Idaho National Laboratory

5G Core Operate Through Quarterly Update (Q3-2023)

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 March and 31 May 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.

Vulnerabilities Listed in NIST NVD

No new pertinent vulnerabilities were identified.

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.

PACMAN Attack: A Mobility-Powered Attack in Private 5G-Enabled Industrial Automation System

16 February 2023

https://arxiv.org/abs/2302.08563

Assessment: This paper presents a novel mobility-powered Wi-Fi emulation attack model named "PACMAN attack," which exploits the medium access control (MAC) layer vulnerabilities in a private 5G-enabled Industrial Automation System (IAS). The INL 5G security research and assessment team assesses the probability of Operate Through War Fighters running into an IAS through the use of unlicensed spectrum in 5 GHz bands is low unless the 5G attack is taking place in a factory. As such, this attack is not directly pertinent to the Operate Through scenario.

Abstract: The 3rd Generation Partnership Project (3GPP) has introduced private 5G to support next-generation IAS due to the versatility and flexibility of 5G architecture. Beside the 3.5 GHz Citizens Broadband Radio Service (CBRS) band, unlicensed spectrum bands (such as 5GHz) are considered as an additional medium because of their free and abundant nature; however, while utilizing the unlicensed band, industrial equipment must coexist with existing signals such as Wi-Fi, which could introduce new security threats and resuscitate old ones. In this paper, the authors propose a novel attack strategy conducted by a mobility-enabled malicious Wi-Fi access point (mmAP), the \textit{PACMAN} attack, to exploit vulnerabilities introduced by heterogeneous coexistence. An mmAP can move around the physical surface to identify mission-critical devices, hop through the frequency domain to detect the

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victim's operating channel, and launch traditional MAC layer-based attacks. The multi-dimensional mobility of the attacker makes it impervious to state-of-the-art detection techniques that assume static adversaries. In addition, the authors propose a novel Markov Decision Process (MDP)-based framework to intelligently design an attacker's multi-dimensional mobility in space and frequency. Mathematical analysis and extensive simulation results exhibit the adverse effect of the proposed mobility-powered attack.

Attacks Against Security Context in 5G Network

20 March 2023

https://arxiv.org/abs/2303.10955

Assessment: This describes a third-party attack where the attacker can impersonate a legitimate subscriber to gain access to the 5G network and is not initiated by an untrusted operator.

Abstract: The security context used in 5G authentication is generated during the Authentication and Key Agreement (AKA) procedure and stored in both the user equipment (UE) and the network sides for the subsequent fast registration procedure. Given its importance, it is imperative to formally analyze the security mechanism of the security context. The security context in the UE can be stored in the Universal Subscriber Identity Module (USIM) card or in the baseband chip. The authors present a comprehensive and formal verification of the fast registration procedure based on the security context under the two scenarios in ProVerif. Their analysis identifies two vulnerabilities, including one that has not been reported before. Specifically, the security context stored in the USIM card can be read illegally and the validity checking mechanism of the security context in the baseband chip can be bypassed. Note that these vulnerabilities also apply to 4G networks. Consequently, an attacker can exploit these vulnerabilities to register to the network with the victim's identity and then launch other attacks, including one-tap authentication bypass, leading to privacy disclosure, location spoofing, etc. To ensure that these attacks are indeed realizable in practice, the authors have responsibly confirmed them through experimentation via three operators. Their analysis reveals that these vulnerabilities stem from design flaws of the standard and unsafe practices used by operators. Finally, the authors proposed several potential countermeasures to prevent these attacks. They reported their findings to the GSM Association (GSMA) and received a coordinated vulnerability disclosure (CVD) number, CVD-2022-0057[a].

The Vulnerability and Enhancement of AKA Protocol for Mobile Authentication in LTE/5G Networks

June (sic) 2023

https://www.sciencedirect.com/science/article/abs/pii/S1389128623001305

Assessment: Possible third-party attacks on the Long-Term Evolution (LTE)/4G authentication procedure with Evolved Packet System (EPS)-AKA are described along with proposed enhancement of the EPS-AKA with asymmetric encryption. Since 5G-AKA does have improvements over EPS-AKA for LTE/4G, the author should verify their statement about the proposed solution: "very easy to be adopted into the current 5G network implementation."

Abstract: The LTE/5G network connects much of the world's population to provide subscriber's voice calls and mobile data delivery, with security provided by the AKA defined by 3GPP, which makes the LTE/5G network more secure than all its predecessors. Primarily due to the access limitations of LTE systems, the vulnerabilities of AKA protocol and potential attacks have not received much investigation, which is essential to LTE users. In this study, the authors focus on two questions: (i) what are the vulnerabilities that can be exploited to carry out attacks in practice? and (ii) how to design an enhanced AKA protocol against such attacks? They examined the detailed procedures of EPS-AKA protocol by 3GPP and have identified three types of attacks with respect to catching, location tracking, and jamming. The authors have designed and implemented attacks with commercial equipment to evaluate these threats in practice. In addition, they propose an enhanced AKA protocol that essentially relies on asymmetric encryption, rather than symmetric,

[a] Note that CVD-2022-0057 is listed in the NVD as reserved, and no specific details were available as of this writing.

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in the AKA protocol and additional digital signatures to counter these attacks. Finally, the authors verified their solution through formal verification to prove that it can mitigate these newly found vulnerabilities.

5Greplay: a 5G Network Traffic Fuzzer - Application to Attack Injection

12 April 2023

https://arxiv.org/pdf/2304.05719.pdf

Assessment: This paper has introduced a 5G replay tool to perform security testing in 5G networks. To achieve this goal, the tool provides a flexible way to modify 5G protocol packets before injecting them into the target services to be tested. The experimentation results show that the altered packets are correctly formatted with respect to the 5G standard protocols, such as Non-access Stratum (NAS)-5G and NG Application Protocol (NGAP) and are accepted by the 5G core services. The tool even provoked crashes in the targeted services when performing Denial-of-Service (DoS) attacks on a 5G network. Not directly related to the untrusted operator scenario since the 5G operator is the target.

Abstract: The fifth generation of mobile broadband is more than just an evolution to provide more mobile bandwidth, massive machine-type communications, and ultra-reliable and low-latency communications. It relies on a complex, dynamic, and heterogeneous environment that implies addressing numerous testing and security challenges. In this paper, the authors present 5Greplay, an open-source 5G network traffic fuzzer that enables the evaluation of 5G components by replaying and modifying 5G network traffic by creating and injecting network scenarios into a target that can be a 5G core service (e.g., Access and Mobility Function [AMF], Session Management Function [SMF]) or a Radio Access Network (RAN) (e.g., gNodeB). The tool provides the ability to alter network packets online or offline in both control and data planes in a very flexible manner. The experimental evaluation conducted against open source 5G platforms showed that the target services accept traffic being altered by the tool and that it can reach up to 9.56 Gbps using only one processor core to replay 5G traffic.

A Defensive Strategy Against Beam Training Attack in 5G mmWave Networks for Manufacturing

6 April 2023

https://ieeexplore.ieee.org/document/10093907

Assessment: This paper describes attacks on the signaling beams between a transmitter and a receiver before connections can be confirmed for 5G applications in manufacturing, particularly those involving mmWave carriers. It also proposes a defensive strategy based on machine learning (ML) with autoencoders. The is a potential third-party attack on the air-interface of a 5G network using beam-based transmission and not an attack originated by an untrusted operator.

Abstract: Millimeter-wave (mmWave) carriers are an essential building block of fifth-generation (5G) systems. Satisfactory performance of the communications over the mmWave spectrum requires an alignment between the signal beam of the transmitter and receiver, achieved via beam training protocols. Beam training is vulnerable to jamming attacks, where the attacker intends to send jamming signals over different spatial directions to confuse legitimate nodes. This paper focuses on defending against this attack in smart factories where a moving Automated Guided Vehicle (AGV) communicates with a base station via a mmWave carrier. We introduce a defensive strategy to cope with jamming attacks, including two stages: jamming detection and jamming mitigation. Developed based on autoencoders, both algorithms can learn the characteristics/features of the received signals at the AGV. They can be employed consecutively before performing the downlink data transmission. Once a jamming attack is identified, the jamming mitigation can be utilized to retrieve the corrupted, received signal-strength vector, allowing a better decision during the beam training operation. In addition, the proposed algorithm is straightforward and fully compliant with the existing beam training protocols in 5G New Radio. The numerical results show not only the proposed defensive strategy can capture more than 80 percent of attack events, but it also improves the average signal-to-interference-plus-noise-ratio significantly, up to 15 dB.

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Online Schedule Randomization to Mitigate Timing Attacks in 5G Periodic URLLC Communications

20 May 2023

https://dl.acm.org/doi/abs/10.1145/3600093

Assessment: This paper presents the possibility of an attack on industrial control system (ICS) communications, which generally use ultra-reliable low-latency communication supported by 5G. As 5G is now being considered for applications in ICS for power distribution in Distributed Energy Resources, warehouses, manufacturing, etc., this attack is likely to be of interest, even if it does not directly pertain to the Operate Through scenario.

Abstract: Ultra-reliable low-latency communication (URLLC) in 5G networks is designed to support time-critical applications such as ICS, where UEs communicate with a base station (BS) with very high reliability and low latency. Most of these communications in ICSs are periodic and associated with hard deadlines. To provide a reliable service while satisfying the hard deadlines, the BS usually reserves slots and frequencies and precomputes the schedule for such UEs. The same schedule repeats over time, which makes the slots and frequencies predictable. However, an attacker can exploit this aspect and launch timing attacks disrupting specific communication, thereby undermining the safety of the system. To mitigate such attacks, the authors present an online strategy that randomizes the scheduled slots and frequencies over time without violating the flow deadlines. They use Kullback-Leibler divergence to measure the randomness in the schedules generated by their strategy with reference to a hypothetical truly random strategy. They perform security analysis of their proposed strategy using Prediction Probability to measure the predictability in the slots of the generated schedules. They evaluate the performance of their strategy against a state-of-the-art baseline and show that their strategy performs better than the baseline across all parameter settings.

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 31 May 2023.[b] As of this publication, 39 operators in 22 countries, excluding the United States, claim to have launched commercial 5G SA services.

Table 2. Foreign 5G SA 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]
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), URLLC, and Massive Machine-Type Communications (mMTC) services.[8]

[b] 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
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. Companhia de Telecomunicacoes de Macau (CTM) launched 5G SA services in November 2022.[20]
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 bands and has also acquired spectrum in the 26 GHz band. The company is working on rolling out 5G services to all 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]

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Country	Operator	5G SA Launch	Remarks
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]
Philippines	Smart Communications[37] Globe Telecom	October 2021 December 2022	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] Globe Telecom announced the launch of commercial 5G SA services in December 2022.[39]
Saudi Arabia	Zain KSA[40] STC Saudi Arabia[41,42]	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.[43] STC's 5GC supports both 5GNSA and 5G SA services.
Singapore	M1 Limited[44] StarHub Mobile[45] Singtel[46]	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[47]	July 2020	Rain launched the first 5G SA network in Africa in partnership with Huawei. Rain secured bandwidth in the 700 MHz and 2600 MHz bands,[48] although it applied for spectrum in the 800 and 3500 MHz bands as well.[49]
South Korea	KT[50]	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.[51]
Spain	Vodafone[52] 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.[53]
Taiwan	Taiwan Mobile Co.[54]	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.[55]
Thailand	AIS[56]	July 2020	AIS launched 5G SA services in July 2020,[57] and by August 5G SA had reportedly been extended to all 77 provinces in the country.[58] AIS 5G operates in the 700 MHz, 2600 MHz, and 26 GHz bands.[59]
United Arab Emirates (UAE)	Etisalat	5 April 2023	Etisalat launched 5G SA commercial services in April 2023.[60]

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

EU and US Warn Malaysia of 'National Security' Risk in Huawei's Bid For 5G

2 May 2023

https://www.ft.com/content/3da9a1bd-a49c-46f4-acc2-60333e55eaaa

The European Union and United States have warned Malaysia about risks to national security and foreign investment as the Malaysian government finalizes a review of its 5G rollout that could allow China's Huawei a role in the country's telecom infrastructure. One possible outcome of the review is that Malaysia will introduce a second 5G network in 2024. Huawei, which, along with Finland's Nokia, was beaten by Ericsson in the open tender process, has been lobbying heavily for inclusion.

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Unveiling the New Threat Landscape

7 April 2023

https://www.netscout.com/threatreport/ddos-threat-intelligence-report/

The growth of subscribers to 5G wireless to the home, for both mobile users and Internet of Things (IoT) devices, has grown at an incredible pace, from 12.6 million in 2019 to a projected 1.6 billion by the end of 2023, which is a staggering 12,720 percent increase. This growth brings with it a vibrant playground for adversaries to conscript 5G-connected devices into attacks. It also presents an opportunity for attacks to target more types of devices and network access points than ever before. Although not as impressive in growth, distributed denial-of-service (DDoS) attacks on the wireless telecommunications industry have grown 79 percent since 2020, which equates to 20 percent of all DDoS attacks on any industry and is second only to attacks on wired telecommunications carriers. With 80 to 90 percent of all DDoS attacks sourced from and directed at devices on wireline networks, the increases in attacks on wireless coincide with the continued adoption of 5G to the home. Historically, these attacks are motivated by the gaming industry or underground gambling associated with e-sports.

Projected Growth of 5G Global Connections

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

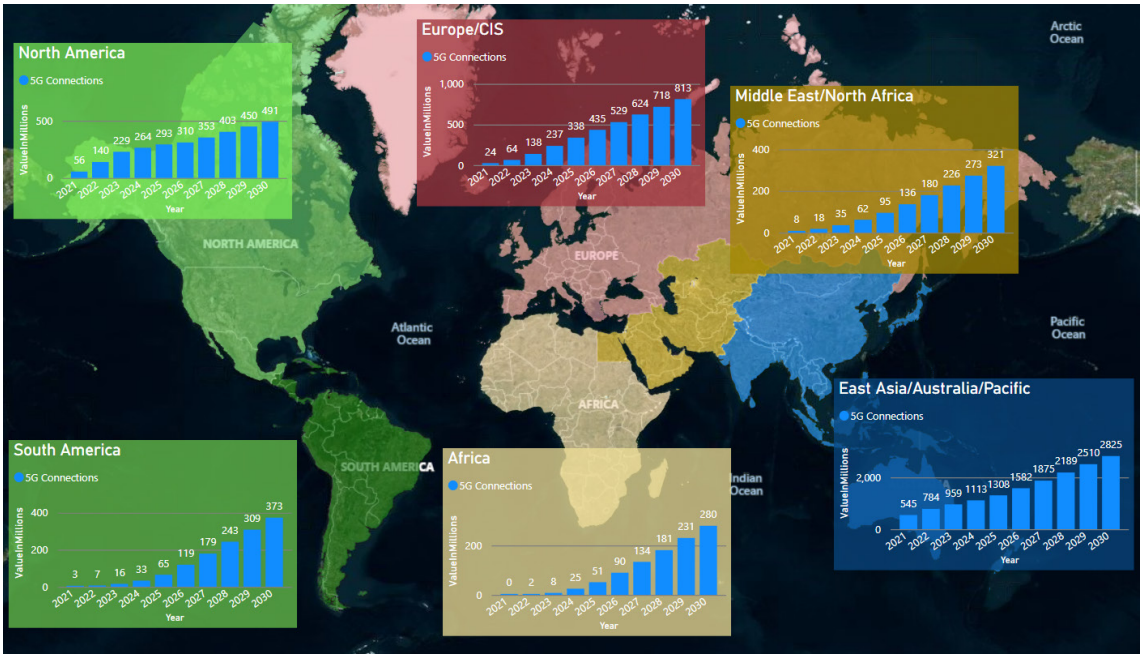

Figure 1: *Growth Projections for Global 5G Connections (GSMA)*

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[c] 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.

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

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