A ULE Security Approach for Satellite Networks on PLATINE Test Bed

L. Liang, L. Fan, H. Cruickshank, and Z. Sun

Centre of Communication System Research, University of Surrey, Guildford, Surrey, UK

C. Baudoin

Alcatel Alenia Space, Toulouse, France

D. Barvaux

B2I, Toulouse, France

Abstract

The satellite network does not have the IP layer where the IPsec [2][3] is designed for. Therefore, a new algorithm is needed to secure the satellite link at link layer or physical layer. This paper will give a short analysis on the advantages and disadvantages of the MPEG-2 TS encryption and present an approach trying to use the extension header of Unidirectional Lightweight Encapsulation (ULE) [6] Protocol Data Unit (PDU) to provide the efficient security solution for satellite networks. This approach is just above the MPEG-2 TS layer and makes the link security as a part of the encapsulation layer.

Thanks to a test bed platform named PLATINE developed by France partners and contributed by other partners within the SATSIX project on which the DVB-S and DVB-RCS have been implemented. The Unidirectional Lightweight Encapsulation (ULE) [6] mechanism working together with MPEG 2 Transport Stream (TS) as a part of the encapsulation in PLATINE is for the transport of IPv6 (& IPv4) Datagrams and other network protocol packets directly over the ISO MPEG-2 Transport Stream as TS Private Data. The proposed security approach is implemented within PLATINE to provide integrated security with ULE protocol at the link layer. The approach is based on the security requirements Internet draft [1]

Introduction

Current broadband satellite services are regarded as a niche market due to the high cost of launching a satellite system, and the relatively limited available bandwidth compared to terrestrial counterparts. To improve take-up of broadband satellite, it is essential to provide cost-effective solutions, to efficiently accommodate new multimedia applications, and to integrate satellites into next generation networks. These issues are being addressed in the EU-funded IST FP6 project Satellite-based communications systems within IPv6 (SATSIX). This project will implement innovative concepts and for broadband satellite systems and services.

The MPEG-2 Transport Stream (TS) has been widely accepted not only for providing digital TV services, but also as a subnetwork technology for building IP networks. RFC 4326 [6] describes the Unidirectional Lightweight Encapsulation (ULE) mechanism for the transport of IPv6 (& IPv4) Datagrams and other network protocol packets directly over the ISO MPEG-2 Transport Stream as TS Private Data. ULE specifies a base encapsulation format and supports an extension format that allows it to carry additional header information to assist in network/Receiver processing.

The encapsulation satisfies the design and architectural requirement for a lightweight encapsulation defined in RFC 4259 [7], which states that ULE must be robust to errors and

security threats. It recommends that any new encapsulation defined by the IETF should allow Transport Stream encryption and should also support optional link-level authentication of the SNDU payload. In ULE, it is suggested that this may be provided in a flexible way using Extension Headers. This requires the definition of a mandatory header extension, but has the advantage that it decouples specification of the security functions from the encapsulation functions. Moreover the use of extension headers for securing the ULE link can also be used for security of Generic Stream encapsulation (GSE) [8] to be used for DVB-S2 systems.

The rest of the paper is organized as following: The section 2 will give a brief discussion on security requirements on MPEG 2 satellite network and the ULE security extension header proposed by [1] The PLATINE satellite network testbed platform is explained in section 3 as well as the implementation of the ULE security approach. The thorough validation test is shown in section 4 with results.

The Secure ULE Approach

MPEG-2 based networks are susceptible to several security attacks, both passive and active. Therefore some mandatory (or optional) security services should be provided such as:

- Data Confidentiality (Mandatory): Data confidentiality is achieved by encrypting the higher layer PDU (and other ULE extensions headers that may be present and require security) before encapsulation in the ULE SNDU.
- Receiver NPA address hiding (optional): This is an important objective for ULE security to prevent any passive attacks like traffic analysis.
- Source authentication (Optional): Message Authentication Code (MAC) is generated for each message to enable receivers to carry out the source authentication
- Data Integrity (Optional): the MAC is also needed for receivers to check the integrity of each packet.
- Replay Attacks Countermeasures (Optional): A traditional way to protect services from replay attacks is to use sequence number in the appropriate packet header.

With these security requirements in mind, a security algorithm is proposed in [1] which is trying to use the ULE extension header to provide link security focusing only on the security between the ULE source and receivers. It is to eliminate the need to consider security issues regarding the remaining system components, such as multiplexers, re-multiplexers and modulators.

The security extension aims to secure the transmission of user traffic over MPEG-2 Transport Streams. In order to address the security issues, Figure 1 shows the SNDU format with the security extension header.

This security extension is a standard extension header as described in Section 5 of [6] and does not affect the ULE base protocol. This security extension header is a Mandatory ULE Extension header. This means that a receiver MUST process this header before it processes the next extension header or the encapsulated PDU, otherwise the entire SNDU should be discarded.

There are four new header fields are added in the ULE extension header, which are:

- Security ULE Type Field: A 16-bit Type Field indicates that this is a Secure ULE SNDU.
- ULE-SID Field: A 32-bit security identifier, the ULE-SID similar to the SPI used in IPsec has been added to uniquely identify the secure session. This ULE-SID represents the security association between the MPEG-2 transmitter and receiver for a particular session and indicates the keys and algorithms used for encrypting the data payload and calculating the MAC. The ULE-SID is used by a receiver to filter PDUs in combination with the NPA address when present.

- **Sequence Number Field:** An optional 32-bit sequence number MAY be included in the ULE SNDU to prevent replay attacks. The gateway monotonically increments this number when it sends a packet to the receiver and the receiver verifies the correct sequence number and MUST discard all SNDUs which do not match. If an adversary tries to inject or replay old packets the sequence number would not match. This would result in discarding the packet.
- **Message Authentication Code (MAC) Field:** To provide both data origin authentication and data integrity, a Message Authentication Code (MAC) is included in the extension header.

Figure 1 ULE Format with Security Extension Header

Secure ULE does not impose the use of any specific encryption algorithm and should be able to support the commonly used algorithms including DES, 3DES etc.

When a receiver received a Secure ULE SNDU, it first filters the received packets according to the receiver destination NPA address (if present). Then The CRC is verified as defined in [6]. The Receiver uses the ULE-SID to obtain the security associations between the transmitter and receiver and determines if the sequence number and the MAC are present or not. The length is also used to determine the algorithms and keys used for both encryption of the encapsulated PDU and for generation of the message authentication code.

The Implementation of Secure ULE over PLATINE

To implement the proposed secure ULE extension header approach above, the satellite testbed was setup using a satellite emulator called PLATINE developed by partner within SATSIX. The PLATINE is based on Linux operation system, in which most of the DVB-S and DVB-RCS satellite network functions have been implemented. These functions include network topology configuration, Quality of Service (QoS), Demand Assigned Multiple Access (DAMA), traffic encapsulation using both Asynchronous Transfer mode (ATM) and ULE/MPEG, satellite network entities configuration and support for both IPv4 and IPv6.

PLATINE satellite emulator runs on top of a network testbed. It has a centralized development component, a single PC, called Satellite Emulator (SE), which also performs the DVB satellite payload functions. The emulator software is installed in this SE and all development work, i.e. programming, is done on it. It has a management user interface, through which the satellite gateway (GW) and terminal (ST) functions can be distributed to the correspondent entities, i.e. PCs or laptops.

The Figure 2 shows the PLATINE testbed constructed in our lab using both desktops and laptops. It has 1 laptop as SE, 2 desktop as STs and 1 other desktop as GW, which are connected

by a hub to form a local network. 2 extra hubs connect each ST with a desktop as end user, which form two other local networks.

Figure 2: PLATINE testbed layout with secure ULE

The proposed ULE security approach has been partially implemented in the PLATINE satellite testbed described above. All the compulsory ULE security extension header fields, i.e. the D field, the length field, the type field and the SID field, have been implemented as well as payload encryption and decryption functions.

The implementation work has been carried out on the SE within the encapsulation functions. The PLATINE has its own ULE encapsulation classes that are needed in the ULE security implementation. Beside these classes, there is another class specifically written for ULE extension headers in PLATINE named UleExt, which has been directly inherited to build the security extension header class called UleExtSecurity. It has two main functions named UleExtSecurity::build() and UleExtSecurity::decode().

The UleExtSecurity::build() function executes the IP packet encapsulation. In another word, it adds the security extension header fields to the PDU in this case. Besides, it will read the key corresponding to the ULE_SID from the key storage file and encrypt the PDU.

The UleExtSecurity::decode() function perform the decryption functions. It reads the ULE_SID when a ULE PDU is received and obtains the corresponding key from its local key storage file to decrypt the PDU. Figure 3 shows the flow chart of both UleExtSecurity::build() and UleExtSecurity::decode() functions.

a) UleExtSecurity::build() b) UleExtSecurity::decode ()

Figure 3 ULE security approach flow chart

ULE Security Validation

The implementation has been validated in a testbed scenario shown in Figure 2 to test if the ULE security can work along with all other DVB-S functions implemented on the PLATINE testbed. We used both PING application, FTP application and VideoLAN (VLC) application to test the behavior of the ULE security function. The detail procedure and results are shown as following:

1. To Patch PLATINE to enable the security functions.
2. To configure the SE, STs and GW to use ULE protocol instead of ATM.
3. To set up the testbed with two end users, workstation 1 and workstation 2, sitting behind different STs as shown in Figure 2.
4. Distribute the correct encryption and decryption keys to all STs and run PING from workstation 1 and workstation 2.
5. Change the decryption key on ST3 and run the PING from workstation 1 and workstation 2.
6. Correct the decryption key and change the encryption key on ST1 and run the PING from User B to User A.
7. Distribute the correct encryption and decryption keys to all STs and start a FTP server on workstation 1.
8. Start a FTP client on workstation 2 and login to the FTP server on workstation 1. Do file listing and download a file from the server. Logout after finishing.
9. Change the decryption key on ST3 and repeat step 8.
10. Distribute the correct encryption and decryption keys to all STs and start a VLC server on workstation 1 and streaming a multimedia file to workstation 2.
11. Start a VLC client on workstation 2 to listen to the streaming.
12. Change the decryption key on ST3.

The results from the PING application test showed that workstation 1 can successfully ping workstation 2 with a RTT around 610ms over the PLATINE testbed when all STs had the right encryption key and decryption key as shown in Figure 4. The PLATINE Figure 5 shows the IGMP messages were processed on ST1. However, when the encryption key did not match the decryption key, either the ping messages or the acknowledge messages were dropped because of failure decryption.

```

Command Prompt
Reply from 192.168.21.2: bytes=32 time=611ms TTL=62
Reply from 192.168.21.2: bytes=32 time=609ms TTL=62
Reply from 192.168.21.2: bytes=32 time=607ms TTL=62
Reply from 192.168.21.2: bytes=32 time=606ms TTL=62
Reply from 192.168.21.2: bytes=32 time=607ms TTL=62
Reply from 192.168.21.2: bytes=32 time=605ms TTL=62
Reply from 192.168.21.2: bytes=32 time=602ms TTL=62
Reply from 192.168.21.2: bytes=32 time=601ms TTL=62
Reply from 192.168.21.2: bytes=32 time=599ms TTL=62
Reply from 192.168.21.2: bytes=32 time=599ms TTL=62
Reply from 192.168.21.2: bytes=32 time=597ms TTL=62
Reply from 192.168.21.2: bytes=32 time=596ms TTL=62
Reply from 192.168.21.2: bytes=32 time=596ms TTL=62
Reply from 192.168.21.2: bytes=32 time=596ms TTL=62
Reply from 192.168.21.2: bytes=32 time=596ms TTL=62
Reply from 192.168.21.2: bytes=32 time=596ms TTL=62
Reply from 192.168.21.2: bytes=32 time=595ms TTL=62

Ping statistics for 192.168.21.2:
    Packets: Sent = 974, Received = 974, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 575ms, Maximum = 638ms, Average = 600ms
Control-C
^C
C:\Documents and Settings\admin>

```

Figure 4 Ping results over secured PLATINE

```

satsix@st1:/
File Edit View Terminal Tabs Help
the size of the payload is 60

the length is 60

Encrypted-test :fef339e8437ddea7cf328d6f66951da7b2368e4bc96835e95b1bdeb738cf800
adce11d0ef96b7c80adf604ab77739298b1a55ca33938a071ad42435c
Decrypted-test :4500003c4acc00003f0187a0c0a81502c0a813020000485c02000b006162636
465666768696a6b6c6d6e6f7071727374757677616263646566676869
the length of the ULE payload is 66

the size of the payload is 66

the payload type is 2048

the size of the payload is 60

the length is 60

Encrypted-test :fef339e8437cdea7cf328d5066951da7b2368e4bc9683ae95b1bd9b738cf800
adce11d0ef96b7c80adf604ab77739298b1a55ca33938a071ad42435c
Decrypted-test :4500003c4acd00003f01879fc0a81502c0a813020000475c02000c006162636
465666768696a6b6c6d6e6f7071727374757677616263646566676869

```

Figure 5 Example of Ping messages processed on ST

Then there is another question needed to be asked that what's the RTT if without security? In another word, how much does the security function impact the system's performance? To find out, the security function was disabled and the above procedure was repeated. The Ping results Figure 6 comparing to Figure 4 showed the security function does not have significant impact to the system performance at all in terms of the RTT, especially considering long satellite delay.

```

Command Prompt
Reply from 192.168.21.2: bytes=32 time=595ms TTL=62
Reply from 192.168.21.2: bytes=32 time=594ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62
Reply from 192.168.21.2: bytes=32 time=591ms TTL=62
Reply from 192.168.21.2: bytes=32 time=590ms TTL=62
Reply from 192.168.21.2: bytes=32 time=589ms TTL=62
Reply from 192.168.21.2: bytes=32 time=588ms TTL=62
Reply from 192.168.21.2: bytes=32 time=588ms TTL=62
Reply from 192.168.21.2: bytes=32 time=595ms TTL=62
Reply from 192.168.21.2: bytes=32 time=595ms TTL=62
Reply from 192.168.21.2: bytes=32 time=595ms TTL=62
Reply from 192.168.21.2: bytes=32 time=594ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62
Reply from 192.168.21.2: bytes=32 time=593ms TTL=62

Ping statistics for 192.168.21.2:
    Packets: Sent = 567, Received = 567, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 574ms, Maximum = 631ms, Average = 599ms
Control-C
^C
C:\Documents and Settings\admin>

```

```

Command Prompt
Reply from 192.168.21.2: bytes=32 time=601ms TTL=62
Reply from 192.168.21.2: bytes=32 time=607ms TTL=62
Reply from 192.168.21.2: bytes=32 time=606ms TTL=62
Reply from 192.168.21.2: bytes=32 time=606ms TTL=62
Reply from 192.168.21.2: bytes=32 time=605ms TTL=62
Reply from 192.168.21.2: bytes=32 time=604ms TTL=62
Reply from 192.168.21.2: bytes=32 time=603ms TTL=62
Reply from 192.168.21.2: bytes=32 time=602ms TTL=62
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Reply from 192.168.21.2: bytes=32 time=600ms TTL=62
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Reply from 192.168.21.2: bytes=32 time=604ms TTL=62
Reply from 192.168.21.2: bytes=32 time=603ms TTL=62
Reply from 192.168.21.2: bytes=32 time=602ms TTL=62
Reply from 192.168.21.2: bytes=32 time=602ms TTL=62
Reply from 192.168.21.2: bytes=32 time=601ms TTL=62
Reply from 192.168.21.2: bytes=32 time=600ms TTL=62

Ping statistics for 192.168.21.2:
    Packets: Sent = 635, Received = 635, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 574ms, Maximum = 631ms, Average = 601ms
Control-C
^C
C:\Documents and Settings\admin>

```

Figure 6 Examples of Ping messages without ULE security

The FTP test provided further validation proves on the ULE security function. After a successful connection between receiver and the FTP server, a file is transferred using "get" command. In the middle of the transfer, the decryption key was modified on ST3 which resulted failure of receiving data from the FTP server immediately. However, the client was keeping on trying to re-establish the connection. After 30 seconds, the decryption key was reversed back and the transfer resumed until the client accomplished the file transfer. The traffic flow diagram Figure 7 shows the data was transferring at a speed of 40Kbps in the beginning of the file downloading with a typical TCP slow start. And then the transfer was interrupted due to the wrong key deployed. However, the FTP application managed to keep the connection alive during this period. When the key is correctly deployed, the connection was resumed and the rest of the file was correctly downloaded. Similarly, the multimedia streaming test using VLC showed that the secure ULE works well with the right keys had been deployed on both STs. The workstation 2 can not play anything when ST3 did not have the right key but the streaming continued on the

server side. Then the workstation 2 started to play the streamed file immediately after the right key is restored at ST3.

Figure 7 File downloading over secured Platine

Figure 8 shows the one ULE SNDU is segmented by MPEG protocol into three MPEG TS frames during the file downloading.

```

the length of the ULE payload is 541
[packet #1] 1 IPv4 packet => 3 MPEG2-TS frames

MPEG frame:
47 00 1f 10 00 82 21 03 10 00 00 11 5c 08 00 fe f3 3b c3 f0 a8 9e a7 b0 35 8e a6 66 95 0a cc 32 77 2a 2a 7b 1e 7d e5 a8 99 c8
bf 53 9d 01 f4 e9 9f 67 36 da 85 17 ec 87 dd 3f fb 29 21 a9 b8 90 83 04 f3 75 6a c9 1e 83 4a 58 41 e9 4b 18 20 95 eb f5 94 7
a f5 35 7b c1 52 67 2e b6 d1 da 9d 05 2f c9 1f eb 35 31 e2 f9 ef d9 2d ac f0 ac 22 42 8e a9 16 39 8a 2b b4 37 4b 51 57 2a b9
af cf aa ed ac 88 8b fc 5e 32 61 c3 6d 57 03 15 8b dc f2 ae 8c 21 dc 19 d9 48 35 aa 41 0b a1 58 5c 07 38 68 52 79 ea 07 c6 81
70 ce b5 e7 3f de 58 f3 0b f7 53 24 e7 0c 41 3d f0 3a 6d 80 79
[packet #1 / frame #1] 1 MPEG2-TS frame => 0 packets

MPEG frame:
47 00 1f 11 0b 2c 41 31 d1 2b 96 b5 a4 dc 24 f2 f5 66 53 83 e1 4c e6 96 56 dd 23 6a 68 26 e8 d1 81 be d3 35 61 cf ce 6d 5b e6
4f ba 9d 5a 45 99 2a b2 8a d3 70 85 02 fe 9f 74 e0 52 ec 87 72 05 47 30 f6 56 74 5f c0 fc 45 75 c1 6f 4c e9 c8 1d 6c a3 d2 9
a 83 50 ee f5 4e 7a ab 98 0e d0 45 46 56 3b 10 16 20 d0 08 d7 cc 06 18 5d 81 99 c5 8f 22 94 01 9d 0a f9 a5 e3 2d 8a 9f 63 9c
46 64 26 0c 11 cb 8f 8a be 75 30 d1 66 5c a9 5e b8 8a de f3 e7 0b 23 4f 25 8a 7b 7a f0 af 18 7a 48 2a 22 fa 69 6a 26 99 35 a3
5e 90 08 f6 c6 dd b9 57 49 e8 a1 04 f1 05 d7 9e bf 04 53 80 23
[packet #1 / frame #2] 1 MPEG2-TS frame => 0 packets

MPEG frame:
47 00 1f 12 45 2b 00 41 f8 eb 7c d7 e4 f0 38 83 13 22 bb a4 30 8b 55 77 9a ef 46 7c 4a f9 9b 0d 95 04 70 04 4c 50 92 44 1f 2c
21 35 c0 08 d7 de 75 b5 64 c7 4d e1 be 24 81 47 32 c4 fd ce ad 76 79 2a c7 53 65 31 13 68 2a 80 a0 12 1c fd c5 17 38 87 13 0
8 b8 06 a3 76 5a ce 72 de 6c d9 ba 2a 9f 83 fa 4c 85 af ff 5e 3f f7 25 ff bb 0f 9d dc 9d 96 f6 fd 4e 49 23 95 bd e1 88 1d 81
e0 d3 55 17 2a 3f 43 c8 70 01 58 56 a4 81 5f 8c bf 54 2d d7 fe bb e5 7f b2 82 54 8f 62 fd 85 8d c4 4e 95 8d 57 af 37 ad 82 44
61 09 a5 91 e4 cd 2a 32 f2 7e 96 26 91 70 a9 ff ff ff ff ff

```

Figure 8 ULE Security header layout

Figure 8 shows clearly both the MPEG TS header and the ULE header with security extension in the first MPEG frame. The highlighted 10 bytes are the 4 bytes ULE header and 6 bytes security extension header. As the Destination Address Absent (D) Field is set to 1, the Destination Address Field is omitted in this case [6]. The ULE length field 0x0221 gives the payload length of 545 including the CRC, which matches the first line in Figure 8 giving the ULE payload length of 541 excluding the 4 bytes CRC. After the ULE length field is the 16 bits long Next-Header Type Fields. Its first 8 bits gives the length of the extension header $3 \times 2 = 6$ bytes according to [6]. And its second 8 bits gives the type of the next header that is the security extension. The following 32 bits of the security extension header is the ULE-SID Field which is given as 0x115C or 4444 in decimal. Following is the next-header type field that is 0x0800 for IPv4.

The impact of the security function on the FTP service performance was also examined. Figure 9 a) is the file downloading result on PLATINE without ULE security and b) is the result with

ULE security. The downloading time was 65 seconds, the same for both cases. The transfer average speed of case a) is even faster than case b), which is on the contras of theory that encryption and decryption of each frame should increase the processing time. This shows that the variability of the testbed itself has even higher impact on the experiment than the security function does. Therefore, the impact of the security function to the testbed can be neglected.

a) with ULE security
b) without ULE security
Figure 9 FTP file downloading service a) without ULE security and b) with ULE security

Conclusions

This document has a brief discussion on the requirements for ULE security provides an approach using the ULE security extension headers based on the ULE standard extension header definition without affecting the ULE base protocol.

A satellite network testbed has been setup where the proposed approach has been partially implemented under the umbrella of a software DVB satellite emulator called PLATINE. The implementation extended the encapsulation functions of PLATINE to support the ULE security extension headers and en/decryption of the PDU.

ULE security implementation has been validated within SATSIX project using different applications and the results showed that the approach can works well on the PLATINE testbed as well as providing confidentiality and access protection to services provided over the satellite network testbed. Moreover, the security function has neglected impact to the testbed performance in terms of RRT and throughput.

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