure 9 the overall architecture of the measurement setup is illustrated.

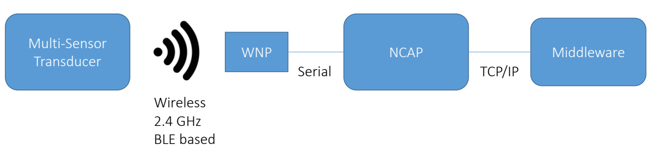

Fig. 9: Experimental setup to test the aggregation approach with a real multi-sensor node.

In the used measurement setup, the transducer node is connected to a Wireless Network Processor (WNP) via a wireless link, which in turn is connected to the NCAP via a serial Universal Asynchronous Receiver Transmitter (UART) link. For further processing of the samples the NCAP can then be connected to various middle-ware such as ROS or OPC-UA. This allows a wider range of condition monitoring tools to connect to the system.

The used transducer node is an nrf51822 microprocessor with Bluetooth Low Energy (BLE) wireless functionality and two different sensors connected via an I2C Interface. The sensors are a three axis accelerometer and a pressure and temperature sensor.

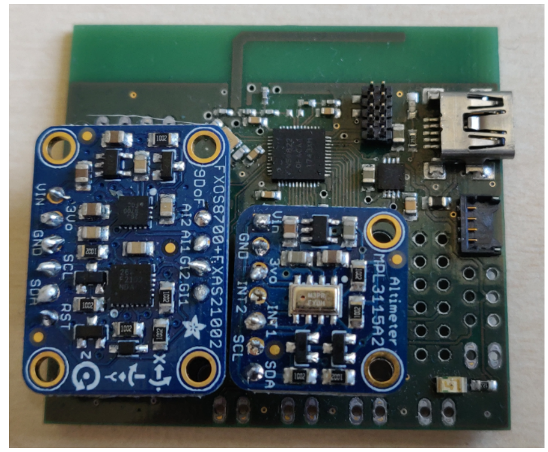

Fig. 10: Used Multi-Sensor Transducer for the experiment. Consists of accelerometer, Pressure and Temperature sensor.

Figures 11 and 12 visualize measurement data taken from the multi-sensor transducer where temperature data, pressure data and acceleration data for three axes is displayed. For this setup the transducer has not been moved and was placed in an environment where temperature and pressure were reduced slightly over time.

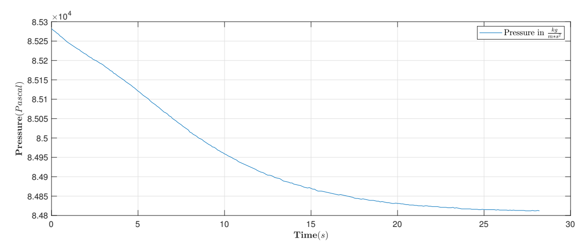

Fig. 11: Pressure sensor data received by the NCAP from the Multi-Sensor node using the aggregation approach.

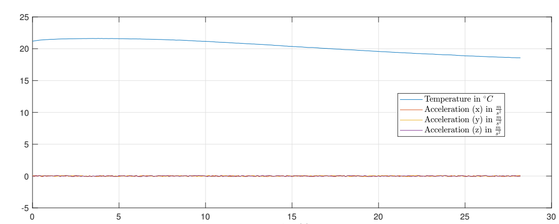

Fig. 12: Temperature and accelerometer data received by the NCAP from the Multi-Sensor node using the aggregation approach.

The measurement data is split into two figures for better visibility of the measured samples as the pressure samples are by a factor of 10^3 greater than the temperature samples.

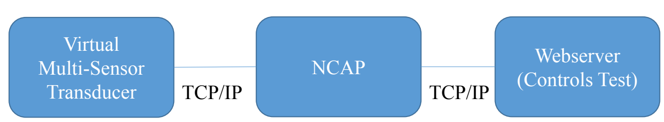

Fig. 13: Measurement setup where a simulated Multi Sensor node is connected to an NCAP system.

To get an overview over the advantages of using this aggregation approach in contrast to using no aggregation approach, a simulated sensor node which is connected to an NCAP and controlled via a web-server is used to perform tests. This is displayed in Figure 13. In the tests the node is using both the proposed aggregation approach and the above mentioned case of no aggregation approach used over a predetermined amount of time. The overall number of bytes transmitted via the duration is then measured for both approaches and illustrated in Figure 14.

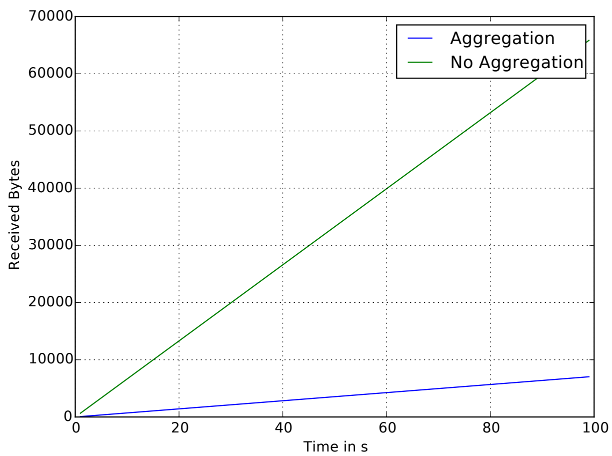

Fig. 14: Number of bytes received from the Multi-Sensor node using no aggregation approach and using the custom aggregation approach respectively.

As shown in Figure 14, the aggregation approach uses overall less bytes to transmit data, which in most parts is due to the overhead of the packets. As each byte transmitted uses energy to be transmitted via the medium, each byte that is not transmitted reduces the overall energy needed to transmit a packet. Additionally, as packets are send more sparsely, the wireless part of the transducer could be set into a power-saving mode in between sending to reduce power consumption further.

V. Conclusion

In this work an extension of the ISO/IEC/IEEE 21450 standard is proposed in order to allow for customized data aggregation approaches and application specific optimization of the power consumption. The main parameters are individual measurement rates for each channel and the permitted latency, which may allow to collect a number of samples into one transmission packet. As the configuration capabilities are provided by the electronic datas-heet the approach allows to use general purpose transducer nodes in an optimized way without the need for an application specific software on the node. The benefit of the approach in terms of data reduction and thus reduction of power consumption is demonstrated in an example of a condition monitoring system.

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