Today in Cryptography (5830)

Digital signatures
Schnorr signatures, DSA
PKI

Katz-Lindell Chapter 12
Various PKI sources available on web (some references within slides)

Client

TLS handshake for Diffie-Hellman Key Exchange

Server

Pick random Nc

ClientHello, MaxVer, Nc, Ciphers/CompMethods →

Pick random Ns

← ServerHello, Ver, Ns, SessionID, Cipher/CompMethod

Pick random x

$X = g^x$

← CERT = (pk_s , signature over it)

← p , g , X , σ = Sign(sk_s, p || g || X)

Check CERT using CA public verification key

Check σ

Pick random y

$Y = g^y$

Y →

PMS = g^{xy}

PMS = g^{xy}

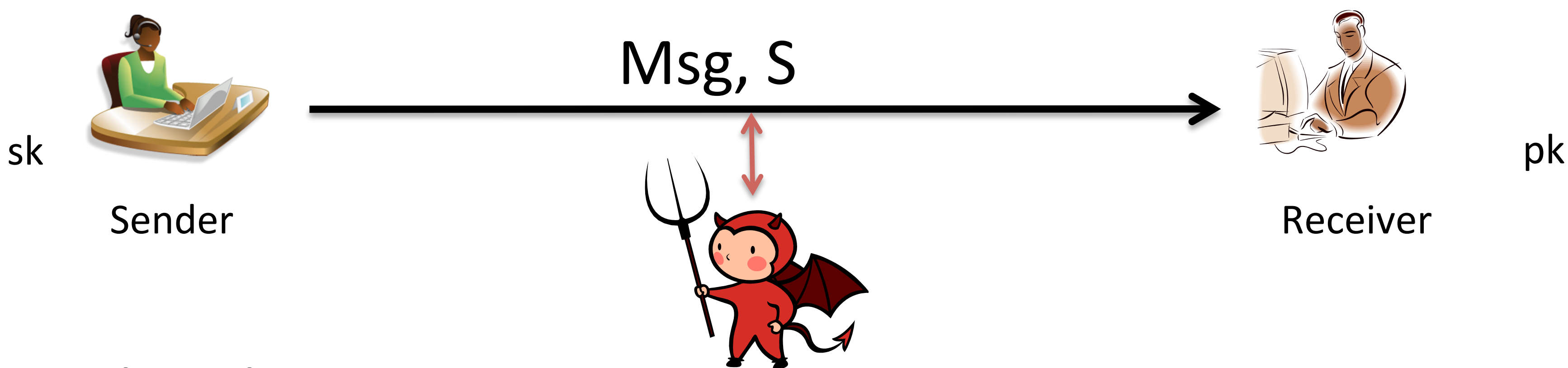
ChangeCipherSpec,
{ Finished, PRF(MS, "Client finished" || H(transcript)) } →

Bracket notation means contents encrypted

ChangeCipherSpec,
{ Finished, PRF(MS, "Server finished" || H(transcript')) } ←

MS <- PRF(PMS, "master secret" || Nc || Ns)

Digital signatures



<u>Two algorithms:</u>

(1) Key generation outputs (pk,sk)
(2) Sign (sk,Msg) outputs a signature S (may be randomized)
(3) Verify(pk,Msg,S) outputs 0/1 (invalid / valid)

Correctness: Verify(pk,Msg,Sign(sk,Msg)) = 1 always

Security: No computationally efficient attacker can forge signatures for a new message even when attacker gets

$$(\text{Msg}_1, S_1), (\text{Msg}_2, S_2), \ldots, (\text{Msg}_q, S_q)$$

for messages of his choosing and reasonably large q.

Underlying groups

Let p be a large prime number
Let q be a prime such that q divides p-1
Example: p = 2q + 1 (so-called safe prime p)

Fix the group G = $\mathbf{Z}_p^*$ = {1,2,3,…, p-1}
Let g be generator of sub-group of order q:

$$\{ g^0, g^1, g^2, \dots , g^{q-1} \} \text{ subset of } G$$

How to pick g?
$g = h^{(p-1)/q} \bmod p$ for some h and check $g \neq 1 \bmod p$
If so, try repeat with another h. Usually use h = 2

Schnorr signatures

p,q,g specified

sk = x chosen randomly from $\mathbf{Z}_q$ pk = X = g^x

<u>Sign(x, M)</u>

r <-\$ $\mathbf{Z}_q$

$R = g^r$; $c = H(M \| R)$; $z = r + cx \mod q$

Return (R,z)

<u>Ver(X, M, (R,z))</u>

$c = H(M \| R)$

If $g^z = RX^c$ then Return 1

Return 0

Correctness? $g^z = g^{r+cx} = g^r g^{xc} = RX^c$

Security of Schnorr signatures

Assume an adversary that can output forgery (M,(R,z))
Then to be valid:

$$g^z = RX^c \quad \text{implies} \quad z = r + cx$$

for $c = H(M \,||\, R)$.
Assume c is random (H is random oracle)

Imagine we can run adversary twice but force forgery to be on same R, different c .
In second execution, getting (M',(R,z'))

Then success second time around gives:

$$g^{z'} = RX^{c'} \quad \text{implies} \quad z' = r + c'x$$

But now can compute $z - z' / (c - c') = x$ the secret key

Fragility of Schnorr

Repeat randomness failure:

Sign two messages $M \neq M'$ and reuse random

Sign(x,M) -> (R,z)

Sign(x,M') -> (R,z')

Then: $x = (z - z') / (H(M||R) - H(M'||R))$

If r is predictable, can recover secret as well

Can improve security by "hedging":

choose $r = H(x || M || \text{randomness})$

DSA (digital signature algorithm)

p,q,g specified

sk = x chosen randomly from $\mathbf{Z}_q$ pk = X = g^x

<u>Sign(x, M)</u>

r <-$ $\mathbf{Z}_q$; R = $(g^r \bmod p) \bmod q$

z = $r^{-1}(H(M) + x R) \bmod q$

Return (R,z)

<u>Ver(X, M, (R,z))</u>

w = $z^{-1} \bmod q$

u1 = $H(m) * w \bmod q$

u2 = $R*w \bmod q$

If R = $(g^{u1} X^{u2} \bmod p) \bmod q$

then Return 1

Else Return 0

Correctness?

$$g^{u1} X^{u2} = g^{H(M)\, w}\, g^{x\, R\, w} = g^{(H(M)+xR)\, w}$$

$$= g^{(H(M)+xR)\, (H(M)+xR)^{-1}\, r} = g^r$$

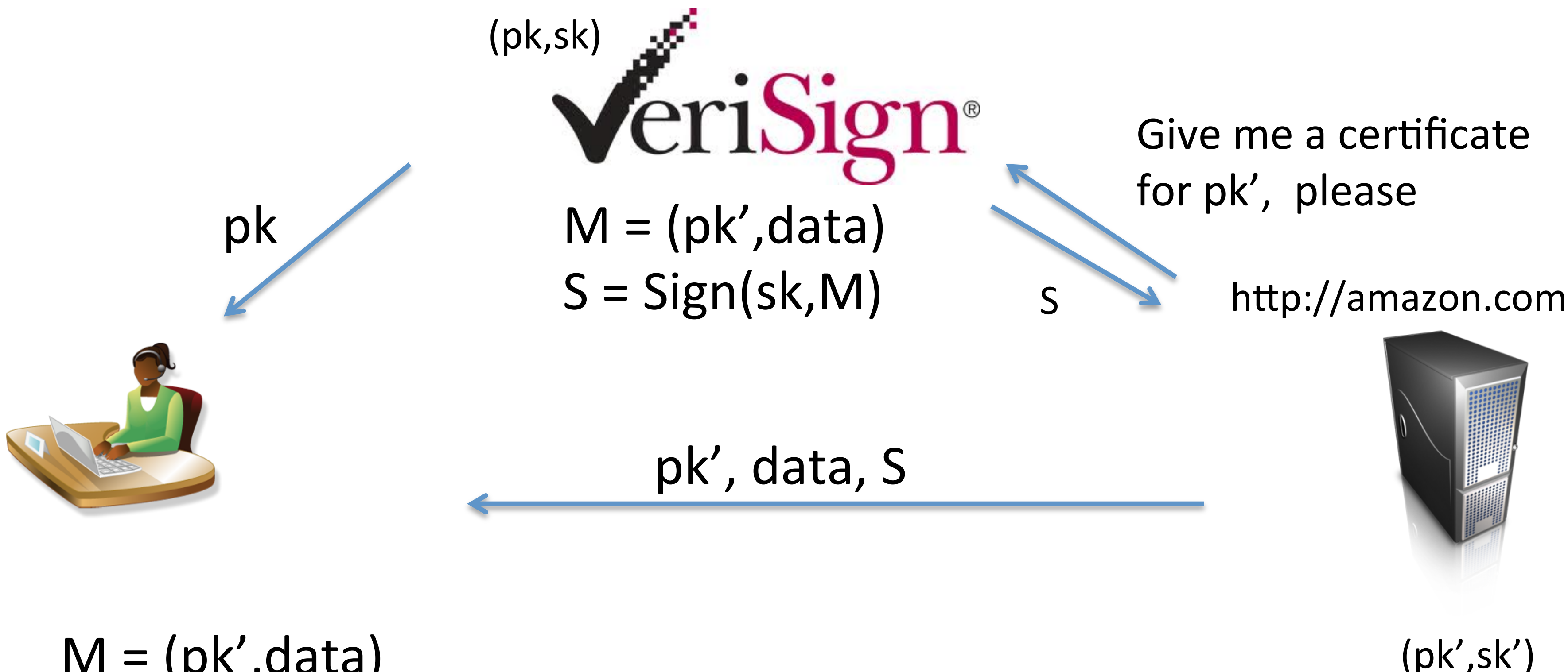
Hackers Describe PS3 Security As Epic Fail, Gain Unrestricted Access

BY MIKE BENDEL DECEMBER 29, 2010 @ 11:19 AM

Digital signature schemes

	Problems?	Proofs?	Uses
RSA PKCS#1 v1.5	Bleichanbacher attacks		TLS, Certificates, XML
RSA PSS (PKCS#1 v2)		Security reduces to hardness of inverting RSA	
Schnorr	Randomness fragility	Security reduces to discrete log problem	
DSA	Randomness fragility	No security reduction	Bitcoin (ECC version), TLS, SSH, elsewhere

Certificate Authorities and Public-key Infrastructure

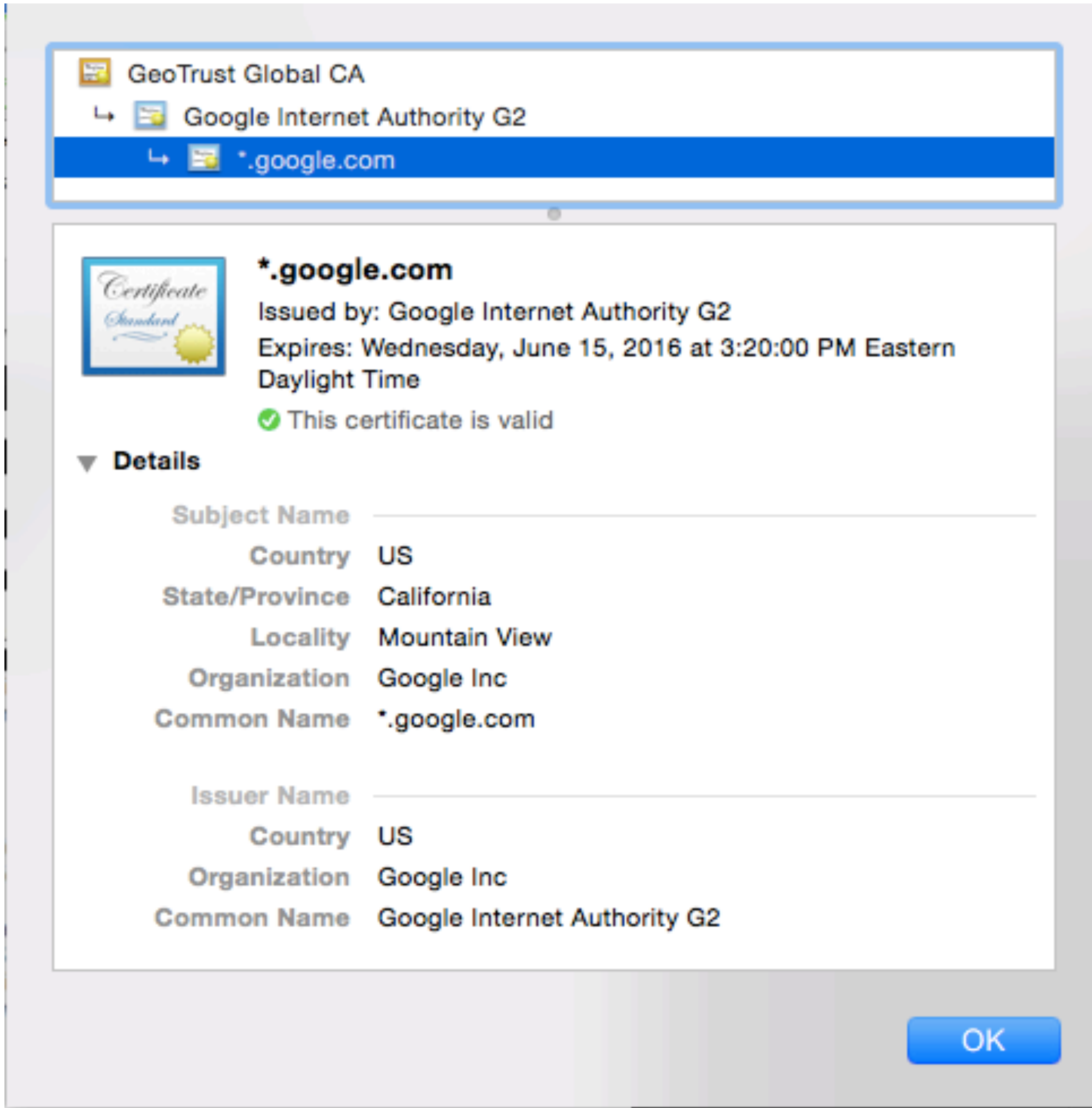


M = (pk',data)
If Ver(pk,M,S) then
trust pk'

This prevents man-in-the-middle (MitM) attacks

```
Certificate:
   Data:
       Version: 1 (0x0)
       Serial Number: 7829 (0x1e95)
       Signature Algorithm: md5WithRSAEncryption
       Issuer: C=ZA, ST=Western Cape, L=Cape Town, O=Thawte Consulting cc,
               OU=Certification Services Division,
               CN=Thawte Server CA/emailAddress=server-certs@thawte.com
       Validity
           Not Before: Jul  9 16:04:02 1998 GMT
           Not After : Jul  9 16:04:02 1999 GMT
       Subject: C=US, ST=Maryland, L=Pasadena, O=Brent Baccala,
                OU=FreeSoft, CN=www.freesoft.org/emailAddress=baccala@freesoft.org
       Subject Public Key Info:
           Public Key Algorithm: rsaEncryption
           RSA Public Key: (1024 bit)
               Modulus (1024 bit):
                   00:b4:31:98:0a:c4:bc:62:c1:88:aa:dc:b0:c8:bb:
                   33:35:19:d5:0c:64:b9:3d:41:b2:96:fc:f3:31:e1:
                   66:36:d0:8e:56:12:44:ba:75:eb:e8:1c:9c:5b:66:
                   70:33:52:14:c9:ec:4f:91:51:70:39:de:53:85:17:
                   16:94:6e:ee:f4:d5:6f:d5:ca:b3:47:5e:1b:0c:7b:
                   c5:cc:2b:6b:c1:90:c3:16:31:0d:bf:7a:c7:47:77:
                   8f:a0:21:c7:4c:d0:16:65:00:c1:0f:d7:b8:80:e3:
                   d2:75:6b:c1:ea:9e:5c:5c:ea:7d:c1:a1:10:bc:b8:
                   e8:35:1c:9e:27:52:7e:41:8f
               Exponent: 65537 (0x10001)
   Signature Algorithm: md5WithRSAEncryption
       93:5f:8f:5f:c5:af:bf:0a:ab:a5:6d:fb:24:5f:b6:59:5d:9d:
       92:2e:4a:1b:8b:ac:7d:99:17:5d:cd:19:f6:ad:ef:63:2f:92:
       ab:2f:4b:cf:0a:13:90:ee:2c:0e:43:03:be:f6:ea:8e:9c:67:
       d0:a2:40:03:f7:ef:6a:15:09:79:a9:46:ed:b7:16:1b:41:72:
       0d:19:aa:ad:dd:9a:df:ab:97:50:65:f5:5e:85:a6:ef:19:d1:
       5a:de:9d:ea:63:cd:cb:cc:6d:5d:01:85:b5:6d:c8:f3:d9:f7:
       8f:0e:fc:ba:1f:34:e9:96:6e:6c:cf:f2:ef:9b:bf:de:b5:22:
       68:9f
```

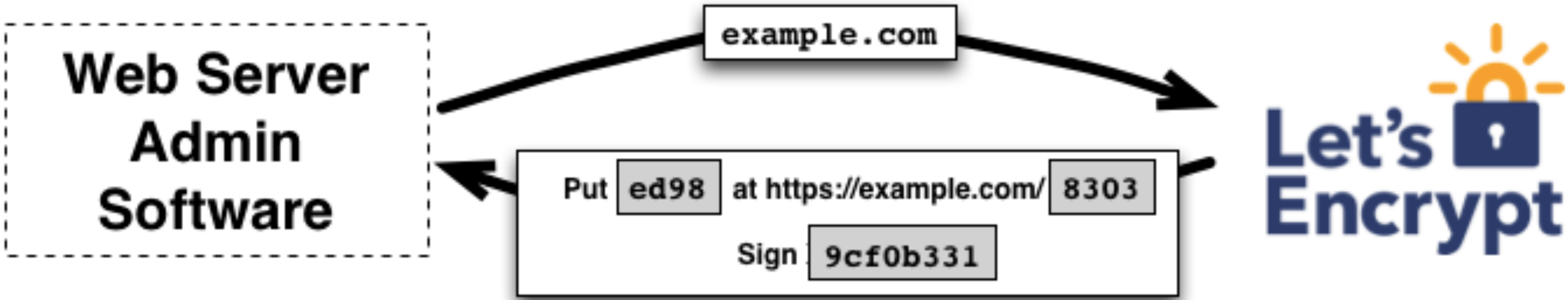
Certificate chains



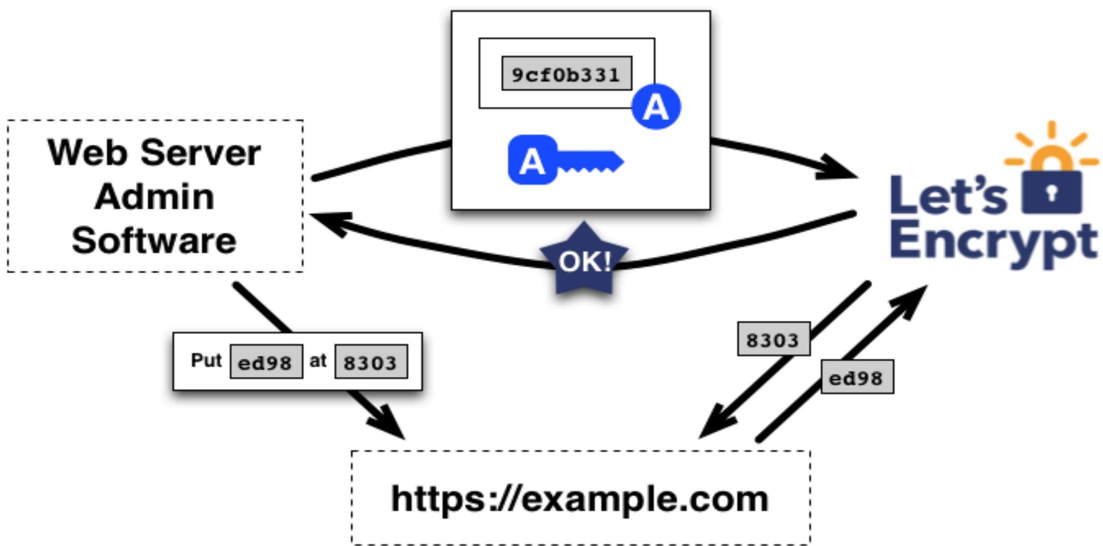
Identity checks?

- CA's must check that requestor of cert is who they say they are
- Domain validated
  - Prove ownership of domain
- Extended validation
  - Establish legal identity of requestor
  - Physical presence of website owner
  - Confirm ownership of domain
  - Etc.

Free CAs



Web Server Admin Software
example.com
Let's Encrypt
Put ed98 at https://example.com/ 8303
Sign 9cf0b331



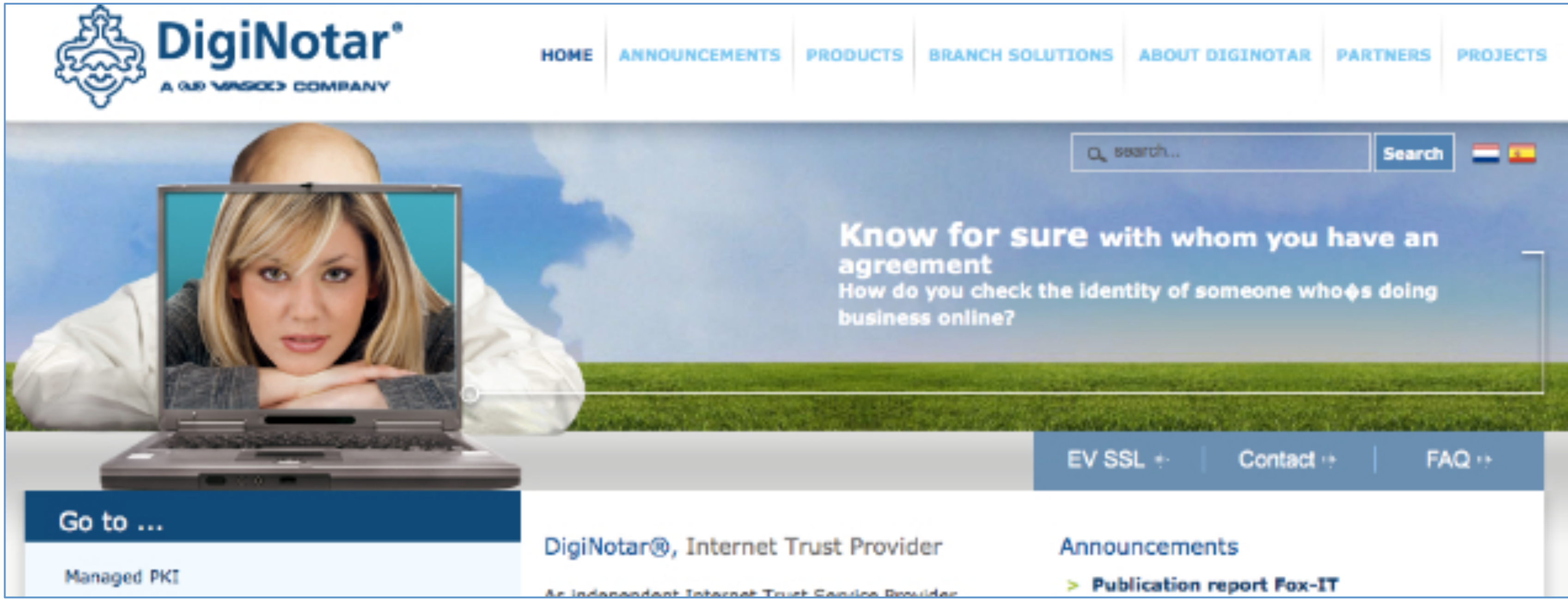
9cf0b331
A
A
Web Server Admin Software
Let's Encrypt
OK!
Put ed98 at 8303
8303
ed98
https://example.com

Revocation

- Certificates must often be revoked
  - Short expirations
  - CRLs (Certificate revocation lists)
  - OCSP (online certificate status protocol)
    - Client queries CA to check on validity of cert
      - privacy concerns, performance / scalability issues
    - Stapling: server periodically gets fresh, time-stamped OCSP signature from CA. Sends to clients

The Web PKI Ecosystem

- http://conferences.sigcomm.org/imc/2013/papers/imc257-durumericAemb.pdf
- ~1800 CAs that can sign *any* domain controlled by 683 organizations



Today, Microsoft issued a Security Advisory warning that fraudulent digital certificates were issued by the Comodo Certificate Authority. This could allow malicious spoofing of high profile websites, including Google, Yahoo! and Windows Live.

https://nakedsecurity.sophos.com/2011/03/24/fraudulent-certificates-issued-by-comodo-is-it-time-to-rethink-who-we-trust/

https://technet.microsoft.com/library/security/2524375

Certificate/public-key pinning

- Client knows what cert/pk to expect, rejects otherwise
  - Pre-install some keys
  - HPKP (HTTP Public Key Pinning)
    - HTTP header that allows servers to set a hash of public key they will use

```
Public-Key-Pins:
    pin-sha256="d6qzRu9zOECb90Uez27xWltNsj0e1Md7GkYYkVoZWmM=";
    pin-sha256="LPJNul+wow4m6DsqxbninhsWHlwfp0JecwQzYpOLmCQ=";
    max-age=259200
```

https://developers.google.com/web/updates/2015/09/HPKP-reporting-with-chrome-46?hl=en

Certificate transparency

- Force CAs to log the certificates they sign in a public tamper-evident register
  - Experimental IETF standard
- Google has been pushing this
  - Chrome requires it for "extra validation" certs
  - DigiCert has implemented

Summary

- Web PKI relies on various trust assumptions
  - Can be undermined in many ways

- Digital signature schemes power PKI and verifying identities:
  - unforgeability under chosen message attack
  - RSA based schemes PKCS#1 1.5 and 2.0
  - Schnorr, DSA based on discrete log problem