

TLS
Internet-Draft
Intended status: Standards Track
Expires: July 22, 2014

P. Wouters, Ed.
Red Hat
H. Tschofenig, Ed.

J. Gilmore

S. Weiler
SPARTA, Inc.
T. Kivinen
AuthenTec
January 18, 2014

**Using Raw Public Keys in Transport Layer Security (TLS) and Datagram
Transport Layer Security (DTLS)
draft-ietf-tls-oob-pubkey-11.txt**

Abstract

This document specifies a new certificate type and two TLS extensions for exchanging raw public keys in Transport Layer Security (TLS) and Datagram Transport Layer Security (DTLS). The new certificate type allows raw public keys to be used for authentication.

Status of This Memo

This Internet-Draft is submitted in full conformance with the provisions of [BCP 78](#) and [BCP 79](#).

Internet-Drafts are working documents of the Internet Engineering Task Force (IETF). Note that other groups may also distribute working documents as Internet-Drafts. The list of current Internet-Drafts is at <http://datatracker.ietf.org/drafts/current/>.

Internet-Drafts are draft documents valid for a maximum of six months and may be updated, replaced, or obsoleted by other documents at any time. It is inappropriate to use Internet-Drafts as reference material or to cite them other than as "work in progress."

This Internet-Draft will expire on July 22, 2014.

Copyright Notice

Copyright (c) 2014 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to [BCP 78](#) and the IETF Trust's Legal Provisions Relating to IETF Documents

(<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

Table of Contents

- [1. Introduction](#) [2](#)
- [2. Terminology](#) [4](#)
- [3. Structure of the Raw Public Key Extension](#) [4](#)
- [4. TLS Client and Server Handshake Behavior](#) [6](#)
 - [4.1. Client Hello](#) [7](#)
 - [4.2. Server Hello](#) [8](#)
 - [4.3. Client Authentication](#) [9](#)
- [5. Examples](#) [9](#)
 - [5.1. TLS Server uses Raw Public Key](#) [9](#)
 - [5.2. TLS Client and Server use Raw Public Keys](#) [10](#)
 - [5.3. Combined Usage of Raw Public Keys and X.509 Certificate](#) . [11](#)
- [6. Security Considerations](#) [12](#)
- [7. IANA Considerations](#) [13](#)
- [8. Acknowledgements](#) [13](#)
- [9. References](#) [14](#)
 - [9.1. Normative References](#) [14](#)
 - [9.2. Informative References](#) [15](#)
- [Appendix A. Example Encoding](#) [15](#)
- [Authors' Addresses](#) [17](#)

1. Introduction

Traditionally, TLS client and server public keys are obtained in PKIX containers in-band as part of the TLS handshake procedure and are validated using trust anchors based on a [PKIX] certification authority (CA). This method can add a complicated trust relationship that is difficult to validate. Examples of such complexity can be seen in [Defeating-SSL]. TLS is, however, also commonly used with self-signed certificates in smaller deployments where the self-signed certificates are distributed to all involved protocol end points out-of-band. This practice does, however, still requires the overhead of the certificate generation even though none of the information found in the certificate is actually used.

Alternative methods are available that allow a TLS client/server to obtain the TLS server/client public key:

- o The TLS client can obtain the TLS server public key from a DNSSEC secured resource records using DANE [[RFC6698](#)].
- o The TLS client or server public key is obtained from a [[PKIX](#)] certificate chain from an Lightweight Directory Access Protocol (LDAP) [[LDAP](#)] server or web page.
- o The TLS client and server public key is provisioned into the operating system firmware image, and updated via software updates. For example:

Some smart objects use the UDP-based Constrained Application Protocol (CoAP) [[I-D.ietf-core-coap](#)] to interact with a Web server to upload sensor data at a regular intervals, such as temperature readings. CoAP can utilize DTLS for securing the client-to-server communication. As part of the manufacturing process, the embedded device may be configured with the address and the public key of a dedicated CoAP server, as well as a public/private key pair for the client itself.

This document introduces the use of raw public keys in TLS/DTLS. With raw public keys, only a subset of the information found in typical certificates is utilized: namely, the SubjectPublicKeyInfo structure of a PKIX certificates that carries the parameters necessary to describe the public key. Other parameters found in PKIX certificates are omitted. By omitting various certificate-related structures, the resulting raw public key is kept fairly small in comparison to the original certificate, and the code to process the keys requires only a minimalistic ASN.1 parser, no code for certificate path validation, and other PKIX related processing tasks are also omitted. Note, however, the SubjectPublicKeyInfo structure is still in an ASN.1 format. To further reduce the size of the exchanged information this specification can be combined with the TLS Cached Info extension [[I-D.ietf-tls-cached-info](#)], which enables TLS peers to just exchange fingerprints of their public keys.

The mechanism defined herein only provides authentication when an out-of-band mechanism is also used to bind the public key to the entity presenting the key.

[Section 3](#) defines the structure of the two new TLS extensions "client_certificate_type" and "server_certificate_type", which can be used as part of an extended TLS handshake when raw public keys are to be used. [Section 4](#) defines the behavior of the TLS client and the TLS server. Example exchanges are described in [Section 5](#). [Section 6](#) describes security considerations with this approach. Finally, in [Section 7](#) this document also registers a new value to the IANA certificate types registry for the support of raw public keys.

2. Terminology

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC 2119](#) [[RFC2119](#)].

We use the terms 'TLS server' and 'server' as well as 'TLS client' and 'client' interchangeable.

3. Structure of the Raw Public Key Extension

This section defines the two TLS extensions 'client_certificate_type' and 'server_certificate_type', which can be used as part of an extended TLS handshake when raw public keys are used. [Section 4](#) defines the behavior of the TLS client and the TLS server using this extension.

This specification uses raw public keys whereby the already available encoding used in a PKIX certificate in the form of a SubjectPublicKeyInfo structure is reused. To carry the raw public key within the TLS handshake the Certificate payload is used as a container, as shown in Figure 1. The shown Certificate structure is an adaptation of its original form [[RFC5246](#)].

```
opaque ASN.1Cert<1..2^24-1>;

struct {
    select(certificate_type){

        // certificate type defined in this document.
        case RawPublicKey:
            opaque ASN.1_subjectPublicKeyInfo<1..2^24-1>;

        // X.509 certificate defined in RFC 5246
        case X.509:
            ASN.1Cert certificate_list<0..2^24-1>;

        // Additional certificate type based on TLS
        // Certificate Type Registry
    };
} Certificate;
```

Figure 1: Certificate Payload as a Container for the Raw Public Key.

The SubjectPublicKeyInfo structure is defined in Section 4.1 of [RFC 5280](#) [[PKIX](#)] and does not only contain the raw keys, such as the

public exponent and the modulus of an RSA public key, but also an algorithm identifier. The algorithm identifier can also include parameters. The SubjectPublicKeyInfo value in the Certificate payload MUST contain the DER encoding [X.690] of the SubjectPublicKeyInfo. The structure, as shown in Figure 2, therefore also contains length information as well. An example is provided in Appendix A.

```

SubjectPublicKeyInfo ::= SEQUENCE {
    algorithm          AlgorithmIdentifier,
    subjectPublicKey   BIT STRING }

AlgorithmIdentifier ::= SEQUENCE {
    algorithm          OBJECT IDENTIFIER,
    parameters        ANY DEFINED BY algorithm OPTIONAL }
    
```

Figure 2: SubjectPublicKeyInfo ASN.1 Structure.

The algorithm identifiers are Object Identifiers (OIDs). RFC 3279 [RFC3279] and [RFC5480], for example, define the following OIDs shown in Figure 3. Note that this list is not exhaustive and more OIDs may be defined in future RFCs. RFC 5480 also defines a number of OIDs.

Key Type	Document	OID
RSA	Section 2.3.1 of RFC 3279	1.2.840.113549.1.1
.....
Digital Signature Algorithm (DSA)	Section 2.3.2 of RFC 3279	1.2.840.10040.4.1
.....
Elliptic Curve Digital Signature Algorithm (ECDSA)	Section 2 of RFC 5480	1.2.840.10045.2.1
.....

Figure 3: Example Algorithm Object Identifiers.

The extension format for extended client and server hellos, which uses the "extension_data" field, is used to carry the ClientCertTypeExtension and the ServerCertTypeExtension structures. These two structures are shown in Figure 4. The CertificateType structure is an enum with values taken from the 'TLS Certificate Type' registry [TLS-Certificate-Types-Registry].


```
struct {
    select(ClientOrServerExtension) {
        case client:
            CertificateType client_certificate_types<1..2^8-1>;
        case server:
            CertificateType client_certificate_type;
    }
} ClientCertTypeExtension;

struct {
    select(ClientOrServerExtension) {
        case client:
            CertificateType server_certificate_types<1..2^8-1>;
        case server:
            CertificateType server_certificate_type;
    }
} ServerCertTypeExtension;
```

Figure 4: CertTypeExtension Structure.

4. TLS Client and Server Handshake Behavior

This specification extends the ClientHello and the ServerHello messages, according to the extension procedures defined in [[RFC5246](#)]. It does not extend or modify any other TLS message.

Note: No new cipher suites are required to use raw public keys. All existing cipher suites that support a key exchange method compatible with the defined extension can be used.

The high-level message exchange in Figure 5 shows the 'client_certificate_type' and 'server_certificate_type' extensions added to the client and server hello messages.



Figure 5: Basic Raw Public Key TLS Exchange.

4.1. Client Hello

In order to indicate the support of raw public keys, clients include the 'client_certificate_type' and/or the 'server_certificate_type' extensions in an extended client hello message. The hello extension mechanism is described in [Section 7.4.1.4](#) of TLS 1.2 [[RFC5246](#)].

The 'client_certificate_type' in the client hello indicates the certificate types the client is able to provide to the server, when requested using a certificate_request message.

The 'server_certificate_type' in the client hello indicates the types of certificates the client is able to process when provided by the server in a subsequent certificate payload.

The 'client_certificate_type' and 'server_certificate_type' sent in the client hello may carry a list of supported certificate types, sorted by client preference. It is a list in the case where the client supports multiple certificate types.

The TLS client MUST omit the 'client_certificate_type' extension in the client hello if it does not possess a raw public key/certificate that it can provide to the server when requested using a

certificate_request message or is not configured to use one with the given TLS server. The TLS client MUST omit the 'server_certificate_type' extension in the client hello if it is unable to process raw public keys or other certificate types introduced via this extension.

4.2. Server Hello

If the server receives a client hello that contains the 'client_certificate_type' extension and/or the 'server_certificate_type' extension then three outcomes are possible:

1. The server does not support the extension defined in this document. In this case the server returns the server hello without the extensions defined in this document.
2. The server supports the extension defined in this document but it does not have any certificate type in common with the client. Then, the server terminates the session with a fatal alert of type "unsupported_certificate".
3. The server supports the extensions defined in this document and has at least one certificate type in common with the client. In this case the processing rules described below are followed.

The 'client_certificate_type' in the client hello indicates the certificate types the client is able to provide to the server, when requested using a certificate_request message. If the TLS server wants to request a certificate from the client (via the certificate_request message) it MUST include the 'client_certificate_type' extension in the server hello. This 'client_certificate_type' in the server hello then indicates the type of certificates the client is requested to provide in a subsequent certificate payload. The value conveyed in the 'client_certificate_type' MUST be selected from one of the values provided in the 'client_certificate_type' extension sent in the client hello. The server MUST also include a certificate_request payload in the server hello message.

If the server does not send a certificate_request payload (for example, because client authentication happens at the application layer or no client authentication is required) or none of the certificates supported by the client (as indicated in the 'client_certificate_type' in the client hello) match the server-supported certificate types then the 'client_certificate_type' payload in the server hello MUST be omitted.

The 'server_certificate_type' in the client hello indicates the types of certificates the client is able to process when provided by the server in a subsequent certificate payload. If the client hello indicates support of raw public keys in the 'server_certificate_type' extension and the server chooses to use raw public keys then the TLS server MUST place the SubjectPublicKeyInfo structure into the Certificate payload. With the 'server_certificate_type' in the server hello the TLS server indicates the certificate type carried in the Certificate payload. This additional indication allows to avoid parsing ambiguities since the Certificate payload may contain either the X.509 certificate or a SubjectPublicKeyInfo structure. Note that only a single value is permitted in the 'server_certificate_type' extension when carried in the server hello.

4.3. Client Authentication

Authentication of the TLS client to the TLS server is supported only through authentication of the received client SubjectPublicKeyInfo via an out-of-band method.

5. Examples

Figure 6, Figure 7, and Figure 8 illustrate example exchanges. Note that TLS ciphersuites using a Diffie-Hellman exchange offering forward secrecy can be used with raw public keys although we do not show the information exchange at that level with the subsequent message flows.

5.1. TLS Server uses Raw Public Key

This section shows an example where the TLS client indicates its ability to receive and validate raw public keys from the server. In our example the client is quite restricted since it is unable to process other certificate types sent by the server. It also does not have credentials at the TLS layer it could send to the server and therefore omits the 'client_certificate_type' extension. Hence, the client only populates the 'server_certificate_type' extension with the raw public key type, as shown in [1].

When the TLS server receives the client hello it processes the extension. Since it has a raw public key it indicates in [2] that it had chosen to place the SubjectPublicKeyInfo structure into the Certificate payload [3].

The client uses this raw public key in the TLS handshake together with an out-of-band validation technique, such as DANE, to verify it.


```

client_hello,
server_certificate_type=(RawPublicKey) // [1]
    ->
    <- server_hello,
        server_certificate_type=(RawPublicKey), // [2]
        certificate, // [3]
        server_key_exchange,
        server_hello_done

client_key_exchange,
change_cipher_spec,
finished
    ->

    <- change_cipher_spec,
        finished

Application Data
    <-----> Application Data

```

Figure 6: Example with Raw Public Key provided by the TLS Server.

5.2. TLS Client and Server use Raw Public Keys

This section shows an example where the TLS client as well as the TLS server use raw public keys. This is one of the use case envisioned for smart object networking. The TLS client in this case is an embedded device that is configured with a raw public key for use with TLS and is also able to process raw public keys sent by the server. Therefore, it indicates these capabilities in [1]. As in the previously shown example the server fulfills the client's request, indicates this via the "RawPublicKey" value in the server_certificate_type payload [2], and provides a raw public key into the Certificate payload back to the client (see [3]). The TLS server, however, demands client authentication and therefore a certificate_request is added [4]. The certificate_type payload in [5] indicates that the TLS server accepts raw public keys. The TLS client, who has a raw public key pre-provisioned, returns it in the Certificate payload [6] to the server.


```

client_hello,
client_certificate_type=(RawPublicKey) // [1]
server_certificate_type=(RawPublicKey) // [1]
->
<- server_hello,
    server_certificate_type=(RawPublicKey)//[2]
    certificate, // [3]
    client_certificate_type=(RawPublicKey)//[5]
    certificate_request, // [4]
    server_key_exchange,
    server_hello_done

certificate, // [6]
client_key_exchange,
change_cipher_spec,
finished
->

<- change_cipher_spec,
    finished

Application Data <-----> Application Data

```

Figure 7: Example with Raw Public Key provided by the TLS Server and the Client.

5.3. Combined Usage of Raw Public Keys and X.509 Certificate

This section shows an example combining raw public keys and X.509 certificates. The client uses a raw public key for client authentication and the server provides an X.509 certificate. This exchange starts with the client indicating its ability to process X.509 certificates and raw public keys, if provided by the server. Additionally, the client indicates that it has a raw public key for client-side authentication (see [1]). The server provides the X.509 certificate in [3] with the indication present in [2]. For client authentication the server indicates in [4] that it selected the raw public key format and requests a certificate from the client in [5]. The TLS client provides a raw public key in [6] after receiving and processing the TLS server hello message.


```

client_hello,
server_certificate_type=(X.509, RawPublicKey)
client_certificate_type=(RawPublicKey) // [1]
    ->
    <-  server_hello,
        server_certificate_type=(X.509)//[2]
        certificate, // [3]
        client_certificate_type=(RawPublicKey)//[4]
        certificate_request, // [5]
        server_key_exchange,
        server_hello_done

certificate, // [6]
client_key_exchange,
change_cipher_spec,
finished
    ->

    <-  change_cipher_spec,
        finished

Application Data    <----->    Application Data

```

Figure 8: Hybrid Certificate Example.

6. Security Considerations

The transmission of raw public keys, as described in this document, provides benefits by lowering the over-the-air transmission overhead since raw public keys are naturally smaller than an entire certificate. There are also advantages from a code size point of view for parsing and processing these keys. The cryptographic procedures for associating the public key with the possession of a private key also follows standard procedures.

The main security challenge is, however, how to associate the public key with a specific entity. Without a secure binding between identifier and key, the protocol will be vulnerable to man-in-the-middle attacks. This document assumes that such binding can be made out-of-band and we list a few examples in [Section 1](#). DANE [[RFC6698](#)] offers one such approach. In order to address these vulnerabilities, specifications that make use of the extension need to specify how the identifier and public key are bound. In addition to ensuring the binding is done out-of-band an implementation also needs to check the status of that binding.

If public keys are obtained using DANE, these public keys are authenticated via DNSSEC. Pre-configured keys is another out-of-band method for authenticating raw public keys. While pre-configured keys

are not suitable for a generic Web-based e-commerce environment such keys are a reasonable approach for many smart object deployments where there is a close relationship between the software running on the device and the server-side communication endpoint. Regardless of the chosen mechanism for out-of-band public key validation an assessment of the most suitable approach has to be made prior to the start of a deployment to ensure the security of the system.

An attacker might try to influence the handshake exchange to make the parties select different certificate types than they would normally choose.

For this attack, an attacker must actively change one or more handshake messages. If this occurs, the client and server will compute different values for the handshake message hashes. As a result, the parties will not accept each others' Finished messages. Without the master_secret, the attacker cannot repair the Finished messages, so the attack will be discovered.

7. IANA Considerations

IANA is asked to register a new value in the "TLS Certificate Types" registry of Transport Layer Security (TLS) Extensions [[TLS-Certificate-Types-Registry](#)], as follows:

Value: 2
Description: Raw Public Key
Reference: [[THIS RFC]]

This document asks IANA to allocate two new TLS extensions, "client_certificate_type" and "server_certificate_type", from the TLS ExtensionType registry defined in [[RFC5246](#)]. These extensions are used in both the client hello message and the server hello message. The new extension type is used for certificate type negotiation. The values carried in these extensions are taken from the TLS Certificate Types registry [[TLS-Certificate-Types-Registry](#)].

8. Acknowledgements

The feedback from the TLS working group meeting at IETF#81 has substantially shaped the document and we would like to thank the meeting participants for their input. The support for hashes of public keys has been moved to [[I-D.ietf-tls-cached-info](#)] after the discussions at the IETF#82 meeting.

We would like to thank the following persons for their review comments: Martin Rex, Bill Frantz, Zach Shelby, Carsten Bormann, Cullen Jennings, Rene Struik, Alper Yegin, Jim Schaad, Barry Leiba, Paul Hoffman, Robert Cragie, Nikos Mavrogiannopoulos, Phil Hunt, John Bradley, Klaus Hartke, Stefan Jucker, Kovatsch Matthias, Daniel Kahn Gillmor, Peter Sylvester, Hauke Mehrtens, Alexey Melnikov, Stephen Farrell, Richard Barnes, and James Manger. Nikos Mavrogiannopoulos contributed the design for re-using the certificate type registry. Barry Leiba contributed guidance for the IANA consideration text. Stefan Jucker, Kovatsch Matthias, and Klaus Hartke provided implementation feedback regarding the SubjectPublicKeyInfo structure.

Christer Holmberg provided the General Area (Gen-Art) review, Yaron Sheffer provided the Security Directorate (SecDir) review, Bert Greevenbosch provided the Applications Area Directorate review, and Linda Dunbar provided the Operations Directorate review.

We would like to thank our TLS working group chairs, Eric Rescorla and Joe Salowey, for their guidance and support. Finally, we would like to thank Sean Turner, who is the responsible security area director for this work for his review comments and suggestions.

9. References

9.1. Normative References

- [PKIX] Cooper, D., Santesson, S., Farrell, S., Boeyen, S., Housley, R., and W. Polk, "Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 5280](#), May 2008.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", [BCP 14](#), [RFC 2119](#), March 1997.
- [RFC3279] Bassham, L., Polk, W., and R. Housley, "Algorithms and Identifiers for the Internet X.509 Public Key Infrastructure Certificate and Certificate Revocation List (CRL) Profile", [RFC 3279](#), April 2002.
- [RFC5246] Dierks, T. and E. Rescorla, "The Transport Layer Security (TLS) Protocol Version 1.2", [RFC 5246](#), August 2008.
- [RFC5480] Turner, S., Brown, D., Yiu, K., Housley, R., and T. Polk, "Elliptic Curve Cryptography Subject Public Key Information", [RFC 5480](#), March 2009.
- [TLS-Certificate-Types-Registry]

"TLS Certificate Types Registry", February 2013,
<<http://www.iana.org/assignments/tls-extensiontype-values#tls-extensiontype-values-2>>.

[X.690] "Information technology - ASN.1 encoding rules: > Specification of Basic Encoding Rules (BER), Canonical > Encoding Rules (CER) and Distinguished Encoding Rules > (DER).", [RFC 5280](#), 2002.

9.2. Informative References

[ASN.1-Dump]

Gutmann, P., "ASN.1 Object Dump Program", February 2013,
<<http://www.cs.auckland.ac.nz/~pgut001/>>.

[Defeating-SSL]

Marlinspike, M., "New Tricks for Defeating SSL in Practice", February 2009, <<http://www.blackhat.com/presentations/bh-dc-09/Marlinspike/BlackHat-DC-09-Marlinspike-Defeating-SSL.pdf>>.

[I-D.ietf-core-coap]

Shelby, Z., Hartke, K., and C. Bormann, "Constrained Application Protocol (CoAP)", [draft-ietf-core-coap-18](#) (work in progress), June 2013.

[I-D.ietf-tls-cached-info]

Santesson, S. and H. Tschofenig, "Transport Layer Security (TLS) Cached Information Extension", [draft-ietf-tls-cached-info-15](#) (work in progress), October 2013.

[LDAP]

Sermersheim, J., "Lightweight Directory Access Protocol (LDAP): The Protocol", [RFC 4511](#), June 2006.

[RFC6698]

Hoffman, P. and J. Schlyter, "The DNS-Based Authentication of Named Entities (DANE) Transport Layer Security (TLS) Protocol: TLSA", [RFC 6698](#), August 2012.

Appendix A. Example Encoding

For example, the hex sequence shown in Figure 9 describes a SubjectPublicKeyInfo structure inside the certificate payload.

	0	1	2	3	4	5	6	7	8	9
1	0x30	0x81	0x9f	0x30	0x0d	0x06	0x09	0x2a	0x86	0x48
2	0x86	0xf7	0x0d	0x01	0x01	0x01	0x05	0x00	0x03	0x81
3	0x8d	0x00	0x30	0x81	0x89	0x02	0x81	0x81	0x00	0xcd
4	0xfd	0x89	0x48	0xbe	0x36	0xb9	0x95	0x76	0xd4	0x13
5	0x30	0x0e	0xbf	0xb2	0xed	0x67	0x0a	0xc0	0x16	0x3f
6	0x51	0x09	0x9d	0x29	0x2f	0xb2	0x6d	0x3f	0x3e	0x6c
7	0x2f	0x90	0x80	0xa1	0x71	0xdf	0xbe	0x38	0xc5	0xcb
8	0xa9	0x9a	0x40	0x14	0x90	0x0a	0xf9	0xb7	0x07	0x0b
9	0xe1	0xda	0xe7	0x09	0xbf	0x0d	0x57	0x41	0x86	0x60
10	0xa1	0xc1	0x27	0x91	0x5b	0x0a	0x98	0x46	0x1b	0xf6
11	0xa2	0x84	0xf8	0x65	0xc7	0xce	0x2d	0x96	0x17	0xaa
12	0x91	0xf8	0x61	0x04	0x50	0x70	0xeb	0xb4	0x43	0xb7
13	0xdc	0x9a	0xcc	0x31	0x01	0x14	0xd4	0xcd	0xcc	0xc2
14	0x37	0x6d	0x69	0x82	0xd6	0xc6	0xc4	0xbe	0xf2	0x34
15	0xa5	0xc9	0xa6	0x19	0x53	0x32	0x7a	0x86	0x0e	0x91
16	0x82	0x0f	0xa1	0x42	0x54	0xaa	0x01	0x02	0x03	0x01
17	0x00	0x01								

Figure 9: Example SubjectPublicKeyInfo Structure Byte Sequence.

The decoded byte-sequence shown in Figure 9 (for example using Peter's ASN.1 decoder [[ASN.1-Dump](#)]) illustrates the structure, as shown in Figure 10.

Offset	Length	Description
0	3+159:	SEQUENCE {
3	2+13:	SEQUENCE {
5	2+9:	OBJECT IDENTIFIER Value (1 2 840 113549 1 1 1)
	:	PKCS #1, rsaEncryption
16	2+0:	NULL
	:	}
18	3+141:	BIT STRING, encapsulates {
22	3+137:	SEQUENCE {
25	3+129:	INTEGER Value (1024 bit)
157	2+3:	INTEGER Value (65537)
	:	}
	:	}
	:	}

Figure 10: Decoding of Example SubjectPublicKeyInfo Structure.

Authors' Addresses

Paul Wouters (editor)
Red Hat

Email: paul@nohats.ca

Hannes Tschofenig (editor)
Cambridge CBI 9NJ
UK

Email: Hannes.Tschofenig@gmx.net
URI: <http://www.tschofenig.priv.at>

John Gilmore
PO Box 170608
San Francisco, California 94117
USA

Phone: +1 415 221 6524
Email: gnu@toad.com
URI: <https://www.toad.com/>

Samuel Weiler
SPARTA, Inc.
7110 Samuel Morse Drive
Columbia, Maryland 21046
US

Email: weiler@tislabs.com

Tero Kivinen
AuthenTec
Eerikinkatu 28
HELSINKI FI-00180
FI

Email: kivinen@iki.fi

