Session Management for Security Systems in 5G Standalone Network

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ABSTRACT As 5G telecom services evolve rapidly across a broad technological environment, network security in 5G landscape emerges as a critically challenging issue. One of typical network security tools is an intrusion prevention system (IPS) that monitors a network for malicious activity across the cyber-attack chain and takes action to prevent it. Vulnerabilities in 5G core networks become more varied and protocols become increasingly complex, whereby conventional Next Generation Firewall (NGFW) is not enough anymore to respond to cyber attacks. As a typical 5G vulnerability attack, PFCP-in-GTP and IPSec disable attack are highly complex to detect and cannot identify attackers without integrated session management. However, the 5G core network uses various protocols such as Non-Access Stratum (NAS), Hyper Text Transfer Protocol (HTTP), Packet Forwarding Control Protocol (PFCP), and GPRS Tunnelling Protocol (GTP), and packets of the interface used by each protocol are managed as identities that are difficult to identify. Analyzing the relationship of these interfaces in real time is an important key to integrated session management. In addition, unlike existing 4G, as 3rd Generation Partnership Project (3GPP) specs mandate encrypting 5G Standalone (SA) user IDs, it is much more difficult to identify from which user traffic has occurred in IPSs exclusive for cellular network. With regard to the above subject, this paper introduces an efficient session management scheme for users not affordable in conventional NFGW but necessarily useful for security systems in 5G SA. Furthermore, this study compared performances between conventional NGFWs and a 5G IPS system with the scheme employed, to ascertain that the scheme is feasibly implementable in 5G SA network. The actual test results show a detection rate of 99.7% and reasonable resource overhead (Memory usage 37.8%, CPU usage 42-44%).

INDEX TERMS Mobile network security, Availability attacks, Confidentiality attacks, Integrity attacks, Authentication attacks, Impersonation attacks, Intrusion Prevention System, Intrusion Detection, Next Generation Firewall, Signaling attacks, Spoofing attacks, Flooding attacks

I. INTRODUCTION

5G standard is divided into two modes—5G Non-Standalone (NSA) and 5G Standalone (SA). The former is 5G core network that permits 4G Long Term Evolution (LTE) core network to coexist, which was first launched by Korea in April, 2019 [1], and is currently used worldwide. Meanwhile, the latter is 5G-only core network, which was initiated by the US in August, 2020, and is commercially serviced, as of June, 2021, by 12 mobile network operators across 9 countries worldwide [2]. 5G SA is still underway for commercialization along with development for advanced architecture, where research on security technologies is indispensable for provision of stable 5G SA services.

Vulnerabilities if found in 5G core network are tackled with patches released by system vendors. However, there are cases in which the vulnerability cannot be fixed with such patches depending upon the on-premise environment of 5G core network. Vulnerabilities that can be corrected via operating system patching encompass those triggered by bugs or flaws of the system per se and those caused by imperfect standards requiring system modification and update [3-5]. On the other hand, vulnerabilities hardly correctable
via system patching include those often failing to be patched when product vendor patches are not enforced in place or security considerations are insufficient in standards [6-11]. Options for tackling non-correctable vulnerabilities via system patching might be to procure and operate an additional security system alongside core network systems, where such system can be used to respond to vulnerability disclosures during the window of vulnerability prior to release of patches by vendors of core network systems. In mobile networks, tremendous traffic created by numerous mobile users are carried by diverse cellular systems and protocols in core networks. Therefore, 5G security systems are required, in addition to security features, to collect packets transmitted through diverse routes as a basic function and to identify and track users from packet data collected.

Representative 5G vulnerability attacks include attacks such as PFCP-in-GTP and IPSec disable attack [12]. These attacks are very complex to detect, and the attacker cannot be identified without integrated session management. However, the 5G core network uses a wide variety of protocols such as NAS, HTTP, PFCP, and GTP. Also, packets of the interface in which each protocol is used are managed with identities that are difficult to identify. Analyzing the relationship of these interfaces in real time is an important key to integrated session management. Also, SA unlike NSA does not send International Mobile Subscriber Identity (IMSI) but sends the encrypted Subscription Concealed Identifier (SUCI) to conceal the user’s identity, thereby making it more complex to identify and track users through network traffic.

There have been many studies related to session management in the past, but it is difficult to apply to a 5G SA network using a complex and special protocol [13]. Therefore, this paper proposes the 5G security system for security assurance within 5G core network and in relation thereto carries out evaluation of performances and security features regarding: 1) traffic collecting technology, 2) session management technology and 3) proposed technique.

The main contributions of this paper are summarized as follows:

1) We analyzed the interfaces used in NAS, HTTP, PFCP, and GTP protocols in real time in the 5G core network and presented a method to manage 5G SA user sessions in an integrated manner. The proposed technique defines traffic collection phase and describes a way to create session information for user identification.

2) We proposed an effective detection algorithm for PFCP-in-GTP and IPSec disable attack, which are representative 5G vulnerability attacks.

3) In practice, we verified the performance superiority through the performance test of the security system equipped with the proposed integrated session management method and detection method.

The proposed system with the proposed technique incorporated can surely be utilized to reinforce SA core network security. In particular, the scheme can independently improve on the defenses to address vulnerabilities without waiting for security patches from product vendors. This paper consists of: Chapter II, titled Preliminary, describes 5G SA network architecture and 5G SA registration procedure; relevant researches in Chapter III; Chapter IV presents the proposed technique; Chapter V shows the environment under which the proposed technique is to be validated; the result of the evaluation performed in Chapter VI; Chapter VII presents the content of analysis on the evaluation result; and, Chapter VIII draws a conclusion outlining the outcome of this work.

II. PRELIMINARY

In this chapter we will discuss 5G SA network architecture and 5G SA registration procedure, i.e. the procedure for the User Equipment (UE) registration with the 5G core network.

A. 5G SA NETWORK ARCHITECTURE

The 5G SA core network architecture comprises 26 split network functions (NFs) and entities [14]. Fig. 1 depicts main NFs necessary for user session management, majority of which constitutes 5G network architecture that also corresponds to the scope of this work. Each of these elements is described hereunder.

1) UE (User Equipment)
   : A user terminal connected to the mobile core network including ME (Mobile Equipment) and SIM (Subscriber Identity Module), to use network services.

2) gNB (next generation Node B)
   : A base station that supports 5G NR (New Radio).

3) AMF (Access and mobility Management Function)
   : 5G core network function that performs registration, connection, reachability, mobility management, etc.

4) SMF (Session Management Function)
   : 5G core network function that manages subscriber session.

5) AUSF (Authentication Server Function)
   : 5G core network function that supports authentication and security features with respect to UE being connected to 5G core network.

6) UPF (User Plane Function)
   : 5G core network function that supports packet routing/forwarding, interconnect to DN (Data Network),
etc. with respect to UE’s UP (User Plane) data.

7) DN (Data Network)
: Refers to the service part outside 5G core network, including Internet and service provider.

B. 5G SA REGISTRATION PROCEDURE

As shown in Figure 2, the 5G SA Registration procedure can largely be divided into two processes, where the one covers from Registration Request to Registration Accept, enabling UEs to register with 5G core network, and the other covers from PDU Session Establishment Request to PDU Session Resource Response, during which an IP address is allocated the session is created. The registration process in 5G SA is different from the 5G NSA Attach process in which IP allocation as well as session creation are made during the registration with the network.

1) 5G AUTHENTICATION AND NAS SECURITY SETUP PROCEDURE

The procedural sequences numbered from 1 to 5 in Fig. 2 are detailed below.

(a) The UE attempts to gain access to the network through Registration Request message. For an initial registration, reaching the UE is made through SUCI that encrypts Subscriber Permanent Identifier (SUPI) with the UE ID value. If the UE that is in a registered state attempts to gain access again to the network, reaching the UE is made through the old 5G-GUTI mapped from the network during the previous registration procedure.

(b) As the UE identification and authentication process is made through SUCI, if the Registration Request has not been performed through SUCI or if an AMF cannot find SUCI corresponding to 5G-GUTI, the AMF will request SUCI to the UE. This step can be skipped when the AMF can verify SUCI or if an AMF cannot find SUCI made through SUCI, if the Registration Request has not been registered procedure.

(c) This step relates to authentication of UE and creation of cryptographic key between AMF-UE communication. For the authentication, 5G Authentication and Key Agreement (AKA) or Extensible Authentication Protocol-AKA' (EAP-AKA') may be used by selecting an algorithm the UE and 5G core network support. If SUCI or the UE’s SUPI is known by the AMF that received Registration Request message, the Authentication Request is sent to the AUSF through the SUPI. The AUSF gets issued SUPI and Authentication Vector (AV) through Unified Data Management (UDM), and 5G AKA forwards 5G Serving Environment (SE) AV and EAP-AKA’ forwards AV and AKA’ Challenge to the UE to request for authentication. For the UE, the USIM of the UE verifies the freshness of the AV and authenticates the 5G core network. 5G AKA computes RES*, and EAP-AKA' computes RES, and then sends Cipher Key (CK) and Integrity Key (IK) to the ME. RES* and RES are sent to the 5G core network. As for 5G AKA, the verification is made on both AMF and AUSF; as for EAP-AKA', the verification is made on AUSF.

If successfully verified, then the authentication finishes. After the completion of the authentication on AUSF, K_SEAF is forwarded to the AMF. The AMF creates K_AMF and K_ASME, and creates on K_SEAF the cipher key and integrity key between AMF-UE, being used for the Non-Access Stratum (NAS) message ciphering.

(d) The step of Security Mode relates to determining ciphering algorithm and integrity algorithm to be used in NAS messages between the UE and the AMF. By referencing to the UE security capability forwarded by the Registration Request, the AMF selects one among algorithms it supports, either being the highest strength of cryptographic algorithm or following the priority set by the network. Then, the AMF sends the Security Mode Command. The UE that received the Security Mode Command applies the corresponding cryptographic algorithm from the rest of NAS messages, whereby all NAS messages from the Security Mode Complete message shall be ciphered and integrity protected.

(e) In this last step for the registration with the network, 5G-GUTI shall be sent to the UE. The gNB creates K_gNB through K_ASME and sends it to be used in UE-gNB Access Stratum (AS) security. The UE that has received 5G-GUTI responds it with the Registration Complete message.

2) 5G PDU SESSION ESTABLISHMENT PROCEDURE

The procedural sequences numbered from 6 to 7 in Fig. 2 are detailed below.

(f) This step relates to sending the PDU Session Establishment Request message including Protocol Data Unit (PDU) Session ID selected by the UE and whether to support Internet Protocol (IP) v4/v6. The AMF forwards the message to the SMF to create a session on the SMF and sets up diverse rules for the session management of the UE on the UPF. During this process, Uplink tunnel endpoint identifier (TEID) with respect to the UE session is created and is sent, including UPF IP, through the PDU Session Establishment Accept message.

(g) In Next Generation Application Protocol (NAGP) that is the lower layer, PDU Session Resource Setup Request is sent at the time when the PDU Session Establishment Accept message is sent. In response to it, Downlink TEID is created and is sent, including gNB IP, to the PDU Session Resource Setup Response message. Downlink, The gNB IP information shall be updated to the UPF, then the session creation procedure ends.

III. STUDIES OF SECURITY CHALLENGES

GPRS Tunnelling Protocol (GTP) is an important protocol used to allocate UE IP or manage network resources in mobile networks, but it is a UDP-based, disconnected protocol that has a vulnerability that facilitates forgery of packets. A GTP-in-GTP packet refers to a packet containing a GTP-Control (GTP-C) message in a payload corresponding to the user data portion of a GTP-User (GTP-U) packet, and can be easily produced using a packet manipulation tool. In addition, GTP-in-GTP packets can be used to scan the internal equipment of the mobile network or to drain resources of the mobile network [15].
Flooding in a mobile network is an attack that causes a large amount of traffic to occur in the base station or core network systems, making the service disabled. This is mainly in the form of Denial-of-Service (DoS) attacks which are utilized to drain resources on core network systems such as the UPF. In addition, it exists in various forms depending on the target of attack, such as a method of consuming all the bandwidth allowed by the base station. There is no problem in using the system, but increasing network traffic makes mobile services impossible. Small-cell with low capacity can easily be exposed to such attacks, and if attacked, pure connection requests from legitimate users will no longer be possible, making it difficult to provide 5G services [16].

Spoofing attacks are a technique of deceiving identification information to attack other target systems, and appear in the form of disguising and hiding IP addresses, DNS names, and MAC addresses. An attacker on a 5G network is based on a vulnerability in the NAS or SIP protocol. These attacks enable various other attacks, such as packet sniffing, DoS, and session hijacking. Types of spoofing attacks include Mobile Station Integrated System Digital Network (MSISDN) spoofing, IP spoofing, DNS spoofing, etc. [17].

Sniffing refers to collecting and eavesdropping data flowing on a network. In the 5G network, the radio area is the most vulnerable, and sniffing can be performed using fake base stations. Typically, Software Defined Radio (SDR) devices using a USRP may be used to access a fake base station in which nearby terminals are randomly made. All hosts in a area share the same frequency on a base station, so that all traffic communicated by nearby UEs can be seen. However, since the 3GPP standard defines the radio access to be confidential by utilizing multiple cryptographic algorithms, existing papers have dealt with various techniques for breaking encryption, which allows all traffic passing through fake base stations to be intercepted [18].

Ruhr University in Bochum, Germany, first introduced an attack that aboids encryption and integrity checks on NAS messages that have been applied from 4G mobile networks. This can also be valid in 5G networks, which are defined in the 3GPP standard to enable null-encryption and null-integrity in AMF in charge of authentication in 5G core network. However, in the case of integrity, it is a mandatory option. If it is set not to be encrypted, all messages exchanged by the UE are transmitted to the plane-text, thereby infringing confidentiality. Connection using the null-encryption and null-integrity options is allowed due to implementation or device configuration issues, as indicated by M. Closta et al. In particular, The "UE Security Capability" value of the Registration message is used to determine AS security. Therefore, if a connection is made after sending the registration message to the null-encryption and null-integrity option in the field, the AS connection will be null-encryption and null-integrity as well. Because AS security is an RAN segment, an attacker can easily capture network traffic from nearby normal UE via sniffing tool such as a fake base station [19]. In addition, many fuzzers have been created in the past, where these attacks are possible on 5G networks. The National Computing Centre (NCC) group which is an information assurance firm to claim over 15,000 clients worldwide in Manchester, UK, introduces three representative things : Fuzzowski 5GC, Frizzer2, and AFLNet. Among them, Frizzer2 and AFLNet are open source network protocol fuzzers that anyone can access [20].

Also, there have been many studies using session management [21-22]. There have been studies that use metadata such as session generation time, packet size, and packet reception time to generate features at the packet layer and use them for machine learning, or create features at the session layer and use them for machine learning [23]. In particular, studies have been conducted to detect attack traffic by utilizing large-sized payloads occurring at the session layer in machine learning algorithms. However, there has been no research on detecting abnormal traffic through Session Management in 5G networks.

IV. PROPOSED TECHNIQUE FOR SESSION MANAGEMENT

Chap. 4 describes the proposed technique with focus on traffic collection phase and how to collect fields for the session management.

A. SESSION MANAGEMENT TECHNIQUE

1) TRAFFIC COLLECTION PHASE

Fig. 3 depicts traffic collection phases with reference point representation. Phases essentially required for the user identification and session management are AMF-SMF N11 interface and gNB-UPF N3 interface. Other phases are those added to tackle vulnerabilities targeted on 5G SA core networks. The gNB-AMF N2 interface was added to respond to Null ciphering attack [24], and collecting AMF-AUSF interfaces is also required for deciphering of encrypted NAS phase. The SMF-UPF N4 phase was added to detect Packet Forwarding Control Protocol (PFCP)-in-General Packet Radio Service Tunneling Protocol (GTP) attack, that is, association of GTP-in GTP vulnerability [25] on the SA mode.
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2) COLLECTING MAJOR FIELDS ON 5G SA

Fig. 4 and Fig. 5 summarize fields collected for the UE registration procedure with the network, and Fig. 6 and Fig. 7 summarize fields collected for the session creation procedure.

Table 1 outlines collected fields, collected messages and fields for identifying the pertinent messages in a matrix format. As information on N4 phase is also delivered over N11, it is possible to collect major session fields within the N11 phase, if the N4 phase is not needed. The CreateSMContext Request message of the N11 phase extracts PDU Session ID for the identification of user session, and besides can collect as necessary Data Network Name (DNN) and single Network slice selection assistance information (sNssai), etc. that is network slicing information.

3) CREATION AND MANAGEMENT OF SESSION MANAGEMENT TABLE

Fig. 8 prunes down a UE session table for the user session identification and a key table for NAS phase deciphering. K_AMF in the key table can be created from collected K_SEAF according to the procedure specified in Annex A.7 of 3GPP TS 33.501 [26], and K_NASint and K_NASenc can be created from K_AMF according to the procedure specified in Annex A.8 of 3GPP TS 33.501 [27]. Created session tables need to be modified or deleted in the event of PFCP Modification and PFCP Deletion messages where Session Endpoint Identifier (SEID) and TEID coincide.

B. DETECTION EXAMPLES

1) PFCP-in-GTP Attack

The PFCP-in-GTP attack is shown in Fig. 9. Security features of the proposed system were validated by testing 2 vulnerabilities exploitable in 5G SA network [11][27]. The first vulnerability involves detection algorithm against PFCP-in-
TABLE 1. Collected fields in messages of 5G Standalone.

| Collected field | Collected message | Field for identifying collected message | Description |
|-----------------|-------------------|----------------------------------------|-------------|
| SUPI            | N12 Authentication Success | HTTP/2 Stream Identifier of Authentication Confirmation | Subscriber’s unique ID |
| SUCI            | N2 Registration Request | N2: NONE, N12: SUCI | Encrypted SUPI |
| 5G-GUTI         | N2 Registration Request | NONE | Subscriber’s temporary ID |
| MSISDN          | N4 PFCP Session Establishment Request | SUPI | Mobile Station International Integrated Services Digital Network Number |
| RAN UE / AMF UE NGAP ID | N2 The first UP/Downlink NGAP message | NONE | AMF-gNB NGAP communication ID |
| nRCell Identity | N2 Registration Request | SUCI | Global unique gNB ID |
| UE Security Capability | N2 Registration Request | SUCI | Encryption and integrity algorithm that UE supports |
| Selected NAS Security Algorithm | N2 NAS Security Mode Command | RAN/AMF UE NGAP ID | Encryption and integrity algorithm selected by core network |
| SEID            | N4 PFCP Session Establishment Request/Response | Request: SUPI, Response: Sequence number of Request message | SMF-UPF tunnel ID |
| TEID            | N2 PDU Session Establishment Accept | N2 : RAN/AMF UE NGAP ID N4 : SUPI, TEID | gNB-AMF Tunnel ID |
| PDU Session ID  | N2 PDU Session Establishment Request | N2 : RAN/AMF UE NGAP ID N4 : SUPI | UE’s session ID |
| UE IP address   | N4 PFCP Session Establishment Request | SUPI | UE’s session IP address |
| UE Authentication Ctx | N12 Authenticate Response | HTTP/2 Stream Identifier of Authentication Request | Authentication Context (location) |
| K_SEAF          | N12 Authentication Success | HTTP/2 Stream Identifier of Authentication Confirmation | Used to create K_AMF with Security Anchor Function Key |
| K_gNB           | N2 Registration Accept | RAN/AMF UE NGAP ID | Used to create AS security key with gNB Key |

GTP attack. This type of attack is accomplished such that PFCP protocol message used only in the 5G core network is injected into data the user transmits and sent to the targeted UE. If successful, the attacker can plug into the 5G core network system to issue its arbitrary command.

A security system to counteract such type of attack must inspect and block the injected packet at the front door of the core network from a security standpoint. The detection algorithm mentioned above checks if the PFCP header exists in payload of GTP-U packet through Deep Packet Inspection (DPI).

Fig. 10 is a PFCP-in-GTP attack detection algorithm that goes through a total of three procedures. The first checks whether the packet entering the detection system is a GTP-U protocol. GTP-U has a port fixed at 2152 according to the 3GPP TS 29.281 defined for the GPRS tunneling protocol. Therefore, it checks whether the destination port of the packet is 2152. Second, the payload of the packet must be checked. In general, the user data packet is TCP or UDP, and the detection algorithm should find a case of UDP and PFCP. PFCP has a port fixed at 8805 in accordance with the 3GPP TS 29.244 that defines the interface between the Control Plane and the User Plane. Therefore, the algorithm checks whether the UDP port of the payload in the packet is 8805. Third, it is possible to know the type of attack depending on which message among PFCPs is used. Extracting the top 4 bytes results in a message type, for example, 0x2*32 (where "*" may contain a value of 0 or 1 depending on whether or not the endpoint of the entity sending the message) as a PFCP Session Estimation Request, requesting the creation of a session between SMF and UPF. If the detected packet contains the corresponding PFCP message, it is a request to create a false session and can intentionally consume session...
2) SIP IPSec disable attack

The second vulnerability involves detection algorithm against SIP malformed attack. This type of attack can make the system unstable, such as eavesdropping, by arbitrarily disabling the user’s use of IPSec that encrypts packets of data. The SIP IPSec disable attack is shown in Fig. 11.

A security system to counteract such type of attack must inspect and block the SIP Register packets at the front door of CSCF that is a SIP server. The detection algorithm mentioned above checks if the use of IPSec is disabled, by grouping records as to normal SIP Register messages to Reference Packet Group (RPG) and comparing Experimental Packet Group (EPG) with the RPG.

Fig. 12 is a IPSec disable attack detection algorithm that goes through a total of four procedures. The first checks whether the packet entering the detection system is a GTP-U protocol. As mentioned in the previous chapter, the port is fixed at 2152. Therefore, it checks whether the destination port of the packet is 2152. Second, the payload of the packet must be checked. In general, since the voice service packet used in the 5G network is SIP, it is necessary to find a case in which the detection algorithm is UDP and SIP. The port of the SIP is fixed at 5060 according to the RFC3261 standard. Accordingly, the UDP port of the payload in the packet uses 5060. Third, the algorithm should find a message in SIP where the method value is Register and request. A register request is a message in which a UE wishing to use a voice service registers with an IP Multimedia Subsystem (IMS) network that controls the voice service. Finally, it checks whether the SIP header in the Register message contains the Security-Client or Security-Server header. If the SIP Register Request packet contains those headers, this is the case of requesting SIP encryption, and if there is no such header, the UE does not use SIP encryption. If the proposed Session Management Technique is used in the detection system, the SIP encryption request record of the UEs may be recorded. If a user who has previously used encryption requests a
register without an encryption-related SIP header, this can be suspected as a change in the UE or a SIP IPSec disable attack. If a UE is changed, a device that uses SIP encryption is white-listed for each UE, and if there is no encryption-related SIP header in the register message, the 5G network security operator needs to upgrade from the suspected SIP IPSec disable attack to the dangerous level. In this case, the security operator needs to monitor voice call traffic for the user and warn the user that the current call is not encrypted.

V. EVALUATION ENVIRONMENT
The evaluation environment will be described by dividing it into three parts. That is, Part A pertains to the experimental architecture for the evaluation, Part B pertains to 5G security threats and test case for security testing, and Part C pertains to metric, reference group and test case for performance testing.

A. EXPERIMENT ARCHITECTURE FOR EVALUATION
The proposed 5G security system was tested under the environments physically as shown in Fig. 9 and logically as shown in Fig. 10. In addition, the control-plane and the user-plane were separated by configuring VLAN as shown in Fig. xx. Furthermore, a 5G core network system simulator (traffic generator) was built making it possible to monitor packets over a total of 4 interfaces composed of N2 interface (b/w gNB and AMF), N3 interface (b/w gNB and UPF), N4 interface (b/w SMF and UPF) and N11 interface (b/w SMF and AMF). The 5G core network system simulator used is Spirent Landslide C100-M4.

The test system used hardware specification as shown in Table II.

B. DETECTION TEST ENVIRONMENT
The testing hereof was made after, as for each traffic scenario, setting the Number of Subscribers field to 100 persons, normal packets to UDP, and Transaction Rate to 1.

1) PFCP-in-GTP Attack Detection Test Cases
To reproduce the security scenario for PFCP-in-GTP attack, 8 types in total of payload data of abnormal packets were created, for which 100 packets by each type were prefabricated in advance into one PCAP file. Spirent’s Landslide STC-C1 package was used as the test case simulator. Table III classifies the types of attacks for each PFCP message included in the detected packet.

2) SIP IPSec disabled attack Detection Test Cases
SIP message packets with IPSec applied and SIP message packets with IPSec not applied were individually created, and, to transmit test cases to the proposed 5G security system, “a_ipsec = rdpcap” and “a_no_ipsec = rdpcap” were set up in the SIP message packet transmission tool. The SIP headers for IPSec association are shown in Table IV.
TABLE 3. Injected Packets for PFCP-in-GTP attack

| No. | Injected Packets                  | 4bytes | Threat                      |
|-----|-----------------------------------|--------|-----------------------------|
| 1   | Heartbeat Request                 | 0x2*01 | SBA Entity Scanning         |
| 2   | Heartbeat Response                | 0x2*02 | SBA Entity Scanning         |
| 3   | Session Establishment Request     | 0x2*32 | Session Depletion           |
| 4   | Session Establishment Response    | 0x2*33 | Session Depletion           |
| 5   | Session Modification Request      | 0x2*34 | Deny of Service             |
| 6   | Session Modification Response     | 0x2*35 | Deny of Service             |
| 7   | Session Deletion Request          | 0x2*36 | Deny of Service             |
| 8   | Session Deletion Response         | 0x2*37 | Deny of Service             |

FIGURE 18. Sent Packet Statistics for PFCP-in-GTP Attack in Traffic Generator.

TABLE 4. SIP Headers for IPSec Association

| No. | SIP Headers                  | Values                                      |
|-----|------------------------------|---------------------------------------------|
| 1   | security-client              | "Security-Client" HCOLON sec-mechanism       |
|     |                              | *(COMMA sec-mechanism)                      |
| 2   | security-server              | "Security-Server" HCOLON sec-mechanism      |
|     |                              | *(COMMA sec-mechanism)                      |
| 3   | security-verify              | "Security-Verify" HCOLON sec-mechanism      |
|     |                              | *(COMMA sec-mechanism)                      |

1514bytes. A steady stream of the proper packet size is sent bidirectionally across each Packet Generator Appliance port pair, together with varying source and destination IP addresses. And, each packet contains dummy data and is directed to a valid port on a valid subnet IP address. Before each test, network monitoring tools verify the percentage load and frames per second (fps) data across each inline port pair. Furthermore, many tests for correctness are performed, and averages are calculated. The test result shows maximum UDP Throughput (Mbps) achievable when each device uses varying packet sizes.

(c) MAX TCP CPS(Concurrent TCP Connection): Maximum TCP CPS refers to the maximum number of TCP Connection that can be created per second. The purpose of this test is to put the System under Test (SUT) engine to the test and see how well it handles large numbers of TCP connections per second. The use of Packet Generator Appliance enables an engineer to create traffic at varying Gbps rates as the background load in testing. At various connection/transaction rates, these tests provide a good simulation of a live network because all packets contain valid payload and address data.

All tests use the key Breaking Point which is where the final measurements are taken. (1) Concurrent TCP connections in excess, (2) Excessive con-current HTTP connection, (3) Unsuccessful HTTP transaction (usually, 0 transaction). Connection Rates, in addition to overall throughput, are critical in sizing a security device that won’t stifle a system’s or application’s performance. A device can be scaled more precisely by evaluating Maximum Connection rates rather than only looking at throughput. Once the maximum CPS of a device is established, it is possible to anticipate its maximum throughput depending on the traffic mix in an enterprise setting. If the maximum TCP CPS on the device is 2000 and the average traffic size is 44kb (2500cps = 1Gbps), the device can be considered to have a maximum capacity of 800Mbps, which is (2000/2500)*1000Mbps = 800Mbps by arithmetic.

When attempting to size a device appropriately, maximum concurrent TCP connections and maximum TCP CPS rates are also useful. Low Connection/Throughput ratio products risk depleting connections before reaching their optimum throughput capabilities. It is also possible to forecast when a device may fail in a specific organizational context by knowing the maximum CPS of a system in operation.

(d) MAX HTTP CPS(Concurrent HTTP Connection): The HTTP capacity tests are used to determine how effectively the HTTP detection engine manages network loads with var-
ied average packet sizes and connections per second. Because the device is compelled to track genuine HTTP sessions by using traffic with different session lengths, it has a higher effort than if it were just dealing with packets. This simulates real-world situations as closely as possible while assuring precise precision and repeatability. Each transaction is made up of a single HTTP GET request, with valid payload (a combination of binary and ASCII objects) and address data in each packet. This simulation is a great portrayal of a real-time network at various network loads. The greatest performance attained across a range of different HTTP response sizes is shown in the test result. It also shows the maximum APL connection rates (HTTP Connections per second) attained with various HTTP response sizes (from 44kb up to 1.7kb).

2) COMMERCIALIZED PRODUCTS

Security systems for mobile telecom networks already exist as commercialized products. Some of them are Next Generation Firewall (NGFW) products for packet analysis as to protocol used in existing LTE networks. Typical products are Check Point 15600 NGTP, Cisco Firepower4120, Forcepoint NGFW 2105, Fortinet FortiGate 500E, Palo Alto Networks PA-5220, etc. These appliances include features such as GTP using it in 5G LTE network, diameter protocol using it in DDoS and feature capable of identifying abnormal packets. Of those products, however, there is almost nothing that can be used in 5G network. Therefore, comparative test devices for the purpose of this paper are limited to the context of LTE NGFWs.

3) PERFORMANCE TEST CONFIGURATION

(a) LATENCY TEST : For each traffic scenario, latency testing was performed by setting the number of subscribers to 10,000, UDP packet size to 1400byte, and Transaction Rate to 75.

(b) UDP THROUGHPUT TEST : As identical to performance testing of NSS Labs, a variety of UDP packets were used. UDP packet sizes used are 6 types consisting of 64byte, 128byte, 256byte, 512byte, 1024byte, and 1514byte, and the test was made by setting to RFC-2544 of STC.

(c) MAX CAPACITY TEST : This test was made such that, for each traffic scenario, the number of subscribers is set to 10000 persons and connection rate is set to create maximum TCP Connections of between 20 and 50 per second. Therefore, measuring the performance was undertaken in an environment of sending/receiving 200,000 to 500,000 TCP SYNs ACKs per second.

VI. EVALUATION RESULTS

A. SESSION MANAGEMENT AND DETECTION TEST

1) PFCP-IN-GTP ATTACK DETECTION TEST

The detection test results of the proposed system for PFCP-in-GTP attacks are shown in Table V. Assuming that packets of 100 normal subscribers and 8 malicious subscribers send attacks, three tests showed that 100 packets were normal in all three times and 8 abnormal packets were detected.

| Test No. | TP | FN | TN | FP |
|----------|----|----|----|----|
| 1        | 100| 0  | 8  | 0  |
| 2        | 100| 0  | 8  | 0  |
| 3        | 100| 0  | 8  | 0  |
| Average  | 100| 0  | 8  | 0  |

2) SIP IPSec Disable ATTACK DETECTION TEST

The test result as to the proposed system’s capability to detect SIP IPSec Disable attack is given in Table VI. Resulting from three tests by transmitting 100 normal packets and 12 abnormal packets, it was found that in each of all three tests 100 packets were judged as normal and a total of 13 packets including 12 abnormal packets are detected, addressing that there occurs false detection.

| Test No. | TP | FN | TN | FP |
|----------|----|----|----|----|
| 1        | 100| 0  | 12 | 0  |
| 2        | 100| 0  | 12 | 0  |
| 3        | 99 | 0  | 12 | 0  |
| Average  | 99.7| 0.3| 12 | 0  |
3) DETECTION TEST RESULT

The detection test result revealed that the proposed system was also able to identify the attacker with maximum detection capacity of at least 99% when using the session management technique. However, there was false detection case when detecting SIP IPSec disable attack, so an attempt was made to check errors in given algorithms. Only the SIP header in the SIP Request was supposed to be determined, but this requires algorithm supplementation to look at the SIP header in the SIP Response together. Exceptionally, the terminal requests IPSec Association, but in some cases, the IMS network does not support it. Therefore, the detection system should check the SIP Response from the network to distinguish if IPSec is not used.

B. PERFORMANCE TEST

1) UDP LATENCY

The UDP latency test results of the proposed system are shown in Table VII. To accurately measure latency time span of the proposed 5G security system, latency introduced by a switch existing in the test environment was measured at the system’s maximum load of 90% to measure latency of the equipment under test by subtracting the switch latency time from the total latency time. As the measurement indicates round-trip UDP latency taken until the response packet is arrived as to the request packet in the in-line configuration, final UDP latency can be deemed as a half of the measured latency.

| Test No. | Packet Size | UDP Latency |
|---------|-------------|-------------|
| 1       | 128-bytes   | 29.72us     |
| 2       | 256-bytes   | 24.04us     |
| 3       | 512-bytes   | 23.31us     |
| 4       | 1024-bytes  | 23.02us     |
| 5       | 1280-bytes  | 23.35us     |
| 6       | 1514-bytes  | 23.68us     |
| Average |             | 24.52us     |

2) UDP THROUGHPUT

The UDP throughput test results of the proposed system are shown in Table VIII. As identical to performance testing of NSS Labs, a variety of UDP packets were used. Note, however, that the minimum size of UDP packet must be at least 86bytes because of encapsulation to GTP protocol given characteristic features of the mobile communication packet. Therefore, tests were performed in the condition of 128bytes, 256bytes, 512bytes, 1024bytes, 1280bytes and 1514bytes, respectively, where maximum throughput was 20Gbps. As for UDP throughput, its performance can be enhanced by way of changing hardware as it is dependent upon performance of network card mounted in the system.

| Test No. | Packet Size | Throughput |
|---------|-------------|------------|
| 1       | 128-bytes   | 18.2Gbps   |
| 2       | 256-bytes   | 19.5Gbps   |
| 3       | 512-bytes   | 20Gbps     |
| 4       | 1024-bytes  | 20Gbps     |
| 5       | 1280-bytes  | 20Gbps     |
| 6       | 1514-bytes  | 20Gbps     |
| Average |             | 19.62Gbps  |

3) MAX CAPACITY (TCP/HTTP CPS)

Measuring volumes of TCP Connections per second and loss of any Connection message was conducted by checking statistical data of the simulator and checking the network card interface information on the monitoring screen of SUT. TCP CPS (Socket SYNC Messages Sent (P-I) and Socket ACK Messages Received (P-I)) shown in Fig. 22 is the statistical values for 15 seconds. Therefore, to calculate TCP CPS, it is required to divide Socket SYNC Messages Sent (P-I) or Socket ACK Messages Received (P-I) by 15 seconds. For example, by dividing 3,000,000 by 15 seconds, 200,000 CPS is obtained. In this test, the Request message size for TCP Connection was 151 bytes, and the Response message size was 266 bytes.

The Max capacity test results of the proposed system are shown in Table IX and X. Resulting from three tests in total, it was found that loss of TCP Connection happened from 400,000 CPS for the second test, and from 450,000 CPS for the first and third tests.

It was tested three times in total, and in the case of TCP CPS, it was measured at an average of 399,933 CPS. Each
test considered the step immediately below the CPS, starting with 100,000 CPS and increasing by 200 CPS, where TCP or HTTP message misses occur, to be the maximum CPS. In the case of TCP, the first and third tests had a TCP message drop of 400,200 CPS, with a Max TCP CPS of 400,000, and the second test had a drop of 400,000 CPS. Similarly, HTTP CPS was measured at an average of 399,866 CPS.

4) PERFORMANCE COMPARISON RESULT

Comparative analysis was made on the overall performance between the proposed 5G security system and NGFW systems tested in NSS Labs’ NGFW Performance Report [28]. In this analysis, box plots were used, where the box plot created by John W. Tukey is a graph that is used to show the distribution of data sets. A box plot represents the minimum and maximum values of data, as well as providing information at a glance such as the median, the upper quartile and lower quartile. It can further represent Interquartile range (IQR) to show data points outside the min and max values as outliers [29].

The NGFW Comparative Report of NSS Labs contains overall performance data for 10 devices of such vendors as Cisco, Check Point, etc. By comparing the proposed system with these vendor products, it is possible to determine if the proposed system with 5G session management features employed is comparatively good or bad, in terms of performance.

When it comes to UDP Latency, to begin with, the proposed system showed the lowest latency time, except products of Fortinet and Palo Alto Networks. The product of Fortinet shows latency of 7 10us and the product of Palo Alto Networks shows latency of 13 20us, meaning that their performance capabilities are higher than the proposed system showing latency of 23 to 29us. When it comes to the second parameter, UDP Throughput, the proposed system was found to be better than vendor-products except Fortinet’s. The proposed system’s UDP Throughput shows 19.62Gbps on average, whereas Fortinet device shows the best performance with 20Gbps.

When it comes to the third parameter, Max Capacity, the proposed system was found to show excellent performance compared to most of vendor-products. As for TCP protocol, whereas vendor-products show capacity of not greater than approx. 200,000 CPS, the proposed system shows capacity of nearest 400,000 CPS. As for HTTP protocol, whereas vendor-products show capacity of not greater than approx. 100,000 CPS, the proposed system shows capacity of over 350,000 CPS.

Finally, when we performed performance tests, the resource overheads of the proposed system were very reasonable. Memory showed an average usage rate of 37.8%, and CPU usage rate was between 42% and 44%.

VII. DISCUSSION

Thanks to the advancement in 5G wireless technology, 5G offers network speeds and bandwidth not less than what we could get in wireline network. 5G security systems shall also be engineered to achieve high-speed bandwidth comparable with, or even exceeding, those of site systems in order to provide seamless services. The scheme this paper proposes for the session management enables to identify by whom malformed packets have been transmitted, when a cyber attack is detected. In addition to that, it is found that the
scheme contributes to increasing the performance via the efficient session management. Despite the foregoing, the scheme when deployed causes lagging in latency time to happen than does the existing NGFW, which is likely to give rise to a problem when providing a 5G URLLC service that is sensitive to latency time. This side effect is left behind calling for further research to rectify the drawback.

Meanwhile, the complexity in available session management techniques for the user identification leads to the architecture requiring us to reference a variety of interfaces. The complicated architecture as such possibly renders the failure in creating the user session as intended, due to various variables in real-world network environments such as wireless signal cutting-out, delay and packet drop. Therefore, complex techniques for creating sessions must be simplified such that the session management can be achieved only with critically vital interfaces.

VIII. CONCLUSION AND FUTURE STUDY

Through our work, we validate session management techniques that require security systems available on 5G networks and present performance comparison results with other existing products. In addition, we compared and analyzed the performance with other existing products based on the NSS performance evaluation criteria.

In the future, it is expected that 5G security systems provided by service providers will need to be tested and verified. In addition, study into the verification and performance of
previously presented and newly proposed technologies will be required. Furthermore, the 5G service provider will create a secure 5G environment that has never existed before, as well as new and convenient services that take advantage of its benefits. However, it is also necessary to think about how to effectively design security systems for new 5G services and think about ways to build them.

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FIGURE 27. Max Capacity Comparison with NGFW Vendors.
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