Cooperative Sensing with Semantic Stream Processing

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I. Motivation

This thesis is motivated by the challenge of effectively utilizing real-time sensor data in the IoT. The imbalance between vast data volumes and users' time-sensitive needs necessitates a shift from simplistic cloud-based approaches. The rise of IoT expose this issue, prompting the exploration of Fog/Edge Computing paradigms. This thesis seeks to leverage semantic technologies to enable autonomous, cooperative sensing at network edges, enhancing data discovery and exchange amidst sensor data heterogeneity. The fusion of Fog/Edge computing and semantics holds the promise of optimizing information processing in dynamic sensor environments.

II. Research Questions and Objectives

A. Problem Statement

In a centralized IoT system model, Edge devices primarily collect data but often remain idle, resulting in resource wastage and several issues:

a) The incorporate of sensors: Data collected from diverse sensors is stored and transmitted individually, reducing reliability due to uncertainty and inaccuracy [1].

b) Sensing Operations: Regular IoT systems trigger data collection either continuously or on fixed schedules, causing redundancy or missing data. Basic raw data storage leads to memory and resource redundancy, while complex data processing on the cloud requires excessive time and resources.

c) Cooperative Optimization: Inadequate communication among independent Edge devices results in inefficient resource utilization, bandwidth wastage, and sub-optimal system performance. [2]

All the problems and challenges above lead to the following research questions need to be addressed:

- Sensor Data Integration: How can multiple sensors and their data be effectively integrated to ensure sufficient and reliable data?
- Efficient Edge Processing: What optimized methods can be implemented on Edge devices for stream data processing, storage, and querying, along with enhancing system efficiency?
- Cooperative Sensing Integration: What techniques can be developed to enable Edge devices to collaborate effectively, optimizing resource utilization and system performance?

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B. Objectives

To address the above problem, I propose to build a general solution for the IoT system which will support solving all the above problems so-called "Cooperative sensing with semantic stream processing" with a clear and concise approach:

a) Pushing Sensor Fusions to The edges: Develop a sensor fusion approach optimized for Edge devices. This method will enhance data accuracy by combining inputs from multiple sensors, reducing latency, and minimizing unnecessary data transmission.

b) Federating Multi-modal Sensing Operations: Design intelligent data collection techniques for improved efficiency. Implement selective, event-triggered data collection to minimize unnecessary sensor operations. Utilize standardized data formats for stream storage and retrieval. Employ compression methods to reduce storage requirements and facilitate quick data processing. Optimize data transfer by responding only to server requests and queries.

c) Cooperative Optimization: Maximizing cooperative capabilities among Edge devices. Establish interconnected Edge systems that leverage the strengths of each device, enhancing overall system performance while making the most of available resources.

III. Methodology

To address the research questions and achieve the objectives, I have proposed a design for a declarative programming model for ROS, incorporating Semantic Stream Reasoning and Knowledge Graph in [3]. This design is illustrated in Figure 1, and the thesis will be divided into three interrelated research tasks.

A. Pushing Sensor Fusions to The Edges.

The semantic stream model is a recursive model that allows processing agents to delegate data fusion subtasks to connected edge devices. The agent can do this by sending continuous