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SURVEY

Routing-Based Interference Mitigation in SDN Enabled Beyond 5G Communication Networks: A Comprehensive Survey

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ABSTRACT The outright aim of Beyond Fifth Generation (B5G) communication is to bring a revolution in Quality of Service (QoS) through enhanced Mobile Broadband (eMBB), Ultra-Reliable Low Latency Communication (URLLC), and massive Machine Type Communication (mMTC). Thereby, due to this massive expansion in the communication paradigm, interference is bound to surface unexpected challenges in the wireless domain. Thus, interference mitigation is a foundational aim in the research paraphernalia of B5G communication. Presently, Software Defined Networking (SDN) is emerging to empower wireless communication with centralized routing-based interference mitigation. With this premise, we aim to present a focused review on SDN-based interference mitigation in wireless communication. Initially, we discuss current research horizon in the subject domain and briefly explore literature for routing-based interference mitigation. Thereby, we analyze the potential of SDN through evaluation of existing solutions for interference mitigation in B5G communication. We conclude our survey by highlighting prominent future research directions in SDN-based interference mitigation.

INDEX TERMS Software defined networking, wireless networks, 5G, interference, routing.

I. INTRODUCTION

Wireless communication was historically initiated with voice communication by utilizing Radio Frequency (RF) as medium of information transfer. However, during the last few decades, wireless communication has undergone a gradual yet steady evolution towards a highly saturated and immensely dense plethora of mutually interconnected devices. Primary building blocks behind this technological leap include digital modulations, effective frequency utilization, packet-based data connectivity, and tremendous advancement in physical layer technologies. Similarly, modern wireless networks have transformed towards enhanced Mobile Broadband (eMBB)), Ultra-Reliable Low Latency Communication (URLLC), and massive Machine Type Communication (mMTC) to meet the immensely increasing demand for improved Quality of Service (QoS) [1]. According to an Ericsson Mobility report in November 2021, mobile networks carry almost 300 times more data traffic with 5.5 billion smartphones subscribers than in 2011 [2]. The RF spectrum usage pattern of cellular devices shows a continuous shift towards 5G technologies, as depicted in Fig. 1. Considering the forecasts, if we can gaze at upcoming decades, it is evident that underneath the numbers lies a pile of saturations in wireless RF media.

The emerging B5G paradigm will contain diverse schemes including: Beamforming, Massive Multiple Input Multiple Output (M-MIMO), millimeter-wave (mm-wave), Relay Node (RN), Heterogeneous Network (HetNet) and Device-to-Device (D2D) communication, Cellular cloud computing, Power optimization, Handover processes, Artificial Intelligence (AI) enabled micro base stations, Blockchain and

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Human centric communication [1]. However, coherent design models will result in serious cross domain signals interventions. Therefore, interference losses are prone to significantly degrade the overall network efficiency. The simultaneous deployments of diverse technologies have provisioned user end devices with multipath connectivity. In this scenario, optimum routing path selection can play vital role for interference mitigation. For example, path switching between Voice Over LTE (VoLTE) and Voice Over WiFi is a classical emerging model [3].

Therefore, researchers are endlessly exploring interference mitigation techniques through data flow management at higher network layers for long-term consistency in solutions related to budget-intensive implementations. Likewise, frequent hardware upgrades are economically infeasible in specialized fields such as aviation, military hardware, healthcare and satellites. Hence, higher network layers implementations such as routing is considered as a potential area for interference mitigation in dense heterogeneous networks by finding optimal path [4].

The revolutionary concepts in computer communication such as Fog Computing, Could Computing, Bigdata, Edge Computing, Network Function Virtualization (NVF), and IoTs proliferation, are compelling the global communication industry to review the network architecture. Owing to these developments, Open Network Foundation (ONF) introduced a programmable centralized networking architecture of SDN [5]. Software Defined Networking (SDN) is a completely novel emerging solution to tame ultra-dense wireless networks [6]. SDN has opened up new possibilities to remove blockades in conventional networking. SDN provisions a centralized architecture for robust, optimized and unconventional routing opportunities. The implementation of SDN in a holistic format enables several possibilities to incorporate solutions related to interference mitigation [7]. In this scenario, SDN is emerging as a potential technological candidate for interference mitigation in B5G communication [8]. SDN provisions a centralized view of the network, which tremendously empowers the modern communication structures for handling technologies such as Internet of Things (IoT) [9], Unmanned Aerial Vehicles (UAV), etc.

A. RELATED PREVIOUS SURVEYS/REVIEWS IN LITERATURE

To perform a focused systematic coverage of previous related work in literature from 2018 to 2022, we explicitly undertook an online search in major literature repositories, including Google Scholar, WoS (Web of Science), and Scopus. It is pertinent to highlight that the majority of previous work in literature includes various techniques and solutions related to the topic. The SDN enabled routing is an emerging concept; Therefore, the count of surveys or reviews in previous publications related to the subject is relatively minor. After selecting the most relevant previous surveys, we performed a comparative analysis of prior literature with the scope of this survey in Table 1. In subsequent paragraphs, we discuss basic ideas and our observations on the most relevant previous work in literature.

The study in [10], is a consolidated survey on resource allocation and interference mitigation in Device to Device (D2D) communication [11] with Artificial Intelligence (AI) [12] and Machine Learning (ML) [13]. However, the survey does not cover the SDN-based opportunities and challenges in achieving interference mitigation.

The study in [14] is a comprehensive survey on the coexistence of LTE and Wireless Fidelity (WiFi). The article contains a detailed discussion on interference issues, solutions and challenges. However, aspects related to B5G and SDN are missing.

The authors in [15] presented a detailed survey of resource management in IoTs and discussed several aspects related to RF interference issues and challenges. However, it a more focused review is required on potential solutions and challenges of SDN-based implementation for interference mitigation. The article [16] is a detailed survey on interference management issues in 5G networks but does not cover SDN-based implementations and solutions in respective domains.

The authors in [17] provided a short survey on 5G networks with a discussion on interference issues and challenges related to physical layer implementations such as mm-Wave, Smart Antenna, etc. However, the article does not cover SDN-based potential solutions and challenges.

The authors in [18] presented detailed discussion on spectrum sharing for reducing interference in 5G network through network virtualization including SDN. However, techniques, challenges and solution related to SDN implementation needs more discussion for holistic view of interferences related emerging issues in B5G.

The authors in [19] presented a detailed review on the joint implementation of SDN and 5G-based Cognitive Radio Access Networks (C-RANs); it further discussed several challenges, including interference control. However, the survey lacks a dedicated focus on SDN-based interference mitigation in all the emerging scenarios in wireless networks.

The authors in [20] reviewed the network load balancing through SDN; however, B5G technologies are not covered. Moreover, the survey also lacks a clear focus on interference mitigation.

Intentional interference or jamming is considered as a Denial of Service (DoS) attack in wireless networks [21]. The authors in [22] conducted a detailed survey of various technological aspects of ultra-dense 5G networks, including interference issues; however, the article includes a discussion on the role of SDN in ultra-dense networks related to network management but lacks the focus on SDN architecture and interference mitigation solutions. The authors in [23] discussed interference issues and mitigation techniques in the survey on non-terrestrial networks in 5G; however, it does not discuss the impact of SDN-based interference mitigation.

The study in [24] is a comprehensive survey on resource management in 5G networks, however, interference

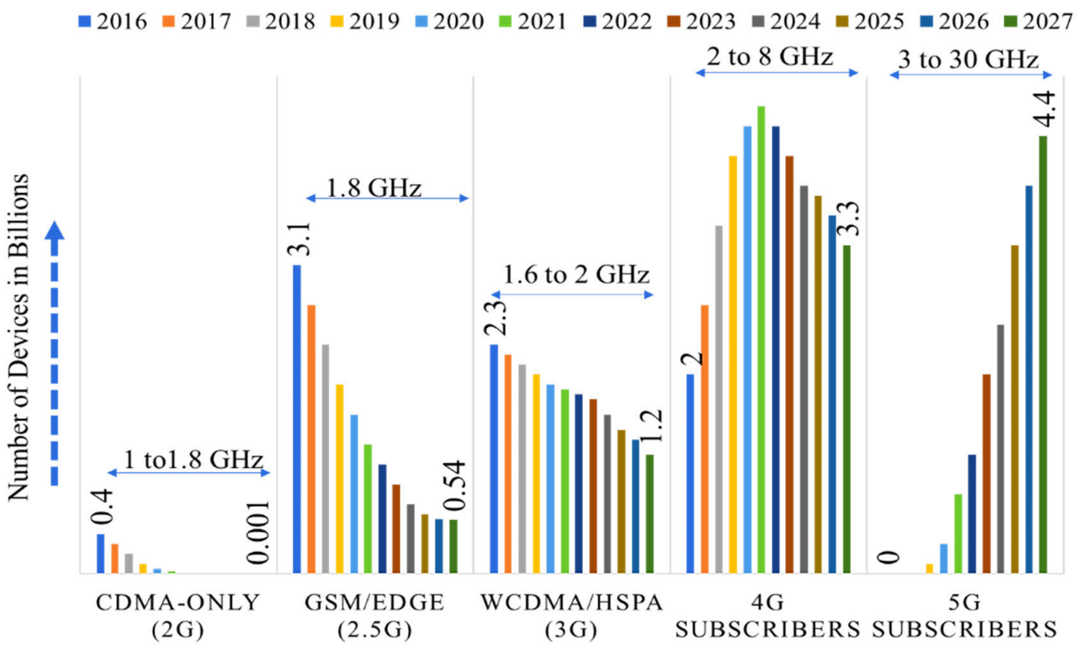

FIGURE 1. RF spectrum current usage and forecast.

mitigation challenges and potential of SDN is not comprehensively discussed.

The authors in [25] surveyed various aspects of interference and resource allocation in Long Term Evolution (LTE) based vehicular networks however, further research is required regarding emerging B5G communication as well SDN technologies. The study in [26] is a survey of spectrum management for Unmanned Aerial Vehicles (UAVs) with discussion on SDN-based spectrum monitoring. However, all-inclusive picture of B5G require more deliberations. Moreover, discussion on potential SDN-based solution and challenges for interference mitigation require further analysis.

The authors in [27] provided a consolidated picture of the 5G wireless network and discusses interference issues. However, it does not cover the SDN paradigm and potential solutions in this domain. The study in [28] is a survey on Distributed DoS (DDoS) attack mitigation techniques in SDN; however, several aspects of unintentional interference are not covered. Thereby, our analysis of related previous work in literature clearly indicates that none of the previous publications has comprehensively covered routing-based interference mitigation methods in next-generation wireless networks.

B. MOTIVATION

Integrated environment of various technologies, such as AI, DL, ML, edge computing, cloud computing and SDN, is primary emerging trend of dense B5G networks, where devices have multipath and complex routing provisions to avoid interference issues. Therefore, it motivated us to analyze existing routing-based and SDN enabled research works for futuristic implementation in B5G networks. This survey aims to provide a consolidated view of the potential remedial role of SDN for routing-based interference mitigation challenges in Next Generation Wireless Networks (NGWNs) i.e., 5G and B5G. Moreover, the non-existence of any such work in current literature is also one of the driving factors behind our research effort.

C. CONTRIBUTIONS

We strongly believe that this survey would potentially serve the research community as a consolidated knowledge for futuristic exploration in routing-based interference for SDN enabled networks. We summarize our contributions as follows:

1) This study systematically scans the existing research span to shortlist highly related previous literature works and presents a comparative analysis with our topic scope, as shown in Table 1.
2) In this study, the discussion is initiated with the approaches in routing-based interference mitigation with past, present and future perspectives in mobile communication. We summarized our analysis in Table 2.
3) The potential of the existing topological classifications of emerging SDN technology is discussed in relation to interference mitigation as Centralized SDN, Decentralized SDN, and Hybrid SDN.
4) Further, this study discusses the prominent SDN-based interference mitigations schemes and critically analyzes their limitations concerning the requirements of

TABLE 1. A comparative analysis of related previous surveys and Scope of this article Annotations: "√" indicates that concepts are covered comprehensively, "0" indicates that scope is partially covered, X" indicates that scope is not covered.

Covered Scope of this Article		**[10]** 2018	**[14]** 2018	**[15]** 2018	**[16]** 2019	**[17]** 2019	**[18]** 2019	**[19]** 2020	**[20]** 2020	**[22]** 2020	**[23]** 2020	**[24]** 2020	**[25]** 2021	**[26]** 2021	**[27]** 2021	**[28]** 2022
Routing based Interference mitigation	3G Networks	0	0	X	√	X	0	X	X	0	0	X	0	0	0	X
	4G Networks	0	√	0	√	X	0	X	X	0	0	0	0	0	0	X
	5G Networks	√	X	X	√	0	0	0	X	0	0	0	X	0	0	X
	B5G Networks	X	X	X	X	X	X	X	X	X	X	X	X	0	0	X
SDN Architecture & Interference Mitigation		X	X	X	X	X	X	0	0	0	X	X	X	X	X	0
SDN related limitations in Interference Mitigation		X	X	X	X	X	X	0	0	X	X	X	X	X	X	0
SDN-based Interference Mitigation till 4G networks		X	X	X	X	X	X	X	0	X	X	X	0	X	X	X
SDN-based Interference Mitigation in B5G Networks		X	0	0	0	0	X	0	X	0	0	0	X	0	X	X
AI enabled interference mitigation in distributed SDN		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Challenges in SDN-based interference mitigation		X	X	X	X	X	X	0	0	X	X	X	X	X	X	X

NGWNs. We provided the crux of our discussion in Table 3.

5) We proposed an architecture for Intelligent Interference Mitigation with distributed SDN controllers and provided a relational representation of a potential solution based a hierarchical architecture of SDN for maintaining centralized control of overall network.
6) Finally, this article suggests possible potential future research directions in SDN-based interference mitigation, including 1) Intelligent Interference Mitigation with SDN controllers, 2) SDN enabled Fog Federation for Interference Mitigation, 3) Interference mitigation through SDN enabled C-RANs, 4) 5G URLLC compatible SDN controller-based interference mitigation and 5) Lightweight SDN-based interference Mitigation in drones.

D. PAPER STRUCTURE AND ORGANIZATION

The deliberations in this survey are organized as follows: We initiated our article through a brief overview of routing in mobile communication and interference issues in Section I-B. After discussing the traditional technological perspective in routing-based interference mitigation, Section I-C focuses on SDN-based interference mitigation techniques in wireless mobile communication and their relevance with B5G communication. Section II analyzes the potential and limitations of existing SDN topologies for interference mitigation. In Section III, we proposed architecture for Intelligent Interference Mitigation with distributed SDN controllers for next generation wireless networks. Section IV discusses the emerging challenges and future research directions on the subject topic. Finally, Section IV-A has concluded the survey. The overall structure and organization of this paper are depicted in Fig. 2.

II. ROUTING-BASED INTERFERENCE MITIGATION

In subsequent paragraphs, we discuss implementations of routing-based interference mitigation approaches in various mobile communication technologies. The unprecedented technological growth in mobile network technologies and advancements in core network schemes are the primary factors behind evolution of various interference mitigation techniques as depicted in Fig. 3. Table 2 summarizes the overall discussion of this section.

Various parameters govern the basic functionality of routing protocols for interference mitigation. Cross Layer Routing (CLR) utilizes interference ratio, queuing and channel occupancy information from mesh routers. CLR subsequently calculates the cost of channel switching to find the optimum interference free paths [29]. CLR schemes have limitations related to delay sensitivity and critical dependence upon the information received from other network layers [30].

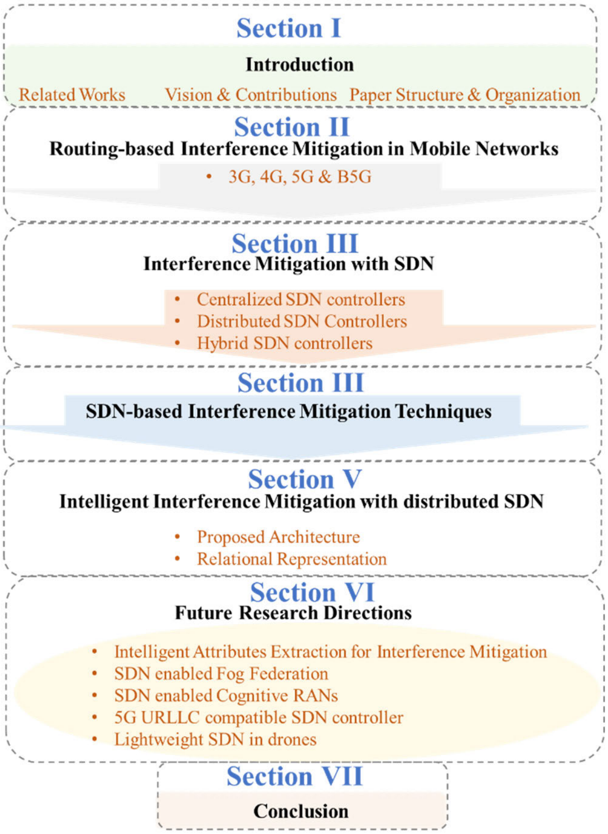

FIGURE 2. Structure and Organization of this paper.

Likewise, Angular deviation method-based geographical noninterference path discovery is used in Directional Geographical Routing (DGR) protocol [31]. DGR enables load balancing, bandwidth aggregation, and efficient packet delivery by improving peak SNR up to 3dB. Routing protocol-based interference avoidance is also used in combination with geographic information. DGR was specifically designed for real time video streaming applications. Moreover, mobility management is not supported in this protocol [32].

Similarly, some initial efforts for routing-based interference mitigation are linked with the routing protocol Interference Minimized Multipath Routing (I2MR) in military Wireless Sensor Network (WSN) [33]. I2MR performance load balancing by taking into consideration the wireless interference by discovering zone-disjoint paths. I2MR includes location information of both the source and the destination. The I2MR faces data loss in the situation when alternative paths are unreachable or a node is unable to serve the traffic rate required by the source [33].

Maximally Radio Disjoint Multipath Routing (MR2) is extensively utilized for optimum routing-based interference mitigation in WiFi-based Mesh networks. MR2 utilizes an adaptive incremental technique with adjacent nodes in passive mode for interference information by discovering minimum-interfering paths. The process contains sequential path buildup with converting neighboring nodes in passive mode to avoid interference in path discovery functionality [34]. The main limitation of MR2 protocol is the high control overhead due to flooding technique used for route discovery process. Moreover, MR2 is specifically suitable only for query driven processes [35].

Similarly, alongside various multipath routing techniques, Metric-based routing such as Expected Transmission Count (ETX) and Expected Transmission Time (ETT) has the potential to reduce the effects of interference implicitly [36]. ETT and ETX face challenges for optimized algorithm design, sensitivity and stability for compatibility with upper layers in network. Moreover, sensitivity of these metrics can trigger several issues during high traffic and obstacles [37].

Similarly, Energy Efficiency and Collision Aware Multipath Routing Protocol (EECA) establishes multipath from source to destination by avoiding interference affected direct path. Besides interference mitigation, routing-based solutions provide optimized energy consumption and reduced end-to-end delay [38]. EECA protocol is dependent upon GPS location; therefore, it causes additional cost and hardware requirements. Similarly, the theoretical results improve by selecting minimum hop paths, however, a minimum hop path with low SNR will cause packet loss and extra overhead [39].

3G mobile network contains interference problems related to Inter-Cell Interference (ICI), which limits the overall system performance [40]. Packet scheduling with intelligent priority and retransmission management can provide load balancing and be substantially enhanced by putting in mobile networks [41]. However, an inappropriate packet scheduling implementation can lead to a more than 45% round trip latency and downgraded throughput from 10 to 0.9 Mbps in 3G mobile networks [42].

The authors in [43] presented a joint ML (Machine Learning) and game theory-based self-organized femtocell network for interference mitigation in next generation networks. The authors demonstrated better system convergence to equilibrium as compared to RL (Reinforced Learning) approach.

Markov Approximation is used for coordinated interference mitigation through offloading in HetNet [44]. Markov chain coverage provides optimum distribution with partial information from 3G network. However, Markov models are problematic at short periodic events handling which leads to compatibility issues with certain applications.

4G LTE stands as a potential candidate to serve several IoTs; however, there are multiple Interference-related concerns due to the swift evolution in global regulations and the link reliability requirements at Beyond Visual Line of Sight (BVLOS) [45].

Wireless communication technology evolved with higher bandwidth till 4G communication. However, B5G communication is result of unprecedented advancements in real-time video streaming, massive IoTs, ultra-low latency and smart infrastructures. B5G technologies are streaming out as eMBB, URLLC and mMTC. In this emerging congested paradigm in wireless mobile networks, unconventional and agile routing protocols are required for interference

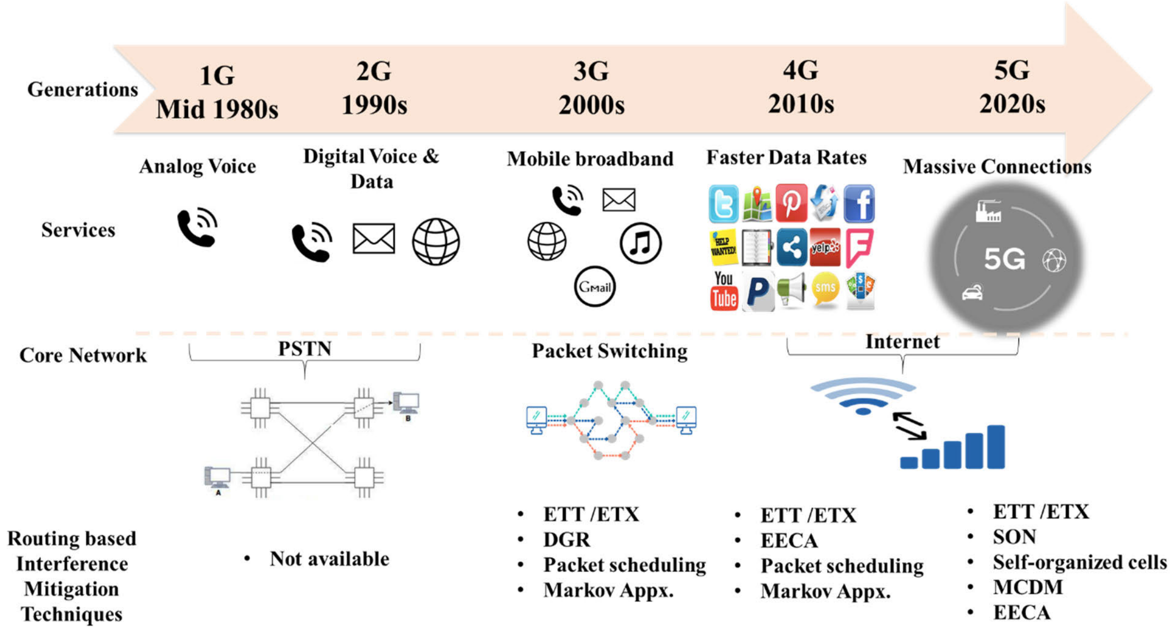

FIGURE 3. Routing techniques in mobile communications.

mitigation [46]. Therefore, the categorization of metrics for multipath routing has emerged as a challenge for routing-based interference mitigation in 5G communication [47].

The authors in [48] suggested an opportunistic routing protocol for 5G-based Self Organized Networks (SON). The proposed protocols focus on interference mitigation and aim for increased throughput and reduced latency. However, existing SON protocols need integration and optimized utilization of ML technique for compatibility with NGWNs [49]. Similarly, B5G networks bring unforeseen challenges to D2D communication, especially in massive IoT networks. The primary concerns include increased end-to-end delays, packet loss, quick energy drop, lack of holistic fairness, and interference.

The authors in [50] adopted a multi-factor approach that considers energy, link quality, mobility, and queueing. Here, the authors suggested a Multi Criteria Decision Making (MCDM) technique for selecting optimal routes for D2D communication in 5G and Beyond. However, MCDC has limitation related to measuring system sustainably in dynamic networking environment [51]. Multipoint relaying-based Optimized Link State Routing (OLSR) protocol is one of the most researched schemes for interference management in mobile networks [52]. However, OLSR require enhancements for compatibility with dynamic environments of NGWN such as restrictions in nodes resource, hostile possessions of the wireless channels, rapidly changed topologies and the absence of essential administrations [53].

III. INTERFERENCE MITIGATION WITH SDN

SDN provisions bird eye view of interference paradigm in entire network through an unconventional multilayered architecture comprising of North, East, West and South (NEWS) bound Application Programming Interface (API) interfaces. SDN-based interference mitigation solutions complement wireless communication through various other enhancements such as power efficiency, resource optimization, security and redundancy [54].

SDN has not only encapsulated the research spectrum of NGWNs but also resulted in a vast expansion in the design and development of SDN controllers. SDN is primarily categorized into three types, including centralized controllers, distributed controllers, and hybrid controllers [55]. Moreover, flexible requirements and highly dynamic future mobile networks would result in the implementation of wireless technologies at all the NEWS interfaces of SDN [56]. The SDN's extensive interaction with wireless connectivity is due to vast possibilities of solutions for diverse domains, including SDN-based airborne solutions [57], SDN-based Satellite networks [58], SDN-based tactical solutions [59], etc.

Therefore, the SDN controllers must be designed according to the emerging wireless paradigm for optimized interference mitigation in all wireless domains [60]. In this section, we specifically analyze the basic topologies of SDN controllers. Further, we evaluate the prominent use cases of the SDN controllers for interference mitigation in each category.

Similarly, SDN technology has potential to resolve backward compatibility issues in coexist scenario of various communication technologies [61]. NGWNs heterogenous will contain integrated environment of industrial communication, Vehicle to X, Internet of Flying Things (IoFTs), Internet of Medical Things (IoMTs), D2D links and IoTs. These scenarios pose serious challenges in terms of end-to-end latency, scalability, reliability and backward compatibility with legacy systems. SDN provisions flexible architecture for solution to compatibility related issues such as Non-access and Management strata, clean-slate forwarding layer, unified

TABLE 2. Routing-based interference Mitigation Techniques Annotations:"√" indicates that Domain is covered, "X" indicates that Domain is not covered.

Ref.	Year	Routing	Domains Covered					Functionality	Limitations
			3G	4G	5G	WiFi	WSN		
[29]	2004	CLR	X	X	X	√	√	Utilizes interference ratio, queuing and channel occupancy information	Delay sensitivity and critical dependence information from other layer in network
[31]	2007	DGR	√	X	X	√	X	Geographical noninterference path discovery	Mobility management is not supported
[33]	2008	I2MR	X	X	X	√	√	Geographical noninterference path discovery	Data loss when alternative paths are unreachable
[34]	2008	MR2	X	X	X	√	√	Utilizes adjacent nodes in passive mode	High control overhead due to use of flooding technique
[36]	2008	ETT /ETX	√	√	√	√	√	Implicitly reduces the effects of interference	Sensitivity issues for compatibility with upper layers
[38]	2009	EECA	X	X	X	√	√	Multipath routes	Dependent upon GPS location and cause packet loss and extra overhead in low SNR
[41]	2010	Packet scheduling	√	√	√	X	√	Retransmission management for load balancing	Optimum implementation
[43]	2010	Self-organized femtocell	X	X	√	X	√	Joint ML and game theory-based interference mitigation	Requires optimized utilization of ML technique
[44]	2016	Markov Appx.	√	X	X	X	√	Optimization for traffic offloading	Problematic at short periodic events handling
[48]	2019	SON	X	X	√	X	√	Opportunistic routing	Requires optimized utilization of ML technique
[50]	2020	MCDM	X	X	√	√	√	Selection of optimal route	Measuring system sustainably in dynamic networking environment
[52]	2021	OLSR	√	√	√	X	√	Multipoint relaying	Compatibility with dynamic environments

signaling unify Access, tunneling protocols for carrier grade mobility etc [62].

Emerging NGWNs are an integrated scenario of various wireless technologies such as WiFi, LTE and B5G. User end devices are bound to have simultaneous links available. SDN has global view of network [63], therefore, it has ability to mitigate interference effects through alternate routing on low interference paths in the network containing Industrial 4.0, Vehicle to X communication, IoFTs, IoMTs, D2D links and IoTs as depicted in Fig. 4.

A. CENTRALIZED SDN CONTROLLERS

The primary type of SDN is based on a physically centralized controller having an entire network view such as topology, traffic flows, and switch load. Centralize SDN controller functions through seamless connections to all the forwarding devices. Centralized SDN architecture provisions robust implementation of network optimization strategies at the application layer such as load balancing and interference mitigation [64]. However, a single centralized SDN controller faces a series of limitations, including bandwidth issues and processing overload in massive communication scenarios. Therefore, the scalability of centralized SDN architecture has emerged as a huge challenge in HetNets-based IoTs () [65]. Software-Defined Wide Area Networks (SD-WANs) architecture is considered out of scope for a single centralized SDN controller [66].

Ryu is a python-based multi-threaded centralized SDN controller with a distinct module for defining interdomain flow in Border Gateway Protocol (BGP) [67]. Ryu controller is used for distributed collaboration and anti-interference optimizations in edge computing scenarios of NGWNs [60].

Ryu is widely used to implement various SDN-based interference mitigation schemes, such as ML-based interference mitigation [64] and NS in 5G [68]. In [69], the authors suggested the addition of middleware in Ryu SDN controller for the optimized transport layer management in 5G networks. Ryu is considered the most resilient among centralized SDN controllers for handling scalability issues [70]. However, the Floodlight SDN controller beats Ryu in terms of bandwidth and latency [71].

B. DISTRIBUTED SDN CONTROLLERS

The concept of the distributed SDN control plane aims to counter the issues related to scalability, reliability, resource availability, and single-point vulnerability of centralized SDN controllers. Distributed SDN architecture is robust to withstand untoward events in networking such as link failure, overwhelming due to flow requests, intrusions, interference etc [72]. Distributed SDN controller architecture is emerging as a potential approach to managing multi-tenant data centers where massive networking events create an extensively dynamic environment [73]. However, the distributed SDN architecture has obvious limitations in terms of load-sharing optimization and flexible interoperability.

Elasticon [74] is a prominently distributed SDN controller with elastically adaptive load balancing capabilities. It consists of three primary modules: the load measurement module, load adaptation module, and decision module. Elasticon contains a distinct switch migration strategy for consistent serializability of events through creating new controller

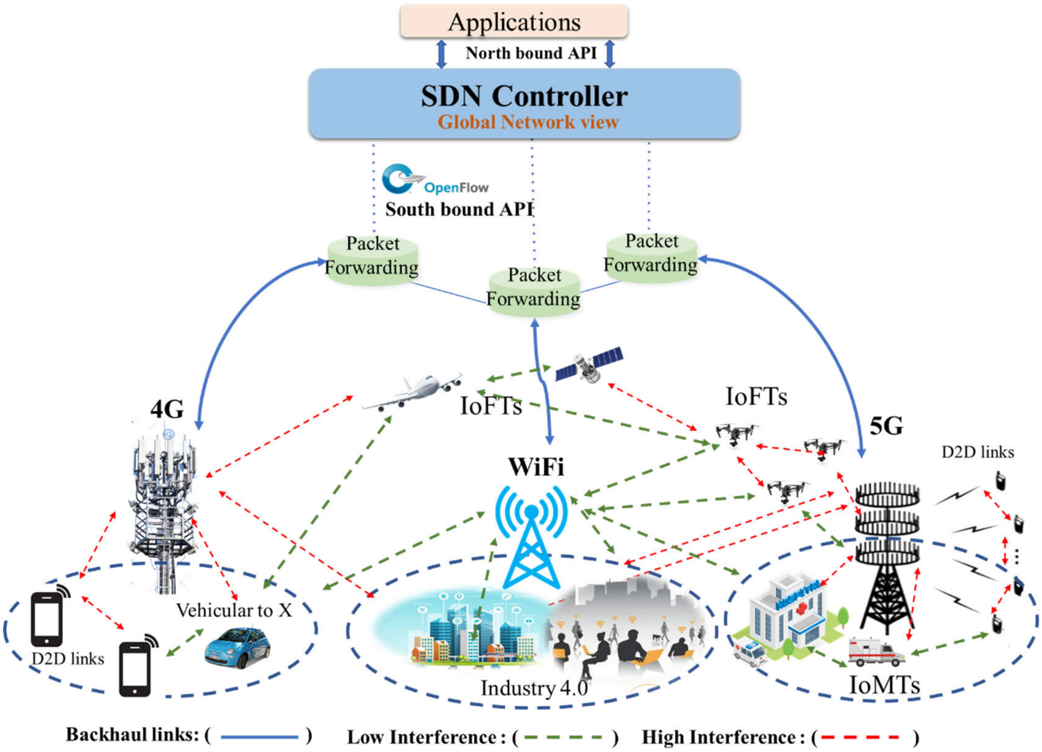

FIGURE 4. SDN-based Interference Mitigation paradigm.

instances for dynamically shifting switches to balance the load. However, the suggested scheme can result in network overhead issues in limited bandwidth scenarios. Elasticon is a potential candidate for employing interference mitigation schemes in NGWNs.

C. HYBRID SDN CONTROLLERS

Hybrid SDN controllers are emerging as the optimum choice for enterprises to include both traditional and SDN-based networking schemes [75]. The most desirable advantage of a hybrid SDN controller is interoperability and backward compatibility. A Hybrid SDN scheme is ideal for countering the traditional limitations with a low initial investment for SDN related qualities incorporation into their system such as global network view and optimum path selection for interference mitigation [76]. Hybrid SDN implementation strongly relies on optimized integration of various SDN and non-SDN entities. Moreover, hybrid SDN controller implementation offers selective employment of available networking schemes for optimized up-gradation and improved control performance [77].

Technological heterogeneity necessitates the utilization of Hybrid SDN controllers due to diversified integration requirements in NGWNs [78]. Prominent Hybrid SDN controllers include Panopticon [79], Hybnet [80] and Telekinesis [81]. Although hybrid SDN is paving the way for the adoption of SDN in modern networks [82]; however, it still faces limitations related to inconsistent data handling due to differences in specification among networking schemes.

IV. SDN-BASED INTERFERENCE MITIGATION TECHNIQUES

The huge opening of research in SDN has proliferated various novel solutions for interference mitigation in modern-day mobile networks [83]. In subsequent paragraphs, we critically reviewed prominent SDN-based interference mitigation techniques. Table 3 provides the overview of our analysis related to various SDN-based interference mitigation techniques.

A. DISTRIBUTED MOBILITY MANAGEMENT

Next-generation network services formulate revised architectural approaches for challenging interference mitigation and mobility management requirements. One of such requirements is backhaul link management, which occurs due to composing a large number of small cells based dense radio access network. SDN has emerged as a promising approach for handling the Distributed Mobility Management (DMM) paradigm in dense wireless communication [84]. The authors in [85] suggested an SDN-based implementation for IPv6 compatible MAC layer control through Southbound API (Application Layer Interface) in SDN. Here, the presented scheme is considered a potential solution for taming extremely dense wireless links in FP7 (Seventh Framework Program) Project Connectivity management for eneRgy Optimised Wireless Dense networks (CROWD) [86]. The CROWD architecture provisions interference mitigation through channel opportunistic transmission/reception techniques.

The overall scheme of this solution covers the interference management from mobile nodes at the user end; however, this approach does not cover the futuristic concepts of the Fog computing, cloud computing and edge computing paradigm. Moreover, tackling interference issues among mmWave based wireless backhaul links in mobile Ad-Hoc networks would require significant modification in the suggested scheme of SDN-based DMM [87].

B. PACKET SCHEDULING ALGORITHM

The heterogeneous amalgamation of the wireless network resulted in the aggregation of cellular networks with WiFi [88]. Serval opportunities and challenges have simultaneously emerged in this new WiFi and cellular networks merger. SDN is a potential solution for the wholistic integration of 5G networks and WiFi, especially to counter dynamic requirements of QoS [88]. The study in [89] suggested an interference mitigation framework for WLAN through SDN OpenFlow protocol based fine-grained packet scheduling in AP's downlink. Here, the authors advocate implementing the solution without any modification in conventional Distributed Coordination Function (DCF).

DCF provisions contention-based MAC mechanism through legacy Binary Exponential Backoff (BEB) algorithm. BEB induces crucial problems due to the high probability of collisions in the pseudorandom sequence. The authors in [90] proposed an algorithm, called, Pseudorandom Sequence Contention Algorithm (PRSCA) to adjust the Contentions Window (CW) size and minimize the collision probability. However, 5G era surfaces several QoS requirements incompatible with conventional DCF of traditional WLAN such as backward compatibility, optimal bonding [91]. However, research to accommodate more advanced DCF models, with finite retransmission attempts and Poisson traffic, can be a solutions interference handling in 5G and Beyond networks [92].

C. TEMPOROSPATIAL COMMUNICATION

SDN-based centralized network management is ideal for spatiotemporal control of the radio spectrum [93]. Moreover, there are several spatiotemporal unconventional vertical applications of wireless networks, such as dense vertical urban environments, dynamic airborne IoTs, UAVs, drones, and aerospace communications [94]. The authors in [95] suggested SDN-based high fidelity modeling for mobility prediction in aerospace network operation. Here, the SDN-based implementation provision substantial empowerment of network management through well-established concepts, such as autonomous beam control and optimal network routing updates. SDN extracts the radio network access functions such as spectrum management, mobility management, and interference management from the radio data plane. Loon SDN is the temporospatial implementation of the above-discussed concept in Open Network Operating System (ONOS) [94].

However, optimum real-time parameters collection is challenging for SDN-based temporospatial communication. Channel state information (CSI) estimation is the fundamental challenge in optimum path and interference assessment in wireless communication. 5G and Beyond communication contain extensive utilization of complex techniques such as mMIMO, OFDM, and mmWave; therefore, it results in a very a computational complexity for CSI estimation [96].

D. SOFTWARE ACCESS POINT

Unprecedented growth in mobile data flux has resulted in integrating cellular services with WiFi. This technological amalgamation has opened various fronts related to interference mitigation and spectrum management [97]. SDN-based centralized approaches emerge as potential candidates to handle the unconventional solution for seemingly less QoS in NGWNs [98]. The authors in [99] presented an SDN-based carrier-grade framework to create a software Access point (SAP). SAP employs a northbound API-based Network Situation Awareness (NSA) technique to abstract user equipment and Access Point (AP). SAP-based approach is propagated as a flexible, user-friendly and scalable approach to cover crucial aspects related to mobility management, load balancing, interference mitigation, QoS guarantee, etc.

However, there are several limitations in the holistic view of SAP-based networking, such as Northbound API scalability in 5G [100], compatibility of the southbound protocol with Wi-Fi requirements [101], delay management [102], and estimation of overhead [103]. Moreover, the study in [99] suggested a modified attractor selection algorithm to evaluate common 802.11 handoffs in inherent Gaussian noise; however, the experimental results do not qualify for Beyond 5G URLLC requirements due to about 1 second disruption in handoffs.

E. COGNITIVE MANAGEMENT FRAMEWORK

AI, DL, ML, and Neural Networks are the emerging revolutionary technologies to surface the self-governed cognitive paradigm in communication technologies. In [104], the authors proposed an SDN-based cognitive management framework to counter several critical issues in heterogeneous networks such as optimal power utilization, interference mitigation, resource management, and end-to-end QoS. This framework explicitly incorporates SDN at Base Station (BS) level to achieve a centralized view of heterogeneous networks [105].

However, this architecture lacks deliberations on SDN-based OpenFlow management with prevailing technologies such as NVF, NS, Cloud Computing, Fog computing, and Edge computing. Moreover, the scenario discussed in the presented architecture does not cover OpenFlow implementations for comparative route selection in multi-route scenarios [106].

F. RFLOW+

The concept of a heterogeneous network is dominating the overall emerging scenario of wireless networks through an integrated approach of various upcoming technologies, such as Visible Light Communication (VLC), WiFi, 5G, and traditional cellular networks [107]. SDN-based solutions are widely idealized to meet the challenging requirements related to network management and scalability. In [108], the authors presented an SDN-based new approach, called RFlow+, to address the limitation of a scalable implementation of OpenFlow-based solutions. $RFlow^+$ works on the principle of onsite real-time local counters combined with short-term and long-term monitoring concepts. The basic difference between RFlow+ and native OpenFlow is the update of flow statistics i.e. RFlow+ updates only changed flows. The counting algorithm performs short-term measurements within the window of 50ms. As per the presented results, RFlow+ generated 100% detection in 23ms.

However, it is pertinent to highlight that time window management would be most crucial in Beyond 5G scenarios, such as the URLLC time requirement reaching as low as 1ms terms of reliability, packet loss of 10−5 for small data packets [109]. RFlow+ may not only meet the latency requirements of 5G. Moreover, 5G and Beyond networks contain distributed HetNet environment, where, single SDN controller cannot sufficiently address the networking requirements. Therefore, RFflow+ require further optimization and experimentation is distributed SDN environment.

G. SELF-ORGANIZING ENERGY EFFICIENT SCHEDULING

It is a strong notion that conventional network architecture is not flexible and robust enough to adapt to the emerging heterogeneous dynamic wireless communication domain. In [110], the authors presented an energy-efficient downlink/uplink scheduling using the Markov approximation-based distributed economical algorithm in the SDN framework. The algorithm supplements into three sub-routines: user association, power control, resource allocation, and interference mitigation. The presented SDN framework is dependent on two constraints, including unique association and channel requirement with maximum available channels at BS.

However, emerging heterogeneous wireless networks surface various scenarios related to multi BS association [111] and beyond capacity channel requirement handling by BS [112]. Moreover, the suggested framework does not include WiFi and cellular integrated wireless ecosystem. Similarly, Markov approximation can emerge as a challenging problem for handling CSI from different technologies and extremely wide bandwidth scenarios such as mMIMO, OFDM, and mmWave.

H. ENHANCED INTER-CELL INTERFERENCE CANCELLATION ON SDN

NGWNs are bringing revolutionary possibilities due to the Integrated employment of Radio Access Networks (RANs) and SDN-based dynamically controlled spectrum [113]. Adaption of HetNets by advanced LTE networks allows robust, efficient, dynamic, and holistic control of network resources for interference mitigation. In the study [114], the authors presented an SDN/RAN-based enhanced Inter-Cell Interference Cancellation (eICIC) and Coordinated Multipoint(CoMP) implementation for efficient spectrum utilization and interference mitigation in cellular networks [115]. The overall achievable throughput of eICIC is evaluated through Shannon's Capacity and Jain's index. The scheme is considered with a simulation scenario of evenly distributed UE (User Equipment) in overall networks.

However, the backhaul handling and SDN functionalities face several challenges due to unconventional technologies and stringent requirements of Beyond 5G technologies [116]. The presented scheme would require major evaluation related to emerging concepts, such as the topological merger of PtP (Point-to-Point)/ PtM (Point-to-Multipoint), MIMO (Multi-Input-Multi-Output), Fog Computing, and Cloud Computing.

I. COORDINATED ADAPTIVE SPECTRUM SHARING

AI-based cognitive paradigm is gaining a foundational position in SDN-based implementations in interference mitigation techniques related to connectivity and data flow handling in dense HetNets [117]. Physical layer-based implementation of AI has introduced the concept of C-RANs. In [118], the authors presented an SDN-based coordinated adaptive spectrum sharing and interference management through CR in HetNets. The technique relies on a specific set of parameters, including network topology and data requirements for reinforcement learning-based optimal handling of fluctuating traffic.

However, CRANs based spectrum management and interference mitigation can be further optimized through extension in input parameters by considering the backhaul capacity [119], mobility requirements [120], and multi-dimensional requirements [121]. Moreover, the presented scheme suggested a cloud-based SDN controller; however, SDN-enabled fog computing scenarios swiftly extend the performance of CR-based heterogeneous networks [122].

J. FUZZY LOGIC ASSISTED FEMTO ACCESS POINTS

The paradigm of mMTC in Beyond 5G networks is extensively approached with Femto Access Points (FAPs) and D2D communications schemes. Dense small cell scenarios create challenging mobility and handover management issues in HetNets. Fuzzy and MADM (Multi-Attribute Decision Making) based algorithms are widely pursued solutions for handover management to ensure QoS [123]. However, network discovery is challenging due to complex scenarios related to delays and co-channel interference. In [124], the authors presented SDN-assisted FAP and D2D predictive discovery mechanism to reduce unnecessary handover using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Analytical Hierarchical Process (AHP) algorithms. TOPSIS and AHP algorithms are tuned on the parameters, including bandwidth, jitter, and bit error rate. Here, interference mitigation is achieved through frequency reuse and optimized power management to complement the overall network capacity. The solution is advocated for improved performance with 20% reduced blocking rate and 11% reduced number of handovers.

However, the 5G related additional parameters would fairly limit the achieved performance, such as UE speed, time to stay, integrated scenarios of HetNets and Reference Signal Received Power (RSRP). Similarly, NGWNs step up these limitations several folds due to computation complexities and delay sensitivities [125].

K. HIERARCHICAL AGGLOMERATIVE CLUSTERING

Exponentially increased demand for seamless QoS has introduced UD-SCNs (Ultra-Dense Small cell networks) in next-generation mobile networks. Therefore, interference-centric sufferings of UD-SCNs are highly imperative. In [126], the authors suggested centralized control of subchannels called SDN-HAC (SDN-based Hierarchical Agglomerative Clustering). SDN-HAC decides cluster merging on suitability function-based similarity criterion. The sustainability functions calculation and merger process govern the overall complexity of this solution. Although the proposed solution advocates improvement in system payoff by 436.34%.

However, there are several limitations in the integrated implementation of this solution. The solution does not cover dynamic scenarios related to the scalability of clusters in cell-free Multi-Input-Multi-Output (MIMO) scenarios [127]. Moreover, evaluations are required on interference faced by massive IoT devices and bandwidth handling. Similarly, the solution lacks the overall handling of latencies and effects of clusters size in this domain. Further, the solution does not cover backward compatibility in coexisted scenarios of various generations of mobile technologies. Similarly, the complexity of sustainability function is dependent upon the number of Small Cell Base Stations (SBSs). Therefore, translation of this solution into 5G and Beyond pico-cell level is a challenge.

L. MM-WAVE V2X NETWORK

It is strongly believed that Beyond 5G technologies will bring a revolution in the concept of safety through URLLC. However, interference mitigation is one of the major challenges in achieving the idealized human-machine connectivity [128]. The spectrum exploitation at the mm-Wave level is the primary distinction of B5G communication advancements. In [61], the authors proposed an SDN-based architecture, called mm-Wave V2X (Vehicle to Everything communication), for 5G enabled High Definition (HD) map distribution to achieve cooperative perception. Here, the interference mitigation is demonstrated on the concept of narrow beam steering in mm-Wave technology. Further to this concept, the same authors presented the improved architecture of the abovementioned scheme for indoor implementation and safe driving requirements [129]. Here, SDN is utilized as a management platform for optimization-centric control of mm-Wave.

However, the presented architecture seems to be over-simplified in B5G-based dense communication [130]. The suggested interaction between the control plane and data plane would be stressed under stringent bounds of security protocols for 5G URLLC. Similarly, the presented architecture is not scalable in terms of applications layer implementation and holistic management. Moreover, the defining specification and segregation of functionalities between primary and secondary controllers would be a challenge.

M. SPECTRUM SHARING AND AGGREGATION

Unconventional dynamic interference issues are introducing the concept of spectrum sharing and aggregation through AI-based control of physical layers known as Cognitive Radios (CRs) [131]. CRs provision possibilities of interference mitigation through various unconventional solutions such as CR-SDN. One of the solutions in this domain is spectrum sharing and aggregation for SDN-based Cognitive networks [132]. Here, in case of bandwidth non-availability, the proposed solution provisions cellular users to access the Television White Space (TVWS) network. The technique is based on an optimal aggregation of licensed and non-licensed networks for requisite QoS. The proposed schemes claim several other outcomes, such as optimal mobility management and efficient handover.

However, the evaluations are only focused on specific parameters, including transmission rate, primary user analysis, and power. But, the solution does not provide discussion for applications related to handling low latency requirements. Moreover, the solution requires evaluation in terms of URLLC in Beyond 5G networks, which is as low as to 1ms [133].

N. STATE- ACTION-REWARD-STATE-ACTION (SARSA)

In [134], the authors proposed a delay based route selection model in SDN enabled wireless Power Line Communication (PLC). The authors formulated a delay model based on parameters such as rate (BER) Pe, the applied coding, and the SNR margin in power line channels. The proposed solution perform an AI assisted route selection through SARSA algorithm. Here, SDN controller collects the channel information to performance feedback and uploads to the AI agent. thereby, the agent learns the optimum route selection technique.

However, the proposed solution contains several limitations for compatibility with B5G environment. The delay model variables exponentially increase, resulting in a dynamically challenging problem to form a comprehensive delay model. Moreover, solely delay model based SARSA algorithm will not be sufficient for optimal path route selection. B5G communication is dependent on series of variables as extension of eMBB, URLLC, and mMTC requirements.

V. PROPOSED ARCHITECTURE

A. INTELLIGENT INTERFERENCE MITIGATION WITH DISTRIBUTED SDN

AI has fairly automated various technological solutions in next-generation computing [135]. However, it is observed that the inclusion of AI-based automation in SDN controller protocol has a wide gap in research. The investigations

TABLE 3. SDN-based interference Mitigation Techniques.

Ref.	Year	Technique	Functionality	Limitations
[87]	2013	Distributed Mobility Management	Opportunistic transmission/reception	• It does not cover the Fog computing paradigm • It does not provide Backhaul link management in mobile AdHoc networks
[89]	2014	Packet Scheduling Algorithm	BEB-based Packet scheduling in AP's downlink	• BEB induces crucial problems due to the high probability of collisions • Not compatible with conventional DCF of traditional WLAN
[95]	2015	Temporospatial communication	High fidelity modeling for mobility prediction	• Optimum real-time parameters collection is challenging
[99]	2016	SAP	Northbound API-based Network Situation Awareness	• Northbound API scalability in 5G • Compatibility of the southbound protocol with Wi-Fi • Delay management for Beyond 5G URLLC
[104]	2016	Cognitive Management Framework	Specifically incorporates SDN at BS (Base Station) level to achieve a centralized overview	• Interactions with prevailing technologies such as NVF, NS, Cloud Computing, Fog computing and edge computing • Comparative route selection in multi-route scenarios
[108]	2017	RFlow $^{+}$	Onsite real-time local counters in combination with short term and long-term monitoring	• Time window management would be most crucial in the Beyond 5G scenario of URLLC
[110]	2017	Self-Organizing Energy Efficient Scheduling	Unique association and channel requirement within maximum available channels	• Multi BS association • Beyond capacity channel requirement handling
[114]	2017	Enhanced Inter-Cell Interference Cancellation	eICIC and CoMP implementation through Shannon's Capacity and Jain's index	• Backhaul handling of Beyond 5G technologies • Topological merger of PtP/PtM, MIMO, fog computing and cloud computing
[118]	2018	Coordinated Adaptive Spectrum Sharing	Network topology and data requirements for reinforcement learning	• Limited Parameters included for optimization • It does not cover the Fog computing paradigm
[124]	2018	Fuzzy logic assisted Femto Access Points	TOPSIS	• Additional parameters would fairly limit the achieved performance
[126]	2018	Hierarchical Agglomerative Clustering	SDN-HAC decides cluster merging on suitability function-based similarity criterion	• It does not cover dynamic scenarios related to the scalability of clusters in cell free MIMO • The solution lacks the overall handling of latencies and effects of clusters size
[61]	2019	mmWave V2X Network	SDN is utilized as a management platform for optimization centric control of mmWave	• Oversimplified under the lens of the security paradigm • Scalability issues in applications layer wholistic management
[132]	2021	Spectrum Sharing and Aggregation	Optimal aggregation on licensed and non-licensed networks	• The solution does not provide discussion for applications related to handling low latency requirements in 5G
[134]	2022	SARSA	Delay based route selection model in SDN enabled wireless PLC	• Solely delay model based SARSA algorithm will not be sufficient for optimal path route selection. B5G communication is dependent on series of variables as extension of eMBB, URLLC, and mMTC requirements.

related to AI-enabled SDN-based interference mitigation are not widely available in publications, especially concerning the control layer functionalities in a challenging 5G communication environment. Moreover, AI along with ML and Deep Learning (DL), has fairly revolutionized several smart concepts such as predictive analysis in health care [136], food industry automation [137], future warfare [138], fault detection in aviation [139], etc. Therefore, this paper has proposed an AI-enabled distributed SDN controller architecture for automated flow management and load sharing for interference mitigation. The broad illustration of the proposed architecture is shown in Fig. 5. The distributed primary SDN controllers are arranged in a hierarchical format and interference parameters are extracted as AI attributes for B5G wireless networking systems. All associated distribute SDN controllers are supervised through root SDN controller. The root SDN controller performs further DL-based optimization of primary SDN controller.

Root SDN controller governs the overall concept, however, the basic interference parameters-based DL learning is performed at primary controllers. DL-based learning at the Root SDN controller is dependent on parameters of primary SDN controllers. The algorithms in proposed model can be segregated into four categories. The first category of algorithm is to classify the 5G communication interference parameters and attribute extraction using DL techniques. This approach reduces computational overload for edge computing in end nodes and SDN switches. The second category algorithms

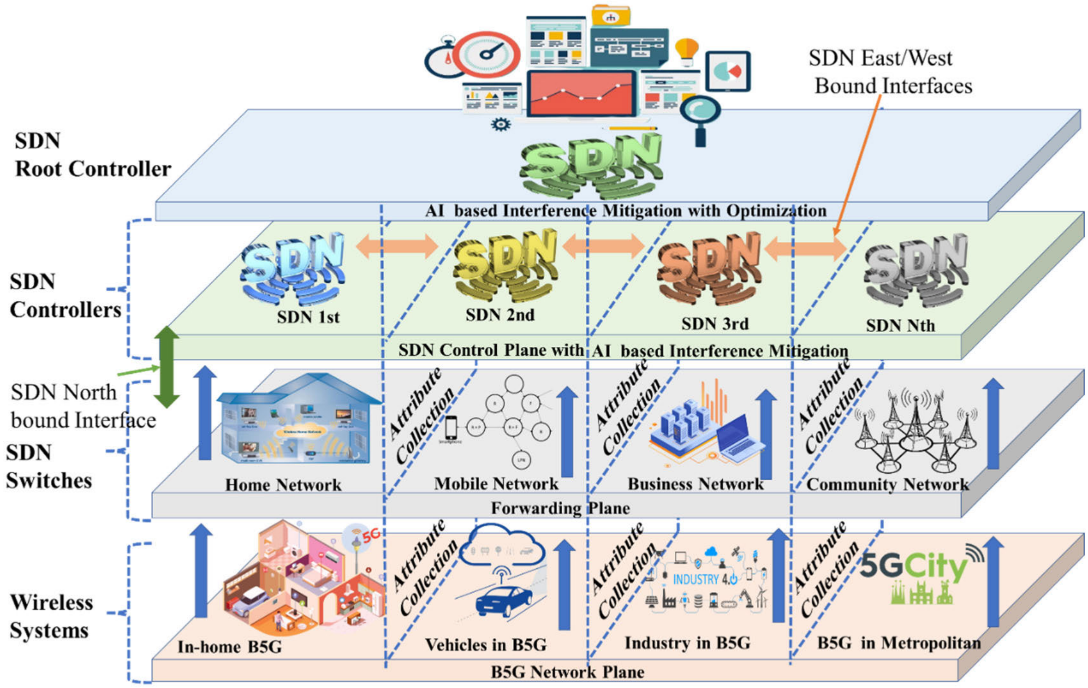

FIGURE 5. Proposed architecture for Intelligent Interference Mitigation with distributed SDN.

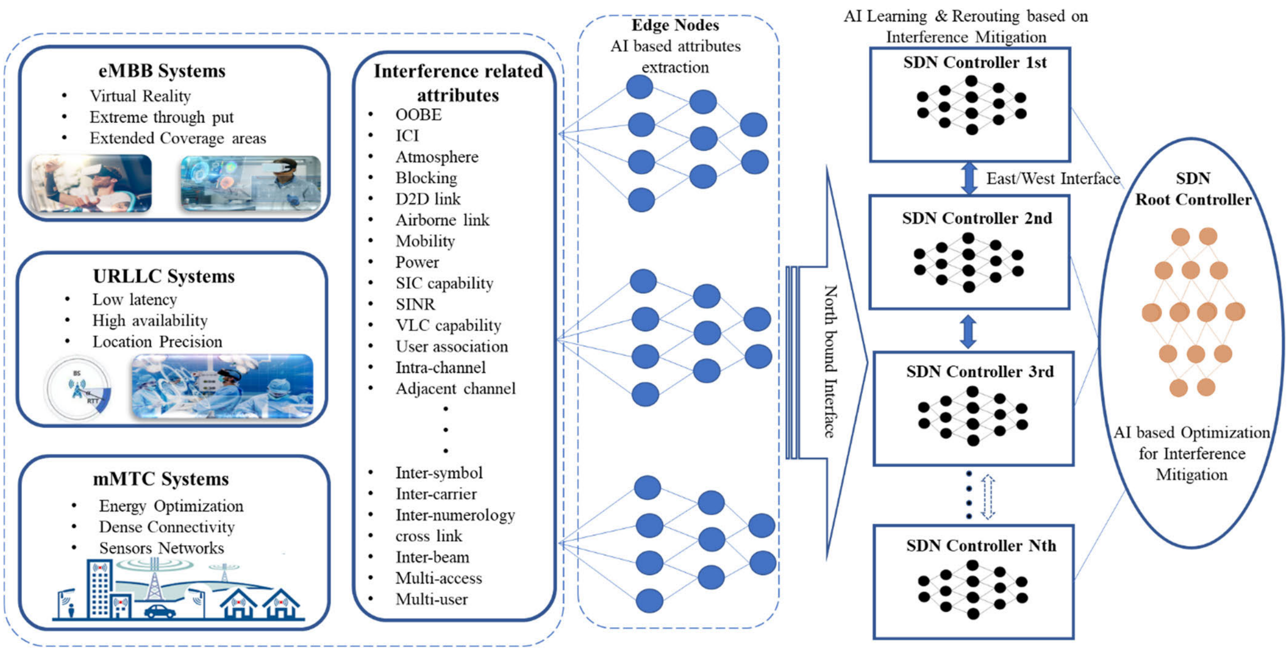

FIGURE 6. Relation Representation of Proposed architecture.

are required for optimum dynamically controlled routing for interference mitigation. These computations are performed at primary SDN controllers.

The third category of algorithm is for attribute extraction from SDN controller for further optimization through root controller. The same attributes are also shared between primary SDN controllers through East/West bound interfaces. The fourth category includes DL-based optimization of distributed primary SDN controllers for route optimization. The fourth category is most complex and includes DL techniques to perform computations at Root SDN controller. The proposed architecture aims to provide hierarchical optimization for SDN-based interference mitigation. However, Root and primary SDN controller placement in 5G architecture requires detailed analysis, simulation and experimentation [140].

B. RELATIONAL REPRESENTATION OF PROPOSED ARCHITECTURE

Efficient solutions are critically dependent on accurate problem scenario formation. We formulated a relational representation [141] of the proposed architecture for structured analysis and DL-based solution generation. The relational representation includes series of DL attributes and their relations with higher layers in the proposed architecture. Similarly, it involves the DL attributes-based relations among primary SDN controllers and with the root SDN controller. The relational representation provides an estimation of system complexity and algorithmic requirement for further solution formation.

DL-based learning approaches are largely dependent on data preprocessing for attribute selection and extraction [142]. SDN separates the control plane from data plane, thereby, interference parameters based refined attributes extraction is proposed at edge nodes based SDN switched in the proposed architecture [143]. The refined attributes are employed for learning at primary SDN controllers for alternate route calculation and multi route scenario generation. Moreover, a separate process is proposed for further SDN controller at root level. Interference parameters are extracted and shared among primary SDN controller as well root SDN controller

Therefore, the proposed architecture includes three distinct attribute extraction schemes for integration DL algorithmic interfaces. 1) East/West bound Interfaces of primary SDN controllers 2) Northbound Interfaces of Primary SDN controllers and 3) South bound interfaces between Primary SDN controllers and Root controller.

We categorized the B5G interference parameters in three types for attribute extraction, including, eMBB, URLLC, and mMTC as illustrated in Fig. 6. The attributes related to interference issues cover wide spectrum of possibilities, such as Out of band Emission (OOBE) level, weather satellites, GPS interference, Inter Cell Interference (ICI), atmospheric conditions, blocking, D2D links, Airborne links, Mobile Terminal, Power Allocation, Successive interference cancellation (SIC) capability, Signal-to-interference-plus-noise ratio (SINR), Vehicle-to-vehicle (V2V) links, Visible Light Communication (VLC) capability, user association, Intra-channel interference, adjacent channel interference, inter-symbol interference, inter-carrier interference, inter-numerology interference, cross link interference, inter-beam interference, multi-access interference, multi-user interference etc [144], [145]. Moreover, the attributes will also cover the link parameters of B5G communication such as Jitter, Latency, Energy/bit, Traffic Capacity, Location Precision (LP), User Experience and Peak data rate [146].

VI. FUTURE RESEARCH DIRECTIONS

Specifications of NGWNs necessitate conceiving an unconventional robust yet flexible networking architecture for interference mitigation. SDN-based implementations are widely researched for optimization, scalability, and flexibility in Beyond 5G networks. However, the embryonic status of SDN technology provokes several challenges for researchers in both academia and industry. In subsequent paragraphs, we critically analyze the prevalent issues in the subject domain to highlight the future research direction.

A. INTELLIGENT ATTRIBUTES EXTRACTION FOR INTERFERENCE MITIGATION

AI is revolutionizing solutions through automatic control of requirement manual interventions in various schemes. Similarly, we proposed Intelligent Interference Mitigation with distributed SDN controllers. However, the proposed scheme critically depends upon the attribute extraction mechanism. Due to unconventional implementation algorithm design for AI-based attributes extraction for SDN controllers is a challenging future research domain [147]. Moreover, AI enabled SDN controller placement in overall wireless architecture also requires detailed analysis and experimentation.

B. SDN ENABLED FOG FEDERATION FOR INTERFERENCE MITIGATION

Fog Federation is an emerging paradigm for flexibility and scalability in next-generation communication [148]. Fog computing leverages several technological limitations such as IoTs [149], UAVs [150], Vehicular networks [151], etc. However, the available publications do not provide any substantial research in fog computing-enabled SDN-based interference mitigation. Moreover, the ecosystem of 5G networks creates tremendous challenges in this domain [152], [153]. Likewise, analysis of existing SDN controllers for interference mitigation in mobile fog environments is also a scarcely pursued area of research.

C. INTERFERENCE MITIGATION IN SDN ENABLED COGNITIVE RANS

Cognitive RANs are widely researched for optimization in B5G networks for intelligent resource management and spectrum control [154], [155]. SDN integration has further enhanced the possibility of achieving the boundary of spectrum utilization through cognitive RANs [156]. However, the concept of SDN-enabled cognitive RANs face is researched at a limited scale without covering the interference mitigation requirements [157]. Therefore, it is considered an open area in various aspects, such as algorithmic level experimentation of possible solutions and ascertaining the limitations of existing SDN controllers in this domain.

D. 5G URLLC COMPATIBLE SDN CONTROLLER-BASED INTERFERENCE MITIGATION

Both academics and industry widely research URLLC as a key usage scenario in 5G communication. The stringent requirements of URLLC create challenges and bottlenecks in various concepts in wireless networking, including interference mitigation [158]. During our focused review, none of the existing SDN implementations cover the aspects of interference mitigation in URLLC environments of 5G communications. URLLC also brings challenges related to the efficiency of SDN controllers software design and implementation hardware [159], [160].

E. LIGHTWEIGHT SDN-BASED INTERFERENCE MITIGATION IN DRONES

Drone communication is one of the most prominent emerging revolutionary concepts. Optimized and secure implementation of drone technology faces a series of challenges, including interference mitigation [161]. Moreover, drones and UAVs face distinct unconventional limitations such as low processing power, low energy, and multi-dimensional positioning [162], [163]. Meanwhile, SDN is researched to encapsulate all aspects of communication, including drones and UAVs [164]. However, none of the available SDN-based solutions cover interference mitigation in a highly dynamic and resource-constrained drone environment.

VII. CONCLUSION

The unprecedented adoption of wireless communication in the technological paradigm has faced various challenges. Interference Mitigation is one of the major challenges faced by intensive wireless implementation in communication. Network routing is one of the approaches for interference mitigation, but it is researched at a limited scale in conventional networks due to the non-availability of a holistic view of the communication environment. However, SDN has emerged as an unconventional architecture to address the challenge of interference in NGWNs. We have critically analyzed prominent SDN-based interference mitigation techniques. Moreover, we also discussed the potential and limitations of primary SDN topologies for countering the interference mitigation issues in B5G networks. We proposed an architecture for Intelligent Interference Mitigation with distributed SDN controllers. Finally, we concluded our review by highlighting potential future research directions in the subject domain, including, areas related to Fog Federation, Cognitive RANs, 5G URLLC compatible SDN controllers and Lightweight SDN in drones.

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