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Bio-Inspired Network Security for 5G-Enabled IoT Applications

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ABSTRACT Every IPv6-enabled device connected and communicating over the Internet forms the Internet of things (IoT) that is prevalent in society and is used in daily life. This IoT platform will quickly grow to be populated with billions or more objects by making every electrical appliance, car, and even items of furniture smart and connected. The 5th generation (5G) and beyond networks will further boost these IoT systems. The massive utilization of these systems over gigabits per second generates numerous issues. Owing to the huge complexity in large-scale deployment of IoT, data privacy and security are the most prominent challenges, especially for critical applications such as Industry 4.0, e-healthcare, and military. Threat agents persistently strive to find new vulnerabilities and exploit them. Therefore, including promising security measures to support the running systems, not to harm or collapse them, is essential. Nature-inspired algorithms have the capability to provide autonomous and sustainable defense and healing mechanisms. This paper first surveys the 5G network layer security for IoT applications and lists the network layer security vulnerabilities and requirements in wireless sensor networks, IoT, and 5G-enabled IoT. Second, a detailed literature review is conducted with the current network layer security methods and the bio-inspired techniques for IoT applications exchanging data packets over 5G. Finally, the bio-inspired algorithms are analyzed in the context of providing a secure network layer for IoT applications connected over 5G and beyond networks.

INDEX TERMS 5th generation network, artificial intelligence, biological, the Internet of Things, network layer, security, wireless sensor networks.

I. INTRODUCTION

With rapid global development, new applications and technologies emerge to meet ever-increasing needs. Technologies have an important effect on personal interactions, governments, and businesses. The Internet of Things (IoT) is a computing paradigm that has a major role in modern data communication, mobility, and monitoring technologies [1]. IoT enables everyday objects to connect with the Internet and communicate with each other. By using IoT, a huge number of devices and applications can be interoperable [2]. Over time,

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IoT requires new performance criteria such as large-scale connectivity, security, ultra-reliability, and throughput [3]. To meet these requirements, the evolving 5G technology is expected to provide a new platform for IoT applications and to handle IoT system requirements. 5G technologies aim to provide a high data rate, extensive coverage, efficient capability of networking, and improved quality of service [4]. In supporting IoT, 5G plays a vital role in connecting and facilitating communication of the massive number of objects over the Internet [5].

According to a 2018 McNamee report, IoT faces security concerns due to its rapid growth and evolution [6], [7]. Although security is the most important challenge for IoT
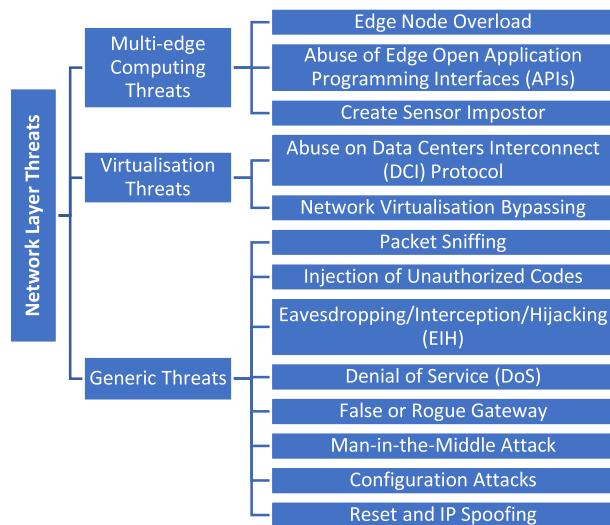
FIGURE 1. Threats on the network layer of 5G enabled IoT applications.

system and with the evolution of 5G and beyond [8], other enormous challenges need to be addressed to provide an interoperable and reliable architecture for the data packet exchange between heterogeneous devices in a 5G environment. According to [9], [10], several factors multiply the security issues in 5G networks, including the IP-based open architecture, the diversity of the underlying access network technologies, the huge number of interconnected mobiles, the dynamic heterogeneity device types, and the cloud, which uses information exchange and data preprocessing [9], [11].

IoT data routing security over 5G is the biggest challenge that must be addressed before the massive utilization of IoT. The large number of users and the data transfer speed over gigabits per second in 5G leads to a high number of threats in transferring malicious files [5]. Before the formal use of these IoT systems over 5G that are meant to transfer enormous data every minute, 5G must ensure data reliability and security [12]–[14]. Billions of IoT entities communicating over 5G make the system vulnerable and opens for attackers to launch denial-of-service (DoS) or man-in-the-middle (MITM) attacks [3]. Furthermore, 5G and beyond networks change the way of transmitting data by the significant reduction in latency that requires massive updates in network protocols security meant for 4G networks to protect data routing between IoT devices over 5G networks. Figure 1 present the threat landscape at the network layer 5G enabled IoT applications [15]–[19].

The challenges encountered by IoT applications increase the need for new algorithms that are able to provide efficient data routing. The authors in [4] conducted a comparative study between bio-inspired and classical solutions to address IoT challenges and found bio-inspired techniques promising. These bio-inspired algorithms are rare because to build these solutions, a researcher needs to have a detailed background in the relevant biology field. Bio-inspired solutions can

solve complex problems in a reliable manner and with high accuracy; such solutions include ant-colony optimization, artificial immune systems, swarm optimization, bee-colony optimization, and genetic algorithms. These intelligent algorithms use techniques that mimic the behavior of biological organisms to solve computer science problems. In particular, in computer network security, the word ''virus'' was adapted from life sciences to emphasize their similar behavior [20], [21].

Several published studies have dealt with IoT challenges for 5G using biologically inspired algorithms. These studies focus on various aspects such as flexibility, reliability, mobility, scalability, and availability. However, very few studies concentrate on data routing security in 5G networks. Many cybersecurity projects can gain from implementing diverse nature-inspired solutions such as genetic algorithms, increasing the prevention of cybercrime [22]. Furthermore, the use of genetic algorithms can help in detecting cyberattacks and anomalies [22].

The performance improvement for 5G networks attained by the Autonomous Distributed Mobile Management Entity solves selection problems. The bio-inspired solution is based on the attractor-selection mechanism in the biological systems gene expression; a computer simulation shows the solution's positive effect in the system performance, load distribution, decreasing overhead, and achieving load balance [23]. Other research targets the IoT communications in 5G networks by developing a bio-inspired resource allocation scheme that considers a group of users who share similar social characteristics including their relationship and behavior using a cellular automaton-based model in which the best features of the biological systems are imitated; this process simplifies the complexity in the large-size sliced network and support resource allocation optimization [24]. A new bio-inspired solution based on the genetic algorithm is designed to solve the Physical Cell Identifier configuration problems in 5G ultra-dense networks; the new algorithm is automated, efficient, and has computationally feasible time [25]. In addition to a highly efficient and reliable platform designed for 5G mobile communication, the platform based on the bacterial communication concept mimics three bacterial behaviors, namely, perception, infection, and diffusion [26].

The recent literature indicates that the nature-inspired algorithms provide better outcomes compared with traditional ones when facing IoT challenges. From 2010 to 2018, approximately 75% of bio-inspired studies focused on gateway problems in IoT applications, and 20% focused on interoperability challenges. By contrast, essential and important IoT challenges need to be studied such as security, privacy, reliability, flexibility, and mobility [4]. Therefore, more research should focus on these aspects using nature-inspired solutions. Given that few studies concentrate on the security aspect, this paper focuses on bio-inspired network security in 5G networks for IoT applications.

The main contributions of this paper are as follows.

i Thoroughly investigates the security of 5G-enabled IoT applications to discover the main challenges and solutions.

ii Describes and reiterates the security vulnerabilities and requirements for WSNs, IoT, and 5G-enabled IoT applications.

iii The viability of bio-inspired approaches is reviewed and analyzed for security of 5G-enabled IoT applications.

Section II provides an IoT application scenario of data routing in 5G networks, then discusses the security requirements and loopholes in IoT technology, and explores network layer security issues in IoT–5G systems. Section III reviews current approaches to provide network security in 5G-enabled IoT applications. Section IV studies the bio-inspired techniques that can address the network security issues in 5G-enabled IoT applications. Section V demonstrates the analysis of bio-inspired network security algorithms for 5G-enabled IoT applications. Section VI concludes.

II. SECURITY REQUIREMENTS IN THE NETWORK LAYER OF IoT OVER 5G

IoT has a significant role in several important fields such as education, healthcare, business, transportation, and agriculture, as shown in Fig. 1 [27]. Therefore, addressing and analyzing network layer security issues in IoT applications is critically important, helping developers and corporations to design and propose appropriate solutions to provide the most reliable IoT-based services. A mobile gateway-based remote eHealthcare solution was given in [28] that acts as a router for the Body Sensor Network (BSN). The body sensors autonomously collect vital sign data such as patient location using GPS sensor, heart rate using optical heart rate sensor, and possible fall detection using accelerometer sensor. The data are sent in real-time to the intelligent personal assistants (IPAs) platform called AMBRO (storage side) for further analysis and appropriate actions in case of emergency. Therefore, in the given scenario, data routing security is an essential requirement to protect sensitive information against malicious behavior. To secure the data routing security between BSN and AMBRO, authors in [29] propose using ECG based Multiple Fiducial-points based Binary Sequence Generation (MFBSG) algorithm for data encryption.-

The security architectures for previous generations (3G [30] and 4G [31]) are not adequate for 5G because of the security challenges that originated in 5G technologies. Therefore, researchers in [32] presented a security architecture for 5G networks that consider the dynamic environment, new services, and technologies in 5G. The architecture is divided into four main components: domains, strata, security realms, and security control classes. First, domains are the core of 5G security architecture and represent a set of network physical and logical entities, various services, and different functionalities in 5G. Then, the strata offer a high-level view of data, protocol, and functions related to domain services.

Next is the security realm (SR). Unlike the previous two components at a high abstraction level, SR is the main tool in 5G security architecture that captures all security threats from strata and domains by focusing on security assessment for different network functionality and areas. The relevant security realms for 5G networks are access network, core network, and management SRs. Some of the security requirements under the access network security realm are data storage protection, false selection detection, illegitimate data injection prevention, and radio control message protection. In the core network security realm, the requirements are authentication, authorization, privacy protection, secure mobility, key distribution, and algorithm negotiations. The security requirements for the management security realm are access monitoring and management, secure orchestrations, and key management. The final component is the Security Control Classes, which provides a set of needed security functions and mechanisms [32].

With the advancement in IoT services and 5G technologies, studying the security requirements and accordingly addressing the vulnerabilities in IoT applications are important. The security requirements and loopholes based on IoT architecture layers (Application, Network, and Edge layers) are classified in [33]. The application layer provides a range of services and functions, usually performing functionalities using APIs in which mostly the least level of security is enabled. Moreover, current IoT devices by default trust the third-party service providers that are found to have potential flaws, such as weak authentication and misbehaving service. Thus, the application layer required to include a secure API, application verification, and information forensics. Next, the network layer maintains data transmission and supports IoT applications in collecting massive amounts of data. Therefore, the network layer requires on the security side, at minimum, traffic monitoring, channel encryption, anomaly detection, and traffic shaping. On the edge layer that is related to performing the interaction between the IoT environment and end-point devices, it requires at least authentication, limited access, threat hunting, and data encryption. The generated data from the edge are valuable, critical, and sensitive.

Thus, confidential data should be protected and can only be accessed by authorized persons. Moreover, one of the edge layer applications is the wireless sensor network (WSN) that includes a set of sensor nodes that is controlled and managed by a coordinator [34]. WSN is an enabler of technology and one of the main components in IoT environments [35]. Figure 2 shows a graphical abstract of possible applications and security requirements of WSN, IoT, and 5G–IoT systems. The research community recently began to notice the enormous security issues that arise with the integration of IoT-based systems and 5G networks and its massive effects on global data communication [36].

5G-based IoT systems bring extensive improvements in several critical domains such as security monitoring, mHealth care systems, traffic safety, and e-Banking [36], as shown in Figure 2. Therefore, applying extreme levels of security is
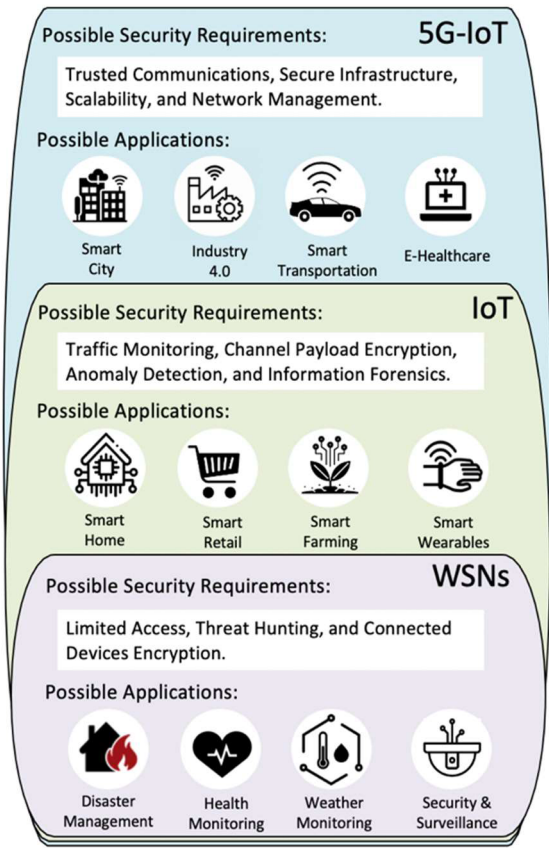
FIGURE 2. WSN, IoT, and 5G–IoT applications with security requirements.

TABLE 1. Network layer vulnerabilities and security requirements.

	Vulnerabilities	Security Requirements
WSN [33, 39-42]	Weak physical security, Insecure interfaces, Spoofing attack, Deprivation attack, Insufficient energy harvesting.	Limited authorized access, Threat hunting, Mobile Application Framework (MAF) authentication, Connected devices encryption.
IoT [33, 43-47]	Weak programming practices, Inadequate authentication, Insecure interfaces, Software and OS misconfiguration, Algorithm computational overhead, Privacy violation on the cloud, Buffer overflow, Replay attack, RPL routing attack.	Traffic monitoring, Channel payload encryption, Anomaly detection, Traffic shaping, Secure API, Application verification, Information forensics.
5GIoT [37, 38, 48-52]	Several attacks (DoS, MITM, Sybil, Flooding, and Jamming), Misconfiguration, Hacking, Data manipulation, Node subversion, Node failure and outage, Message corruption, Managing massive number devices, Interruption interception.	Trusted communication over 5G networks, Flexible and scalable security architecture, Energy-efficient security, Secure infrastructure, Scalability, Hardware and software security, Network management.

essential to avoid problems and provide reliable data routing. Crucial security issues in 5G include DoS and distributed denial of service (DDoS) attacks caused by the massive number of connected devices; these attacks are the result of vulnerabilities on both sides of the system, namely, the infrastructure and the edge devices [36]. In addition, the high diversity of IoT devices, functionalities, and routing protocols that can lead to security issues need to be addressed by using authentication mechanism such as cryptographic algorithms, considering the computational overhead that accompanies it and attempting to find a balance between robustness, performance, and efficiency [33].

Generally, data attacks can be made by unauthorized access to data in a repository or attacking this data while in transit by launching on data routing using eavesdropping, message modification, MITM, authentication, and replay attacks [5]. The assurance of data packets' security and privacy will always be a key issue for 5G–IoT systems until it is given full consideration at every step, mainly in the development stage [37]. In addition to common concerns that involve device access control, authentication, authorization, and privacy preservation, new issues are recently highlighted, such as the building of trusted communications over 5G networks with early threat detection and quick response mechanisms [37]. Mainly, known or even zero knowledge-based threats can be addressed by designing a scalable security

architecture and a highly energy-efficient security solution that can handle billions of resource-constrained devices [38]. Table 1 summarizes the security requirements and vulnerabilities of network layers in WSN, IoT, and 5G–IoT systems.

III. CURRENT 5G NETWORK SECURITY APPROACHES FOR IoT APPLICATIONS AND THE CHALLENGES THEREOF
The network layer security and privacy is the most critical aspect that needs to be addressed with the development of 5G–IoT systems. This advancement affects users' social trust, personal safety, and confidence [52]. Recently, some of the research has attempted to address the issues by introducing different approaches to leverage network layer security and the protection of consumer privacy.

A service-oriented authentication framework that supports network slicing in 5G–IoT systems (ES^{3}A) is given in [53]. Network slicing allows the network core infrastructure to share resources efficiently across different services by using the privacy-preserving slice selection mechanism that enables anonymous access to IoT services by users, without exposing slice/service types. Moreover, to guarantee secure access to service data, a three-party session key negotiation mechanism was introduced among IoT servers, local fog nodes, and end-users. However, the given authentication framework is lacking in a proper design of the security algorithm and a valid

simulated result that is required to build secure communication between end-users and IoT servers.

Authors in [54] focused on the IoT edge devices communication security in 5G networks. They propose techniques using crowdsourcing in that a reward is given to participants for their participation to mitigate security threats and cyber-attacks in 5G networks. All sharing is at high speed due to 5G-amplified power. The authors presented a set of use cases, such as sharing information on attacks and known vulnerabilities among service providers and malware information and sharing platform where organizations can share critical information related to recent attacks and threats that allows the development of countermeasures and the implementation of the digital witness concept. However, concerns arise on how IoT devices will adapt to the resource sharing of network slicing, which is a major aspect of 5G networks. Additionally, using the crowdsourcing technique in some cases is not feasible, especially when privacy and trust need to be considered.

In [55], the authors propose a new control strategy by using statistical channel state information to investigate intelligent secure communication for IoT networks. This strategy is based on Q-learning. This learning uses game theory, in which the transmit power of the sender changed according to the attack mode, and the attacker changes their mode according to the current transmit power. Then, the sender adjusts the transmit power based on the current attacker mode to prevent attacks. Afterward, the best strategy is learned by using Q-function that uses Q-function that uses statistical information of the sender and attacker to obtain the optimal value of transmitter power.

The authors in [56] protect 5G–IoT technologies by an encryption method. This method involves a block cipher technique by using s-box. This mechanism is constructed by using features of quantum walks. S-box is based on one-dimensional one-particle quantum walks on circle 1D1PQWs. The authors in [56] found that the quantum walk features were not used to encrypt videos. Thus, the s-box mechanism is used to encrypt videos and other sensitive data before sending over 5G networks. The data are encrypted with the key sequence generated from controlled alternate quantum walks (CAQWs) that is a two-dimensional single walker and is controlled by a binary string with the keys used to substitute the original and then permutate the generated by using s-box.

In [57], a secure and efficient routing system between nodes in Cloud-MANET-IoT integrated framework used mobile ad hoc network (MANET) to construct a network between neighbor devices without using a centralized point. The IoT devices can interact with each other using MANET and is able to communicate to share information. One of the MANET smart devices should be tied to a Wi-Fi network and independently enrolled on the cloud. Accordingly, the cloud provider will provide its services to the MANET device/network in real time. Communicating with the cloud over 5G offers efficient connectivity with smart devices; on the other end, smart devices are able to submit required

TABLE 2. Current 5G network security approaches comparison.

	Methods Utilized	Performance Evaluation
[53]	privacy-preserving slice selection mechanism	theoretical and simulation analysis in terms of computational and communication overheads
[54]	Crowdsourcing mechanism	OMNET+ + in terms VoIP service
[55]	Q-learning	Simulation results obtained based on game theory and in terms of eavesdropping rate, jamming rate and spoofing rate
[56]	s-box based encryption method with key sequence generated from controlled alternate quantum walks (CAQWs)	MATLAB software R2017a to simulate the evolution of 1D1PQWs in terms of nonlinearity, bit independence (BIC), strict avalanche (SAC), linear (LP) and differential (DP)
[57]	Cloud-MANET-IoT framework	Simulated and analyzed in terms of Data Transmission
[58]	elliptic curve cryptography (ECC) and lightweight authenticated encryption	Simulated in terms of processing time and energy consumption. Perform security analysis theoretically

data on the cloud for the complete session. The approach specifically addresses the security issues that arise because of the ubiquity, the increase in cloud consumption, and cloud performance.

Given that complex security could lower the lifetime of IoT, the authors in [58] propose an D2D communication system is designed based on lightweight cryptography. The adaption is first done at the D2D token generation step. Second, by using 5G-AKA the SUSI is verified. Furthermore, the gNB avails the outcome and based on that generates D2D token. This D2D token is then transmitted to the UE that requests for token. The approach helps in increasing the security of 5G–IoT while maintaining energy consumption. Table 2 summarizes the comparison of current 5G network security approaches for IoT applications.

IV. BIO-INSPIRED TECHNIQUES TO ADDRESS 5G NETWORK LAYER SECURITY FOR IoT APPLICATIONS

Bio-inspired cybersecurity plays a very important role and provides promising mechanisms in securing the network layer from different threats [21]. Acquiring and enhancing these bio-inspired mechanisms for securing 5G–IoT is a vital requirement. The cybersecurity infrastructure has many limitations, such as the absence of self-awareness, lack of interactions between network devices, and the absence of self-correcting mechanisms [59]. Thus, bio-inspired intelligent algorithms that can handle these limitations in cyberspace are needed [21], as is supporting networks and communications systems to protect against attacks, cyber-criminals, hackers, and anomalies efficiently.

Biologically inspired systems have many appealing characteristics, such as adapting to various environmental

conditions and self-resiliency toward damages [59]. Thus, defense algorithms that are inspired by natural organisms can be effective to deal with complexities in cybersecurity. Some examples of cybersecurity technologies that include bio-inspired techniques are anti-virus, honeypots, attribution, intrusion detection, counterattacks, and threat behavior analysis [21]. Several studies have contributed to the improvement of cybersecurity using bio-inspired techniques for communications and networking systems.

In [60], authors developed a distributed, self-organized, honeybee-inspired algorithm for early anomaly detection in a connected system over a wireless network. The algorithm is derived by observing the colonies of honeybees and imitates the way that honeybees use to forage efficiently. Similarly, the participants defined the target (resources such as computer networks) and encountered them based on decision making and information extraction methods to detect and mitigate attacks such as SYN flooding attacks. The proposed approach uses a distributed coordination framework (DIAMoN) to dynamically and automatically detect distributed attacks using a feedback mechanism. Even though they succeeded in mitigating the attacks by improving the early intrusion detection, the limitation of this approach is it does not support the scalability and the heterogeneity that comes with 5G–IoT systems.

With the fast development of WSNs, studies used intelligent features to handle security issues. For example, in [61], the authors focused on the routing where the attacker can easily perform sniffing, tamper with the data, induce path loss, or overtake all over the network. They proposed a trust routing algorithm (BiTRS) inspired by ant colony activities to prevent and detect attacks without interrupting the data routing between network devices. The proposed algorithm adapts the ant colony optimizations (ACO) and the physarum autonomic optimization (PAO) to handle the dynamical node changes in the network. Every node in the network will define the target node route. Then, all neighbor node behavior is monitored to gather trust-based information and send it as feedback for trust assessment. The proposed algorithm provided a solution for addressing routing problems while combining the features of ACO and PAO. However, it does not consider energy conservation, which is a crucial part of IoT.

A new approach proposed by the authors in [62] was named Bio-Inspired Secure IPv6 Communication Protocol. This approach improves routing protocols for low-power and lossy networks with classification algorithms supported by an artificial immune system, which classifies the node as self or non-self-based on the behavior using a correlation coefficient algorithm and according to the given threshold. Node energy, link throughput, latency, and quality are used as metrics to detect misbehavior. This approach improves the performance of the routing protocol and the security against most common attacks. However, the authors did not consider all security parameters.

The authors in [63], propose Swarm Intelligence for Wireless Sensors Networks Cybersecurity,(SIWC) which is a
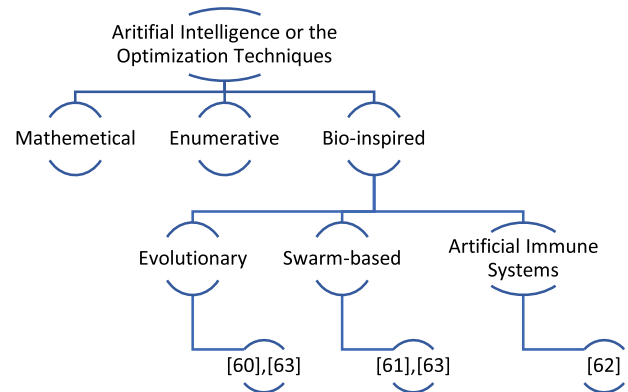

FIGURE 3. Taxonomy of bio-inspired network security techniques.

generic bio-inspired model. Periodically, each node calculates critical parameters such as collision rate and arrival rate and sends them to the protector node as a control packet. Then, the weights assigned to each parameter are based on the importance of the parameter to define the attack. The node is categorized as a protector, using the weight parameter maximum likelihood estimation that is trained based on the swarm intelligence optimization algorithm to find the highest probability of cyberattack. The parameter is then detected and compared with a prefixed threshold beyond which is the cyberattack risk. Afterward, appropriate action to the malicious node is taken by the base station. SWIC checks authentication and integration at the local level as one of the protector's responsibilities. In this approach, the sensor nodes are highly dependent on the protector node. Figure 3 demonstrates the taxonomy of bio-inspired techniques that can address 5G network layer security for IoT applications.

Recently, most studies addressing security issues and enhancing network layer security are based on bio-inspired techniques. In [22], Choraś *et al.* show different bio-inspired techniques with their applications and how these techniques useful in detecting cyberattacks and how they can improve computer network protection. Moreover, researchers are led by different reasons for bio-inspired techniques for cybersecurity. These reasons include adjusting to different environmental circumstances, robustness, resilience with failures, fault tolerance, complex behaviors with limited basic rules, and ability to self-evolve [59].

V. ANALYSIS AND FUTURE PROSPECTS

In this section, the biologically inspired mechanisms that can address the issues of 5G-enabled IoT network layer security, as discussed in Section IV, are further compared in terms of methods utilized and the performance criteria as shown in Table 3.

The gained improvement by these biological security methods, and how they can help in securing the network layer of 5G-enabled IoT applications is discussed and presented in Figure 4.

The heterogeneity in 5G requires distributed security solutions and [60] can help in providing distributed cyber defense systems, especially to address DDoS attacks.
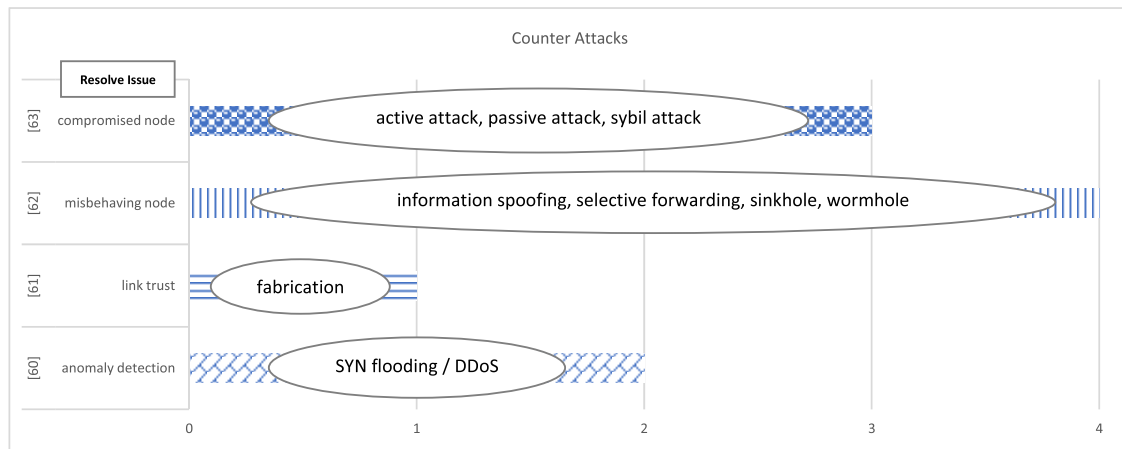
FIGURE 4. The issues and attack/s counter by the biological network security mechanisms.

TABLE 3. Bio-inspired network security mechanisms comparison.

	Methods Utilized	Performance Evaluation
[60]	Colonies of honeybees	Mininet 2.0 network emulator BLID in terms of sensitivity and accuracy
[61]	Ant colony optimization (ACO) and Physarum autonomic optimization (PAO)	Network Simulator ns-2 (version 2.34) AODV, AntHocNet, and TGRP in terms of delay, delivery ratio, and traffic overhead
[62]	Artificial immune system (AIS).	Contiki OS RPL in terms of power consumption
[63]	Swarm intelligence algorithm and neural network	Theoretically

Moreover, the trusted routing scheme given in [61] can assist 5G-enabled IoT applications for reliable and efficient data delivery. [62] secured the network layer of 5G-enabled IoT from different routing attacks autonomously and was able to enhance the data routing reliability. Cyberattacks on the side of cyber-physical systems, which play a major part in 5G-enabled IoT applications are studied and addressed in [63]. Many other weak points remain in the network layer of 5G-enabled IoT applications that require in-depth consideration.

VI. CONCLUSION

This paper performs an in-depth review of the recent literature on network layer security in 5G&IoT systems, including future challenges. Additionally, the network layer vulnerability and security requirements in WSN, IoT, and 5G&IoT are investigated and compared. Moreover, the scholarly literature on current approaches and the bio-inspired mechanisms that provide secure routing in 5G networks for IoT applications is thoroughly reviewed. The bio-inspired techniques are more promising in addressing challenges in 5G&IoT and providing secure and reliable data transfer. Furthermore, this paper conducts a detailed comparative analysis to identify open research topics.

In the future, this survey will help researchers adopt the best possible solution for their studies and to address the issue in 5G network layer security for IoT applications.

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