Wireless Sensor Networks Control: Drawing Inspiration from Complex Systems

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Abstract— **Recent approaches on the study of networks have exploded over almost all the sciences across the academic spectrum. In this context, the analysis and modeling of networks as well as networked dynamical systems as the Wireless Sensor Networks have attracted considerable interdisciplinary interest. On the contrary, even with the unprecedented evolution of technology, basic issues and fundamental principles related to the structural and evolutionary properties of sensor networks still remain unaddressed and need to be unraveled since they affect the function of the network, offering self-properties, such as self-organization, self-adaptability, and so on. This work in progress tries to explore simple models of complex networks from wireless sensor networks perspective, focusing on their structural and evolutionary properties. The constraints, vulnerabilities and requirements of sensor networks drive the necessity to develop new theoretical frameworks to help explain their complex and unpredictable behaviors based on the complex systems' principles, and design alternative network control methods and techniques which may be provably effective and robust.**

I. Introduction

Nowadays a great emphasis has been given to self-organized and self-adaptable networking structures like the Wireless Sensor Networks (WSN). A WSN consists of hundreds or thousands of tiny, low-cost, low-power sensor nodes which are densely deployed and usually work unattended or with little or non human intervention. Sensor nodes are able to interact with their environment by sensing or controlling physical parameters and collaborate to fulfil their tasks since a single node is incapable of doing so on its own. The fundamental aim of a wireless sensor network is to produce globally meaningful information from raw local data obtained by individual sensor nodes. Increasingly, the success of this mission relies on two equally important key goals. The first goal is to save energy for maximizing network lifetime and the second one is to maintain connectivity between nodes for reliable transfer of the information sensed.

A WSN is constrained by computation capability, memory space, communication bandwidth, and energy supply. The unpredictable nature of traffic load variations, link capacity fluctuations, topology modifications, node failures or various types of intentional misbehavior may lead to network congestion. In particular, there are two main causes of congestion in WSNs. Firstly, congestion occurs whenever the aggregated incoming traffic load exceeds the outgoing channel capacity. This is more likely to happen at nodes which are close to the sink. Secondly, congestion may be caused due to channel contention and interference in the shared communication medium. The time varying nature of the outgoing channel leads to fluctuating and unpredictable congestion levels. The problem is worsened in the cases of high density deployment.

Congestion causes energy waste, throughput reduction, and information loss leading to the deterioration of the quality of service (QoS) offered by the network and to the decrease of the overall network lifetime. This stressful situation is more likely to occur in wireless ad-hoc and sensor environments due to the nature of the system and the possible scenarios of operation (e.g., event-driven traffic load). Under these circumstances, there is an imperative need to effectively and efficiently manage the emerged crisis. This can be carried out by addressing congestion with appropriate mechanisms or algorithms which will strive to prolong the network lifetime and provide adequate levels of QoS according to WSN users/applications demands.

II. Related Work

Over the last few years, many protocols and implementations have been developed for congestion control in wireless sensor networks. The overwhelming majority are based on traditional methodologies and protocols known from the Internet. Among them, Fusion [1] detects congestion based on queue length and channel contention at intermediate nodes. CODA [2] uses a combination of the present and past channel loading conditions and the current buffer occupancy to infer congestion. SenTCP [3] uses local packet inter-arrival packet time, service time and buffer occupancy to detect congestion.

III. Complex Systems in General

The complexity of modern network information systems has reached a level that puts them beyond our ability to deploy, manage and keep functioning correctly through traditional techniques. Part of the problem is due to the sheer size that these systems may reach with a large number of users and heterogeneous interconnected devices. The other aspect of the problem is due to the extremely complex interactions that may result among components even when their numbers are modest. What is required is a paradigm shift in confronting the complexity explosion problem to enable building robust and adaptive network information systems that are self-organizing and self-repairing. In this context, the study of complex systems gives a promise for the future.

Complex systems is a new field of science that cuts across many diverse disciplines as, for example, computer science, mathematics, sociology, etc. Complex systems science studies how elements of a system give rise to the collective behaviors of the system, and how the system interacts with its environment. Qualitatively, to understand the behavior of a complex system one must understand not only the behavior of the constituent elements but also how they act together to form the behavior of the whole. Increasingly, these systems are described as decentralized, self-organized and robust 'networks'. The field of complex networks focuses on certain questions about elements (nodes or hosts), wholes (networks) and relationships (links, information dissemination). These questions are relevant to all traditional fields. The study of most complex networks has been initiated [4] by the desire to understand various real communication networks as, for example, wireless sensor networks. In fact, in the last few years it became clear that in spite of the inherent differences, most of real communication networks as, for example, the Internet [5] and the World Wide Web (WWW) [6] are characterized by similar topological properties as the complex networks structures.

IV. Nature and Biologically-Inspired Systems

Complex networks can draw inspiration from natural and biological processes and mechanisms to develop techniques and tools for building robust, self-organizing and adaptive network information systems as ensembles of autonomous agents. The study of nature and biologically-inspired systems relies primarily on swarm intelligence [7], the artificial immune system [8], evolutionary (genetic) algorithms [9], and cell and molecular biology based approaches [10]. First attempts are in progress to study the behavior of swarms of insects, typically ants and bees, and to adapt the discoveries to build more efficient sensor networks [11].

What renders this approach particularly attractive from a dynamic network perspective is that global properties like adaptation, self-organization and robustness are achieved without explicitly programming them into the individual artificial agents. Yet, given large ensembles of agents, the global behavior is surprisingly adaptive and can cope with arbitrary initial conditions, unforeseen scenarios, variations in the environment or presence of deviant agents. This represents a radical shift from traditional algorithmic techniques to those of obtaining the desired system properties as a result of emergent behavior that often involves evolution, adaptation, or learning.

V. Our Direction

Congestion control models and techniques intended for mobile wireless sensor environments need to integrate tolerance as well as some basic self-* properties such as: (a) Robustness (error tolerance) that allows to withstand or tolerate stress, perturbations or variations in their internal structure or external environment without malfunctioning, but without in any way durably changing either its structure or its dynamics; (b) Resilience that allows to absorb and utilize or even benefit from perturbations and changes that attain them, and so to persist without a qualitative change in the systems structure; (c) Self-organization for evolution into an organized form in the absence of external pressures as a response to the system's environment; (d) Self-healing capability that allows to detect, localize, and repair failures automatically; (e) Self-optimization focusing on the optimal choice or tuning of different parameters based on the system behavior; (f) Self-adaptation to changing environmental conditions.

Beyond mathematical (analytical) models, complex system considerations in general and natural/biological approaches in particular involve the aforementioned properties and may hopefully be used to address network control in an effective manner. Complex system approaches provide a strong research framework within which to study the interactions between the components of a system, and how these interactions give rise to the function and behavior of that system. Further investigation of the nature inspired concept will lead us to develop techniques that extract hypotheses about interaction networks which can be further applied for the control of stressful overload conditions in challenging sensor environments.

VI. Conclusion and Future Work

Motivated by recent studies on complex nature and biological systems, we are planning to adopt and apply the underlying principles, especially for robust and adaptive self-organization and in a wider sense for network control. Our aim is to explore the use of ideas derived from complex adaptive systems in the context of highly dynamic sensor network environments. Further elucidation of the complex system concept will lead us to develop techniques that extract hypotheses about interaction networks which can be further applied for the control of stressful conditions in these networks.

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