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An energy efficient and QoS aware routing protocol for wireless sensor and actuator networks

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ABSTRACT

Wireless sensor and actuator networks are composed of sensor and actuator nodes interconnected via wireless links. The actuators are responsible for taking prompt decisions and react accordingly to the data gathered by sensor nodes. In order to ensure efficient actions in such networks, we propose a new routing protocol that provides QoS in terms of delay and energy consumption. The network is organized in clusters supervised by CHs (Cluster-Heads), elected according to important metrics, namely the energy capability, the riches of connectivity, which is used to select the CH with high node density, and the accessibility degree regarding all the actuators. The latter metric is the distance in number of hops of sensor nodes relative to the actuator nodes. This metric enhances more the network reliability by reducing the communication delay when alerting the actuator nodes, and hence, reducing the energy consumption. To reach efficiently the actuator nodes, we design a delay and energy sensitive routing protocol based on-demand routing approach. Our protocol incurs less delay and is energy efficient. We perform an evaluation of our approach through simulations. The obtained results show out performance of our approach while providing effective gain in terms of communication delay and energy consumption.

1. Introduction

Wireless Sensor Networks (WSNs) consist in a large number of distributed miniature sensor nodes composed of capture unit, data processing, and communication capacities. These nodes can communicate with each other and are capable to detect events and transmit the sensed information (temperature, humidity, motion detection, etc.) to the base station directly or through other intermediate nodes. The need of reaction in the event area has encouraged the emergence of actuator nodes, which have a further actuation unit that converts an electronic signal to a physical movement. Moreover, there is a need for a standardized way of obtaining information related to the physical sensors which are commonly found in networking equipment, such as the current value of the sensor, the current operational status, and the data units precision associated with the sensor [35]. WSN is a class of Low-Power and Lossy Networks (LLNs), in which the network nodes are constrained. LLN nodes operate with constraints on processing power, memory, and energy (battery power). Their interconnects are characterized by high loss rates, low data rates, and instability [36].

Wireless Sensor and Actuator Networks (WSANs) are an extension of WSNs [1]. WSANs are used in various applications such as home automation, battlefield surveillance, networked robot, precision agriculture, animal control, and environmental monitoring [15,18]. The actuator nodes have more communication capability compared to the sensor nodes and are responsible to take decisions and react in the event area according to the received data. To take advantage of the ability of the actuator nodes, an efficient cooperative communication is required. Generally, we find in the literature three levels of coordination, namely sensor-sensor, sensor-actuator and actuator-actuator. The sensor-sensor coordination is executed to gather information in the surveillance field. The sensor-actuator coordination is executed to report the collected data from the sensor to the actuator nodes. Finally, the actuator-actuator coordination is executed to perform the appropriate action by negotiation with the other actuator nodes [15]. Thus, WSANs produce three important operations, namely the event-sensing, the decision-taking and the acting in the event area.

The coordination depends on the network architecture. In the semi-automated architecture, the coordination is ensured by the

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base station, which is responsible for monitoring and managing the overall network. With this architecture, the sensor nodes send the collected information to the base station controller that produces control commands and sends them to the actuator nodes to perform the appropriate actions. The coordination in the automated architecture is provided without the existence of a central controller [1,15]. Our framework focuses on the last approach because the automated architecture is more efficient, in which the detected event is sent directly to the actuator nodes allowing more rapidity in reaction.

As in WSNs, it is critically important to save energy. Several protocols have been proposed to reduce the energy consumption and to maximize the network lifetime [19–21]. WSANs are mainly deployed for critical frameworks, where a short delay reaction to the event is highly required. This requirement is imposed by several types of applications, such as remote medical systems, fire detection systems, industrial monitoring applications, intruder tracking, as well by many other applications. In such systems, timely delivery of the sensed data plays a crucial role in order to react immediately with the appropriate action. Providing Quality of Service (QoS) requirements in terms of end-to-end delay is one of the most important target in such networks, since the actions are performed on the surveillance field immediately after the event occurs. In WSANs, optimizing end-to-end delay and energy consumption must be achieved in order to ensures QoS requirements, since routing decisions can impact the whole network. In this context, many open researches have been discussed in the literature (kindly, refer to [1]).

In this paper, we propose an energy efficient and QoS aware routing protocol for WSANs providing low delay and energy consumption. We organize the network in clusters, where each cluster is supervised by a Cluster-Head (CH). We introduce a novel metric in the CH election process, which is the accessibility of the candidate sensor nodes regarding all the actuator nodes in the network. This metric represents the distance in terms of multi-hop between the candidate node and the actuators. Beside this important metric, the sensor nodes with high energy capability and riches in connectivity will be prioritized. The riches of connectivity represents the riches in terms of neighbor node number. The latter metrics improve the reliability of the network by reducing the communication delay when alerting the actuator nodes, and hence, reducing the energy consumption. We also address the sensor-actuator communication and we propose an on-demand routing-based data communication protocol, which allows to reach the actuator nodes with minimum delay and reduced energy consumption. We perform an overall evaluation of our approach with comparison to other concurrent approaches through simulations. The obtained results show out performance of our approach while providing effective gain in terms of communication delay and energy consumption.

The rest of the paper is organized as follows. In Section 2, we present the related works on clustering and routing for WSANs. In Section 3, we give the detailed description of our framework. In Section 4, we present the results of performance evaluation, and finally in Section 5, we conclude the paper.

2. Related work

In the literature, there have been many protocols proposed for WSNs that cannot be directly applied in the context of WSANs due to the heterogeneous nature of the network. WSANs introduce several open research challenges [1,15,17]. In this section, we review some relevant routing solutions based on clustering in Section 2.1, and some relevant approaches that have addressed uniquely the routing aspect in Section 2.2. In Fig. 1, we classify the reviewed solutions, and finally, we give in Section 2.3 an overall analysis, in which we highlight our contributions regarding the literature.

2.1. Cluster based routing solutions

In [7], Melodia et al. have proposed a distributed coordination framework, which is an event-driven clustering paradigm. The clusters are created on-the-fly and only when necessary to provide reliability with low latency and minimum energy consumption.

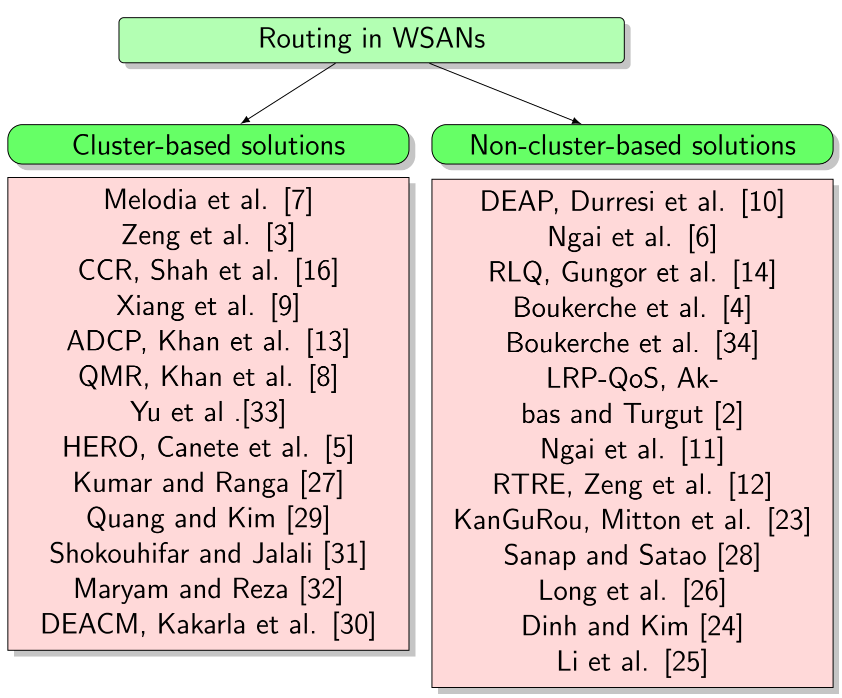

Fig. 1. Classification of the existing solutions.