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Learning methodologies for wireless big data networks: A Markovian game-theoretic perspective

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ABSTRACT

Wireless big data significantly challenges the current network management and control architecture, mathematical modeling techniques, and distributed algorithm design, in particular, in the promising cognitive, distributed, and ultra-dense networks. Motivated by the idea of divide-and-conquer, in this article, we first present a multiple cognitive agent-based divide-and-conquer network management and control architecture. Furthermore, a Markovian game-theoretic modeling framework is proposed to model the state big data-based decision-making problem. Then, we investigate various learning methodologies with respect to different kinds of the state information, in particular, we concentrate on the construction of state space, the state transition computation, and the convergence of parallel *Q*-learning technique. This work provides a suitable network management architecture, an effective modeling tool, and various learning techniques for wireless big data networks.

1. Introduction

Big data exists across all the players in wireless communications including the network equipment vendors, the mobile operators, and the users. This big data is always there, however, we have not fully exploited and explored the meaningful and powerful information. Volume, velocity, and variety are core characteristics of big data which must be taken into account when exploring its valuable applications to more effective network management and control. Big data is related to all walks of life [1]. Today, motivated by the proliferation of smart devices and mobile Internet service, wireless mobile networks are generating a huge amount of big data in the form of network measurements as well as network control and management interactions [2]. It is believed that the big data approach applied to the huge amount of information could yield significant benefits for all the players. Network equipment vendors could offer more competitive solutions, mobile network operators could improve their profit margins, and customers could get better service at lower prices [2]. Big data, with their promise to discover valuable insights for better decision making, have recently attracted significant interest from both academia and industry. Voluminous data are generated from a variety of users and devices, and are to be stored and processed in powerful data centers.

Recent 5G vision activities from all over the world have recognized that 5G mobile networks will feature as the green, cooperative, and cognitive one [3–5] and reference therein. 5G is expected to make even bigger data. Therefore, in this article we hold the perspective that the exploration of big data value in 5G era will make it more flexible, efficient, and green [6].

In fact, various big data approach and applications have been used in wireless communication networks [7,8]. Authors in [7] pointed out that dealing with spatial big data is a key challenge for many future wireless networking applications. Meanwhile, it is a distinct category from relational big data, implementation examples were provided with existing parallel data processing and computational frameworks, such as HBase and Hadoop. A traffic monitoring and analysis system for large-scale networks based on Hadoop were presented in [8], and this system had been deployed in the core network of a large cellular network and extensively evaluated. Collection, storage, and mining of bid data have their own challenges and peculiarities in wireless networks that do not always align with the relational database approach. Authors in [9] identified the major challenges big data applications bring to networking systems and discuss the state-of-the-art research efforts to meet the demand of big data over networking.

With the sheer size of data available today, big data brings big opportunities and transformative potential for various sectors; on the other hand, it also presents unprecedented challenges to harnessing data and information. Many of the most advanced big data

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applications involve the mining of heterogeneous datasets for otherwise-obscured knowledge, patterns, and relationships. Applying advanced machine learning algorithms and techniques from the field of artificial intelligence. However, the current algorithms do not scale well for big data network learning. Deep learning is currently an extremely active research area in machine learning and pattern recognition society. It has gained huge successes in a broad area of applications such as speech recognition, computer vision, and natural language processing. A novel elastic extreme learning machine based on MapReduce framework was proposed to cover the shortage whose learning ability was weak to the updated large-scale training dataset [10]. Authors in [11] proposed a novel parallel Bayesian network learning algorithm called parallel based Bayesian network learning.

As the data keeps getting bigger, deep learning is coming to play a key role in providing big data predictive analytics solutions. In [12], a brief overview of deep learning was provided, and highlight current research efforts and the challenges to big data, as well as the future trends. Applications involving large-scale dictionary learning tasks motivate well online optimization algorithms for generally non-convex and non-smooth problems. In this big data context, the authors in [13] developed an online learning framework by jointly leveraging the stochastic approximation paradigm with first-order acceleration schemes. As a consequence, authors in [14] proposed a new model for large-scale adaptive service composition, which integrated the knowledge of reinforcement learning aiming at the problem of adaptability in a highly dynamic environment and game theory used to coordinate agents' behavior for a common task. In particular, a multi-agent Q-learning algorithm for service composition based on this model was also proposed. Authors in [15] presented a learning automata-based adaptive uniform fractional guard channel algorithm, and authors in [16] concentrated on the reinforcement learning technique application to the agent state occurrence frequency with analysis of knowledge sharing on the agent's learning process in multi-agent environments, and [17] applied reinforcement learning to large state spaces.

Motivated by the idea of divide-and-conquer, in this article, we first present a multiple cognitive agent-based divide-and-conquer management and control architecture. Furthermore, a Markovian game-theoretic framework is proposed to model the state big data-based decision-making problem. Then, we investigate various state information dependent learning methodology, in particular, we concentrate on construction of state space, state transition probability, and distributed Q-learning technique.

2. Multiple cognitive agent-based divide-and-conquer management and control architecture

As we know, current mobile and wireless networks face a series of pressing challenges caused by the inherent design, which will be worse in 5G distributed, cognitive, and ultra-dense deployment of small cell networks. In this article, we extend two latest and promising innovations and ideas from Internet, network virtualization [18] and software-defined networking [19], to the 5G big data networks.

With the idea of wireless network visualization [18], in this article, we propose the management and control architecture. As a use case of the ‘divide-and-conquer’, we first introduce the mobile autonomous decision-making agent-based management and control architecture. An agent is a set of softwares, and these softwares will jointly accomplish specific tasks and functions. Meanwhile, nodes in networks can download it according to the actual requirements as shown in Fig. 1. Different nodes in the physical networks can be associated to the same agent. Each cognitive agent is with the capabilities of sense context state, analyze and establish the overall state space database. Based on this, agent predicts the possible action and the state transition. All above functions in a agent are summarized as the context awareness. Meanwhile, agent has more advanced learning, reasoning capabilities from the context awareness, and the strategy history. This is termed as the self-awareness in this article. Finally, agent concludes the most suitable control policy.

2.1. Functions of a cognitive agent

Fig. 2 summarizes the detailed controlling stream for each specific process control. There are totally two parts including the awareness and policy-making parts. Furthermore, the awareness part is divided into another two parts, which are the context awareness part and the self-awareness part.

2.1.1. Context awareness

Three steps are included in the context awareness part, which are the state detection, the state space establishment, and further state prediction based on its self-information and that from the other agents. First, each cognitive agent should be with the detection capabilities, then it can sense the context and strategies information from its opponents. As follows, each agent should infuse multiple kinds of awareness, information, and strategies to establish its own state space as the history. The most important

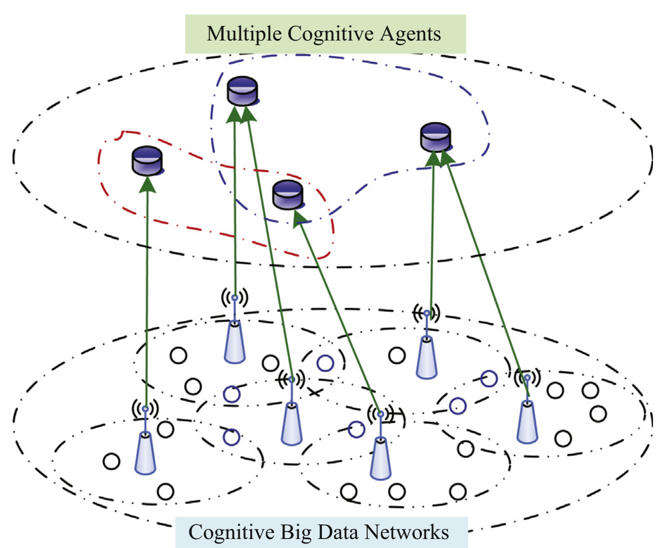

Fig. 1. Multiple cognitive agent-based divide-and-conquer management and control architecture.

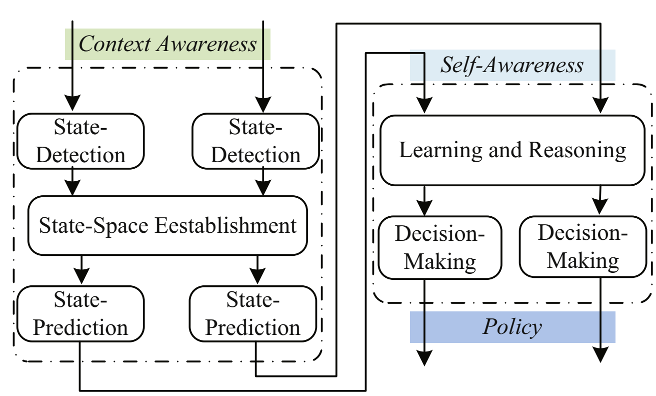

Fig. 2. Detailed decision process at each time slot.