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Performance evaluation of a WSN system for distributed event detection using fuzzy logic

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ABSTRACT

The research field of event detection in realistic WSN environments has attracted a lot of interest, with health monitoring being one of its most pronounced applications. Although efforts related to the healthcare applications exist in the current literature, there is a significant lack of investigation on the performance of such systems, when applied in error prone and limited resource wireless environments. This paper aimed to address this need by porting a Fuzzy Inference System (FIS) to a WSN simulation framework. The considered FIS is implemented on TelosB motes and evaluates the health status of a monitored person, in an energy conserving manner. A distributed implementation of the above FIS is also proposed, comprising an additional contribution of this paper, based on an objective function, attempting to reduce the network congestion and balance the energy consumption between network nodes. This work presents a thorough performance evaluation of the FIS under the distributed and the centralized approach, while varying the communication conditions and highlighting the advantages of the distributed execution of the FIS, leading to packet loss gain and transmission gain up to 67% and 25% respectively. The networking benefits from the distributed approach are reflected to the FIS performance. Respective results and comparative evaluation against Matlab simulations reveal strong dependencies of the application's performance to critical WSN network parameters.

1. Introduction

In recent years, Wireless Sensors Networks (WSNs) have emerged as a promising research field and have been used in a wide variety of applications including industrial control, environmental monitoring, and healthcare applications. The primary objective in such WSN applications was the accurate and reliable monitoring of an environment, based on the processing of the sensors values and the identification of irregular situations or dynamic real life events. The collaborating monitoring tasks lead to specific action scenarios, so as to control the monitored environment. The process of observing a real phenomenon and evaluating its behavior is known as event detection in WSNs [1].

Generally, the real events can be distinguished in two categories: single modality and multi-modality events [2]. The former concerns the examination of the values of each parameter separately, and based on the assumption that if any of these exceed a specific "normal" range, an event occurs [3]. The latter category includes the multi-modality events which are based on the correlation of several attribute values, the processing of whom indicates the occurrence of an event [4]. The target of event detection in WSN focuses on energy saving, data integrity and deeper

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insight into the monitored environment. Therefore, the development of a classification model is essential for the accurate recognition of an event, along with the reduction of the communication overhead.

The classification of an event can be defined as the process of evaluating an event of interest using multiple sensor nodes (multi-modality event). This processing may vary from a trivial rule engine machine to a complex machine learning algorithm, while the final outcome of this process triggers specific action scenarios. From this perspective, the classification of an event is strongly connected with the communication conditions between the actuation units in order to optimize the monitoring and control of the environment.

More specifically, considering an application which is based on single-modality events when a sensor value exceeds an upper/lower bound (i.e. temperature in an environmental monitoring application), this indicates the generation of an event (i.e. fire alarm). However, in many cases, such decisions may lead to false alarms, since most of the events depend on multiple monitored parameters. In the fire alarm example, an accurate decision should take into consideration the existence of smoke and luminosity level along with the temperature value. Alarm situations trigger specific reactions and thus, node to node communication (actor-to-actor coordination schemes) [5]. Therefore, false alarms will lead to an application's performance degradation, as well as to an increase of network traffic and energy consumption. Hence, the need for more sophisticated multi-modality classification processes arises that will optimize the application's accuracy and will avoid redundant communication among the actuation units. Considering also that the communication modules are the most energy consuming components of a sensor node, the lifetime of the node and the network's health status is anticipated to be increased respectively. In that respect, the utilization of classification algorithms [6] (i.e. Fuzzy Inference Systems-FIS), in WSNs regarding the identification of complex events is crucial in achieving the aforementioned objectives.

Existing data mining techniques can offer several algorithmic solutions [7] to this field. However, they require high processing capabilities and abundant memory availability, in order to satisfy specific execution time limitations. Such assumptions contradict to typical WSN characteristics, where the sensor nodes suffer from limited processing power and available memory. The aforementioned characteristics, in combination with the error prone nature of wireless communications, raise the challenge for designing distributed, highly efficient, yet low complexity and low resource-demanding data mining algorithms in WSNs. As a result, in realistic WSN applications, the distributed implementation of these computational intensive-algorithms proves to be highly beneficial toward balancing CPU load among several nodes. In addition, the distributed implementation of an algorithm increases onsite processing, and can potentially reduce the number of transmissions, leading to bandwidth saving and network relaxation.

Moreover, the performance of these algorithms in WSNs effectively pertains to the network's QoS metrics. An indicative example could concern the case where, the outcome of the classification process is extracted using invalid inputs. This could be caused by several factors, i.e. the input values may not be up-to-date because of some transient problematic network conditions, such as network congestion, resulting to increased packet loss and delay, or node mobility leading to network dis-connectivity. Traditional data mining approaches do not consider these problems. Specifically, the input data are assumed to be always valid (in time and without errors), while the execution delay is assumed negligible due to abundant processing resources.

This work offers a comprehensive study of these problems under a WSN environment and propose a framework enabling application of existing data mining algorithms in the WSNs, considering the distributed processing power, the communication cost, and the algorithm's sensitivity to invalid inputs. Hence, we study a fuzzy logic system in a healthcare scenario by simulating a realistic WSN infrastructure characterized by significant communication challenges. In our previous work [8] a centralized implementation of this system was presented, where a TelosB mote was considered as a cluster head, being responsible for the reception of all the generated packets and the FIS execution. The evaluation results proved the sensitivity of the system's performance to the networking conditions and the cluster head's overloading. Driven by these observations this paper addresses the lack of a comprehensive study on implementing in an efficient way data mining algorithms for WSNs applications. Toward this objective, this work investigates the FIS's performance under two different scenarios: centralized and distributed execution. As the centralized approach is characterized by unbalanced CPU and communication workload among the sensor nodes, we propose a distributed approach to split the execution of the FIS among the nodes, trying to optimally balance the energy consumption between the nodes and diffuse the network traffic avoiding the all-to-one communication scenarios. Moreover, we try to explore how the wireless channel conditions, the network topology (1-hop and multihop routing paths) and the packet arrival rate affect the overall performance of the FIS and the final outcome of the system.

The contribution of this paper is threefold. Firstly, to the best of our knowledge it is the first attempt for an online execution of a fuzzy logic system considering the limitations and the restrictions of a WSN infrastructure. We implemented a centralized health FIS in a well known WSN platform, and port the Matlab oriented algorithms–Mamdani's model [9], fuzzy max aggregation, max implication, centroid of the graph defuzzification method [10] to C based functions which are able to be executed on a TelosB platform, taking into account the processing and memory resources. Secondly, a comprehensive comparative study and evaluation effort is presented, concerning the execution of the FIS following a centralized and a distributed approach, trying to allocate efficiently the CPU and communication workload over multiple nodes. For the task distribution we considered an objective function, which is based on the CPU workload of each task, and the communication cost that the network topology