

# The spear to break the security wall of S7CommPlus

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**Abstract.** *Siemens PLCs was widely used in industrial control system(ICS). The new version of Siemens PLCs like S7-1500 and S7-1200v4.0 used an encrypted protocol names S7CommPlus to prevent replay attacks. In this paper, based on reverse debugging techniques, we will demonstrate the encryption algorithms of S7CommPlus and program a MFC to control the Siemens PLC. Finally, some more security protective measures have been proposed according to our research.*

## 1. Introduction.

Industrial Control System involves national level critical infrastructure and requires highly Security. In the past few years, attacks against industrial control systems (ICS) have increased year over year. Stuxnet in 2010 exploited the insecurity of the S7Comm protocol, the communication protocol used between Siemens Simatic S7 PLCs to cause serious damage in nuclear power facilities. After the exposure of Stuxnet, Siemens has implemented some security reinforcements into the S7Comm protocol. The current S7CommPlus protocol implementing encryption has been used in S7-1200 V4.0 and above, as well as S7-1500, to prevent attackers from controlling and damaging the PLC devices.

Is the current S7CommPlus a real high security protocol? This talk will demonstrate a spear that can break the security wall of the S7CommPlus protocol. First, we use software like Wireshark to analyze the communications between the Siemens TIA Portal and PLC devices. Then, using reverse debugging software like WinDbg and IDA we can break the encryption in the S7CommPlus protocol. Finally, we write a MFC program which can control the start and the stop of the PLC, as well as value changes of PLC's digital and analog inputs & outputs. This paper is based on the Siemens SIMATIC S7-1200v4.1.

## 2. Related Work

At Black Hat USA 2011, Dillon Beresford demonstrated how to use

reconnaissance, fingerprinting, replay attacks, authentication bypass methods, and remote exploitation to attack a Siemens Simatic S7-300 PLCs. These PLCs use S7Comm protocol which does not contain any security protection. At Black Hat USA 2015, Ralf Spennberg et. al. demonstrated a worm lives and runs on the Simatic S7-1200v3 PLCs. These PLCs use the early S7CommPlus protocol with a simple mechanism to prevent replay attacks.

### **3. Siemens PLCs**

Siemens PLCs are widely used in industrial control systems, like power plants, fuel gas station, water and waste.

#### **3.1 Programmable Logic Controllers**

Programmable Logic Controllers (PLC) is responsible for process control in industrial control system. A PLC contains a Central Processing Unit (CPU), some digital/analog inputs and outputs modules, communication module and some process modules like PID. Engineers programmed user programs for automated process control in PLC software and then downloaded the user program to the PLC. The authorized engineers can also run or stop the PLCs from PLC software.

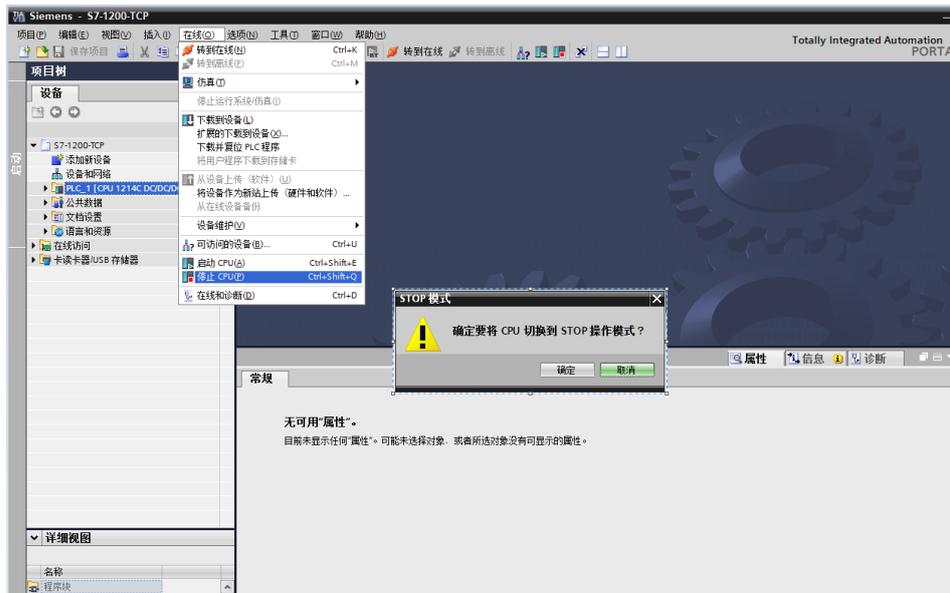
#### **3.2 Siemens PLCs protocols**

Siemens PLCs use a private protocol to communicate. It is a binary protocol utilizing both TPKT and ISO8073. Typically, both of these protocols use port 102/TCP.

The newest version of Wireshark(V2.1.1) supports Siemens PLC protocols recording that will permit the analysis of message frames. Siemens PLC protocol has 3 versions, S7Comm protocol, early S7CommPlus protocol and new S7CommPlus protocol. S7Comm protocol is used in the communication among S7-200, S7-300 and S7-400 PLCs. This protocol did not involve any anti-replay attack mechanism and can be easily exploit by attackers. The early S7CommPlus protocol used in the communication among S7-1200v3.0 is more complicated than S7Comm protocol and use two-byte field called session ID for anti-replay attack. However, the session ID is too easy to calculate. The new S7CommPlus protocol used in the communication among S7-1200v4.0 and S7-1500 has a complex encryption part to against replay attack. In this paper, we will focus on the encryption part of S7CommPlus.

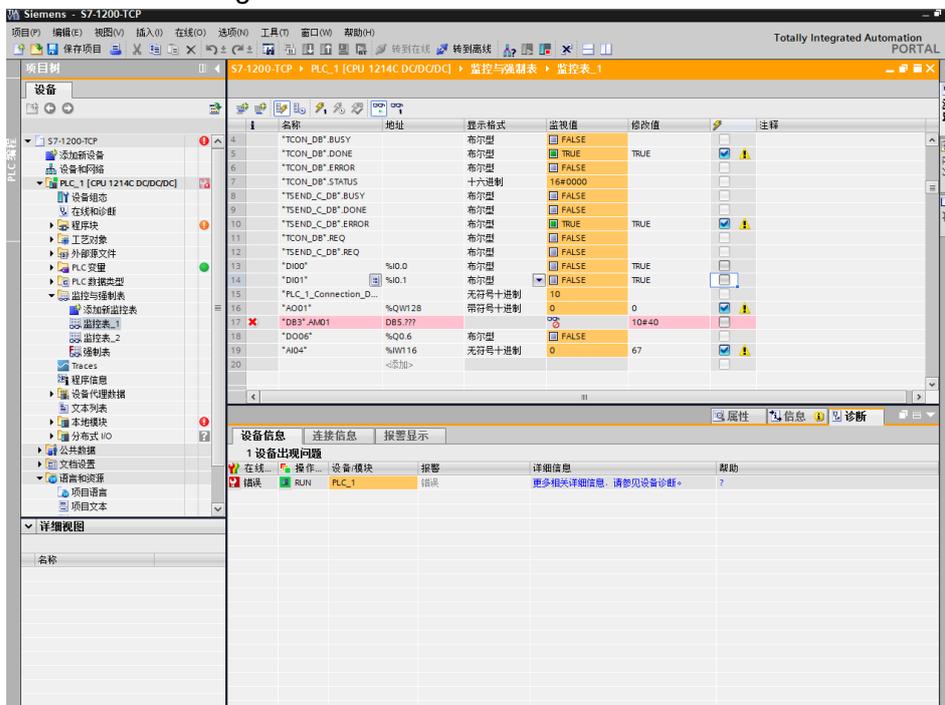
### 3.3 TIA Portal

TIA Portal is the configuration and programming software for Siemens PLCs. Engineers rely on this software to design logic and program to control the process attached to the PLC. The software offers the programmer the ability to configure hardware parameters, such as Profinet parameters, communication type, diagnostics. Authorized engineers can also run or stop the PLCs, monitor and modify the input/output values.



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Figure 3.1 TIA Portal CPU STOP



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Figure 3.2 TIA Portal value monitor and modify

## 4. Replay Attacks

Replay attacks have been widely used in PLC attacks. We build up a small net environment with a TIA Portal PC, a PLC and a hub. First, click the Stop PLC button in TIA Portal to stop the PLC. Then launch the Wireshark or other packet capturing tool to capture the packets between PC and PLC. Once the PLC has stopped, stop capturing the packets. Use the packets we have already obtained and send these packets back to any PLC in sequence, the PLC could be controlled with these packets.

It is also possible for attackers to run PLCs, monitor or modify the analog/digital input/output values, download user program or system program, monitor the diagnostics of PLC.

No.	Time	Source	Destination	Protocol	Length	Info
1010	2017-02-24 13:37:26.264282	10.65.96.89	10.65.60.73	TCP	66	5208->102 [SYN] Seq=0 Win=8192 Len=0 MSS=1460 WS=4 SACK_PERM=1
1022	2017-02-24 13:37:26.266384	10.65.60.73	10.65.96.89	TCP	60	102->5208 [SYN, ACK] Seq=0 Ack=1 Win=8192 Len=0 MSS=1460
1022	2017-02-24 13:37:26.266509	10.65.96.89	10.65.60.73	TCP	54	5208->102 [ACK] Seq=1 Ack=1 Win=64240 Len=0
1032	2017-02-24 13:37:26.267364	10.65.96.89	10.65.60.73	COTP	89	CR TPDU src-ref: 0x0003 dst-ref: 0x0000
1026	2017-02-24 13:37:26.276317	10.65.96.89	10.65.60.73	S7COMM-PLUS	289	+5208 PDU-Type: [Connect] Op: [Request] Function: [CreateObject] S...
1027	2017-02-24 13:37:26.286598	10.65.60.73	10.65.96.89	S7COMM-PLUS	251	+5208 PDU-Type: [Connect] Op: [Response] Function: [CreateObject] S...
1039	2017-02-24 13:37:26.331976	10.65.96.89	10.65.60.73	S7COMM-PLUS	61	DT TPDU (0) [COTP fragment, 0 bytes]
1039	2017-02-24 13:37:26.360397	10.65.60.73	10.65.96.89	S7COMM-PLUS	472	+5208 PDU-Type: [Data] Op: [Request] Function: [SetMultiVariables] -
1054	2017-02-24 13:37:26.459946	10.65.60.73	10.65.96.89	TCP	60	102->5208 [ACK] Seq=233 Ack=696 Win=8192 Len=0
1054	2017-02-24 13:37:26.459946	10.65.60.73	10.65.96.89	S7COMM-PLUS	86	+5208 PDU-Type: [Data] Op: [Response] Function: [SetMultiVariables] -
1056	2017-02-24 13:37:26.460261	10.65.96.89	10.65.60.73	COTP	61	DT TPDU (0) [COTP fragment, 0 bytes]
1072	2017-02-24 13:37:26.556614	10.65.60.73	10.65.96.89	TCP	60	102->5208 [ACK] Seq=265 Ack=703 Win=8192 Len=0
1092	2017-02-24 13:37:26.693001	10.65.96.89	10.65.60.73	S7COMM-PLUS	155	+5208 PDU-Type: [DataFW1_5] Op: [Request] Function: [GetVarSubStre...
1093	2017-02-24 13:37:26.697851	10.65.60.73	10.65.96.89	S7COMM-PLUS	129	+5208 PDU-Type: [DataFW1_5] Op: [Response] Function: [GetVarSubStre...
1094	2017-02-24 13:37:26.697987	10.65.96.89	10.65.60.73	COTP	61	DT TPDU (0) [COTP fragment, 0 bytes]
1150	2017-02-24 13:37:27.081996	10.65.96.89	10.65.60.73	S7COMM-PLUS	155	+5208 PDU-Type: [DataFW1_5] Op: [Request] Function: [SetVariable] S...
1151	2017-02-24 13:37:27.087581	10.65.60.73	10.65.96.89	S7COMM-PLUS	118	+5208 PDU-Type: [DataFW1_5] Op: [Response] Function: [SetVariable] -
1152	2017-02-24 13:37:27.087691	10.65.96.89	10.65.60.73	COTP	61	DT TPDU (0) [COTP fragment, 0 bytes]
1153	2017-02-24 13:37:27.157371	10.65.60.73	10.65.96.89	TCP	60	102->5208 [ACK] Seq=1221 Ack=1780 Win=8192 Len=0
1163	2017-02-24 13:37:27.246673	10.65.96.89	10.65.60.73	S7COMM-PLUS	149	+5208 PDU-Type: [DataFW1_5] Op: [Request] Function: [DeleteObject] -
1165	2017-02-24 13:37:27.251266	10.65.60.73	10.65.96.89	S7COMM-PLUS	121	+5208 PDU-Type: [DataFW1_5] Op: [Response] Function: [DeleteObject] -

Figure 4.2 Stop PLC communication sequence

Figure 4.1 shows the communication sequence packets when stopping the PLC using Wireshark. We separated these packets into 4 parts, TCP Connection packets, COTP Connection packets, S7CommPlus Connection packets and S7CommPlus Function packets. Performance as TIA Portal, first establish the TCP connection and COTP connection to the target PLC. Then, send the two S7CommPlus connection packets. After the S7CommPlus connection was established, the S7CommPlus function packets could be used to control the target PLC, or read/write the PLC's input/output values.

## 5. S7CommPlus Protocol

Siemens S7-1200v4.0 and S7-1500 use the new S7CommPlus protocol including the S7CommPlus Connection packets and S7CommPlus Function packets. Every packets used by S7CommPlus protocol has a similar structure.

	Type	Sub-Type	Sequence Number	Protocol ID	PDU Type	Data Length
0030	fa cd b2 29 00 00	03 00 00 eb 02	f0 80 72 01 00		...	.....r..
0040	dc 31 00 00	04 ca 00 00 00 01	00 01 20 36 00		.1.....	..... 6.
0050	00 01 1d 00 04 00 00 00 00 00	a1 00 00 00 d3 82			.....	.....
0060	1f 00 00 a3 81	69 00 15 15 53 65 72 76 65 72 53			.....i..	.ServerS
0070	65 73 73 69 6f 6e 5f 31	43 39 43 33 38 30 a3 82			ession_1	C9C380..
0080	21 00 15 35 31 3a 3a 3a	36 2e 30 3a 3a 49 6e 74			!..51:::	6.0::Int
0090	65 6c 28 52 29 20 45 74	68 65 72 6e 65 74 20 43			el(R) Et	hernet C
00a0	6f 6e 6e 65 63 74 69 6f	6e 20 49 32 31 37 2d 4c			onnectio	n I217-L
00b0	4d 2e 54 43 50 49 50 2e	31 a3 82 28 00 15 00 a3			M.TCPIP.	1..(....
00c0	82 29 00 15 00 a3 82	2a 00 15 13 43 48 45 4e 47			.).....*	...CHENG
00d0	4c 45 49 2d 50 43 5f 31	38 35 39 39 32 31 a3 82			LEI-PC_1	859921..
00e0	2b 00 04 01 a3 82 2c 00	12 01 c9 c3 80 a3 82 2d			+.....,	.....-
00f0	00 15 00 a1 00 00 00 d3	81 7f 00 00 a3 81 69 00			.....i.	.....i.
0100	15 15 53 75 62 73 63 72	69 70 74 69 6f 6e 43 6f			..Subscr	iptionCo
0110	6e 74 61 69 6e 65 72 a2	a2 00 00 00 00 72 01 00			ntainer.	.....r..
0120	00				.	.

Frame Boundary

Figure 5.1 First S7CommPlus Connection Request Packet

Figure 5.1 shows the first S7CommPlus Connection Packet. Byte 0x72 represents the start of the S7CommPlus packet. Then following the PDU Type byte, 0x01 means this packet is a connection packet. The Data Length field does not take into account the frame boundary. Following the Data Length is the type of this packet, 0x31 means this packet is a request packet. The Sub-type byte further specifies this packet. The sequence number is incremented for each message. Additional data is transferred in separate attribute blocks begin with the two bytes “0xa3, 0x8x”. Frame Boundary is used as the end of S7CommPlus packet.

	Type:Response	Object ID	
0030	20 00 70 5c 00 00 03 00 00 c5 02 f0 80 72 01 00		.p\.... ..r..
0040	b6 32 00 00 04 ca 00 00 00 01 36 00 02 87 0f 87		.2..... ..6.....
0050	1a a1 00 00 01 20 82 1f 00 00 a3 81 69 00 15 02		..... ..i...
0060	30 31 a3 82 2b 00 04 82 80 80 80 00 a3 82 2d 00		01..+... ..-.
0070	15 10 4f 4d 53 50 2e 52 45 4c 2e 37 30 37 30 2e		..OMSP.R EL.7070.
0080	31 34 a3 82 2f 10 02 14 1c 16 84 ed 01 be 4f fc		14../... ..0.
0090	2d dd 3c 34 d4 a1 83 aa 3b 61 56 03 a3 82 32 00		-.<4.... ;aV...2.
00a0	17 00 00 01 3a 82 75 00 04 87 40 82 3c 00 04 83		.....; ..@.<...
00b0	00 82 3d 00 04 84	04 84 80 c1	..=..... @.>.....
00c0	00 82 3f 00 15 1t	Value Array	..?...1; 6E57 214
00d0	2d 31 41 47 34 30 2d 30 58 42 30 20 3b 56 34 2e		-1AG40-0 XB0 ;V4.
00e0	31 82 40 00 15 05 32 3b 38 31 38 82 41 00 03 00		1.@...2; 818.A...
00f0	03 00 a2 00 00 00 00 72 01 00 00		.....r ...

Figure 5.2 First S7CommPlus Connection Response Packet

Figure 5.2 shows the first S7CommPlus Connection response packet. Type byte 0x32 means this packet is a response packet. The 17<sup>th</sup> and 18<sup>th</sup> bytes

presents the Object ID. The 17<sup>th</sup> byte is constant with the value of 0x87 and the 18<sup>th</sup> byte is a random byte ranges from 0x06 to 0x7f generated by the PLC. The 76<sup>th</sup> to 95<sup>th</sup> bytes presents the value array. This value array is a random array generated by the PLC.

		Session ID											
0030	fa 08 b2 e0 00 00 03 00	01 a2 02 f0 80 72 02 01	.....	.....	r..								
0040	93 31 00 00 05 42 00 00	00 02 00 00 03 8f 34 00	.1...B..	.....	4.								
0050	00 03 8f 02 02 8e 26 82	32 01 00 17 00 00 07 08	.....&.	2.....									
0060	8e 09 00 04 00 8e 0a 00	02 00 8e 0b 00 17 00 00	.....	.....	.....								
0070	07 21 8e 22 00 05 de d0	cd b0 c8 fc 90 f3 1a 8e	!.\"....	.....	.....								
0080	23 00 04 84 82 10 8e 24	00 04 00 00 8e 0c 00 17	#.....\$	.....	.....								
0090	00 00 07 21 8e 22 00 05	c1 e5 ba f1 82 a4 a1 dc	...!.\"..	.....	.....								
00a0	ec 8e 23 00 04 84 82 01	8e 24 00 04 00 00 8e 0d	..#.....	.\$.....	.....								
00b0	00 14 00 81 34 ad de e1	fe b4 00 00 00 01 00 00	....4...	.....	.....								
00c0	00 01 00 00 00 ec dc 10	49 10 d7 95 83 01 01 00	.....	I.....	.....								
00d0	00 00 00 00 00 1a 73 08	1f 09 6b 42 bd 10 01 00	.....s.	..kB....	.....								
00e0	00 00 00 00 00 01 99 ec	e4 62 a6 13 5c ac 6f d5	.....D...	.l.....	.....								
00f0	bf fa d9 85 44 bd b0 11	80 6c 95 91 9b e9 f8 ed	.....U5.>Z...	..W.BG..	.....								
0100	60 55 35 97 3e 5a f6 0c	fb 85 57 8b 42 47 f2 7f	.....n.H.	..a.>g/E	.....								
0110	d6 8b 1b e1	3e 67 2f 45	.....n.H.	..a.>g/E	.....								
0120	f9 53 59 7b e7 d0 21 70	20 40 01 41 08 3b bb 22	..SYu..?{	&F.O.;;"	.....								
0130	cb 10 c4 f0 42 48 1b f7	bc d5 a7 55 42 0a a0 5c	....BH..	...UB.\	.....								
0140	f7 ff 66 bf 3f 1d 4b 2d	52 b2 1a 87 4b 6e 2c 13	..f.?..K-	R...Kn,.	.....								
0150	4c 85 20 bf 55 9c 2d 7e	c8 01 ce 62 94 44 bd 8a	L. .U.-~	...b.D..	.....								
0160	9d e1 7a 6f 74 e9 95 66	82 00 02 00 17 00 00 01	..zot..f	.....	.....								
0170	3a 82 3b 00 04 83	00 00 00 00 00 00 00 00	..;	.....	<.....=.								
0180	04 84 80 c1 00 82	00 00 00 00 00 00 00 00	.....>.	.....?	.....								
0190	15 00 82 40 00 15 1a 31	3b 36 45 53 37 20 32 31	...@...1	;6ES7 21	.....								
01a0	34 2d 31 41 47 34 30 2d	30 58 42 30 3b 56 34 2e	4-1AG40-	0XB0;V4.	.....								
01b0	30 82 41 00 03 00 03 00	00 00 00 04 e8 89 69 00	0.A.....	.....i.	.....								
01c0	12 00 00 00 00 89 6a 00	13 00 89 6b 00 04 00 00	.....j.	...k....	.....								
01d0	00 00 00 00 72 02 00 00		.....r...	.....	.....								

Figure 5.3 Second S7CommPlus Connection Request Packet

Figure 5.3 shows the second S7CommPlus Connection packet. The 16<sup>th</sup> and 17<sup>th</sup>, 21<sup>th</sup> and 22<sup>th</sup> bytes is called Session ID. The 16<sup>th</sup> and 21<sup>th</sup> byte is constant with the value of 0x03. The 17<sup>th</sup> and 22<sup>th</sup> byte is calculated by TIA Portal with the following formula:

$$\text{Session ID} = \text{Object ID} + 0x80$$

In the second S7CommPlus Connection packet, there are two variable array, we called them Connection Encryption arrays. These two arrays are calculated by TIA Portal and we will talk this in the next chapter.

	Encryption length	Encryption Part	
0030	f6 6c b1 a3 00 00 03 00	00 65 02 f0 80 72 03 00	.l..... .e...r..
0040	56 20 68 ad 71 74 34 cb	34 89 19 4d ae 03 0a d2	V h.qt4. 4..M....
0050	e6 f5 7c 5e c3 07 a9 89	a5 5d 31 b0 c2 23 42 80	.. ^..... .]1..#B.
0060	b8 fc 31 00 00 04 f2 00	00 00 0c 00 00 03 8f 34	1 . .....4
0070	00 00 00 34 01 90 77 00	08 01 00 00 04 e8 89 69	.....i
0080	00 12 00 00 00 00 89 6a	00 13 00 89 6b 00 04 00	.....j .....k...
0090	00 00 03 00 00 00 00 72	03 00 00	.....r ...

Type:Request SubType:SetVariable

Figure 5.4 S7CommPlus Function Request Packet

Figure 5.4 shows a S7CommPlus Connection packet. From the 5<sup>th</sup> to 37<sup>th</sup> bytes, is the encryption array. The 5<sup>th</sup> byte represented the Encryption length and the rest represented the Encryption Part which is calculated by TIA Portal. This Encryption Part will be talked in the next chapter.

## 6. Fun with the Encryption

In chapter 5, we found two encryptions in the S7CommPlus protocol packets, one in the second connection packet and the other in function packets. Using reverse debugging techniques, we found these encryption is calculated by TIA Portal through a file named OMSp\_core\_managed.dll. In this .dll file, TIA Portal generated the encryption parts using private algorithms.

### 6.1 Connection packet encryption

The Connection Encryption arrays in the Second connection packet send by TIA Portal are two 16 bytes' arrays. These two arrays are both calculated by OMSp\_core\_managed.dll.

In the first connection response packet, we have already known a random value array generated by the PLC with the length of 20. Using Windbgv6.1.12, we can find this value array is the input parameter for the first encryption of connection packet encryption. Figure 6.1 shows a first connection response packet send by the PLC. The Value Array is "0xc2, 0x11, 0x70, 0xdf, 0xd4, 0x03, 0x6c, 0xf1, 0x52, 0x9f, 0x47, 0x90, 0x1c, 0xd0, 0xca, 0xac, 0x63, 0x7f, 0xd5". Figure6.2 shows a debugging procedure, we found that the eax+244 is "0x70, 0xdf, 0xd4, 0x03, 0x6c, 0xf1, 0x52, 0x9f, 0x47, 0x90, 0x1c, 0xd0, 0xca, 0xac, 0x63". Compare to the first connection response packet, we found these arrays has the same value in the Value Array's 3<sup>rd</sup> to 17<sup>th</sup> bytes.

0030	20 00 df 31 00 00 03 00 00 c5 02 f0 80 72 01 00	..1.... ..r..
0040	b6 32 00 00 04 ca 00 00 00 01 36 00 02 87 53 87	.2..... ..6...S.
0050	4a a1 00 00 01 20 82 1f 00 00 a3 81 69 00 15 02	J.... .. ..i...
0060	30 31 a3 82 2b 00 04 87 80 80 80 00 a3 82 2d 00	01..+... ..-..
0070	15 10 4f 4d 5:Value Array 5 4c 2e 37 30 37 30 2e	..OMSP.R EL.7070.
0080	31 34 a3 82 2f 10 02 14 c2 11 70 df d4 03 6c f1	14../... ..p...1.
0090	52 9f 99 47 90 1c d0 ca ac 63 7f d5 a3 82 32 00	R..G.... ..c...2.
00a0	17 00 00 01 3a 82 3b 00 04 83 40 82 3c 00 04 83	.....:;. ..@.<...
00b0	00 82 3d 00 04 84 80 c1 40 82 3e 00 04 84 80 c1	..=..... @.>.....
00c0	00 82 3f 00 15 1b 31 3b 36 45 53 37 20 32 31 34	..?...1; 6E57 214
00d0	2d 31 41 47 34 30 2d 30 58 42 30 20 3b 56 34 2e	-1AG40-0 X80 ;V4.
00e0	31 82 40 00 15 05 32 3b 38 31 38 82 41 00 03 00	1.@...2; 818.A...
00f0	03 00 a2 00 00 00 00 72 01 00 00	.....r ...

Figure 6.1 First S7CommPlus Connection Response Packet with Value Array

Figure 6.2 First encryption part in the second S7CommPlus Connection packet

With the value array as input, TIA Portal used a XOR (we call this Encryption1) to generated the first encryption part in the second S7CommPlus Connection packet:

Value Array + Encryption1 = Connection Encryption Part 1

Using the Connection Encryption Part 1 as input, TIA Portal continue its private algorithm which is more complex than a XOR(we call this Encryption2) to calculated the second encryption part in the second S7CommPlus Connection packet:

Connection Encryption Part 1 + Encryption2 = Connection Encrytion Part 2

Figure 6.3 shows the result of Connection Encryption Part 1 and Connection Encryption Part 2 from the Windbg and the second S7CommPlus Connection packet.

```

0030 fa 08 b2 e0 00 00 03 00 01 a2 02 f0 80 72 02 01 .....r..
0040 93 31 00 00 05 42 00 00 00 02 00 00 03 d3 34 00 .1...B.. .....4.
0050 00 03 d3 02 02 8e 26 82 32 01 00 17 00 00 07 08 .....&. 2.....
0060 8e 09 00 04 00 8e 0a 00 07 00 8e 0b 00 17 00 00 .....
0070 07 21 8e OMSp_core_managed+0x1dd056:
182cd056 83c40c add esp,0Ch ...
0080 23 00 04 0:024:x86> dd 1913703c
0090 00 00 07 1913703c ff25f6e4 fe88166b ff11d470 f5cbc059 First Encryption
1913704c 00000000 00000000 00000000 00000000 Calculated using Windbg
00a0 ec 8e 23 1913705c 00000000 00000000 00000000 00000000
00b0 00 14 00 1913706c 00000000 00000000 00000000 6b7a1837
00c0 00 01 00 1913707c 80000000 006f020f 0075006d 0069006e
00d0 00 00 00 1913708c 00610063 0069007a 006e006f 003a0065
00e0 00 00 00 1913709c 00540020 00610072 0073006e 007a0061
00f0 bf fa d9 0:024:x86>
0100 60 55 35
0110 d6 8b 1b e5 First Encryption Part 61 9b 3e 67 2f 45 ....n.H. ..a.>g/E
0120 f9 53 59 75 e/ ad 3f /b 2b 4b 8f 4f 08 3b bb 22 .SYu...?{ &F.O.;"
0130 cb e4 f6 25 ff 6b 16 88 fe 70 d4 11 ff 59 c0 cb ...%.k.. .p...Y..
0140 f5 ff 66 bf 3f 1d 4b 2d 52 b2 1a 87 4b 6e 2c 13 ..f.?.K- R...Kn,.
0150 4c 85 20 bf 55 9c 2d 7e c8 bd 85 36 f3 f5 a9 bc L. .U.-~ ...6....
0160 78 8d 94 24 c7 d2 c3 8b 1d 00 02 00 17 00 00 01 x..$. ....
0170 3a 82 3b 00 0:024:x86> dd 3e14e550
0180 04 84 80 c1 Second Encryption Part 1 00 82 3f 00 :;. ....<...=.
0190 15 00 02 40 00 45 1 3a 31 3c 45 03 03 00 00 00 .....?..
01a0 34 OMSp_core_managed+0x1dd615:
182cd615 83c40c add esp,0Ch ...
01b0 34 0:024:x86> dd 3e14e550
01c0 11 3e14e550 f33685bd 78bca9f5 c724948d 1d8bc3d2 Second Encryption
01d0 00 3e14e560 00000010 55b2085 c87e2d9c 00000000 Calculated using Windbg
3e14e570 00000000 63a70f70 3e14e590 182c79c8
3e14e580 3e14e5b0 19137064 3e14f814 00000000
3e14e590 3e14f818 182c73c0 3e14e5b0 1913705c
3e14e5a0 3e14f814 00000000 00000000 00000000
3e14e5b0 00000001 9d9a5ef8 f3e19f57 3ca5c89e
3e14e5c0 17df3b51 00000004 1eb3fd9a 01cfdc35
0:024:x86> h1

```

Figure 6.3 Encryption part in the second S7CommPlus Connection packet

## 6.2 Function packet encryption

Each function packet send by the TIA Portal has a 32 bytes' array called Encryption Part. This array is calculated by OMSp\_core\_managed.dll.

Using Windbg, we found an array with Session ID in it, is the input parameter of Function packet encryption. Except the Session ID, the other value is constant, as Figure 6.4 shows.

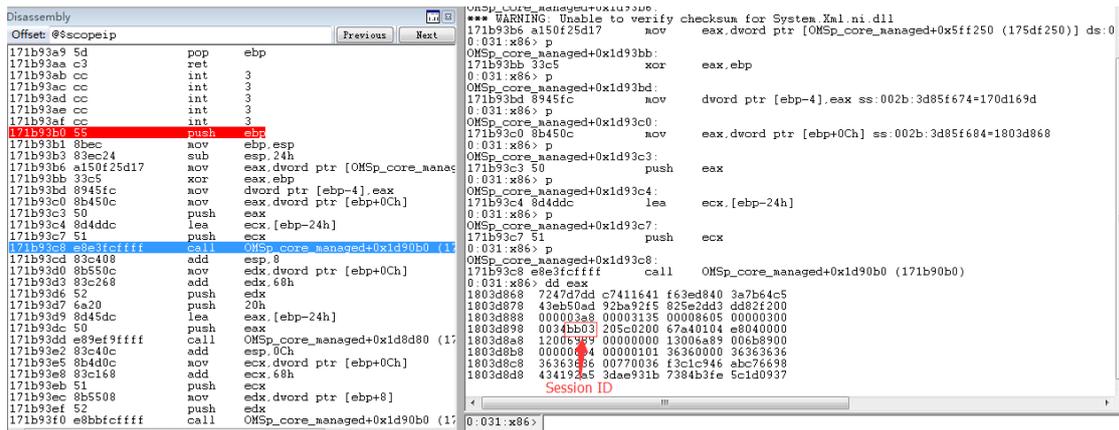


Figure 6.4 Input parameter for S7CommPlus Function packet encryption

TIA Portal used a complex algorithm (we call this Encryption3) to generated the Encryption Part of S7CommPlus Function packet:

Constant Array (with Session ID) + Encryption3 = Function Encryption Part

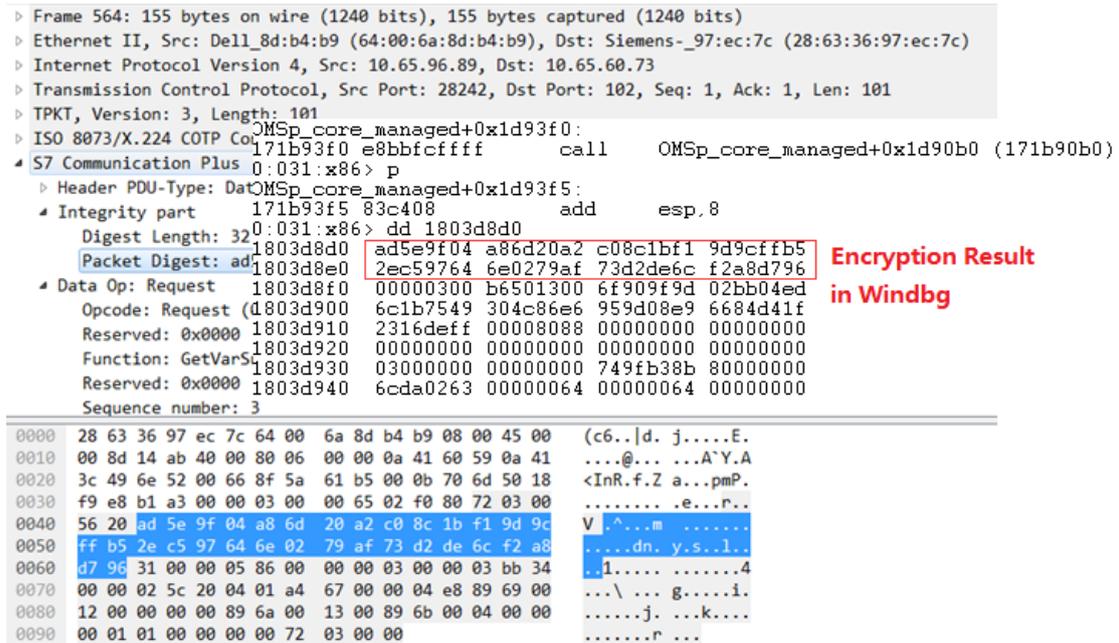


Figure 6.5 Function Encryption part in S7CommPlus Function packet

Figure 6.5 shows the result of Function Encryption Part from the Windbg and the S7CommPlus Function packet.

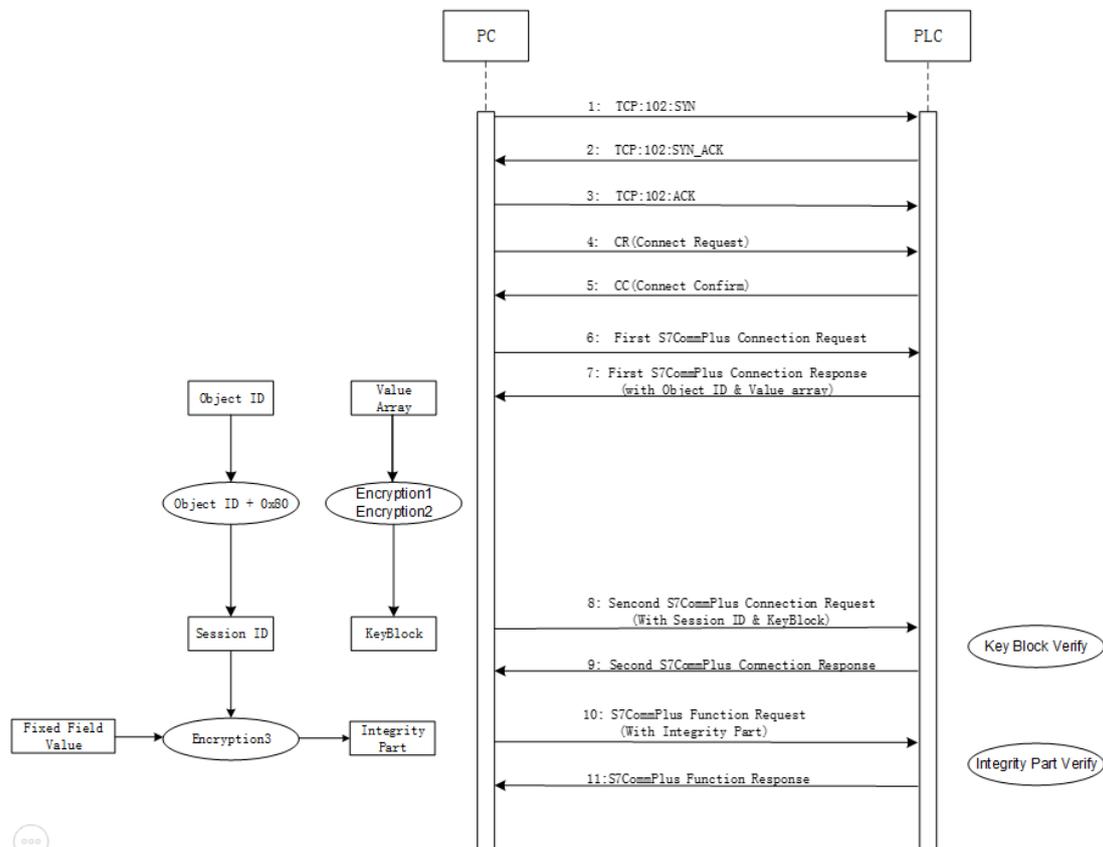
### 6.3 S7CommPlus Communication

Based on the research of S7CommPlus protocol encryptions above, we can get the S7CommPlus protocol communication sequence shown in figure 6.6. To establish a connection between the TIA Portal and PLC, the three-way handshake TCP connection has been used first. After the COTP connection

(CR & CC), TIA Portal will send an S7CommPlus Connection request. The first S7CommPlus Connection Response packet include an Object ID and a Value Array which is generated by the PLC. When receiving the Object ID and the Value Array, the Session ID and Key Block will be calculated by TIA Portal. Then, the second S7CommPlus Connection request packet including Session ID and Key Block will send to the PLC. If the Session ID and Key Block is correct, after the verify of PLC, a response packet will be send back to finish the S7CommPlus connection. Each S7CommPlus Function Request packet include an integrity part. The integrity part is calculated by TIA Portal using the Session ID and a fixed Field Value as its input parameter. When the PLC receives the S7CommPlus Function Request packet, the integrity part will be verified. The S7CommPlus Function Response packet could be send only when the verify was correct.

Figure 6.6 S7CommPlus protocol communication sequence with encryptions

## 7. Protections



### 7.1 Code level

Use code confusion techniques and anti-Debug techniques for the key DLL files like OMSp\_core\_managed.dll. Siemens didn't do any code protection to

the key DLL files. Therefore, it is very easy for attackers to debug and then find the encryption algorithm.

### **7.2 Design level**

In the new S7CommPlus protocol, some complex encryption algorithm has taken by Siemens to against the replay attack. However, the input parameter and the encryption algorithm are not variable. We recommended to use a private key as an input parameter for encryption algorithm in the communication between Siemens software and PLCs.

### **7.3 Protocol level**

Encrypt the whole packets instead of the key byte encryption.

## **8. Conclusion**

In this paper, we found that the secure Siemens protocol still has the risk of being exploited. Using reverse debugging techniques, the encryption algorithm of TIA Portal for anti-replay attack can be break. Then, using replay attack, the PLC can be controlled. According to our research, some protections were proposed in code level, design level and protocol level.

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