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# MACHINE LEARNING AT THE EDGE: A DATA-DRIVEN ARCHITECTURE WITH APPLICATIONS TO 5G CELLULAR NETWORKS

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## ABSTRACT
To meet the ultra-low latency demands of future applications, the fifth generation of cellular networks (5G) will rely on edge cloud installations. In this research, we show that similar deployments may also be deployed in mobile networks to allow sophisticated data-driven and Machine Learning (ML) applications. We propose an edge- controller-based cellular network design and assess its performance using real-world data from hundreds of base stations of a large US operator. In this context, we will discuss how to dynamically cluster and associate base stations and controllers based on users' worldwide movement patterns. The controllers will then be used to run ML algorithms to forecast the number of users in each base station, as well as a use case in which these predictions are utilized by a higher-layer application to direct vehicular traffic based on network Key Performance Indicators (KPIs). We demonstrate that prediction accuracy increases when based on machine learning algorithms that depend on the controllers' view and, as a result, on the spatial correlation provided by user mobility, compared to when the prediction is based only on the local data of each individual base station.
**Keywords:** 5g, machine learning, edge controller, mobility, big data

## Introduction
The fifth generation (5G) of cellular networks is being developed to meet the significant increase in capacity demand, number of connections, and expanding use cases of a connected society in 2020 and beyond.

### 1.1 5G
5th-generation wireless is the most recent version of cellular technology, designed to significantly improve the speed and responsiveness of wireless networks. Data carried through wireless broadband connections may now move at multigigabit rates, with some estimates putting peak speeds as high as 20 gigabits per second (Gbps). These speeds outperform wire line network rates and provide latency of less than 5 milliseconds (ms) or less, which is beneficial for applications requiring real-time input. Because of increased accessible bandwidth and enhanced antenna technology, 5G will enable a significant rise in the volume of data delivered across wireless systems. To meet the growing reliance on mobile and internet-enabled devices, 5G networks and services will be deployed in stages over the next several years. As the technology matures, 5G is likely to spawn a slew of new applications, uses, and business cases. It also works on Wireless networks are made up of cell sites that are separated into sectors that carry data through radio waves. Long-Term Evolution (LTE) wireless technology of the fourth generation (4G) serves as the foundation for 5G. In contrast to 4G, which requires huge, high-power cell towers to broadcast signals over larger distances, 5G wireless signals are carried by a large number of tiny cell stations positioned in areas such as light poles or building rooftops. Multiple small cells are required because the millimeter wave (mmWave) spectrum—the band of spectrum between 30
and 300 gigahertz (GHz) that 5G relies on to generate high speeds can only travel short distances and is susceptible to interference from weather and physical obstacles such as buildings or trees. Previous versions of wireless technology employed lower-frequency spectrum bands. To address the issues of distance and interference with mmWave, the wireless industry is investigating the use of a lower-frequency spectrum for 5G networks, allowing network operators to roll out their new networks using

spectrum they currently hold. Lower-frequency spectrum travels farther but has less speed and capacity than mmWave.

### 1.2 MACHINE LEARNING

Machine learning (ML) is an artificial intelligence (AI) science that enables machines to automatically learn from data and previous experiences while finding patterns to generate predictions with minimum human interaction. Machine learning approaches allow computers to function independently without the need for explicit programming. ML apps are fed fresh dataand may learn, grow, evolve, and adapt on their own. Machine learning extracts useful information from enormous amounts of data by using algorithms to recognize patterns and learnin an iterative process. Instead of depending on any preconceived equation that may serve as a model, ML algorithms employ computing methods to learn directly from data. During the 'learning' processes, the performance of ML algorithms improves adaptively as the number of accessible samples increases. Deep learning, for example, is a sub-domain of machine learning that trains computers to mimic natural human features such as learning from examples. It outperforms traditional ML algorithms in terms of performance parameters. While machinelearning is not a new idea, it has been utilized since World War II with the Enigma Machine, the capacity to apply complicated mathematical computations automatically to rising quantities and kinds of accessible data is a comparatively recent development.

### 1.3 EDGE CONTROLLER

An edge controller is a component of an Internet of things (IoT) system used in the industrial sphere, which includes industrial activities. It gathers information from numerous field devices put on-site at client sites. In addition to gathering field device data, recent edge controllers have emerged to execute data processing that demands more complicated capabilities and high-speed response by splitting the processing performed in the higher layer. This is known as edge-heavy computing. This paper describes the edge controller problems, the function and characteristics of Fuji Electric's edge controllers, application examples, and the future view.

### 1.4 MOBILITY

The present design and standardization of the next generation, or Fifth Generation (5G), will enable new use cases, applications, and impressively difficult mobility performance requirements. Next-generation mobile networks, for example, should provide seamless mobility with minimal data interruption at each handover, even at high speeds. This paper provides a novelstudy analysis of Mobility Management (MM) solutions in next-generation cellular networks. Traditionally, Mobility Management solutions were built for LTE, however owing to a rise in demand for high-speed seamless mobility without interruption at every changeover in recent years, the solutions have remained ineffective. As a result, in order to increase QoS and reduce delay, this proposed work technique would comprise minimizing delay during handoff andanalyzing mobility management in both low and high speed scenarios.

### 1.5 BIG DATA

Big data refers to vast, diversified collections of information that are growing at an exponential rate. It includes the amount of information, the velocity or speed with which it is generated and gathered, and the variety or scope of the data points covered (the "three v's" of big data). Big data is frequently derived by data mining and arrives in a variety of formats. It also works on Big data may be classified as either unstructured or organized. Structured data is information that an organization has already controlled in databases and spreadsheets; it is typically numerical in nature. Unstructured data is disorganized information that does not fit into a preset model or format. It contains information obtained from social media sources to assist organizations in gathering information on client demands. Big data may be taken via publicly published comments on social networks and websites, as well as from voluntarily collected personal gadgets and applications, questionnaires, product transactions, and electronic check-ins. Theinclusion of sensors and other inputs in smart devices enables data to be collected across a wide range of settings and conditions. 1 Big data is typically kept in computer systems and processed using software created expressly to handle huge, complicated data sets. Many software-as-a- service (SaaS) firms specialize in handling complicated data.

**Literature Review**

NGMN Alliance et al.'s perspective on 5g architecture [1] offers The fifth era of versatileinnovation (5G) will deal with 2020 and past financial requests and corporate circumstances. Leading operators from around the world came up with their vision for 5G in an effort led by the NGMN Alliance. They took into account consumer and business contexts, potential technologies,and migration concerns. The NGMN 5G whitepaper lays out their precise vision, but it also discusses important topics that will affect the design of 5G architecture, such as 5G design principles, 5G components, network slicing, 5G radio access technologies, and 5G interfacing alternatives.NGMN sees 5G as an all-encompassing system that will boost productivity, sustainability, and well-being for a society that is fully mobile and connected by 2020 and beyond [1-3]. It will also empower a wide range of businesses. A new set of use cases will be made possible by 5G's expansion of the network capacity envelope, which will increase things like data speeds, latency, and connection density. As this would be prohibitively expensive, 5G should avoid a monolithic design focused on the most stringent requirements because not all use cases require the same level of performance and capability. Five Disruptive Directions for 5g Technology[2] Federico Boccardi et al.suggest that new research initiatives will change the way fifth-generation (5G) cellular networks are built in the future. Five technologies are discussed in this article that could alter component and architectural design: millimeter wave, massive MIMO, smarter devices, and native support for machine-to-machine communications are all examples of device-centric architectures. The most important ideas behind each technology, as well as how they might affect 5G and the other research questions, are discussed. The cellular network of the fifth generation, or 5G, is nearing completion. Which technology will give it its shape? Will 5G simply be an extension of 4G, or will it cause such a disruption to established cellular concepts that they need to be rethought? Using the Henderson-Clark paradigm, we will examine the implications of potentially disruptive technologies for 5G in this article. The following are some ways in which we will characterize the influence of new technologies: Minor changes at the architectural and node levels (such as the introduction of codebooks and signaling support for more antennas).

Millimeter Wave Cellular Wireless Networks: Opportunities and Threats[3] Sundeep Rangan et al.propose in this paper that millimeter wave (mmW) frequencies somewhere in the range of 30 and 300 GHz are another wilderness for cell correspondence, promising significant degrees more noteworthy data transmissions joined with extra gains through bar framing and spatial multiplexing from multi-component radio wire exhibits. The measurements and capacity studies used to evaluate this technology are the focus of this study, which focuses on small cell installations in urban areas. The findings provide a lot of hope;Non-line-of-sight (NLOS) outdoor, street level coverage is possible up to about 200 meters from a potential low power micro- or microcell base station, according to tests conducted in New York City at 28 and 73 GHz. Based on statistical channel models derived from these data, mmW systems can also offer acapacity improvement of more than an order of magnitude over the current state-of-the-art 4G cellular networks at the current cell densities. It will be necessary to significantly alter cellular networks in order to fully reap these benefits.

Networks Based on Minds: A Fresh Look at Distributed Intelligence and Learning for Network Optimization [4] in this study, Michele Zorzi et al.In this position paper, we propose a novel system paradigm known as Cognition Based Networks (COBANETS) as a response to emerging issues in the design and operation of communication networks. We draw inspiration from how living things deal with complexity and scalability. For system-wide modeling, optimization, and data representation, the proposed approach is based on the systematic application of sophisticatedmachine learning methods, such as unsupervised deep learning and probabilistic generative models. In addition, we propose in COBANETS that the learning architecture be combined with emerging network virtualization paradigms. This will make it possible to activate automatic optimization and reconfiguration methods at the system level, thereby completely unlocking the learning approach's potential. This paper's technical approach is more comprehensive and deeply interdisciplinary than previous and ongoing efforts in this area. It requires a synergistic combination of expertise from computer scientists, communications and networking engineers, and cognitive scientists with the ultimate goal of breaking new ground through a profound rethinking of how modern cognition can be used in the management and optimization of telecom systems.

In Intelligent 5g, cellular networks and artificial intelligence meet [5] in this study. argue that 5G cellular networks are the most important facilitator and infrastructure provider in the ICT sector, providing a wide range of services to meet a wide range of needs. The accelerated standardizationof 5G cellular networks suggests that additional candidate technologies will be selected. Consequently, it is beneficial to examine the design philosophy that underpins the various potential approaches and to provide insight into them as a whole. One of the most fundamental characteristics of the revolutionary methods of the 5G era is highlighted in this article:the emergence of initial intelligence in nearly all significant aspects of cellular networks, including service provisioning management, radio resource management, mobility management, and so forth. In any case, despite ever-progressively complex arrangement challenges and thriving new help necessities, it is as yet deficient for 5G cell organizations in the event that it needs full artificial intelligence capabilities.

In this study, Sandeep Chinchaliet al. use deep reinforcement learning in cellular network traffic scheduling [6].offered A new category of traffic from Internet of Things (IoT) devices like smart wearables and self-driving cars is driving extraordinary demand growth for modern mobile networks. While maintaining strict service guarantees for traditional real-time applications like phone and video, future networks will need to plan for delay-tolerant software updates, data backup, and other transfers of IoT devices. Because conventional traffic is highly dynamic across time and location, scheduling all IoT traffic as it arrives immediately has a significant impact on its performance. A scheduler based on reinforcement learning (RL) that can dynamically adapt to traffic variance and multiple incentive functions that network operators have established tooptimize the scheduling of IoT traffic are described in this study.

Big Data Analytics in Mobile Cellular Networks [7] The authors of this paper, YING HE et al.suggest that mobile cellular networks have become both carriers and producers of data. Big data analytics has the potential to boost operator income while also improving the operation of mobile cellular networks. In this study, we present a single data model that is based on random matrix theory and machine learning. After that, we offer a design framework for putting big data analytics into mobile cellular networks. We also talk about a lot of examples from mobile cellularnetworks, like a lot of signaling data, a lot of traffic data, a lot of location data, a lot of radio waveform data, and a lot of heterogeneous data. In conclusion, we discuss a number of unsolved issues in mobile cellular network big data analytics research.

Predictive Mobile Networking: A Study Prediction Methodologies, Context-Based Classification,and Optimization Techniques [8] In this study, Nicola Bui et al.suggest that rather than reacting to changes, a growing trend in information technology is to anticipate them. New solutions, like recommendation systems, are already ubiquitous in digital transactions today because of this paradigm.In order to enhance network performance, anticipatory networking applies the concept to communication technologies by analyzing patterns and periodicity in human behavior and network dynamics. This study gathers and examines existing research on how context information can be used to anticipate network conditions and improve network performance. The goals and limitations of common applications and situations are specifically identified and correlated with the primary prediction and optimization techniques utilized in this body of work.

Expectant Versatile Figuring: Challenges and State-of-the-Art [9] In this study, veljko pejovic et al.argue that today's mobile phones are more than just tools for communication. Users' location, activities, social context, and other information can be inferred from their phones thanks to their sophisticated sensors and cutting-edge computational technology. From inferring context to predicting context, reasoning, and acting on the expected context, gadgets become more intelligent. This article paves the way for full-fledged anticipatory mobile computing by providing an overview of current research in mobile sensing and context prediction. We provide an overview of the phenomena that mobile phones can infer and predict, as well as a description of the machine learning

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methods used to make these predictions.
Machine Learning Paradigms for Next-Generation Wireless Networks [10] in this study by CHUNXIAO JIANG et al.claim that a new wireless radio technology paradigm is required for next-generation wireless networks to enable fundamentally novel applications and extremely highdata rates. In order to meet the various requirements of next-generation wireless networks, it is necessary to assist the radio in intelligent adaptive learning and decision making. One of the mostpromising approaches to artificial intelligence for smart radio terminals is machine learning.
5g Obstacles: Network densification, a variety of node types, the separation of the control and data planes, network virtualization, heavy and localized cache, infrastructure sharing, concurrent operation at multiple frequency bands, the simultaneous use of different medium access control and physical layers, and flexible spectrum allocations can all be envisioned as potential 5G ingredients, according to this study by Ali Imran and colleagues. Self-organizing networks, or SONs, have recently been actively investigated to address comparable difficulties in the contextof 3G and 4G networks. It is not difficult to predict that with such a mash-up of technologies, the complexity of operation and OPEX will be the most challenging task in 5G.
Ex Machine TCP:Computer-Generated Traffic Control [12] Keith Winstein and colleagues have proposed a novel approach to end-to-end congestion control for multiuser networks. Remy is a computer that creates congestion control algorithms for execution at the endpoints rather than writing each endpoint's response to congestion signals by hand as in traditional protocols. In this method, the protocol designer describes their prior network knowledge or assumptions, as well asan objective that the algorithm will strive for, such as high throughput and minimal queuing time. In an effort to accomplish this, Remy then develops a distributed algorithm with control rules for the various endpoints. In ns-2 simulations, Remy-generated algorithms outperform human- designed end-to-end approaches like TCP Cubic, Compound, and Vegas. In some situations, Remy's algorithms also outperform approaches like XCP and Cubic-over-sfqCoDel (stochastic fair queuing with CoDel for active queue management) that require intrusive in-network adjustments.
D-Dash: Streaming Dash Video with a Deep Q-Learning Framework [13] In this study, Matteo Gadaleta et al.suggest that the widespread adoption of the dynamic adaptive streaming over HTTP (DASH) standard and the growing demand for smooth high-definition video streaming are major contributors to the substantial amount of research that has been done on bitrate adaptation algorithms. This is a great application for learning methodologies due to the mobile wireless channel and the richness and variety of the video contented-DASH is a framework that enhances DASH's quality of experience (QoE) by combining reinforcement learning and deep learning techniques. Feed-forward and recurrent deep neural networks, as well as more advanced approaches, are among the learning architectures discussed and evaluated. Performance metrics like freezing/rebuff ring occurrences and image quality across video segments are evaluated against cutting-edge algorithms that are both heuristic and learning-based.
Characterization of Human Mobility Using Data from Cellular Networks [14] In this study, Richard A. Becker et al.suggest that understanding how people's travels affect society and the environment requires characterizing patterns of human mobility. Location data from mobile phone networks can provide cost-effective, frequent, and extensive insight into human movements. We made apparatuses for examining unknown cell phone areas to research different components of human portability. We have looked at billions of location samples for hundreds of thousands of people, particularly in the metropolitan areas of Los Angeles, San Francisco, and New York. Estimates of the carbon footprints caused by home-to-work commuting, density maps of residential areas that contribute employees to a city, and relative traffic volumes on commutingroutes are among the findings of our research. By comparing our methods to ground truth provided by volunteers and independent sources like the US Census Bureau, we confirmed our findings.
Modeling Cellular User Mobility Using A Leap Graph [15] Wei Dong et al.suggest that coordinated base station selection and intelligent content perfecting are two ways in which user mobility prediction can assist a mobile service provider in making better use of its network resources. We

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examine how to lead portability forecast utilizing base station level area data effectively accessible to a specialist organization in this examination. Handovers between base stations, on the other hand, can occur in the absence of actual user movement (for example, dueto signal fluctuation), making it difficult to differentiate between genuine movements and handovers. The leap graph, in which each edge (or leap) corresponds to actual user movement, is what we propose as a solution to this problem. We demonstrate how leap-based mobility produces a prediction-friendly mobility trace and discuss its characteristics.

Collaborative Mobile Edge Computing in 5g Networks: New Perspectives, Scenarios, and Obstacles [16] Tuyen X. Tran et al.propose in this examination Portable Edge Processing (MEC) as an arising worldview that conveys registering, stockpiling, and systems administration capacities at the versatile Radio Access Organization's edge (RAN).Application execution in close proximity to end users is made possible by MEC servers, which are placed on a generic computing platform within the RAN. Backhaul and core network congestion is alleviated by this paradigm, which is essential for enabling mobile services with low latency, high bandwidth, and flexibility. This article imagines a real-time, context-aware collaboration structure at the edge of the RAN made up of mobile devices and MEC servers that brings together the various resources at the edge. Mobile-edge orchestration, collaborative caching and processing, and multi-layer interference cancellation are three examples we propose and investigate.

Living in Peril:Ejder Bastuget et al.'s study, "Proactive Caching's Role in 5g Wireless Networks," is available here. Given, this article delves into proactive caching, one of the main enablers of tiny cell network deployments in addition to 4G wireless networks. Due to predictive capabilities and current advancements in storage, context awareness, and social networks, anticipatory caching at base stations and users' devices can significantly reduce peak traffic needs. In order to demonstrate the effectiveness of proactive caching, we investigate two case studies that make use of the social and physical structure of the network. To alleviate backhaul congestion, we proposea system that actively caches files during off-peak hours based on file popularity and correlations between user and file trends.

Rededge: In this study, Muhammad Habib ur Rehman et al. present a novel design for big data processing in mobile edge computing environments [18].offer We are witnessing the rise of novelbig data processing architectures as a result of the convergence of the Internet of Things (IoTs), edge computing, and cloud computing. Raw data streams are transferred to a cloud computing environment for processing and analysis by current big data processing systems. This approach is pricey and does not meet the needs of IoT applications for real-time processing. Rededge (data reduction on the edge), a novel big data processing architecture that combines mechanisms to enable the processing of big data streams close to the source, is the subject of this article's introduction and analysis.

Issues and Challenges in Radio Access Networks Based on Fog Computing [19] In this work, Geng Peng et al.offered A spectral and energy-efficient fog computing-based radio access network (F-RAN) is presented in this article as a viable paradigm for the fifth generation (5G) wireless communication system. The central idea is to make full use of the local radio signal processing, cooperative radio resource management, and distributed storage capabilities of edge devices. This could help alleviate a lot of the pressure on the front haul and get rid of large-scale radio signal processing in the centralized baseband unit pool. The fundamental F-RANs methods and system architecture are detailed in this article. The selection of transmission modes and the reduction of interference, two key methodologies with associated solutions, are discussed indepth. Edge caching, software-defined networking, and network function virtualization all have unresolved issues. A system capacity increase of at least 1000 and an increase in energy efficiency (EE) of at least 10 should be achieved by the fifth generation (5G) wireless communication system in comparison to the fourth generation (4G) wireless communication system Long-Term Channel Gain Prediction Methods In Wireless Networks [20] Federico Chiariotti et al. propose the cloud radio access network (C-RAN) as a combination of developing wireless and information technology solutions that incorporate cloud computing into radio access networks (RANs).suggest that modern wireless

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networks require efficient resource allocation and cell handover prediction; However, this can only be accomplished if an effective method for anticipating the network's future state exists. In order to accomplish this, we investigate two learning methods for anticipating long-term channel gains in a wireless network. This prediction can be successfully carried out with the assistance of a GPS signal in the following effective ways: In this work, we only use previous channel samples and no geographical data to forecast future channel gains.

## COMPARISON ANALYSIS

| **Title** | **Techniques & Mechanisms** | **Parameter Analysis** | **Future Work** |
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| NGMN's Perspective on 5G Architecture | the major elements affecting 5G architecture design, such as 5G design concepts, 5G components, network slicing, 5Gradio access technologies, and 5G interfacing choices. | The 5G system will need to support on-demand network function and capability composition, resulting in 5G network slices that use the same 5G infrastructure. | To increase quality such that commercial 5G systems can meet NGMN criteria. |
| Millimeter Wave Cellular Wireless | In the mmW context, various | Our observations and capacity study | Technologies like as carrier aggregation and |
| Networks: Potentials andChallenges | technologies such as adaptive beam forming, multihop relaying, heterogeneous network architectures, andcarrier aggregation can be used. | showed numerous unexpected characteristics: mmW signals are possibly feasible over distances of 100 m to 200 m because to reflections and dispersion, even in absolutely NLOS conditions. | multihop relaying, which have only had minor advantages in presentcellular networks, may play a significant role inthe mmW area in the future. |

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| Cognition-Based Networks: Using Learning and Distributed Intelligence to Optimize Networks | Combining the learning architecture with new network virtualization paradigms, which enable automatic optimization and reconfiguration tactics to be activated at the system level, completely unlocking the learning approach's potential. | This findings might spur innovation in cognitive science and machine learning, leading tothe creation of new learning approaches that must adhere to different limits and boundary conditions than those established in those fields in the past. | having the potential to drive disruptive innovation in these sectors, as well as unforeseeable consequences for other fields that may benefit from the stimulation and shift in viewpoint brought about by the future vision |
| When Cellular Networks Meet Artificial | Radio resource management,mobility | Byimagining several potential opportunities and | 5G wireless networks and shown AI's exciting effectiveness. We could |

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| Intelligence in Intelligent 5G | management, general management and orchestration, and service provisioning management are all part of 5G cellular networks.. | listing some potential challenges, we argued that it is still critical to bring more AI functionalities to 5G cellular networks. | make the bold claim that AI-powered 5G cellular networks will successfully enter the centre of a digitalized world. |
| Deep Reinforcement Learning for Cellular Network Traffic Scheduling | Future networks must provide for delay-tolerant software updates, data backup, and other transfers from IoT devices while preserving rigorous service guarantees for traditional Real-time applications like phone calling and video conferencing. | To properly plan IoT traffic, we describe a reinforcement learning (RL)-based scheduler that can dynamically adapt to traffic variance and multiple incentive functions provided by network operators. | Future work will focus on deploying an RL agent in a live network to validate gains. We also intend to distinguish between global and cell-specific features learned by our deep neural networks. |
| Analytics of Big Data in Mobile Cellular Networks | Mobile cellular networks have evolved into bothdata producers and data carriers. Big data analytics can improve the performance of | Based on random matrix theory and machine learning, we present a unified data model. Following that, we provide an architectural | The issues will be addressed in the future. |

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| | mobile cellular networks while increasing operator revenue. | framework for implementing big data analytics in mobile cellular networks. | |
| Context-Based Classification, Prediction Methodologies, and Optimization Techniques in Anticipatory Mobile Networking | Anticipatory networking applies the concept to communication technologies by investigating patterns and periodicity in human behavior and network dynamics in order to improve network performance. | This survey collects and analyses recent papers that use context information to forecast network conditions and, as a result, improve network performance. | In the future, we believe that a thorough and comprehensive cost-benefit analysis for specific anticipatory networking scenarios is a necessary next step in the field's research. |
| Anticipatory Mobile Computing: A State-of-the-Art Survey and Research Challenges | Phones, which are equipped with sophisticated sensors and modern computational technology, may be used to infer users' location, activities, social context, and other information. Asgadgets grow more intelligent, their capabilities go | We give a survey of phenomena that mobile phones may infer and forecast, as well as a description of the machine learning techniques that are utilized to make such predictions. The user-device feedback loop is then used to discuss | A whole new set of ground-breaking applications may be possible once we combine phone predictions with advanced intelligence capable of steering the future through interaction with the user. |

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| | from inferring context to predicting context, reasoning, and acting on the expected context. | proactive decision making and decision delivery. | |
| Paradigms of machine learning fornext-Generation wireless networks | The challenge is to aid the radio in intelligent adaptive learning and decision making in order to meet the different requirements of next-generation wireless networks. | Machine learning is one of the most promising artificial intelligence methods forsmart radio terminals. With the help of sophisticated algorithms, future smart 5G mobile terminals are expected to autonomously access the most advantageous spectral bands. | The classes of supervised, unsupervised, and reinforcement learning tools, as well as the corresponding modeling methodology and potential future applications in 5G networks, were investigated. |
| 5G Challenges: How to Empower SON with Big Data to Enable 5G | While an al dente character of 5G has yet to emerge, network densification, a variety of node types, the separation of the control and data planes, network | A comprehensive framework for equipping SONs with big data to meet the demands of 5G. We begin by characterizing big data in the context of future mobile networks, | BSON requirements must be incorporated into 5G design and standardization at an early stage to ensure the availability of sufficient and necessary data in the future without jeopardizing user privacy. |

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| | virtualization, heavy and localized cache, infrastructure sharing, concurrent operation at multiple frequency bands, the simultaneous use of different medium access control and physical layers, and flexible spectrum allocations can all be envisioned as potential 5G ingredients. | identifying its sources and future utilities. | |
| TCP ex Machine: Congestion Control Generated by a Computer | The protocol designer specifies their prior network knowledge or assumptions, as well as an objective that the algorithm will try to achieve, such as high throughput and low queuing delay. Remy then creates a distributed algorithm (the | Human-designed end-to-end techniques, such as TCP Cubic, Compound, and Vegas, were outperformed by Remy-generated algorithms. Remy's algorithms also beat approaches that need intrusive in-network adjustments, such as XCP and Cubic- | End-to-end algorithms (in TCP and elsewhere) that adapt to whatever the lower layers are doing should replace today's informal approach of hindering lower layers or providing vague advice on how best to accommodate TCP. Remy offers a solution to this problem. |

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| | control rules for the separate endpoints) in an attempt to attain this goal. | over-sfqCoDel, in several circumstances. | |
| D-DASH: A DASH Video Streaming Deep Q-Learning Framework | Various learning architectures are presented and evaluated, including feed-forward and recurrent deep neural networks, as well as advanced methods. D-DASH designs are rigorously tested against cutting-edge algorithms, both heuristic and learning-based, assessing performance metrics such as image quality across video segments and freezing/rebuff ring occurrences. | Our numerical results, obtained on both real and simulated channel traces, demonstrate D-DASH's superiority in nearly all of the quality metrics considered. Aside from producing a significantly higher QoE, the D-DASH framework achieves faster convergence to the rate-selection strategy than the other learning algorithms studied. | A considerable advancement over previous work on Q-learning DASH adaption designs, achieving good trade-offs between policy optimality and convergence speed. D-DASH outperformed some of the most prominent adaption strategies. |
| Characterization of Human Mobility Using | Characterizing human mobility patterns is crucial | In each of the Los Angeles, San Francisco, and New | Our most recent research aims to provide fully synthetic models that |

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| Cellular Network Data | to gaining a better understanding of how people's travel affects society and the environment. Cell phone network location data can throw light on human movements in a cost-effective, frequent, and large- scale manner. | York metropolitan regions, we evaluated billions of location samples for hundreds of thousands of people. Our findings include estimates of carbon footprints owing to home-to-work commutes, density maps of residential regions that contribute employees to a city, and relative traffic volumes on commuting routes. | replicate the individual and regional mobility patterns observed inmeasured CDRs. |
| Using a Leap Graph to Model Cellular User Mobility | User mobility prediction can help a mobile service provider make better use of its network resources, for as through coordinated base station selection and intelligent content perfecting. We investigate how to conduct mobility | To overcome this issue, we propose the leap graph, in which each edge (or leap) corresponds to actual user movement. We present the properties of leap-based mobility and show how it produces a more suitable mobility | In the future, we intend to apply our technique to real-world location-based services in order todiscover more application- specific improvements and demonstrate its use in real-world systems. |

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| | prediction using base station level location information easily available to a service provider in this research. | trace for prediction. | |
| New Paradigms, Scenarios, and Challenges for Collaborative Mobile Edge Computing in 5G Networks | MEC servers are placed on a generic computing platform within the RAN and enable for the execution of delay-sensitive and context-aware applications in close proximity to end users. This paradigm relieves backhaul and core network congestion and is critical for allowing low-latency, high-bandwidth, and flexible mobile services. | We show how the proposed approaches can help to accelerate the transition to 5G networks. Finally, we discuss the key technical challenges and open-research issues that must be addressed in order to integrate MEC into the 5G ecosystem efficiently. | The technical challenges and open-research issues will be highlighted in future work to provide a glimpse of the development and standardization roadmap of the mobile edge ecosystem. |
| The Importance of Proactive Caching in 5G Wireless Networks | This article delves into proactive caching, one of the main enablers of | We propose a procedure that takes advantage of the network's social | In the future, the proactive caching problem can be formulated from a game theoretic learning |

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| | beyond 4G wireless networks employing tiny cell network deployments. Peak traffic needs can be significantly decreased by proactively supplying expected user requests via caching at base stations and users' devices, thanks to predictive capabilities and current improvements in storage, context awareness, and social networks. | structure by predicting the set of influential users who will (proactively) cache strategic contents and disseminate them to their social ties via D2D communications. | viewpoint, with SBSs minimizing cache misses by striking a fair balance between cached items that will be requested and contents that are not cached but are requested by users. This is known as the exploration vs. exploitation paradigm. |
| Rededge: A Novel Big Data Processing Architecture for Mobile Edge Computing Environments | We present and evaluate Rededge (data reduction on the edge), a novel big data processing architecture that incorporates mechanisms to facilitate the processing of big | In a real-world experiment environment with 12 mobile users, we analyze the Rededge architecture and the related mechanism. The experimental results show that the Rededge model can | Toenhance the compromising energy and memory usage on mobile edge devices in the future. |

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| | data streams near the source of the data. The Rededge approach makes use of mobile IoT edge devices as major data processingplatforms. | cut huge data streams by up to 92.86% without sacrificing energy and memory usage on mobile edge devices. | |
| Radio Access Networks Based on Fog Computing: Issues and Challenges | This article presents a fog computing-based radio access network (F-RAN) as a viable paradigm for the fifth generation (5G) wireless communication system, with great spectral and energy efficiency. | This article describes the system architecture and core methods of F-RANs in detail. Key methodologies and their associated solutions, such as transmission mode selection and interference reduction, are addressed in detail. | IN THE FUTURE Nonetheless, given the field's relative infancy, there are a number of outstanding issues that require further investigation. Notably, the conclusion is that more emphasis should be placed on transforming the F-RAN paradigm into edge caching, SDN, and NFV. |
| Five Disruptive 5G Technology Directions | Device-centric architectures, millimeter wave, massive MIMO, smarter devices, and native support formachine-to-machine communications | We concentrated on technologies that could lead to changes in both architectural and component design: device-centric architectures, mmWave, massive | The efficiency should be increased in the future to provide a better network with the 5G cellular network. |

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| | are technologies that could lead to architectural and component disruptive design changes. | MIMO, smarter devices, and native M2M support. It is expected that a collection of these ideas will form the foundation of 5G. | |
| Learning methods forpredicting long-term channel gain in wireless networks | Efficient resource allocation and cell handover prediction are critical in modern wireless networks; however, this is only possible if there is an efficient way to estimate the network's future state. | In this paper, we look at two learning strategies for predicting long-term channel gains in a wireless network. Previous research in the literature discovered effective ways for performing this prediction using a GPS signal. | Future study might entail refining the prediction algorithms and training the predictors using data from real-world cellular systems. Finally, a possible advance may be the construction of a prediction-based resource optimization system similar to the one shown. |

**Conclusion**

Machine learning, software-defined networks, and edge cloud will play a significant role in the next generation of cellular networks.Using a dataset gathered for more than a month fromhundreds of base stations of a large US cellular network in two distinct cities, we investigated how these three factors could be used together in the system design for 5G networks.We investigated the practical application of big data-based rules and machine learning in 5G cellular networks after examining the relevant state of the art.We proposed an overlay architecture that builds on top of 3GPP NR. In this architecture, a number of different controller layers take data from the RAN, process it, and use it to infer intelligent rules that can be applied to the cellular network.

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