Signal Processing 126 (2016) 77–86

Contents lists available at ScienceDirect

Signal Processing

journal homepage: www.elsevier.com/locate/sigpro

Estimator Goore Game based quality of service control with incomplete information for wireless sensor networks

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ARTICLE INFO

Article history:
Received 25 July 2015
Received in revised form
16 November 2015
Accepted 22 November 2015
Available online 11 December 2015

Keywords:
Wireless sensor networks
Quality of Service
Goore game
Incomplete information

ABSTRACT

Quality of Service (QoS) control is one of the key mechanisms to ensure the effective operation of wireless sensor networks (WSNs). In many specific applications such as battlefield communications, the optimum number of sensors sending information at any given time is an important QoS requirement. For such requirement, some Goore Game based QoS control approaches have been exploited to dynamically adjust the number of active sensors to the optimal one in the literatures, but they assume that the optimum number is known to the base station explicitly, and each method has its own shortcomings.

In this paper, a novel approach is proposed to solve the QoS control problem. A framework for solving such problem is firstly proposed, in which the optimum sensor number is not known in advance but learnt by interacting with upper level applications in a reinforcement manner. On this basis, an algorithm named Estimator Goore Game (EGG) is designed to adjust the number of active sensors effectively. The proposed algorithm cannot only relax the above assumption, but also has a competitive performance. Furthermore, the algorithm is also applicable for both stationary and non-stationary environments. Simulation results on the convergence time, the network life and the ability of tracking dynamic QoS have demonstrated the effectiveness of the proposed algorithm.

1. Introduction

Wireless sensor networks (WSNs) are designed to gather information about the state of physical world and transmit sensed data to interested users, and have been widely applied to many scenarios such as health care monitoring [1,2], battlefield communication [3], space exploration [4,5], and event detection [6]. While WSNs have a broad prospect of applications, due to the limitation of each node's computing ability, communication ability, caching ability and power supply, transmission of data in such applications entails both energy and Quality of Service (QoS) support in order to ensure efficient usage of the sensor resources and effective access to the gathered information [7]. Over the past decades, some important aspects of WSNs such as architecture and protocol design, energy conservation, and locationing have been extensively studied [8]. However, little attention has been paid to supporting QoS and there is currently no standardization on framework or general guidelines in the networking community on how QoS can be achieved in WSNs [9]. With the emergence of more and more critical, multimedia and real-time applications, QoS control is becoming an emergent issue that should be addressed.

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http://dx.doi.org/10.1016/j.sigpro.2015.11.021
0165-1684/

It is well known that QoS is an overused term with various meanings and different technical communities may interpret QoS in different ways [10,8]. Conceptually, the term QoS can be regarded as the capability to provide assurance that the service requirements of applications can be satisfied [11]. It is intuitive that different applications may have different QoS requirements. In the case of many specific applications such as battlefield communications and space exploration, due to sensor death or replenishment, the number of active sensors is an important QoS requirement parameter.

For such situations, Iyer and Kleinrock [12] suggest defining the QoS of sensor networks as the optimum number of sensors that should be sending information to a base station (or sink node) at any given time. Based on this QoS definition, under the assumption that the optimum number of the active sensors is known to base station in advance, [12] proposes a QoS control approach, in which the base station communicates QoS information to each of the sensors by using a broadcast channel and the mathematical paradigm of the Goore Game is exploited to dynamically adjust the number of active sensors to the optimum. However, the original Goore Game approach in [12] is not power-aware, and once the WSN reaches the optimum number of active sensor nodes in the system, those active sensor nodes will remain active for every subsequent epoch until their battery power is depleted or the QoS requirement (optimum number of active nodes) is changed. To solve this problem, several improved approaches are presented with the same assumption above [13–17]. Network life is concerned and the definition of *network life* is provided in [13]. Zhao et al. [14] devoted to maximize the lifetime of network by having sensors periodically power-down to conserve their battery energy. The sensors that are in deep sleep states can power off their MCU (Micro-Controller Unit) and radio system, and a timer is utilized to control the time length of the deep sleep. Ayers [15] developed the original Goore Game model to further address the power consumption problem. Three new mechanisms are introduced into the game: player rotation, proactive referee, and unambiguous reward/punishment. In [16], convergence time and convergence range is improved significantly by using flags to exclude redundant sensors from the game. However, the drawbacks are also obvious, when the desired QoS changes with time or sensor nodes deplete, the algorithm appears to be less attractive, and it leads to the imbalance consumption of system energy further. Adaptive Periodic Goore Game is proposed in [17], the Goore Game is reapplied periodically to alleviate the unbalance of energy consumption, and also the idea of unambiguous reward/punishment is borrowed from [15] to accelerate the convergence. But the periodic restart of the game will lead to a periodical instable performance.

Considering that the approaches above assume that the base station knows explicitly how many active sensors will satisfy the QoS requirement of application, which is often unreasonable in many real environments, and that the approaches have their own other limitations, in the paper we propose a new framework for controlling the QoS with the aforementioned definition. In our proposed framework, the optimum number of the active sensors is learnt by a reinforcement manner, i.e., the upper level application will respond to the information collected by the base station and feed back a signal indicating whether the collected information is enough for supporting application or not. In addition, the approach designs an Estimator Goore Game (EGG) algorithm as an implementation of the proposed framework.

Our work presents a set of novel contributions that are summarized as follows:

1. In the existing QoS control approaches mentioned above, it is assumed that the optimum number of active sensors is known by the base station (or sink node) in advance. Instead, in our proposed approach, the optimum number is learnt in a reinforcement way. To the best of our knowledge, we present the first reported approach for the situation where the optimum number is not known explicitly, and that is the reason we call it *incomplete information* in the title.
2. We provide a rigorous analysis on the behavior of the proposed EGG under stationary environments. The EGG is proved to be able to converge to the required QoS within finite time in any stationary environment almost surely.
3. Simulation results show that our proposed approach outperforms all the existing approaches with regard to network life maintenance. For the proposed approach, all alive nodes can be efficiently employed to support QoS requirement.
4. It is rather fascinating to demonstrate that our proposed approach also possesses an excellent ability to cope with non-stationary environments which may be caused by QoS requirement change, sensor node being out of battery, sensor node battery recharging, sensor node redeployment, etc. In such situations, our approach can also exhibit a fast and accurate tracking ability.

The remainder of this paper is organized as follows. In Section 2, we establish the framework of QoS control for WSNs with incomplete information. On this basis, an Estimator Goore Game algorithm is designed and its behavior is analyzed in Section 3. We run simulations and the results are presented in Section 4, various aspects of analysis are also available in that section. Section 5 concludes the paper.

2. System model

In all the aforementioned literatures, it is assumed that the base station (or sink node) knows the optimum number of active sensors explicitly. However, this assumption holds in very limited circumstances. To be more general, we propose a modified framework to solve the QoS control problem.

Within the proposed framework, as shown in Fig. 1, an application-specific WSN system consists of geographically distributed sensors and a base station. Sensors gather information about states of the physical world and