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A Concept for Cross-Layer Optimization of Wireless Sensor Networks in the Logistics Domain by Exploiting Business Knowledge

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***Abstract*—Energy is limited in wireless sensor networks due to mostly battery-operated wireless sensor nodes. Consequently, an efficient energy usage significantly enhances the lifetime of a wireless sensor network. In this paper, we propose a cross-layer optimization concept that exploits business knowledge in the logistics domain to adapt communication by business relevancy. A corresponding information value is assessed for each detected event. Energy and communication costs can be saved by dropping or postponing the transmission of less relevant event information, without negative impact on the business and application level.**

I. Introduction

Wireless sensor nodes (*motes*) typically are battery-powered, and hence possess only limited energy resources. So, energy usage significantly affects a node's lifetime, making energy-efficient operation mandatory [1].

Efficient management of logistics processes requires comprehensive and up to date information about events during transport processes. Such information can be provided by wireless sensor networks (*WSNs*). Motes can immediately detect critical shock, tilt, or temperature values during a transport and alert corresponding stakeholders. Such an application of WSN technology needs to consider different requirements of the logistics domain, particularly a massive cost pressure (cf. Section IV). Thus, design and operation of a WSN in this domain has to be cost-efficient. Consequently, as data transmission from WSNs to stakeholders in a transport process typically utilizes communication technologies liable to fees [2], an efficient operation in terms of data transmission is also needed.

We propose an approach that uses contextual information, such as business knowledge from the application layer, to differentiate transmission-relevant events and non-transmission-relevant events and control the energy and monetary expenditure by just transmitting data considered worth transmitting (cf. Section II). For the corresponding local evaluation of data gathered in a WSN, an adequate valuation concept is needed (cf. Section III). With this approach, transmission costs in terms of energy and money will be significantly reduced.

II. Transmission-Relevant Events

In the domain of logistics and especially in Supply Chain Event Management (*SCEM*), events are understood as essential state changes for certain addresses [3]. The concept of SCEM focuses on the detection of events and the corresponding adaptation of processes as reaction to these. If, for example, medicine like swine flu vaccine is transported, this transport good must not be exposed to certain shock, tilt and temperature values to avoid damage. The violation of corresponding thresholds marks an essential state change and therefore constitutes an event. In the context of SCEM such an event should be detected and reacted on.

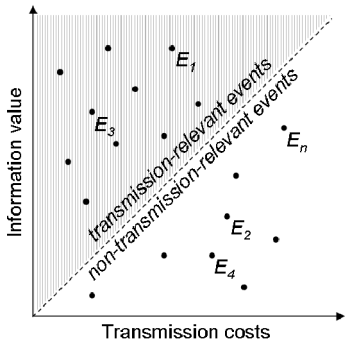

Fig. 1. Differentiation of events based on transmission relevance

Events have different impacts on transported goods and the transport process, e.g., depending on the point in time they occur or the extent of the occurred state change. Therefore, the corresponding event data has different information values as well. Based on this value and energy costs and potential costs (energy, monetary) for transmission of corresponding event data, we divide events in transmission-relevant events and non-transmission-relevant events (cf. Fig. 1).

Consequently, the information value of a transmission-relevant event outweighs the energy and money to be spent to transmit the corresponding event information (1). So, the corresponding event data is worth transmitting. If the information

value is less than the transmission costs, an event is classified as non-transmission-relevant event not worth transmitting (2).

$$Transmission\text{-}relevant\ event_{E_x} \Leftrightarrow Information\ value_{E_x} \geq Transmission\ costs_{E_x} \quad (1)$$

$$Non\text{-}transmission\text{-}relevant\ event_{E_x} \Leftrightarrow Information\ value_{E_x} < Transmission\ costs_{E_x} \quad (2)$$

III. Components of an Information Valuation Concept for Cross-Layer Optimization by Event Detection

The notion of transmission-relevant events is utilized by our information valuation concept, which runs locally on a mote and decides whether state changes measured by the mote constitute transmission-relevant events or not. The designed information valuation concept incorporates an event detection component and a valuation component (cf. Fig. 2).

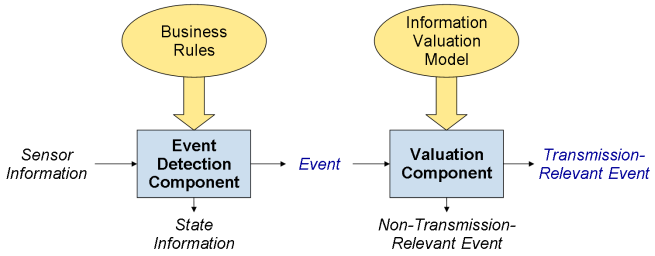

Fig. 2. Information valuation concept to detect transmission-relevant events

The event detection component uses application data in the form of lightweight business rules to differentiate gathered sensor data into pure state information and essential state changes, constituting events. These business rules can for example consist of critical thresholds for transport goods concerning shock, tilt or temperature.

The valuation component applies an information valuation model to differentiate identified events in transmission-relevant events and non-transmission-relevant events. The information valuation model makes use of sophisticated application data in the form of multifaceted business knowledge as well as locally available contextual information and an event history. Applicable business knowledge can consist of the value of the transport good, the extent of quality loss and value loss of the transport good due to the event, the importance of the corresponding customer, etc. Applicable locally available contextual information can consist of the current position in the transport process, currently available energy resources, currently available communication links, etc.

The development of such an approach has to explicitly consider the restricted available computing resources of motes, but as computing only consumes negligible amounts of energy compared to data transmission [4], efficiency gains in energy usage are expected. Additionally, as the described concept does not affect the transmission of transmission-relevant event data itself, the transmission can be further optimized by employing energy-aware communication protocols [5] and compression techniques [6].

IV. Current Research On WSNs in Logistics

Several researchers are working in the field of WSN in logistics [7], [8]. Mostly, the focus is on application of WSN technology in food and cold chain logistics. Furthermore, research is primarily based on a strong technological point of view, e.g., developing specialized nodes or possibilities for fast and energy-efficient reprogramming of motes.

Our investigations of the logistics domain combined with expert interviews have shown that in addition to such technological requirements, originating from the specifics of WSN technology, specifics of the logistics domain have to be explicitly considered for a beneficial application of WSNs in this domain. The resulting logistics market specific requirements are dominated by the need for cost-efficiency as a consequence from the huge cost pressure in logistics. Therefore, WSN solutions for logistics have to explicitly address both energy-efficiency, as technological requirement, and cost-efficiency, as logistics market specific requirement.

V. Conclusions and Outlook

Logistics is a promising application domain for WSNs, especially SCEM will benefit enormously from the possibility of local event detection in real-time by WSNs. To achieve these benefits, research has to consider technological requirements as well as logistics market specific requirements.

Based on our investigations of the application domain, we have introduced the notion of transmission-relevant events and non-transmission-relevant events, and sketched a corresponding local information valuation concept. The described approach allows optimization of transmission costs in terms of money and energy by an application layer-based control of the different communication layers exploiting business knowledge available on the application layer. Thus, technological requirements and logistics market specific requirements are addressed simultaneously. In the next steps, the detailed development of the information valuation concept is needed, followed by a prototypical implementation for evaluation purposes.

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