Vision and Challenges for Knowledge Centric Networking (KCN)

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Abstract—In the creation of a smart future information society, Internet of Things (IoT) and Content Centric Networking (CCN) break two key barriers for both the front-end sensing and back-end networking. However, we still observe the missing piece of the research that dominates the current design, e.g., lacking knowledge in the middle to glue sensing and networking holistically. In this paper, we introduce and discuss a new networking paradigm, called Knowledge Centric Networking (KCN), as a promising solution. The key insight of KCN is to leverage emerging machine learning techniques to create knowledge for networking system designs, and extract knowledge from collected data to facilitate communication with better controllability, improved quality of service, and lower cost. This paper presents the KCN design rationale, the KCN benefits and also the potential research opportunities.

I. INTRODUCTION

We have recently witnessed the proliferation of two emerging technologies that are evolving our sensing, computing and networking capabilities, to enable the vision of a smart future information society: Internet of Things (IoT) [3] and Content Centric Networking (CCN) [4]. The IoT technology strives to fundamentally advance the periphery of sensing and enables the scene that “every” physical object can be sensed for the data collection and exchange. Hence, the data-oriented nature emerges in the global information infrastructure. Aligning with this trend, the CCN technology is further proposed to augment the underlying networking services for the data exchange, tailored for the data-centric feature. CCN emphasizes on the data contents themselves and makes each piece of them directly addressable for routing, to avoid the limitations from traditional IP-based, host-oriented, networking mechanism.

These two technologies together overcome two key barriers for both the front-end sensing and the back-end networking in the creation of a smart information society for a variety of domains, like smart transportation, e-health, social networks, etc., and promising initial success has been achieved in the literature. However, we still observe a dominating challenge that remains unsolved to limit the further advance of the design — lacking of the knowledge in the middle (between sensing and networking) to glue them as an intelligent entirety.

With the increasing number of computing devices, networking systems tend to be larger in terms of the scale, so that more devices will pump data contents into the network. Big data, as a result, is a natural consequence, which could turn into harmful burdens due to the limited computing resources and networking capabilities. In addition, due to the user mobility and the diverse application domain needs, networking systems will also become more sophisticated in the operation. Given these challenges and facts, the traditional networking control and management approaches, mainly based on the manual intelligence and experience, will not be sufficient and flexible enough. Therefore, how to leverage such big data to get remarkable benefits, instead of viewing them as undesired burdens, becomes essential in the design.

In this paper, we introduce and discuss a new networking paradigm — Knowledge Centric Networking (KCN), that could serve as a promising solution. The key insight is to apply emerging machine learning techniques [2], e.g., deep learning, reinforcement learning, and active learning, to create knowledge for networking system designs [1], e.g., Internet, smart transportation, and social networks, due to their recent and great success in many other application domains, such as speech recognition, image/video processing, chatbot, visual dialog machine. The machine learning techniques could extract knowledge or develop intelligent strategies to automatically learn and gradually adapt to complicated and uncertain network conditions and dynamics. On the other hand, there already exists a large amount of data for training machine learning algorithms and distilling knowledge for KCN to facilitate communication with better controllability, improved quality of service, and lower cost. Therefore, we envision KCN as a rewarding solution to leverage machine learning to create knowledge and optimize networking system designs.

In the rest of this paper, we first introduce the nutshell concept of KCN in [III] and then discuss the potential research challenges and opportunities in [IV] before we conclude [V].

II. NUTSHELL OF KCN

The unique feature of KCN is the creation of “knowledge”, e.g., leveraging machine learning to create insightful knowledge to model, control and manage networking systems.

A. Match between KCN and machine learning

Machine learning techniques become increasingly popular and achieve remarkable success nowadays in many application domains, e.g., speech recognition, bioinformatics and computer vision. Machine learning is capable of exploiting the
hidden relationship from voluminous input data to complicated system outputs, especially for some advanced techniques, like the deep learning. Moreover, some other techniques, e.g., reinforcement learning, could further adapt the learning module to new environments and evolve automatically. These features perfectly match the complex, dynamic and time-varying nature of today’s networking systems. As a result, machine learning could serve as an ideal solution candidate to be adopted.

On the other hand, one practical challenge to utilize machine learning is lacking the input data. Benefiting from the IoT, a large amount of data is available for an immediate usage in various networking systems. Therefore, the KCN is expected to grasp this opportunity by the pervasive availability of voluminous data to significantly evolve existing networking systems.

B. KCN benefits

The KCN paradigm could benefit networking system design from three key perspectives, namely, modeling, control, and management. 

**Modeling.** Using machine learning, we can first build various models to deeply understand the input data and extract insightful features to unveil the hidden pattern, the complicated distributions and even the physical meanings behind the data. In addition, we can further leverage the model to guide the data preprocessing for the low-quality data removal, redundancy reduction, new data type acquisition, etc. Finally, we can also use the model to conduct the data prediction. The knowledge derived from this part can be either utilized in the input data processing directly or by other two aspects stated below.

**Control.** With the processed data contents, as well as certain knowledge exploited from the model already, we can further use machine learning techniques to develop new networking protocols for automatically adapting to the network resource and condition dynamics. In addition, the system could further self evolve to pro-actively adjusting networking settings for a better dynamic situation handling. Finally, the derived control logics could also provide useful feedback to intelligently guide the data content sensing to achieve a cross-layer and jointly optimized performance.

**Management.** In addition to the network control, we can also leverage machine learning techniques to conduct a more sophisticated and effective resource management, e.g., energy, computation and bandwidth, especially for the mobile and wireless devices. We can further enable the network service and quality assessment to provide an additional feedback loop for the control logic adaptation. Finally, we can also utilize machine learning to derive more secure and robust privacy perceiving mechanisms to protect end users’ privacy.

C. Summary of KCN

In summary, the KCN is positioned as a middle layer design (between sensing and networking), which contains a primitive knowledge library, covering model, control and management three categories. These primitives in each category can be easily expanded according to the evolving application needs, and can also be shared and leveraged cross different categories.

III. RESEARCH OPPORTUNITIES

Realizing the above KCN benefits entails tremendous challenges and research opportunities throughout big data collection, knowledge management, and network optimization.

A. Big data collection and processing in KCN

Machine learning techniques (e.g., deep learning, deep reinforcement learning) have achieved remarkable breakthroughs. Such techniques however need a large data set to train models and extract knowledge. The training process also involves high computational overhead. Although the increasing number of computing devices would pump more raw data into the network, how to collect relevant quality data and efficiently train models remain elusive. We envision that the data collection in KCN can benefit from current naming primitives and routing protocols of CCN. Machine learning techniques can leverage the CCN to flexibly specify interested data and collect the data set. The extracted knowledge can then serve as input data to other machine learning techniques. Distributed in-network processing promises to reduce network traffic and balance computational overhead.

B. Knowledge management in KCN

Knowledge management in KCN calls for innovative frameworks for knowledge representation, knowledge storage and retrieval, and knowledge transfer. Knowledge in KCN can be represented in different forms, e.g., insights into network dynamics, trained models, key parameters, raw data set. How to effectively represent such knowledge so as to efficiently store, retrieve, transfer the knowledge is challenging. We envision that knowledge as an asset would have different forms to meet various application requirements. For example, a machine learning based access control scheme can exploit a trained classifier as knowledge and directly incorporate the classifier in the control scheme. The control scheme can fetch a set of trained parameters as knowledge and embed them into its feature extraction algorithm. The control scheme can also use raw data set collected by other control scheme to train its model and extract knowledge.

C. Learning-based network optimization

Machine learning based network performance optimization may help better allocate network resources and adapt to network dynamics. Traditional network optimization methods often monitor network metrics (e.g., network throughput, latency, packet loss rates) and heuristically control networks according to handcrafted features extracted from the network metrics. Exploiting knowledge in KCN, machine generated control methods may challenge state-of-the-arts and inspire network scientists and engineers to revisit traditional design principles and better understand network science and engineering. The success of KCN would extend from network as information infrastructure to other complex networks, e.g., transportation network, social network, etc.
IV. CONCLUSION

In this paper, we introduce and discuss the KCN networking paradigm that could leverage the recent success from machine learning to advance and evolve the networking system designs for a smart future information society. We present the KCN design rationale, benefits and also the research opportunities.

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