Small Cell Networks and Machine learning - Survey

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Abstract - A small cell is a radio access point with power output, footprint, and range from low radio frequency (R.F.). It is operator- controlled and can be deployed indoors or outdoors and in the spectrum that is licensed, shared, or unlicensed. For 5G, the importance of small cells will be a crucial component, because they increase network capacity, density, and coverage, especially indoors. Machine learning (ML) can solve complex problems without explicit programming. Big data analytics has a remarkable feature, called scalability, that is, the ability to analyze data with ever-greater scale and complexity and motivated by its successful application to several practical tasks such as image recognition, both industry and the research community. The survey focuses on the architecture of small cells and virtualized small cells. Virtualized small cell adopts next- generation network architecture, responds to the telecom industry's needs by offering easy-to-install, high-performance, expandable functionality and a smooth migration to 5 G networks.

Key Words: Radiofrequency, Virtualized small cell, Machine Learning , Big Data

1.INTRODUCTION

Big Data also involves data collection, storage, retrieval, analysis, querying, and visualization techniques. With the advent of big data analytics, mobile cellular network operations can be less error, more reliable, complex. Due to the large scale of 5G systems, combined with their inherent complexity and heterogeneity, Big Data and analysis techniques are considered to be one of the primary providers of future mobile networks. Due to the large scale of 5G systems, combined with their inherent complexity and heterogeneity, Big Data and analysis techniques are considered to be one of the primary providers. Small Cell Networks Market is likely to play an essential role meeting future network requirements. For 5G Small cells, the importance of small cells will be a crucial component, because they increase network capacity, density, and coverage, especially indoors[1][2].

A small cell is a radio access point with power output, footprint, and range from low radio frequency (R.F.). It is operator-controlled and can be deployed indoors or outdoors and in the spectrum that is licensed, shared, or unlicensed. To improve coverage, add targeted power, and support new technologies and user experiences, small cells complement the macro network. There are various types of small cells, depending on the use case, with varying size, power level, and form factor. The most minor units are for residential use indoors; the largest are outdoor picocells in the urban or rural areas.

The increasing number of massive hotspot areas with demanding capacity and connection requirements has seen an increase in the popularity of small cell solutions. Low-cost small cells operating in the licensed spectrum have been widely regarded as the most promising solution to realize the enormous data capacity and meet user quality of service (QoS) requirements, while at the same time keeping operator costs low. Small cells include femtocells, picocells, metro cells, and microcells to increase cell coverage and capacity. Artificial intelligence, machine learning (ML) can solve complex problems without explicit programming. It was motivated by its successful application to several practical tasks such as image recognition, both industry and the research community[1][9][15].

Small-cell forms and deployment scenarios:

1) Small cells have three types: femtocells, picocells, and microcells. Such words are not fully standardized, and it is essential to remember that they may overlap with use.

2) Femtocells have the smallest number of types of small cells and are usually used in homes or small businesses. Such router-like systems are mounted by consumers and can provide coverage at a time with only a few users. In general, femtocells have a maximum range of fewer than 10 meters[9].

3) In general, picocells are built in larger indoor areas such as shopping malls, offices, or train stations. They can accommodate as many as 100 users at a time and have a range of fewer than 200 meters.

4) Microcells are the small cell with the greatest and most strength. They are usually mounted on traffic lights or signs outside and can be used temporarily for significant events. Microcells are within a range of fewer than two kilometers, whereas macrocell towers can reach up to 20 miles. The network operators usually mount both microcells and picocells.

5) Due to the large scale of 5G systems, combined with their inherent complexity and heterogeneity, Big Data and analysis techniques are considered to be one of the primary providers of future mobile networks. 5G can also be used for remote cloud work, which needs much lower end-to-end latencies when done with responsive interfaces to maintain good user experience. We define the following criteria required for 5 G use cases[4]:

Network criteria: network with 5 G capabilities; faster and higher-capacity networks capable of providing video and other content-rich services; vast system connectivity based on various technologies, etc.

Requirements for application: the application requirements are reliable process mining over Big Data triple store; network power calculation module; reasoning module; learning and prediction module (e.g., Neural Network); optimization module; related Ontologies domain and application; etc.

Storage requirements: Big Data triple storage; capacity to handle huge volumes (a petabyte or more) of data; distributed redundant data storage; massively parallel processing; offers computing capabilities for Textual Big Data; centrally controlled and coordinated.

2. REQUIREMENTS AND ARCHITECTUR OF SMALL CELL NETWORK

For a small cell network to be a financially viable investment for carriers and companies, it needs to meet a few criteria[4][5].

- **Low cost** – Fewer customers are covered, so prices must be held down.
- **Simple to handle** – The large number of small cells being deployed necessitates centralized management.
- **Layout and lightweight design of "outdoor furniture"** – Small cells are often attached to street lights and signs, and landowners can have stringent criteria set.
- **High weather reliability and safe-to-touch – nature-** Small cells provide coverage at street level and are close to human activity.

Small cells are low-powered radio access nodes located in a licensed and unlicensed spectrum ranging from 10 to a few kilometers. Compared with a mobile macrocell, they are "small" partly because they have a shorter range and partly because they usually handle-less simultaneous calls or sessions. While wireless carriers seek to 'densify' existing cellular networks to meet "5 G" data capacity requirements;

Micro-cells are typically considered to be outdoor cells that transmit at power levels below 10 watts. Ray Butler, CommScope's VP for mobility network engineering, said the operators are deploying large numbers of small cells from 1- watt to 5-watt. They are often installed on streetlights or utility poles. Butler said the radio could be connected to t at ground level in an enclosure or about 10 feet away from the ground. As carriers densify their networks to support 5 G, the outdoor Small Cell market is taking off[6]. Typically the antenna is at the top, but it can also be placed a little lower on the pole. Mini macro sites are full-power radios that are deployed on structures typically between 40 and 50 feet tall, Butler said, with both the receiver and antenna at the top. The radio equipment can be connected to a remote baseband unit using fiber.

Small cells are also called outdoor distributed antenna systems. An antenna and DAS remote node are mounted on a pole in this system, and the radio and baseband are at a position at the head end. The remote nodes can be connected to the head end via fiber or cable. An outdoor DAS can accommodate multiple operators and uses about 20 watts of power per band commonly.

A **Femtocell** is the smallest type of small cell used to expand the connectivity of the cellular network within a target geographic area. Femtocells often consume less fuel and do not have the same effect when trying to extend network connectivity. Femtocell technology is implemented into cellular networks in much the same way that other small cell technologies are used, but its main benefit is that it does not need a centralized hub that other network solutions, such as Distributed Antenna Technologies, do. Femtocells are typically deployed at places where there is an established backhaul network, or at a site[9][15].

A. Virtualized small cells

New smaller cell designs include clusters of 'virtualized cells' operating from a central controller; and remote radio heads with low power. Network feature virtualization is an industry swift. Dedicated 'boxes' are replaced with software that can run on standard computing platforms using customized hardware. Virtualization offers significant benefits to mobile operators, including scalability, mobility, co st savings, and the ability to cut off their network slices. To implement virtualization to the RAN, the base station must first be 'functionally divided' into physical and virtual network functions[9][17].

The virtualized small cell, which adopts next-generation network architecture, responds to the telecom industry's needs by offering easy-to-install, high- performance, expandable functionality, and a smooth migration to 5 G networks. The virtualized small cell provides a disruptive approach for the mobile networks by separating the distributed unit

(D.U.) and the control unit (C.U.). The virtualized small cell, with joint processing and cooperative radio sharing capabilities, can be dynamically deployed as needed thanks to its powerful C.U. computing capabilities.The virtualized small cell allows for a real end-to-end native cloud platform that not only significantly improves stability but also enables a heterogeneous network. The tiny virtualized cell supports 4 G LTE and is upgradable to 5 G using renewed D.U.s. By implementing an open, virtualized, and split RAN (Radio Access Network), telecommunications operators will benefit from cost savings and quick time-to- market without the need for. By replacing existing on-site WiFi, deployment efforts are reduced without sacrificing WiFi functionality. The small cell also supports PoE (Power-over- Ethernet), making it suitable for ceiling or wall-mounted installation at residential, commercial, and industrial sites such as restaurants, residential complexes, office buildings, shopping malls, and factories[17][18].

To prevent fragmentation of the industry around the growing adoption of virtualized small cell base stations, SCF developed an open interface called nF-API to support a robust ecosystem of limited interchangeability, setting the groundwork for multi-vendor and multi-operator virtualized small cell deployments. The resulting 'networked FAPI' or nF-API interface supports a stable split.

B. Small cells: Backhaul problems and a vision of 5G

When building a small cell network, it is backhaul that faces the most troublesome and restrictive aspect carriers. This can be a lengthy method to find a site for deploying a small cell. Carriers must first recognize the build site owner and negotiate an implementation schedule. The town also maintains properties and may have a range of limitations on installing devices within its jurisdiction [6][25][26]. There are many ways to transmit a signal from a macro cell to small cells, by using bonded copper, fiber, or wireless microwaves, but each of these approaches has advantages and disadvantages. Fiber connections offer the highest throughputs but can be costly without an infrastructure already developed. DSL or copper provides a limited amount of data and also includes pre-use.

Advantages

Mobile network providers mount several thousand base stations each with a smaller cell instead of using full power transmitters with large cells so we can have the following advantages if the cell size is small:

- **Higher capacity:** Smaller the cell size plus the number of concurrent users, i.e., big cells do not require more concurrent users. Effective and efficient coverage and capacity.
- **Less transmission power**: Huge cells claimHuge cells claim higher capacity of transmission than small cells. A solution to boost coverage at low power outputs in small areas.
- **Local interference only:** There are several interfering signals for huge cells, while only limited intervention is present for small cells.
- **Robustness**: As cellular networks are decentralized, they become more resilient against single component failure—lower comparative costs and greater versatility than macrocells or distributed antenna systems.

Disadvantages

Some of the disadvantages of cellular networks include:

The infrastructure needed: small cells need a complex support to link all base stations. The required infrastructure includes call forwarding switches, localization registers, etc. Backhaul appears to be an expensive and sophisticated problem for carriers.

- **Handover needed:** When moving very frequently from one cell to another, the mobile station will perform a transfer—lack of orchestration through various structures and groups.
- **Frequency planning: The** frequency spectrum should be correctly distributed with a much less frequency spectrum range to avoid interference. Power is needed at the point of installation, which is often not available.

3. HOW MACHINE LEARNING CAN IMPROVE SITTING FOR SMALL CELLS

Techniques in machine learning can typically be categorized as supervised learning, unsupervised learning, and reinforced learning. The learning agent's goal in supervised learning is to learn a general rule mapping inputs to outputs with example inputs and their desired outputs, which constitute the labeled data set. No labeled data is needed in unsupervised learning, and the agent attempts to identify those structures from its data. When learning for reinforcement, the agent consistently communicates with an environment and attempts to produce a suitable policy based on the immediate reward/cost fed back by the environment. The emergence of fast and massively parallel graphical processing units and the tremendous growth of data has led in recent years to this Progress in deep learning, which can achieve the more productive potential for representation. It has the following advantages for machine learning to solve the drawbacks of conventional resource management, networking, mobility management, and localization algorithms [1][6][25][26]

6) Machine learning is capable of learning useful input data information, which can help boost network output. For example, co-evolutionary neural networks and recurrent neural networks can extract spatial characteristics, and following features from time- varying Obtained Signal Strength Indicator (RSSI), which can mitigate the ping-pong effect in mobility management. Progress in deep learning which can achieve the more productive potential for representation. It has the following advantages for machine learning to solve the drawbacks of conventional resource management, networking, mobility management, and localization algorithms

7) Resource management, networking, and mobility management algorithms based on machine learning can well adapt to the dynamic environment. By using the deep neural network, for example, which has proved to be a universal function approximator, conventional high-complexity algorithms can be closely approximated, and comparable performance can be achieved but with far less complexity, which makes it possible to quickly respond to environmental changes.

8) Machine learning helps accomplish the aim of self- organizing the network. Using multi-agent reinforcement learning, for example, each node within the system will self-optimize its transmission capacity, sub-channel allocation, and so on.

9) Machine learning can solve a new problem quickly by involving transfer learning. It is understood that wireless systems, such as traffic loads between neighboring regions, have certain temporal and spatial relevancies. Thus, the information gained in one task can be passed to another related job, which will speed up the learning process for the new task.

MACHINE LEARNING PRELIMINARIES

A variety of machine learning methods are implemented, including supervised learning, unsupervised learning, reinforcement learning, and transfer learning.

A. Supervised Learning

Supervised learning is a task of machine learning, intending to learn a mapping function from input to output, given a labeled set of data. Specifically, supervised learning can be further broken down into regression and classification based on the output continuity[13].

a. Support Vector Machine

Support vector machines (SVMs) are a group of related supervised learning methods, standard with data analysis and pattern recognition for performing classification and regression analyzes. Methods differ according to classifier structure and attributes. Support vector machines are based on the principle of statistical learning of decision planes specifying boundaries for decision. The algorithms can be subdivided into three categories according to what information is used for prediction: GPS position information, domain information (such as coordinates, user speed and direction, and network geometry), and context location arrays information.

b. K Nearest Neighbors

K Nearest Neighbors (KNN) is a non-parametric, lazy learning algorithm for classification and regression, where no data distribution assumption is necessary. Classification function is used as an example for KNN's basic concept is to determine the class of a test point in the form of a feature vector based on the majority vote of its nearest K neighbors. Given that training data belonging to persistent classes can dominate the estimation of test results, a weighted approach can be adopted by involving a proportionate weight for each neighbor to the inverse of its distance to the test point. Therefore, one of the keys to implementing KNN is the tradeoff of parameter K.

B. Reinforcement Learning:

Reinforcement learning is programming models of machine learning to make a series of choices. In an unknown, potentially complex environment, the agent learns to meet a target[17][21][22].

a. Markov decision process (MDP): A Markov decision process (MDP) is an optimization model for unpredictable decision-making. The system remains in a specific state at each time of the decision, and the agent selects an action available at this state. After the operation is carried out, the agent receives an immediate reward R, and the device transits to a new state s0 according to the likelihood of transfer P an s, s0. The MDP is used for wireless sensor node (WSNs) to model the interaction of a wireless sensor node (i.e., an agent) and to achieve any of the goals, their external environment (i.e., a system). For example, in WSNs, the MDP can optimize an energy control or routing decision [21].

The Markov Decision Process Framework

The MDP is defined by a tuple (S, A, P, R, T) where,

- S is a finite set of states,
- A is a finite set of actions,
- P is a transition probability function from state s to state s after action a is taken,
- R is the immediate reward obtained after action a is made, and
- T is the set of decision epoch, which can be finite or infinite.

π denotes a "policy," which is a mapping from a state to action. The goal of an MDP is to find an optimal policy to maximize or minimize a certain objective function. An MDP can be finite or infinite time horizon. For the finite time horizon MDP, an optimal policy π to maximize the expected total reward is defined as follows:

maxVπ(s)=Eπ,s[XmaxVπ(s) = Eπ,s[∑_t^TR (〖s〗 _t^r | 〖s〗 _t^ ,π(at))]   (1)

Where, st and at are the state and action at time t, respectively.

a. ***Q-LEARNING MECHANISM:*** Q-learning is one kind of robust learning algorithm for improving learning. Q-learning is a type of efficient learning algorithm used successfully in many areas, such as network routing, transmission power adaptation, and channel allocation.

4. BIG DATA WILL IMPROVE NETWORK AND APPLICATION INTELLIGENCE WITHIN 5 G

Big Data, of course, applies to such large and complex data sets that conventional database systems can't manage them. Big Data also involves data collection, storage, retrieval, analysis, querying, and visualization techniques. The ability to automatically process large quantities of unstructured data to extract valuable insights and push automated feedback. The conventional analytics sources are mostly centralized in mobile cellular networks, such as from charging and billing systems, operating systems, etc. However, in reality, the vast amount of data is distributed across the enterprise, such as computer data, mobile site data, network data, back-office data, etc[1][2][17].

Big data analytics has a remarkable feature, called scalability, that is, the ability to analyze data with ever-greater scale and complexity. The organizational decisions of mobile cellular networks were typically made manually or depending on the inside hardware. With the advent of big data analytics, mobile cellular network operations can be less error, more reliable, complex.

A. Big data can boost knowledge in networks and applications:

Here, Big Data refers to techniques for automatically improving network and application performance, recovering from error conditions, and delivering enhanced end-user experience through context analysis, location analysis, etc. We are technically at the cusp of useful artificial intelligence and completely self-managing systems, but we need to scurry to ensure that these concepts are integrated as deeply into the 5 G infrastructure as they can be. Precise interface specifications between the 5 G network and the applications that will arise from IoT proliferation are required. Only with these fully defined interfaces will we see the programmable 5 G network achieving its full potential[1][17].

B. Big data analytics role in the architecture of the cellular networks:

Big data can be obtained from either internal or external sources in the mobile-cellular networks. External data comes from state / local statistical offices, market research agencies, customer feedback offices, and so on. Typically, internal sources apply to operating systems, business processes, and other support structures[4][6]

a. **Data Collection:** Methods of data collection categories data sources and auxiliary resources. Mobile devices themselves are tools for gathering data. For example, they can:
   i. Collect audio information via microphones.
   ii. Collect photographs, videos, and other information via cameras.
   iii. To Gather geological locations through GPS, WiFi, or Bluetooth,etc.

Any package capture technologies or specialized applications such as ComView, SmartSniff, etc. will acquire network data. Also, skilled workers may bring other samples into network interfaces, such as air interfaces, A / Gn interfaces, and so on, to collect the signaling information[6][4][9].

b. **Analyzing and preprocessing big data:** The large- scale collected datasets reside in various formats at different locations. The collected data sets are thus typically at a rough state with a lot of duplication, uncertainty, or useless information. To ensure processing performance the data should be preprocessed before it is sent to the storage systems to prevent insufficient storage space and ensure processing performance.

c. **Big Signaling Data:** The transmission of voice and data in mobile cellular networks is accompanied by control signals, which are called signaling. The signaling functions according to the predefined protocols and ensures the protection, reliability, regularity, and efficiency of the communication. Monitoring signals play an essential role in the correct distribution of network resources, enhancing network efficiency. Various signaling protocols are copied from different network interfaces in data collection, without interrupting regular operations. Those copies are then collected and filtered through the protocol processor and sent to the analyzer. The data are analyzed in the analyzer using different algorithms, such as decomposition, correlation analysis, etc.

d. **Big Traffic Data:** The amount of traffic data is growing at an unparalleled pace with the widespread usage of the mobile Internet. Cellular operators, operating as a carrier of traffic data, have to handle the network resource correctly to balance network load and maximize network use. Traffic control and analysis is an essential yet necessary part of network management. Because understanding the dynamics of traffic and conditions of application is critical for improving network performance, the topic of traffic characteristics becomes a hot focus.

e. **Big Location Data**: Human activities are location- based, and location data analysis is useful. Location- based broad data from GPS sensors, WiFi, Bluetooth from mobile devices have become essential strategic tools. Such tools will help policy administration, such as planning of public services, development of transport networks, population patterns, risk alerts for crowds. An end-to-end Hadoop-based system with several functional algorithms operated on call record details (CRDs) was developed. With knowledge about the preferences and desires of users, it is capable of providing insightful information about where, where, and how a specific group (e.g., sports fans, music lovers, etc.) travels. Data sources are abundant in types like data rate, packet drop, mobility, etc. Over time, these data are host in different base stations. They need to be aggregated over time and space to get Big Data analytics.

f. **Big Radio Waveforms Data:** Where a mobile consumer interacts with a vast MIMO base station when traveling, deep data analytics based on the random matrix principle is applied to the collected data from their testbed. The experimental results will estimate the moving speed of the user, whether in motion, at an almost constant rate, at slow speed, or higher speed. This analytics is also applied to represent the association that exists in the signals being transmitted. These applications confirm the fact that the massive MIMO system is not only a communication system but also a massive data platform that, through big data analytics, can carry tremendous values in.

g. **Big Heterogeneous Data:** The incorporation of very heterogeneous data is one of the essential tasks of big data analytics in mobile-cellular networks. Mining of correlations in large repositories. Data sources are abundant in types like data rate, packet drop, mobility, etc. Over time, these data are host in different base stations. To get big data analytics, they need to be aggregated through space and time. There are several various heterogeneous outlets for cyber defense, for example, such as "numerous distributed packet sniffers, system log files, SNMP traps and requests, repositories for user accounts, device messages and operator commands. Essentially, data fusion is a technique that makes sense of data from different sources, commonly having various data structures overall.

5.TECHNICAL ISSUES AND ROAD TO 5 G:

Some of the technical issues regarding the 5G implementation are[1][2][18]:

a. **High-Speed Data-In-Motion:** In just a few minutes, large-scale industrial IoT, Smart Cities, and Autonomous cars can pump data petabytes. Connectivity and low-latency transmission of 5 G will add to that data transmission. Advanced support for fog/cloud infrastructure would be required to enable fast read / to write lightning with low latency computing and cloud storage architectures.

b. **Support for Application and Network Intelligence:** The 5 G network needs to be a lot more than just a big data cable. 5 G systems need to be described and built in such a way that Big Data is integrated with the infrastructure and analytics support that exists for the use of distributed networks and applications.

c. **End-to-End Security:** Big data poses many security issues as in any application today. So, safeguarding the privacy of enterprise data of users without compromise is necessary. Creating a stable, safe network would be vital in 5 G design and architecture from systems to applications.

d. **Real-Time Actionable Insights:** Although low latency is a feature of 5 G networks, it is an essential necessity for 5 G to enable quick data transmission to the cloud, edge and real-time analytics, and continue at ultra-low latencies to take real-time action in mission-critical applications such as public safety, emergency care, and security monitoring.

6. Conclusion and Future Scope

This survey focuses on some of the machine learning and big data methodologies which can be applied for the wireless communication (5G). 5 G by itself is a vast concept and the 5 G network can be analyzed on various performance criteria. As per our key observation application of the machine learning algorithm can improvise the wireless network Big data analysis's the huge data using scalability functionality. Future work is to stimulate a working model. The results of the model can be based on the accuracy of the model by applying the various machine learning algorithms.

REFERENCES

1 Machine Learning-Based Signal Detection for CoMP Downlink in Ultra-Dense Small Cell Networks Wireless Systems Laboratory (WSL), Wireless Networks Research Center, National Institute of Information and Communications Technology (NICT), Yokosuka 239-0847, Japan n January 10, 2020.

2 Y Wang, M. Liu, J. Yang, and G. Gui, ''Data-driven deep learning for automatic modulation recognition in cognitive radios,'' IEEE Trans. Veh. Technol., vol. 68, no. 4, pp. 4074–4077, Apr. 2019.

3 M. Liu, J. Yang, and G. Gui, ''DSF-NOMA: UAV-assisted emergency communication technology in a heterogeneous Internet of Things,'' IEEE Internet Things J., vol. 6, no. 3, pp. 5508–5519, Jun. 2019.

4 M. G. Kibria, G. P. Villardi, K. Nguyen, K. Ishizu, and F. Kojima, ''Heterogeneous networks in shared spectrum access communications,'' IEEE J. Sel. Areas Commun., vol. 35, no. 1, pp. 145–158, Jan. 2017.

5 Mobility Robustness in 5G Networks, Thapliyal, Ashish, 2016-10-27, Thesis submitted for examination for the degree of Master of Science in Technology. Espoo 12-08-2016

6 MONA JABER, MUHAMMAD ALI IMRAN, "5G Backhaul Challenges and Emerging Research Directions: A Survey", Received February 16, 2016, accepted March 31, 2016, date of publication April 20, 2016, date of current version May 9, 2016

7 Ericcson, Heterogeneous networks –increasing cellular capacity, White paper, 2011. Available: https://www.ericsson.com/res/thecompany/docs/publications/ericsson_review/2011/heterogeneous_networks.pdf

8 L. Giupponi, A. Galindo-Serrano, P. Blasco and M. Dohler, "Docitive networks – an emerging paradigm for dynamic spectrum management," IEEE Wireless Commun. Mag., vol. 17, no. 4, pp. 47 - 54, Aug 2010.

9 F. Liu et al., "Dual-Band Femtocell Traffic Balancing Over Licensed and Unlicensed Bands," Proc. IEEE Int'l. Conf. Commun., Canada, June 2012

10 B. Yang, G. Mao, M. Ding, X. Ge, and X. Tao, ''Dense small cell networks: From noise-limited to dense interference-limited,'' IEEE Trans. Veh. Technol., vol. 67, no. 5, pp. 4262–4277, May 2018.

11 C.K. Tseng, S.-H. Wu, H.-L. Chao, C.-L. Liu, and C.-H. Gan, ''An effective antenna allocation for CoMP transmission in dense small cell networks,'' in Proc. IEEE Global Commun. Conf. (GLOBECOM),Washington, DC, USA, Dec. 2016

12 S. Ahmed, Y. Lee, S.-H. Hyun, and I. Koo, ''Feature selection-based detection of covert cyber deception assaults in smart grid communications networks using machine learning,'' IEEE Access, vol. 6, pp. 27518–27529, May 2018

13 E. Balevi and R. D. Gitlin, ''Unsupervised machine learning in 5G networks for low latency communications,'' in Proc. IEEE Int. Perform. Comput. Commun. Conf. (IPCCC), San Diego, CA, USA, Dec. 2017, pp. 1–2

14 L. Shan, R. Miura, T. Kagawa, F. Ono, H.-B. Li, and F. Kojima, ''Machine learning-based field data analysis and modeling for drone communications,'' IEEE Access, vol. 7, pp. 79127–79135, 2019

15 J. G. Andrews, H. Claussen, M. Dohler, S. Rangan, and M. C. Reed, "Femtocells: past, present, and future," IEEE J. Sel. Areas Commun., vol. 30, no. 3, pp. 497–508, Apr. 2012.

16 Luyang Wang, Xinxin Feng, Xiaoying Gan, Jing Liu, Hui Yu "Small Cell Switch Policy: A Reinforcement Learning Approach" 2014 Sixth International Conference on Wireless Communications and Signal Processing (WCSP)

17 Chen Xianfu, Zhifeng Zhao, and Honggang Zhang. "Stochastic Power Adaptation with Multiagent Reinforcement Learning for Cognitive Wireless Mesh Networks." Mobile Computing, IEEE Transactions on 12.11 (2013): 2155-2166.

18 http://cs229.stanford.edu/notes/cs229-notes12.pdf

19 F. Pantisano, M. Bennis, W. Saad, and M. Debbah, "Spectrum leasing as an incentive towards uplink interference mitigation in two-tier femtocell networks," IEEE J. Sel. Areas Commun., vol. 30, no. 3, pp. 617–630,Apr. 2012

20 Yaohua Sun, Mugen Peng, "Application of Machine Learning in Wireless Networks: Key Techniques and Open Issues" Yaohua Sun, Mugen Peng, Senior Member, IEEE, Yangcheng Zhou, Yuzhe Huang, and Shiwen Mao, Fellow, IEEE

21 Y. Mao, C. You, J. Zhang, K. Huang, and K. B. Letaief, "A survey on mobile edge computing: The communication perspective," IEEE Commun. Surveys Tuts., vol. 19, no. 4, pp. 2322–2358, Fourthquarter 2017

22 Y.Li, "Deep reinforcement learning: An overview," arXiv:1701.07274v5, Sept. 2017, accessed on Jun. 30, 2018.

23 X. Chen et al., "Optimized computation offloading performance in virtual edge computing systems via deep reinforcement learning," 1805.06146v1, May 2018, accessed on Jun. 15, 2018

24 J. Wang et al., "A machine learning framework for resource allocation assisted by cloud computing," IEEE Netw., vol. 32, no. 2, pp. 144–151, Apr. 2018.

25 F. Pervez, M. Jaber, J. Qadir, S. Younis, and M. A. Imran, "Fuzzy Q- learning-based user-centric backhaul-aware user cell association scheme," IEEE Access, Jul.

26 D. Soldani and A. Manzalini, ''Horizon 2020 and beyond: On the 5G operating system for a true digital society,''

IEEE Veh. Technol. Mag., vol. 10, no. 1, pp. 32–42, Mar. 2015.

27 G.Wunder et al., ''5GNOW: Non-orthogonal, asynchronous waveforms for future mobile applications,'' IEEE Commun. Mag., vol. 52, no. 2, pp. 97–105, Feb. 2014

28 H.Elshaer, F. Boccardi, M. Dohler, and R. Irmer, ''Load & backhaul aware decoupled downlink/uplink access in 5G systems,'' in Proc. IEEE Int. Conf. Commun. (ICC), Jun. 2015, pp. 5380–5385.

29 D. Bojic et al., ''Advanced wireless and optical technologies for small- cell mobile backhaul with dynamic software-defined management,'' IEEE Commun. Mag., vol. 51, no. 9, pp. 86–93, Sep. 2013.

2. Bruce, K.B., Cardelli, L., Pierce, B.C.: Comparing Object Encodings. In: Abadi, M., Ito, T. (eds.): Theoretical Aspects of Computer Software. Lecture Notes in Computer Science, Vol. 1281. Springer-Verlag, Berlin Heidelberg New York (1997) 415–438
3. van Leeuwen, J. (ed.): Computer Science Today. Recent Trends and Developments. Lecture Notes in Computer Science, Vol. 1000. Springer-Verlag, Berlin Heidelberg New York (1995)
4. Michalewicz, Z.: Genetic Algorithms + Data Structures = Evolution Programs. 3rd edn. Springer-Verlag, Berlin Heidelberg New York (1996)