Towards Semantic Reasoning on the Edge of IoT Systems

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ABSTRACT

Edge computing paradigm moves computation from the Cloud to the edge of the network. We study the benefits of computing at the edge with semantic reasoning. We present our experiments on deploying semantic reasoners on edge nodes and perform reasoning latency and scalability analysis with a real-world smart city scenario.

Author Keywords

Edge Computing; Semantic Reasoning; Analysis.

ACM Classification Keywords

I.2.3. Computing Methodologies: Inference engines.

INTRODUCTION

Internet of Things (IoT) systems typically gather large quantities of data that is generated by things and can be processed, visualized, and possibly acted upon. Edge Computing enables moving this computation from the central high powered Cloud to the edge of the network. Shi et al. define edge computing as the enabling technologies allowing computation to be performed at the edge of the network, on downstream data on behalf of Cloud services and upstream data on behalf of IoT services [1]. The benefits of edge computing result from its proximity to data sources and end users. It has the potential to address the following challenges: 1) low and predictable latency for end users and applications; 2) secure and privacy-preserving services and applications; 3) long battery life and low bandwidth cost; and 4) scalability.

The processing performed independently by a local node depends on the studied phenomena. For instance, if a traffic jam is stretching over two edge node's areas, data from these nodes needs to be aggregated before the traffic jam can be analysed. Sparse events covering multiple edge node's areas can be challenging to analyze at the edge. For instance, if a car model has a characteristic and rare problem, this might not be a statistically relevant event in local data. MAUI [2] and Cloudlet [3] are early efforts for efficient processing of data that is produced at the edge of IoT. Our research focuses on deploying semantic reasoning components on Cloud and edge nodes. We carry out

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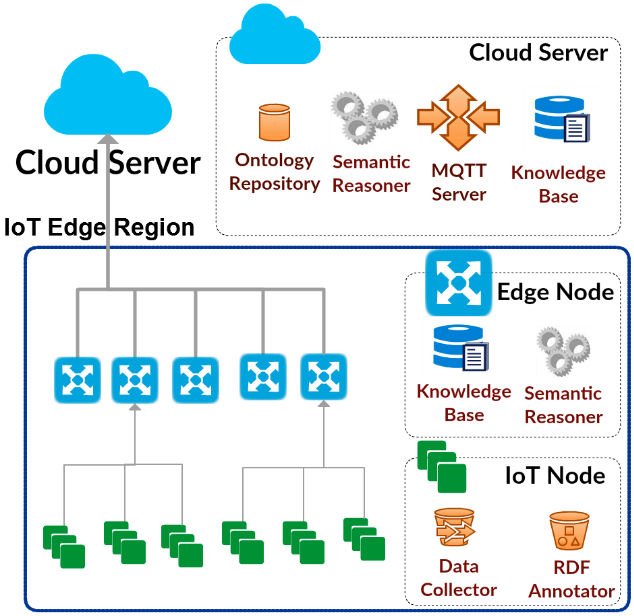

Figure 1. An experimental IoT architecture for semantic reasoning on the edge of IoT.

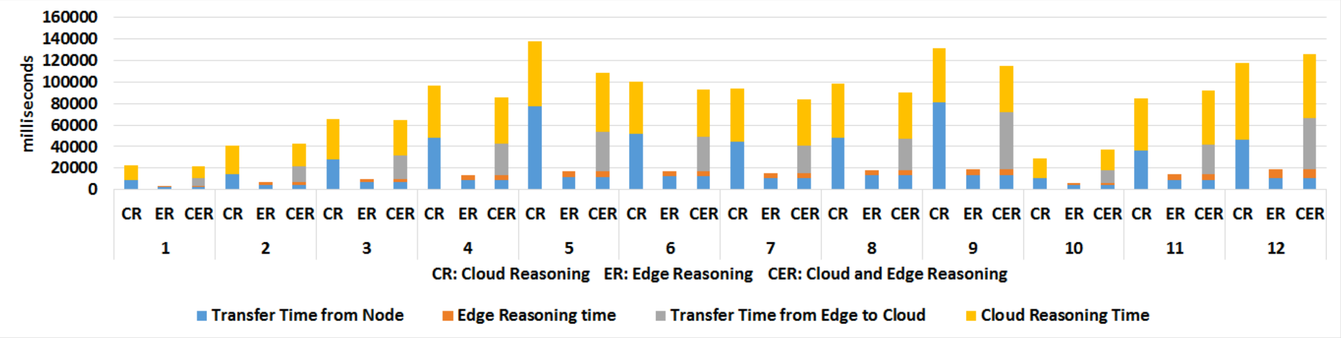

Figure 2: A latency comparison of Cloud Reasoning and Cloud&Edge Reasoning.

experiments to analyze the whole process of delivering IoT data and reasoning on edge nodes and Cloud, based on a real-world smart city scenario.

EXPERIMENTAL IOT ARCHITECTURE FOR SEMANTIC REASONING IN EDGE COMPUTING PARADIGM

Figure 1 presents our IoT architecture that consists of resource-constrained IoT nodes, edge nodes, and a Cloud server. IoT nodes deliver data to edge nodes and further to the Cloud server, depending on the capability of edge nodes. Edge nodes and the Cloud server process IoT data with the knowledge base and semantic reasoner. Computing capability on the Cloud outclasses the capability of the edge nodes. Thus, a small set of reasoning rules are executed on the edge nodes. This architecture enables processing the data with semantic technologies, capturing the insights, and making decisions at the edge of the network – without the need to transport large amounts of data to the Cloud and to transport the decision back to the edge.

ANALYSIS

In our experiments, we focus on the latency of reasoning and data communications when the number of connected IoT nodes and the data volume sizes are increased. We assume that one edge node gathers data from ten IoT nodes. In the scenario, traffic situations are deduced from real GPS location, acceleration, car direction, velocity, etc data. A rule-based semantic reasoner is designed to acquire knowledge from traffic data. Rules are used to infer over temporal relationships between sequential observations received from multiple sensors. The knowledge acquired from the sensor data describes traffic jams, taxis turning left, right, and making U-turns, taxis speeding and stopping for a long time, taxis accelerating and decelerating strongly, and areas where taxis stop often for a while. We use Jena reasoning framework and Amazon EC2 Cloud server. Our rules and ontologies used are available from [4]. Figure 2 presents a latency comparison of Cloud Reasoning (CR) and Cloud & Edge Reasoning (CER) in detail. In CR, each IoT node sends data directly to Cloud reasoners. Edge Reasoning (ER) deduces knowledge with two selected rules. CER deduces new knowledge in the Cloud server with full rules from the knowledge generated with ER and part of the raw data. The twelve different setups are presented on X-axis (Fig. 2). Two to ten mobile devices act as edge nodes and the size of the RDF data varies from 8000 to 48000 triples. When the edge nodes are able to execute selected rules, ER latency is only on average 15.6% of CR latency. In CER, the latency (including data transfer latency from IoT nodes to Edge nodes, data transfer latency from Edge nodes to Cloud, and semantic reasoning time) is about 94.1% of CR latency. Bandwidth usage scales linearly with payload size. When edge nodes execute semantic reasoning, about 9.3% of network bandwidth is saved. However, CR and CER are quite close to each other, in some setups CER is even slower. This is our first experiment and more work is needed to study how reasoning should be distributed to get the best results.

CONCLUSION

This poster presents our first results for studying semantic reasoning on edge nodes in IoT systems. We present analysis regarding latency and scalability in our experimental architecture. Our experiments verify that reasoning at the edge can reduce reasoning latency and network bandwidth usage. Future research involves more complex experiments and optimizing communication and reasoning efficiency, based on different requirements and metrics of IoT systems.

REFERENCES

1. Shi, W., Cao, J., Zhang, Q., Li Y. and Xu L. Edge Computing: Vision and Challenges. *IEEE Internet of Things Journal 3,* 5(2016), 637-646.
2. Cuervo, E., Balasubramanian, A., Cho, D., Wolman, A., Saroiu, S., Chandra, R. and Bahl, P. MAUI: making smartphones last longer with code offload. In *Proc. MobiSys 2010,* ACM Press (2010), 49-62.
3. Satyanarayanan, M., Simoens, P., Xiao, Y., Pillai, P., Chen, Z., Ha, K., Hu, W. and Amos, B. Edge Analytics in the Internet of Things. *IEEE Pervasive Computing 14*, 2(2015), 24-31.
4. Maarala, A.I., Su, X. and Riekki, J. Semantic Reasoning for Context-aware Internet of Things Applications. *IEEE Internet of Things Journal*. In press.