



A data delivery framework for cognitive information-centric sensor networks in smart outdoor monitoring



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ABSTRACT

Cognitive information-centric sensor networks represent a paradigm of wireless sensor networks in which sensory information is identified from the network using named-data, and elements of cognition are used to deliver information to the sink with quality that satisfies the end-user requirements. Specialized nodes called Local Cognitive Nodes (LCNs) implement knowledge representation, reasoning and learning as elements of cognition in the network. These LCNs identify user-requested sensory information, and establish data delivery paths to the sink by prioritizing Quality of Information (QoI) attributes (e.g., latency, reliability, and throughput) at each hop based on the network traffic type. Analytic Hierarchy Processing (AHP) is the reasoning tool used to identify these paths based on QoI-attribute priorities set by the user. From extensive simulations, parameters that can be controlled to improve the values of QoI attributes along each hop were identified, and performance of the AHP-based data-delivery technique was compared with two traditional data-centric techniques in terms of lifetime and QoI attribute performance. It was found that the use of cognition improves the number of successful transmissions to the sink by almost 30%, while closely adapting the data delivery paths to the QoI requirements of the user.

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1. Introduction

Wireless Sensor Network (WSN) applications have evolved from catering to application-specific requirements, to supporting large scale application platforms such as smart cities and Smart Outdoor Monitoring (SOM) in public sensing [1]. These applications typically require a large scale, dense deployment of the sensor network, which generates a large amount of data. However, end-users may be interested in accessing specific information from the network (such as temperature in the north-east region of deployment, or issue pollen alerts for people with allergies). These 'smart' application platforms require the underlying WSN to not only gather information from the relevant information sources, but also prioritize and efficiently manage the heterogeneous traffic flows generated by the requests, and deliver information with quality that satisfies the end-user's requirements in terms of attributes such as reliability and latency. Providing a good quality of experience to end-users in such large-scale deployments requires a shift in focus from traditional address-centric communication abstractions to data-centric

routing and storage, where information from multiple, concurrent information sources produced anywhere in the network can be coherently delivered to the end-user.

Information Centric Network (ICN) is one such paradigm that focuses on content delivery, rather than the point-to-point information flow in the network [2,3]. It makes use of "named data objects" instead of IP addresses to gather data, thus decoupling information source from its location or node identification. ICN is touted as the future technology for content delivery over the internet because of its ability to bring information to the network layer to improve communication efficiency. Moreover, using the information-centric approach in such a resource rich, static environment, positively impacts data delivery to the end-user. Data-Centric Sensor Networks (DCSNs) [4–8] are a parallel paradigm in WSNs where attribute–value pairs are used for named identification of sensed data. Although DCSNs existed much before ICNs, the limited resource and energy capabilities of sensor nodes, and their inability to adapt data delivery decisions to the dynamic network conditions decreased the popularity of this approach in WSNs. Later, with the introduction of the ZigBee standard [9], most of the data processing and communication tasks were off-loaded to relay nodes. However, this also led to a shift to a more address-centric approach for WSNs. Then, with need to enhance the multi-

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objective optimization and dynamic decision making capabilities of the network, increased research activity in the field of applying cognition to sensor networks. These cognitive sensor networks were able to achieve various goals such as making the sensor network aware of user requirements, reduce network resource consumption, and make the network exhibit self-configuration, self-healing and self-optimization properties [10–12]. Despite these advances, it still remains a challenge for sensor networks to differentiate traffic flows in smart environments, where the user requirements change over time. Sensor networks still lack the ability to adapt data delivery techniques to different traffic flows generated by the network. In addition, it is desirable to have the sensor network functioning as an information gathering network, to make it easier for users to make name-based requests, and for ease of adaptability to the future ICN.

To cater to all these requirements, we put together the idea of an information-centric approach from ICNs/DCSNs, along with the concept of cognition in this paper, and propose a Cognitive Information Centric Sensor Network (ICSN) framework-COGNICENSE. The information centric strategy is used to identify relevant sensed information from the network, and the elements of cognition (i.e. knowledge representation, reasoning and learning) are implemented at special nodes called Local Cognitive Nodes (LCNs) and Global Cognitive Nodes (GCNs), to enhance their information processing and intuitive decision making capabilities. GCNs interpret the user request for the network, and the LCNs help to identify appropriate return paths for data delivery. Relay nodes participate in information transmission over multiple hops, thus maintaining the network's scalability. End-user satisfaction is based on the Quality of Information (QoI) delivered to the sink [13,14], characterized by the attributes of latency, reliability, and throughput associated with the application specific traffic. Accordingly, we summarize our contributions in this paper as follows:

- i. We propose a framework called COGNICENSE that makes use of elements of cognition and an information-centric approach for data delivery in WSN applications for Smart Outdoor Monitoring (SOM).
- ii. We investigate three Quality of Information (QoI) attributes: latency, reliability and throughput. Based on simulations considering an IEEE 802.15.4 PHY-MAC model, we identify the parameters that affect these QoI attributes.
- iii. Using a multi-criteria decision making (reasoning) technique called Analytic Hierarchy Process (AHP), we show how the values of the QoI attributes obtained from the simulations can be used to make decision choices about the data delivery path that provides the best value of information at the sink (end-user).

The rest of the paper has been organized as follows: Section 2 reviews related work in literature. Section 3 provides the system models and problem description. Section 4 provides details about the proposed data delivery framework using elements of cognition, i.e. knowledge representation and inference. Section 5 provides simulation results and discussions, and we conclude the paper in Section 6.

2. Related work

The idea of focusing on information objects rather than the host of the information in communication networks is hardly new. Data-centric sensor networks in the wireless world and the TRIAD project [15] for the internet, described early forms of information centric networks, that aim to move away from the end-to-end communication paradigm and focus on the content being delivered

to the end user. In this section, we review DCSNs, and ICNs with respect to their network and design components, and implementation challenges. We also explore the use of cognition in wireless networks with respect to their ability to enable networks to adapt to changing environment conditions, and cater to end-user requirements as they evolve with the applications.

2.1. Information centric networks

Information centric network is an information-oriented communication model proposed for the future internet, to help with managing the huge amount of IP traffic being exchanged globally. Unlike traditional host-centric networks where data routing requires the establishment of single end-to-end path to the host, ICNs decouple senders and receivers by leveraging in-network caching [16,17] and replication of data. User requests for named data objects are addressed irrespective of the source of the publisher or the content's location. This is facilitated by the use of intermediate nodes, which are in-network devices that process and cache named data objects. Thus named data access, routing of requests and data, and information caching comprise the important features of ICNs, and the intermediate nodes play a very important role in implementing these features. These nodes will need to make smart decisions to coordinate their actions and decisions across the network, and also adapt to services and applications as they evolve. Despite the various ongoing research activities in ICNs, not much work is being done with regards to empowering the intermediate nodes to adapt dynamically to changes in the network and end-user behavior, to help them learn and evolve on their own.

2.2. Data-centric sensor networks

The DCSN approach is very similar to ICNs, in naming the sensed objects and in caching data as it is forwarded to the sink. One of the striking differences between DCSNs and ICNs in terms of the network components is that the DCSNs approaches consider only 2 types of devices in the network – sensor nodes and sink, whereas ICNs typically use 3 types of devices – publishers, subscribers and intermediate nodes. Some DCSNs do propose choosing sensor nodes as cluster heads and involve them in routing data to the sink [18], but this approach burdens the sensor node in terms of energy, data processing and memory capacities and affects the network lifetime and performance on the whole. What has not been explored much in DCSN is applying the ZigBee network model for DCSNs. ZigBee routers are a better choice in terms of conserving sensor's energy and making routers available for more functions such as information processing, routing and data caching. ZigBee topology is a big energy saver in terms of off-loading the burden from sensor nodes. Another aspect that has not been explored much in DCSNs is the ability to deal with heterogeneous traffic flows generated in the network as a result of the different request that the network receives. The request could be event-driven, time-driven, query-driven or a mix of any of these types [19]. Most DCSNs deal with one type of traffic, typically query-driven traffic. However, the challenge is in enabling the network to deal with all types of requests and provide satisfactory service to the end-user while adapting to changing network conditions and application requests at the same time [20]. But just as the case with intermediate nodes in ICNs, routers in DCSNs would be burdened with too many responsibilities, if they had to carry out all these function and are not empowered with techniques to deal with them effectively. Hence we look at the possibility of introducing cognition in the routers of the DCSNs.

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