Scoresheet-based Event Relevance Determination for Energy Efficiency in Wireless Sensor Networks

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***Abstract*—As wireless sensor nodes are mostly battery-powered, energy-efficient operation is a necessity to use their confined energy budget optimally. This is especially true in the logistics domain, where timely and accurate monitoring of containers is required, while the cost pressure is high. Thus, besides the need for energy efficiency, wireless sensor network deployments in logistics require cost efficiency as well. As data transmission represents the most expensive operation in terms of energy consumption and monetary costs, we present a concept for the local determination of transmission relevance in this paper. By omitting irrelevant events from transmission, the amount of data to transmit is effectively reduced. Our approach employs concepts from the business economics sector and is based on the use of scoresheets, which evaluate information on a wireless sensor node to decide whether they are "worth" transmitting or not. Thus, a scoresheet-based approach provides a viable solution for local filtering to realize energy- and cost-efficient operation of a wireless sensor network while maintaining the benefits of data fidelity and real-time event notifications.**

I. INTRODUCTION

Wireless sensor nodes (*motes*) typically rely on batteries as power sources. In consequence, energy is a limited resource in any wireless sensor network (*WSN*) deployment, and the use of the available energy budget is the major influence factor on a mote's lifetime. Energy-efficient operation thus represents an essential necessity [1].

With regard to the energy consumption of a mote, wireless data communication and the use of on-board Flash storage have been shown to be the most costly consumers [2]. While the use of local storage can be avoided in many applications, radio communication represents an inherent characteristic of WSNs, having inspired many researchers to realize energy-efficient data transmission schemes (e.g., discussed in [3]). Nevertheless, data transmission still constitutes the major source of energy consumption of a mote and still consumes significantly more energy than data processing (cf. [4]). In this paper, we propose to exploit this relative cheapness of data processing to realize a local filtering of gathered data with regard to the data's relevance. Only when the collected data is deemed "worth" transmitting, an event termed *transmission-relevant event* [5] is being generated and sent over the radio. In contrast, data "not worth" transmitting, which we call *non-transmission-relevant*, is not communicated, to reduce the number of data transmissions.

Besides energy efficiency, several other requirements have to be considered for WSN deployments, depending on their application domain [6]. When focusing on the logistics domain, which represents the selected application domain in this paper, cost efficiency is one such dominant requirement [5]. This urgent need for high cost efficiency is a result of the massive cost pressure prevailing in the logistics market. Therefore, we address cost-efficient operation of a WSN in addition to energy efficiency in our approach. To be of any immediate use for the parties involved in a logistics process, data gathered by a WSN has to be made available in real time to the corresponding stakeholders. This usually requires a long-range data transmission between a WSN and a backend system, for which communication technologies liable to fees need to be used, such as satellite uplinks or cellular networks [7]. Monetary costs are thus also driven by data transmissions, as is energy consumption. Consequently, by realizing local filtering on a mote to identify transmission-relevant events and thereby reducing the number of data transmissions, our approach contributes to both cost efficiency and energy efficiency.

The remainder of this paper is structured as follows: In Section II, existing approaches using data filtering in WSNs are presented, with a distinct focus on approaches applied in the logistics domain. Afterwards, we briefly cover our concept of transmission-relevant and non-transmission-relevant events in Section III. Section IV introduces the basics of scoring models. Based on these, a scoring model is developed for the local distinction of events in transmission-relevant and non-transmission-relevant events in Section V. Section VI presents conclusions and future work.

II. RELATED WORK

The approach of locally assessing and filtering data using context parameters has already been employed in several WSN routing methods, e.g., SCAR [8], EM-GMR [9], or EMA [10].

In addition, for example, Jedermann et al. have already emphasized that a shift of decision-making to the individual mote is a very promising approach and will extend a mote's battery lifetime by reducing communication [4]. Consequently, several approaches have emerged in this context.

Evers and Havinga propose a solution for efficient and secure sensor reprogramming in a logistics context [11]. They describe the option for an autonomous verification of correct handling conditions during a transport, specifically the detection of overtemperature conditions and signalling a corresponding alarm. Nevertheless, the decision to raise an alarm is based on a single environmental parameter instead of taking other relevant context parameters into account and balancing them against each other. In an earlier work, Evers et al. focussed on storage logistics, but also mentioned the idea of "transferring additional intelligence and responsibility to sensor nodes" [12]. There, they mention the use of rules and a rule engine on a mote to decide whether an alarm should be raised or not. However, in this context, their primary intention is focused on localization issues.

Concerning business rule usage on motes within logistics processes, Marin-Perianu et al. provide a work on protocol issues and the efficient distribution and update of rules [13]. They also emphasize the advantages of an enhanced local logic to transmit data only when certain conditions are violated to save on network communication overhead and energy. Their idea is to allow the mapping of simple business logic on rules executed by a rule engine on a mote. This rule engine monitors several parameters and checks if given conditions are violated and, in this case, initiates a certain action, such as informing the backend. However, the authors focus primarily on how rules can be efficiently distributed and updated and present a tree-based dissemination protocol for this purpose.

Son et al. present another rule-based approach for a WSN deployment in logistics [14]. Similar to [13], their aim is to bring node-centric context-awareness to WSNs in logistics, and thereby reduce traffic and thus enhance energy efficiency. The rules employed are designed to check whether relevant parameters exceed a given interval or not. However, no linkage possibilities between rules are explicitly described by the authors. Thus, dependencies between parameters to fully evaluate the current context and decide whether to send data or not are not considered.

Several of the described approaches already realize local filtering in WSN deployments designed for logistics, but on a relatively strict and static basis. In contrast, our approach balances strictly dynamical various criteria against each other and explicitly incorporates more (qualitative) application related parameters to assess the transmission relevance of gathered data. This does not only allow the integration of simple business logic, but also enables the incorporation of complex logic and the explicit consideration of diverse dependencies. Compared to context-aware routing methods, we focus on the step before data is routed and decide directly at the originating mote if gathered data needs to be sent. Thus, our approach can beneficially be combined with such routing mechanisms.

III. TRANSMISSION RELEVANCE

For WSN deployments in the context of transport logistics, energy efficiency is mandatory as for all WSN deployments. Additionally, a cost-efficient operation of WSN deployments is necessary [5]. As data transmission accounts for the major parts of both energy consumption and costs in this context, we focus on reducing data transmission to simultaneously achieve energy-efficient and cost-efficient operation. To reach this goal, we use our concept of transmission-relevant events, introduced in [5]. The basic idea is to categorize events into transmission-relevant events, which are deemed "worth" transmitting, and non-transmission-relevant events, which are deemed "not worth" transmitting. The according classification of events is realized by comparing the information value of an event with its transmission costs, comprising energy costs as well as monetary costs:

$$\begin{aligned} &Transmission\text{-}relevant\ event_{E_x} \Leftrightarrow \\ &Information\ value_{E_x} \geq Transmission\ costs_{E_x} \end{aligned} \tag{1}$$

$$\begin{aligned} &Non\text{-}transmission\text{-}relevant\ event_{E_x} \Leftrightarrow \\ &Information\ value_{E_x} < Transmission\ costs_{E_x} \end{aligned} \tag{2}$$

A crucial point for this concept is the efficient implementation of this comparison on a mote, and particularly, how to operationalize information value and transmission costs of an event to be able to compare them locally. For this, we propose the use of an adapted scoring model with a corresponding scoresheet.

IV. SCORING MODELS: BASICS

Scoring models are basically used for a systematic analysis of alternatives in order to rank them. They are, e.g., used in business economics for alternative selection, particularly in cases where valuation criteria are hard to quantify.

For ranking, scoring models make use of utility values (*scores*) and individually consider preferences of decision makers and support multidimensional goal systems [15]. The specific application of a scoring model comprises the four steps of i) *defining relevant goals*, ii) *describing alternatives' consequences with relevance for the goals*, iii) *valuating alternatives based on their consequences*, iv) *selecting the alternative with the highest score*. These generic steps lead to the formalized setup for scoring models depicted in Fig. 1.

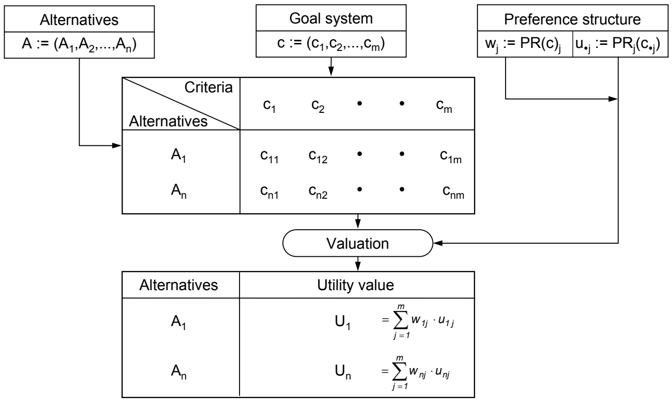

Fig. 1. Generic setup of scoring models (based on [15])

A set of action alternatives *A* constitutes the input for the scoring model as the alternatives to be valuated and ranked. The goals which should be reached with the afterwards implemented alternative are reflected in a goal system. This goal system is operationalized by defining a set of different criteria *c* contributing to the achievement of the defined goals. For every criterion in *c*, every alternative in *A* has to be valuated and assigned a utility value *u* based on a preference structure, e.g., of a domain expert. On the basis of this preference structure, the different criteria in *c* are assigned weights *w* representing their relative importance. With the utility values *u* and the weights *w*, the alternative valuation is performed by calculating an overall utility value U_n for each action alternative in *A*. Typically, this calculation is performed by summing up the weighted utility values for each criterion of an action alternative (cf. Fig. 1).

V. A SCORING MODEL FOR LOCAL DETECTION OF TRANSMISSION-RELEVANT EVENTS

After having introduced the concept of scoring models, we adapt this concept for the use in WSNs, in our case particularly for the application in transport logistics. It is operationalized to realize the local differentiation of transmission- and non-transmission-relevant events (cf. Sec. III) in this context.

Taking the notion of transmission-relevant events and non-transmission-relevant events as basis, the set of alternatives *A* can basically be interpreted as comprising those two or deriving from them the two action alternatives of sending or not sending corresponding event information:

$$\begin{aligned} A :=& (\textit{Transmission-relevant event}, \textit{Non-}\\ &\textit{transmission-relevant event})\\ =& (Send\ event\ information, Do\ not\ send\\ &event\ information) \end{aligned} \tag{3}$$

Based on the requirements for the beneficial use of WSNs in logistics described in [16], the required goal system operationalization takes place on the basis of the overall goal of efficiency. In our application context, the notion of efficiency is further broken down into energy efficiency and cost efficiency. These two aspects have already been initially incorporated in the concept of transmission-relevant events by jointly using energy and monetary transmission costs as the transmission costs to be compared to the information value of an event. Thus, *information value* and *transmission costs* are derived as main criteria for the operationalization of the goal system.

As these two main criteria are very generic, they have to be further broken down and operationalized. As already mentioned, to account for energy efficiency and cost efficiency simultaneously, the criterion transmission costs can be subdivided in the more fine-grained criteria *energy costs of data transmission* and *monetary costs of data transmission*. To realize a sufficiently long lifetime of a WSN, not just the absolute energy for sending the event data is relevant. Additionally, this value has to be related to the remaining energy. For example, if there is still plenty of energy left related to the initial energy budget of a mote and the required lifetime of a WSN, the data transmission is relatively seen cheaper in terms of energy as in the case where the energy resources are already low. Thus, the *current energy reserves* at the time of the event detection have to be considered as well and constitute a third criterion for the operationalization of the main criterion of transmission costs.

Similarly, the main criterion information value has to be broken down into more specific criteria. In this respect, we use the concept of opportunity costs and deduce that the information value of event information basically depends on an event's impact. Therefore, our understanding is that the impact of an event is directly correlated to the event's information value. This is exploited for deriving fine-grained criteria for the main criterion of information value.

An event normally affects the condition of transported goods, e.g., reaching a critical temperature can significantly reduce the shelf life of food products [17]. Therefore, an event usually has a physical impact on the transported goods. This physical impact and the corresponding degree of damage depends on the extent of the violation of parameter thresholds critical for the transported good's condition as well as on the duration of this threshold violation. Consequently, we use the *extent of threshold violation* and the *duration of threshold violation* as derived criteria of physical impact of an event.

With the physical impact on the condition of a transported good by an event, a direct influence of the value of the transported good is associated, constituting a direct monetary impact. This direct monetary impact expresses itself either in a degradation of the value of the affected good or in penalty or insurance payments. The direct monetary impact is expected to be correlated to the value of the transported goods. Therefore, the *value of goods* can be used as derived operationalization criterion of direct monetary impact of an event.

Considering that every event during the transport process with an impact on the transported good influences the customer satisfaction negatively, a corresponding impact of an event on the relationship between transport company and customer has to be noted. This is reflected by the indirect monetary impact of an event. This impact can be expected to correlate to the value of a customer for a company. Thus, to incorporate the potential indirect monetary impact of an event, the criterion *customer value* is used.

In the sense of opportunity costs, considering the amount of reaction possibilities to an encountered event, the information value of an event is not solely depending on the event's impact, but as well depending on the current position in the supply chain, because this position typically correlates to the available reaction possibilities. Furthermore, one can imagine a situation in which a temperature violation occurs very shortly before reaching the next warehouse in the transport chain. In such a situation, it might be beneficial to save energy by not transmitting the event information. Thus, we map the current position in the supply chain during an event occurrence to the criterion of current *time to next warehouse*.

This leads to the overall operationalization of the goal system for our scoring model with a set *c*:

$$\begin{aligned} c := \{&energy\ costs\ of\ data\ transmission, monetary\ costs\\ &of\ data\ transmission, current\ energy\ reserves, extent\\ &of\ threshold\ violation, duration\ of\ threshold\ violation,\\ &value\ of\ goods, customer\ value, time\ to\ next\ warehouse\} \end{aligned} \tag{4}$$

At last, the criteria in c have to be assigned with individual weights to determine their importance and thus operationalize decision makers' preference structures. This can for example be realized by conducting a pairwise criteria comparison or the distribution of a fixed number of points.

Finally, to evaluate if an event is transmission- or non-transmission-relevant, the deduced input parameters of our scoring model are integrated in a scoresheet (Fig. 2). Within this scoresheet the individual criteria are valuated on a 7-step scale every time an event occurs. Afterwards, the valuation scores get weighted. Subsequently, utilizing the notion of transmission-relevant events from (1) and (2), the transmission relevance of the occurred event is deduced by subtracting the sum of the weighted scores of the sub-criteria of the major criterion transmission costs from the sum of the weighted scores of the sub-criteria of the major criterion information value. If this subtraction yields a value less than zero, the encountered event is a non-transmission-relevant event, otherwise it is considered a transmission-relevant event, and its data is transmitted. Such valuation of detected events with this scoresheet is to be carried out on every mote to filter between transmission-relevant and non-transmission-relevant events and decide whether a corresponding data transmission shall take place or not.

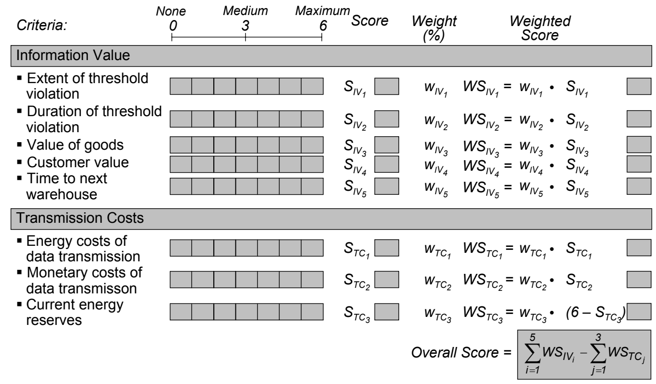

Fig. 2. Operationalization of a scoring model in a scoresheet for detection of transmission-relevant events in WSN deployments in a logistics context

VI. CONCLUSIONS AND FUTURE WORK

Data transmission is the major source of energy consumption in WSNs. Therefore, in this paper, we proposed to locally evaluate on wireless sensor nodes whether sensed data should be transmitted or not to avoid irrelevant data transmissions. As we explicitly address the logistics domain as application domain for WSNs, both energy and cost efficiency are required. Because monetary costs are mainly driven by data transmission, the proposed local evaluation of data also helps to improve cost efficiency.

We have presented our concept of transmission relevance as a basis for this local evaluation of gathered data. Afterwards, we have introduced scoring models as a means of determining the transmission relevance of data. Consequently, we have developed a specific scoring model for WSN deployments in a logistics context, resulting in a scoresheet for local relevance determination of sensor data.

Currently, our concept focuses on individual motes. In future work an extension towards a distributed use appears promising. Furthermore, possibilities to dynamically adapt the scoresheet and incorporate more action alternatives will be considered.

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