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5G Core Operate Through Quarterly Update (Q2-2023)

Summary

This report summarizes information on vulnerabilities associated with the 5G network that potentially could be employed or leveraged by an untrusted network operator. The report is in support of the Under Secretary of Defense for Research and Engineering (OUSD R&E) 5G Operate Through Program. The information in this report is based on open-source material published or made available between 1 December 2022 and 28 February 2023.

5G Network Vulnerabilities for Operate Through

The vulnerabilities in this section were obtained from the National Institute of Standards and Technology (NIST) National Vulnerability Database (NVD) for this reporting period. Any vulnerabilities of direct interest to the Operate Through program, as well as 5G-related vulnerabilities of potential general interest, are included.

Vulnerabilities Listed in NIST NVD

NIST CVE-2023-23846: Denial-of-service Vulnerability in Open5GS GTP Library

CVSS Severity V3.1: High; V2.0 (Not available)

https://nvd.nist.gov/vuln/detail/CVE-2023-23846

Due to insufficient length validation in the Open5GS General Packet Radio Service (GPRS) tunneling protocol (GTP) library versions prior to versions 2.4.13 and 2.5.7, when parsing extension headers in GTP (GPTv1-U) messages, a protocol payload with any extension header length set to zero causes an infinite loop. The affected process becomes immediately unresponsive, resulting in denial of service and excessive resource consumption.

Because the code resides in a common GTP library that is shared across different functions, this vulnerability is effectively present in all deployed endpoints configured to accept and handle GTP-U messages, including the 5G user plane function (UPF, provided by open5gs-upfd), the 5G session management function (SMF, provided by open5gs-smfd), and the LTE/Evolved Packet Core (EPC) serving gateway user plane function (SGW-U, provided by open5gs-sgwud).

Sending GTPv1-U message payloads with extension headers whose length is set to zero causes the target process to get stuck and remain running but unresponsive. This vulnerability can be triggered by any suitable GTPv1-U message type, including the Supported Extension Headers Notification message, which typically does not require an existing GPRS tunnel to be present and uses a zeroed tunnel end point ID (TEID).

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Literature Review of 5G Vulnerabilities for Operate Through

The following section summarizes open-source literature focused on 5G-related vulnerabilities that either directly pertain to 5G Operate Through or are of potential general interest.

A Synthetic Dataset for 5G UAV Attacks Based on Observable Network Parameters

5 November 2022

https://www.catalyzex.com/paper/arxiv:2211.09706

Assessment: This article employs simulated data in a jamming scenario where attacker drones jam the communications of a legitimate drone. This represents a third-party attack on a 5G device not initiated by the operator and is not directly applicable to the Operate Through scenario.

Abstract: Synthetic datasets are beneficial for machine learning researchers due to the possibility of experimenting with new strategies and algorithms in the training and testing phases. These datasets can easily include more scenarios that might be costly to research with real data or can complement and, in some cases, replace real data measurements, depending on the quality of the synthetic data. They can also solve the unbalanced data problem, avoid overfitting, and be used in training, while testing can be done with real data. In this paper, we present, to the best of our knowledge, the first synthetic dataset for Unmanned Aerial Vehicle (UAV) attacks in 5G and beyond networks based on the following key observable network parameters that indicate power levels: the Received Signal Strength Indicator (RSSI) and the Signal to Interference-plus-Noise Ratio (SINR). The main objective of this data is to enable deep network development for UAV communication security, especially for algorithm development or the analysis of time-series data applied to UAV attack recognition. Our proposed dataset provides insights into network functionality when static or moving UAV attackers target authenticated UAVs in an urban environment. The dataset also considers the presence and absence of authenticated terrestrial users in the network, which may decrease the deep network's ability to identify attacks. Furthermore, the data provides deeper comprehension of the metrics available in the 5G physical and Medium Access Control (MAC) layers for machine learning and statistics research.

Towards Automatic Mapping of Vulnerabilities to Attack Patterns Using Large Language Models

8 February 2023

https://www.pnnl.gov/publications/towards-automatic-mapping-vulnerabilities-attack-patterns-using-large-language-models

Assessment: This article is included for general reference, as it maps vulnerabilities already available in existing databases and does not discuss any new ones.

Abstract: With the advent of new devices and applications, the cyber-attack surface is continuously evolving due to the emergence of new attack techniques and vulnerabilities. Hence, security management tools must assess the cyber risk of an enterprise on a regular interval basis by comprehensively identifying associations among attack techniques, weaknesses, and vulnerabilities. However, existing repositories providing such associations are incomplete (i.e., missing associations), which may lead to underestimating the risk of a particular set of attack techniques. Moreover, such associations still rely on manual interpretation, which is slow compared to attack speed and ineffective for the increasing list of vulnerabilities and attack actions. Therefore, new methodologies must be developed for automatically associating vulnerabilities to all relevant attack techniques. In this paper, we present a framework, named VWC-MAP, that can automatically identify, via natural language process (NLP) techniques, all relevant attack techniques of a vulnerability based on their text descriptions. To achieve that, the authors present a novel two-tiered classification approach, where the first tier classifies vulnerabilities to weakness, and the second tier classifies weakness to attack techniques. This research has improved the scalability of the current state-of-the-art tool to make vulnerability to weakness mapping significantly faster. Moreover, this paper presents two novel approaches for weakness

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to attack technique mapping applying text-to-text and link prediction techniques. Our experiment results were cross-validated through cybersecurity experts and show that VWC-MAP can associate vulnerabilities to weakness types with 87% accuracy and to new attack patterns with 80% accuracy.

ESF Potential Threats to 5G Network Slicing

13 December 2022

https://media.defense.gov/2022/Dec/13/2003132073/-1/-1/0/POTENTIAL%20THREATS%20TO%205G%20NETWORK%20SLICING_508C_FINAL.PDF

Assessment: This reference focuses on attacks on the 5G network, rather than an attack on 5G devices by an untrusted network operator.

Abstract: Building upon the work published in the Enduring Security Framework's Potential Threat Vectors to 5G Infrastructure, the Enduring Security Framework (ESF) established a working panel comprised of government and industry experts and conducted an in-depth review of network slicing, a key component of 5G infrastructure. This working panel assessed the security, risks, benefits, design, deployment, operations, and maintenance of a network slice. For this paper, a network slice is defined as an end-to-end logical network that provides specific network capabilities and characteristics for a user.

As with any emerging technology, with increased benefits come increased risks. This paper intends to introduce 5G stakeholders to the benefits associated with network slicing and introduce perceived risks and management strategies that may address those risks.

The following associated threat vectors were identified:

- DoS attack on signaling plane
- Hijacking attacks
- Unauthorized access
- Configuration attacks
- Saturation attacks
- Penetration attacks
- User identity theft
- Man-in-the-Middle attack
- TCP Level attacks
- Key exposure
- Session replay attack
- IP spoofing
- Scanning attacks
- IMSI caching attacks
- Jamming attacks
- Channel prediction attacks
- Active eavesdropping
- Passive eavesdropping
- NAS signaling storms
- Traffic bursts by Internet of things (IoT).

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Threatening the 5G Core Via PFCP DoS Attacks: The Case of Blocking UAV Communications

15 November 2022

https://jwcn-eurasipjournals.springeropen.com/articles/10.1186/s13638-022-02204-5

Assessment: This article discusses an attack method against the 5G core and network infrastructure, rather than an attack on 5G devices by an untrusted network operator.

Abstract: The modern communications landscape requires reliable, high-speed, high-throughput, and secure links and sessions between user equipment instances and the data network. The 5G core implements the newly defined 3GPP network architecture enabling faster connectivity, low latency, higher bit rates, and network reliability. The full potential of this group of networks will support a set of critical IoT and industrial use cases. However, several components and interfaces of the next-generation radio access network (NG-RAN) have proven to be vulnerable to attacks that can potentially obstruct the network's capability to provide reliable end-to-end communication services. Various inherent security flaws and protocol-specific weaknesses have also been identified within the 5G core itself. However, little to no research has gone into testing and exposing said core-related weaknesses, contrary to those concerning the NG-RAN. In this paper, the authors investigate, describe, develop, implement, and finally test a set of attacks on the Packet Forwarding Control Protocol (PFCP) inside the 5G core. They found that by transmitting unauthorized session control packets, they were able to disrupt established 5G tunnels without disrupting subscribers' connectivity to the NG-RAN, thus hindering the detection of said attacks. The authors then evaluate the identified PFCP attacks in a drone-based scenario involving 5G tunneling between two swarms.

You Have Been Warned: Abusing 5G's Warning and Emergency Systems

December 2022

https://dl.acm.org/doi/abs/10.1145/3564625.3568000

Assessment: This article describes a third-party attack on devices using a fake base station and abusing 5G's Public Warning System with fake messages, rather than an attack on 5G devices by an untrusted network operator.

Abstract: The Public Warning System (PWS) is an essential part of cellular networks and a country's civil protection. Warnings can notify users of hazardous events (e. g., floods, earthquakes) and crucial national matters that require immediate attention. PWS attacks disseminating fake warnings or concealing precarious events can have a serious impact, causing fraud, panic, physical harm, or unrest to users within an affected area. In this work, the authors conduct the first comprehensive investigation of PWS security in 5G networks. They demonstrate five practical attacks that may impact the security of 5G-based Commercial Mobile Alert System (CMAS) as well as Earthquake and Tsunami Warning System (ETWS) alerts. In addition to identifying the vulnerabilities, they investigate two PWS spoofing and three PWS suppression attacks, with or without a man-in-the-middle (MitM) attacker. They discovered that MitM-based attacks have more severe impact than their non-MitM counterparts. The authors' PWS barring attack is an effective technique to eliminate legitimate warning messages. The authors also performed a rigorous analysis of the roaming aspect of the PWS, including its potentially secure version, and report the implications of the attacks on other emergency features (e.g., 911 Session Initiation Protocol (SIP) calls).

The Top 4 DDoS Attack Vectors Threatening 5G Networks

5 December 2022

https://www.allot.com/blog/top-ddos-attack-vectors-threatening-5g/

Assessment: This describes a Distributed Denial-of-Service (DDoS) attack on the 5G network originating from 5G devices, rather than an attack on 5G devices by an untrusted network operator.

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Abstract: To achieve lower latency, which is critical for many new applications, such as Vehicle-to-Vehicle communications, 5G has a distributed network architecture with Multi-access Edge Computing (MEC) at multiple remote locations. These additional points of access, combined with a growing densification of connected devices and the proliferation of open-source applications, increase the attack surface and create additional vulnerabilities. Furthermore, higher wireless speeds dramatically increase the impact of DDoS attacks over the network as each device can generate an order of magnitude higher attack throughput to the network (at MECs and at the core). As mentioned, this effect is amplified by the plurality of IoT devices, as IoT devices tend to be more vulnerable to cyberattacks.

WaterPurifier: A Scalable System to Prevent the DNS Water Torture Attack in 5G-Enabled SIoT Network

19 December 2022

https://www.sciencedirect.com/science/article/abs/pii/S0140366422004698

Assessment: This article is included for general interest, as it describes an attack method on a Domain Name System (DNS) server in a 5G network, rather than an attack on 5G devices by an untrusted network operator.

Abstract: A Social Internet of Things (SIoT) network contains a huge number of smart devices and is rich in social behavior relationships between these objects, especially in 5G-enabled SIoT networks. However, vulnerable devices and assailable applications or services in SIoT give attackers the opportunity to conduct DNS water torture (DNSWT) attacks for DNS infrastructures, which can cause the device to be unavailable. In this work, we comprehensively analyze the characteristics of DNSWT attacks in a 5G-enabled SIoT network and propose a collaborative and hierarchical defensive system called WaterPurifier to protect the SIoT network from DNSWT attacks. WaterPurifier consists of the Gateway Layer, Server Layer, and Cloud Layer. An asynchronous communication mechanism is implemented in the defensive system to ensure its flexibility. The components in the Gateway Layer and Server Layer execute lightweight functions, like flow forwarding and attack monitoring, to guarantee a high level of scalability. The Cloud Layer deploys an end-to-end domain encoding and a real-time training process, which can filter out DNSWT attack traffic effectively and efficiently. The authors implement a prototype of WaterPurifier in an in-lab environment and perform an evaluation on the experiment's result with performance indicators like packet loss rate. Both results and evaluations show high effectiveness and efficacy of the proposed system.

Active Foreign Commercial 5G Standalone Networks

Table 2 lists foreign network operators that claim to have launched 5G Standalone (SA) commercial mobile services as of 28 February 2023.[a] As of this publication, 36 operators in 21 countries, excluding the United States, claim to have launched commercial 5G SA services.

Table 2. Foreign 5GSA Commercial Networks

Country	Operator	5G SA Launch	Remarks
Australia	Telstra[1] Optus[2] TPG Telecom[3]	May 2020 November 2021 November 2021	Telstra claimed to be the first Australian provider to enable 5G SA services to its customers. Telstra's spectrum operates in Low (700-900 MHz), Mid (1800-3600 MHz), and High (26-28 GHz) bands.[4] Optus is providing 5G SA services in the 3500 MHz, 2300 MHz, and 2100 MHz spectrum bands; TPG's standalone core network runs on TPG's 700 MHz spectrum holdings. Note that TPG now incorporates Vodafone Australia.[5]

[a] This list does not include commercial 5G SA fixed wireless access (FWA) or private networks, or operators engaged in testing or trials.

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Country	Operator	5G SA Launch	Remarks
Austria	Hutchison Drei Austria	September 2022[6]	Drei bought 5G licenses to operate in the 700 MHz and 1.5 GHz bands and employs equipment from Qualcomm and ZTE.[7]
Bahrain	STC Bahrain	May 2022	STC Bahrain launched the country's first 5G SA network using Huawei equipment. The network supports enhanced mobile broadband (eMBB), ultra-reliable low latency communications (URLLC) and Massive Machine-Type Communications (mMTC) services.[8]
Brazil	TIM Brasil Claro Brasil Vivo	July 2022 July 2022 July 2022	All three of Brazil's wireless providers activated 5G SA commercial services in July 2022 in the capital of Brasilia in the 3500 MHz band (TIM soft-launched its 5G SA services in April to select users).[9,10] 5G services in the 26 GHz band, primarily aimed at hotspot coverage for industrial applications or point to point solutions, are also planned.[11]
Bulgaria	A1 Bulgaria	October 2022	A1 Bulgaria completed the rollout of its 5G SA network, which employs Nokia-made RAN and Ericsson dual-mode 5G Core backbone network.[12]
Canada	Rogers Communications[13] Bell Canada	March 2022 July 2022	Rogers' 5G SA network is Canada's first. The company's 5G services operate in the 600, 1700, and 2500 MHz bands.[14] The company expanded its spectrum to the 3500 MHz band in June 2022.[15] Bell Canada launched its 5G SA network in July 2022 in the 3500 MHz band, initially providing services in southern Ontario before expanding to nationwide coverage.[16]
China	China Mobile[17] China Telecom China Unicom CTM	November 2020[18] November 2020[19] November 2020 November 2022	As of early 2021, these three operators had deployed over 700,000 5G SA base stations; China Mobile commissioned 5G SA services in all prefectures and cities across China; and China Telecom and China Unicom jointly built the world's largest shared 5G SA network covering 300 cities.
Finland	Telia Company[21]	November 2021	Telia was the first commercially available 5G SA network in the Nordic and Baltic regions. The company offers 5G services in the 700 and 3500 MHz and has also acquired spectrum in the 26 GHz band. The company is working on rolling out 5G services to all of its markets across the Nordic and Baltic countries.[22]
Germany	Deutsche Telekom[23] Vodafone[24]	April 2022 March 2022	As of early 2022, Deutsche Telekom's network had 5,000 antennas operating in the 3600 MHz spectrum, providing coverage to over 200 urban centers and cities. Vodafone had over 4,000 antennas supporting 5G SA services, operating in the 3600, 1800, and 700 MHz spectra and is projected to reach nationwide coverage by 2025.
India	Reliance Jio	October 2022	Reliance Jio launched 5G SA services in select Indian cities in October 2022, with the goal of achieving national coverage by December 2023.[25,26] Jio acquired spectrum in the 700 MHz, 800 MHz, 1800 MHz, 3300 MHz, and 26 GHz bands in auctions in mid-2022.[27]
Italy	OpNet (formerly Linkem)[28]	October 2021	Linkem's 5G SA network is Italy's first and operates in the 3500 MHz band. Linkem changed its name to OpNet following the sale of its retail operations to Tiscali in 2022. Note that OpNet/Linkem currently only operates 5G SA Fixed Wireless Access (FWA) in the 3.5 and 26 GHz bands and was inadvertently included in this list of 5G SA commercial operators.[29] However, the company plans to introduce 5G SA wireless services in the future using Ericsson's dual-mode 5G Core technology.[30]
Japan	SoftBank Corp.[31] NTT Docomo[32] au by KDDI	October 2021 August 2022 February 2022	Supporting SoftBank Air Terminals, SoftBank provides coverage in the 3.9-4.0 GHz and 29.1-29.5 GHz ranges.[33] NTT Docomo launched the world's first commercial 5G SA network allowing smartphones to simultaneously utilize both mid-band (sub-6 GHz) and mmWave frequencies, providing 5G NR Dual Connectivity (NR-DC) to users. au by KDDI launched 5G SA services in Kanagawa in February 2022, employing a virtualized RAN (vRAN).[34]
Kuwait	STC Kuwait[35]	May 2021	STC's 5G services were launched in the 3500 Mhz band and the company expanded its services into the 2100 MHz band, as well.[36]

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Country	Operator	5G SA Launch	Remarks
Philippines	Smart Communications[37]	October 2021	Smart launched the first 5G SA network in the Philippines in Makati City. Based on available information, the company's 5G services appear to mainly be in the 700 and 3500 MHz bands, although 5G carrier aggregation tests have also been carried out using the 2600 and 3500 MHz bands.[38]
Saudi Arabia	Zain KSA[39] STC Saudi Arabia[40,41]	February 2022 August 2021	At launch, Zain's network comprised 5,000 towers and covered 51 cities. The provider operates 5G in the 2600 and 3500 MHz bands.[42] STC's 5GC supports both 5GNSA and 5G SA services.
Singapore	M1 Limited[43] StarHub Mobile[44] Singtel[45]	July 2021 July 2021 September 2021	M1 and StarHub Mobile engaged in a joint venture to build their 5G SA network; both the M1/StarHub and the Singtel networks were commissioned in the 3500 MHz spectrum.
South Africa	Rain[46]	July 2020	South Africa's Rain launched the first 5G SA network in Africa in partnership with Huawei. Rain secured bandwidth in the 700 MHz and 2600 MHz bands,[47] although it applied for spectrum in the 800 and 3500 MHz bands, as well.[48]
South Korea	KT[49]	July 2021	KT is the first provider in South Korea to launch 5G SA services. In 2018, KT secured 5G spectrum in the 3500-3600 MHz and 26.5-27.3 GHz bands.[50]
Spain	Vodafone[51] Orange	December 2021 February 2023	Vodafone's initial 5G SA commercial rollout in Spain was for the businesses in the Almeria Science and Technology Park. Orange launched 5G SA commercial services in February 2023 as "5G+" with roughly 90% coverage in Madrid, Barcelona, Valencia, and Seville, with additional locations to be added later in the year.[52]
Taiwan	Taiwan Mobile Co.[53]	October 2021	Taiwan Mobile 5G services operate in the 700 MHz and 700 MHz + 3500 MHz/28 GHz (low+high) bands. The company also operates 4G/5G EUTRA-NR EN-DC in the 700 MHz, 1800 MHz, 2100 MHz, 3500 MHz, and 28 GHz bands.[54]
Thailand	AIS[55]	July 2020	AIS launched 5G SA services in July 2020,[56] and by August 5G SA had reportedly extended services to all 77 provinces in the country.[57] AIS 5G operates in the 700 MHz, 2600 MHz, and 26 GHz bands.[58]

Literature Review of Other Pertinent 5G-Related Items of Interest

ZTE's 5G NR Kit Gets Security Certification in Germany

10 February 2023

https://www.rcrwireless.com/20230210/5g/zte-5g-nr-kit-gets-security-certification-germany

Assessment: The use of ZTE equipment in German 5G networks could pose potential security threats to DOD communications transiting those networks.

Abstract: Chinese vendor ZTE said its 5G New Radio (NR) gNodeB product has been approved under Germany's Federal Office for Information Security's (BSI) NESAS (network equipment security assurance scheme) certification program. ZTE noted that NESAS Cybersecurity Certification Scheme – German Implementation (NESAS CCS-GI) is Germany's national certification framework for 5G networks, which includes process audits and product testing.

In July 2022, the Federal Office for Information Security (BSI) had announced the introduction of a new certification program for components of 5G telecommunications networks. The BSI outlined that, with the new certification, manufacturers of 5G mobile communications components may have the IT security properties of their 5G products independently checked and thus comply with the certification obligation for critical components in 5G networks contained in the Telecommunications Act of 23 June 2021.

However, on 8 March, additional reporting emerged based on an unspecified German Government source that Germany was considering a ban on certain components from Huawei and ZTE in its telecommunications networks, although specific details on which equipment were not available.

Additional Reporting: Reuters (https://www.reuters.com/technology/germany-set-ban-chinas-huawei-zte-parts-5g-networks-source-2023-03-07/); CNBC (https://www.cnbc.com/2023/03/08/germany-reportedly-weighing-huawei-5g-ban-china-says-it-is-puzzled.html)

Projected Growth of 5G Global Connections

Figure 1 illustrates the projected growth of 5G global connections[b] from 2021 through 2030 based on data from GSMA, divided by Combatant Command.[c]

Figure 1: *Growth Projections for Global 5G Connections (GSMA)*

[b] Each connection is defined as being associated with a unique SIM. Note also that the statistics for connections include estimates for devices that use multiple SIMs.

[c] This graphic will be updated periodically to reflect any significant changes in trend projections.

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