Authentication protocols

Identity attributes

▷ Set of attributes for setting apart individuals

- Name
- Numerical identifiers
  - Fixed for life
  - Variable with context
- Address
- Photo
- Identity of relatives
  - Usually parents
- …

Authentication: Definition

- Proof that an entity has a claimed identity attribute

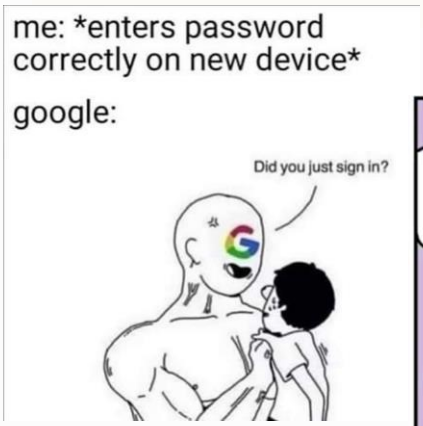
—Hi, I'm Joe
—Prove it!
—Here are my Joe's credentials
—Credentials accepted/not accepted

—Hi, I'm over 18
—Prove it!
—Here is the proof
—Proof accepted/not accepted

Authentication: proof types

- Something we know
  - A secret memorized (or written down…) by Joe
- Something we have
  - An object/token solely held by Joe
- Something we are
  - Joe's Biometry
- Multi-factor authentication
  - Join or consecutive use of different proof types

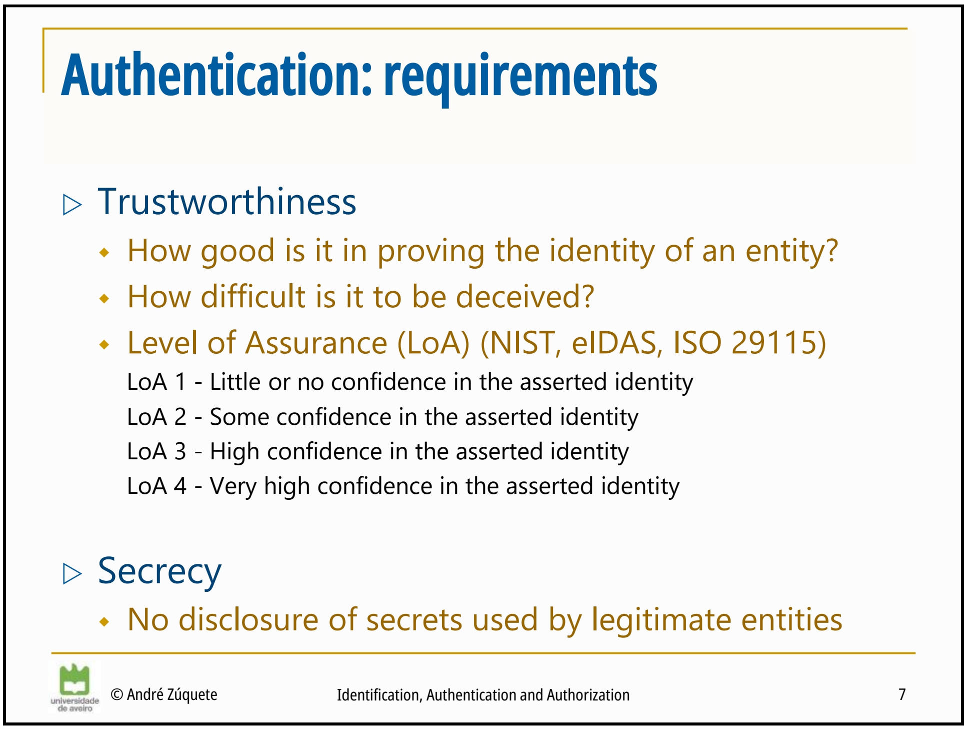
Multi-factor verification jokes



AT HOME WITH THE CISOs
DAD, CAN BEN SLEEP OVER?
THIS REQUEST REQUIRES TWO-FACTOR AUTHORIZATION. ASK YOUR MOTHER.
ACCESS DENIED.

Authentication: goals

- ▷ Authenticate interactors
  - People, services, servers, hosts, networks, etc.
- ▷ Enable the enforcement of authorization policies and mechanisms
  - Authorization ⇒ authentication
- ▷ Facilitate the exploitation of other security-related protocols
  - e.g. key distribution for secure communication



Authentication: requirements

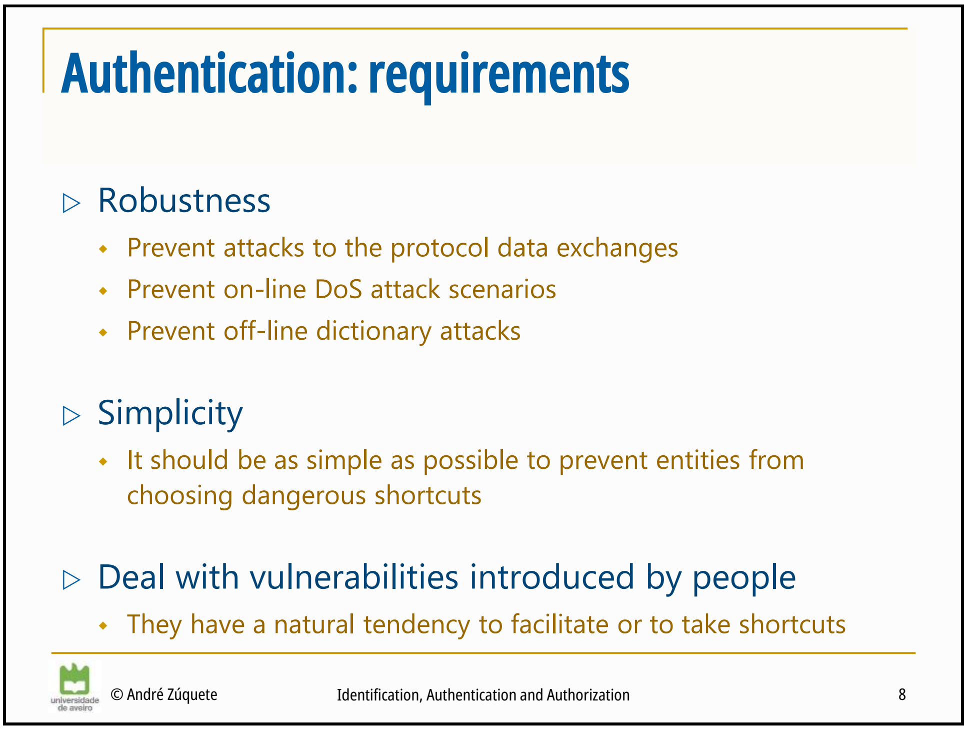
- ▷ Trustworthiness
  - How good is it in proving the identity of an entity?
  - How difficult is it to be deceived?
  - Level of Assurance (LoA) (NIST, eIDAS, ISO 29115)

    LoA 1 - Little or no confidence in the asserted identity

    LoA 2 - Some confidence in the asserted identity

    LoA 3 - High confidence in the asserted identity

    LoA 4 - Very high confidence in the asserted identity
- ▷ Secrecy
  - No disclosure of secrets used by legitimate entities



Authentication: requirements

- ▷ Robustness
  - Prevent attacks to the protocol data exchanges
  - Prevent on-line DoS attack scenarios
  - Prevent off-line dictionary attacks
- ▷ Simplicity
  - It should be as simple as possible to prevent entities from choosing dangerous shortcuts
- ▷ Deal with vulnerabilities introduced by people
  - They have a natural tendency to facilitate or to take shortcuts

Authentication: Entities and deployment model

- Entities
  - People
  - Hosts
  - Networks
  - Services / servers
- Deployment model
  - Along the time
    - Only when interaction starts
    - Continuously along the interaction
  - Directionality
    - Unidirectional
    - Bidirectional (or mutual)

Authentication interactions: Basic approaches

- Direct approach
  - Provide credentials
  - Wait for verdict
  - Authenticator checks credentials against what it knows
- Challenge-response approach
  - Get challenge
  - Provide a response computed from the challenge and the credentials
  - Wait for verdict
  - Authenticator checks response for the challenge provided and the credentials it knows

Authentication of people: Direct approach w/ known password

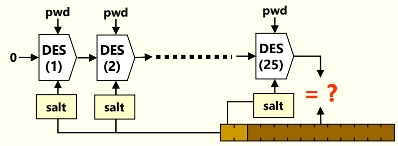
- ▷ A password is matched with a stored value
  - For a claimed identity (username)

- ▷ Personal stored value:
  - Transformed by a unidirectional function
    - Key Derivation Function (KDF)
    - Preferably slow!
    - Bcrypt, scrypt, Argon2, PBKDF2
  - UNIX: DES hash + salt
  - Linux: KDF + salt
  - Windows: digest function

DES hash = $DES_{pwd}^{25}(0)$

$DES_k^n(x) = DES_k(DES_k^{n-1}(x))$

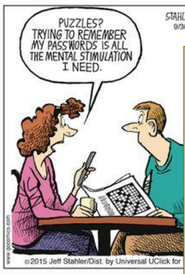
Permutation of 12 subkeys´bit pairs with salt (12 bits)



Authentication of people: Direct approach w/ known password

- ▷ Advantage
  - Simplicity!

- ▷ Problems
  - Usage of predictable passwords
    - They enable dictionary attacks
  - Different passwords for different systems
    - To prevent impersonation by malicious admins
    - But our memory has limits!
  - Exchange along insecure communication channels
    - Eavesdroppers can easily learn the password
    - e.g. Unix remote services, PAP

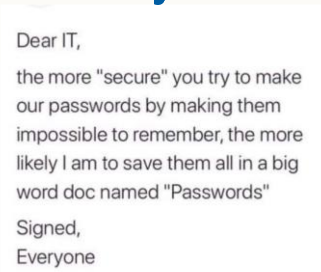

PUZZLES? TRYING TO REMEMBER MY PASSWORDS IS ALL THE MENTAL STIMULATION I NEED.
STAHLER. 9/30
©2015 Jeff Stahler/Dist. by Universal UClick for
www.gocomics.com

Top 15 2019 by Splashdata

1 - 123456
2 - 123456789
3 - qwerty
4 - password
5 - 1234567
6 - 12345678
7 - 12345
8 - iloveyou
9 - 111111
10 - 123123
11 - abc123
12 - qwerty123
13 - 1q2w3e4r
14 - admin
15 - qwertyuiop

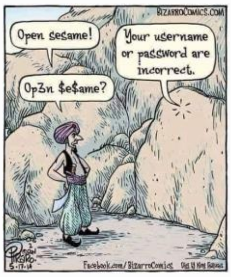
source: https://www.teampassword.com/blog/top-50-worst-passwords-of-2019
Image https://www.pinterest.com/networkboxusa/it-humor

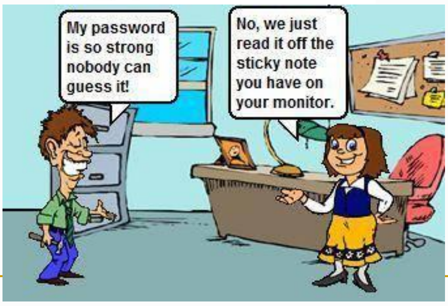
Password selection jokes

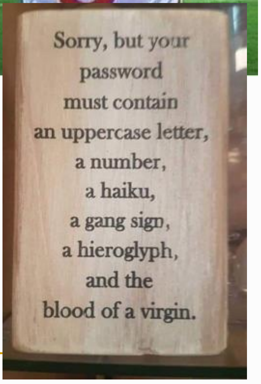

Dear IT,

the more "secure" you try to make our passwords by making them impossible to remember, the more likely I am to save them all in a big word doc named "Passwords"

Signed,
Everyone

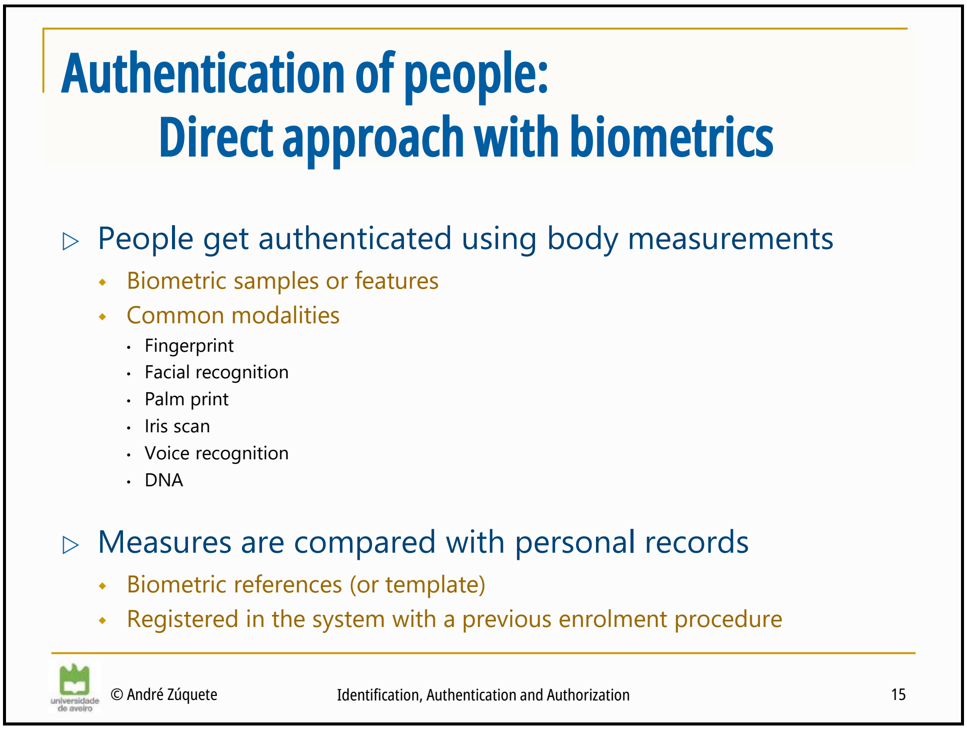

BIZARROCOMICS.COM
Open sesame!
Your username or password are incorrect.
Op3n $e$ame?
Facebook.com/BizarroComics


My password is so strong nobody can guess it!
No, we just read it off the sticky note you have on your monitor.


Sorry, but your password must contain an uppercase letter, a number, a haiku, a gang sign, a hieroglyph, and the blood of a virgin.

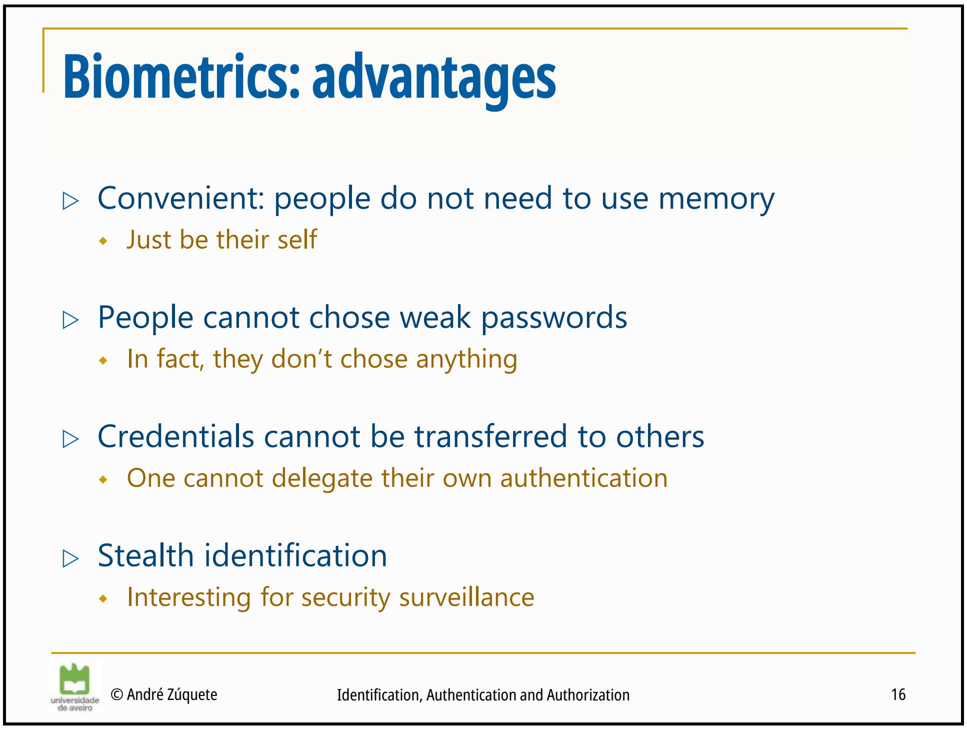
Password bloopers

SIC
DIA MUNDIAL DA VISÃO
JORNAL 10
ACONSELHADAS PAUSAS DE 20 SEGUNDOS A CADA 20 MIN.
10:35 Mais de 180 detidos na Operação "Escola Segura - início do Ano Letivo 2020/2021"



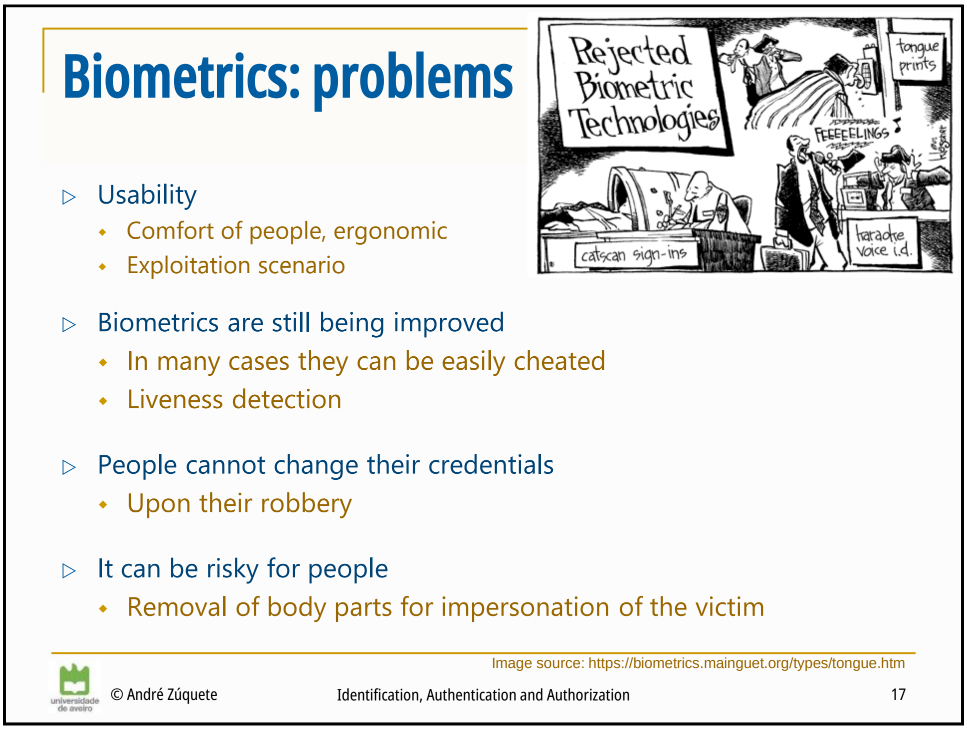
Authentication of people: Direct approach with biometrics

- ▷ People get authenticated using body measurements
  - Biometric samples or features
  - Common modalities
    - Fingerprint
    - Facial recognition
    - Palm print
    - Iris scan
    - Voice recognition
    - DNA
- ▷ Measures are compared with personal records
  - Biometric references (or template)
  - Registered in the system with a previous enrolment procedure



Biometrics: advantages

- ▷ Convenient: people do not need to use memory
  - Just be their self
- ▷ People cannot chose weak passwords
  - In fact, they don't chose anything
- ▷ Credentials cannot be transferred to others
  - One cannot delegate their own authentication
- ▷ Stealth identification
  - Interesting for security surveillance

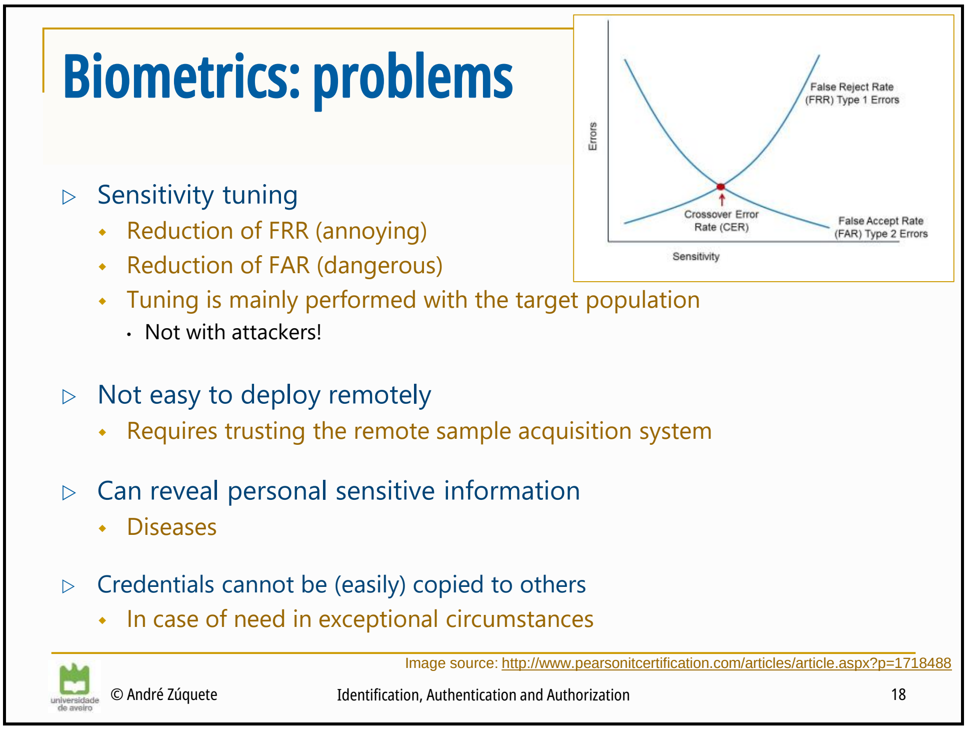


Biometrics: problems

Rejected Biometric Technologies
tongue prints
FEEEEELINGS
karaoke voice i.d.
catscan sign-ins

- ▷ Usability
  - Comfort of people, ergonomic
  - Exploitation scenario
- ▷ Biometrics are still being improved
  - In many cases they can be easily cheated
  - Liveness detection
- ▷ People cannot change their credentials
  - Upon their robbery
- ▷ It can be risky for people
  - Removal of body parts for impersonation of the victim

Image source: https://biometrics.mainguet.org/types/tongue.htm



Biometrics: problems

Errors
Sensitivity
False Reject Rate (FRR) Type 1 Errors
False Accept Rate (FAR) Type 2 Errors
Crossover Error Rate (CER)

- ▷ Sensitivity tuning
  - Reduction of FRR (annoying)
  - Reduction of FAR (dangerous)
  - Tuning is mainly performed with the target population
    - Not with attackers!
- ▷ Not easy to deploy remotely
  - Requires trusting the remote sample acquisition system
- ▷ Can reveal personal sensitive information
  - Diseases
- ▷ Credentials cannot be (easily) copied to others
  - In case of need in exceptional circumstances

Image source: http://www.pearsonitcertification.com/articles/article.aspx?p=1718488

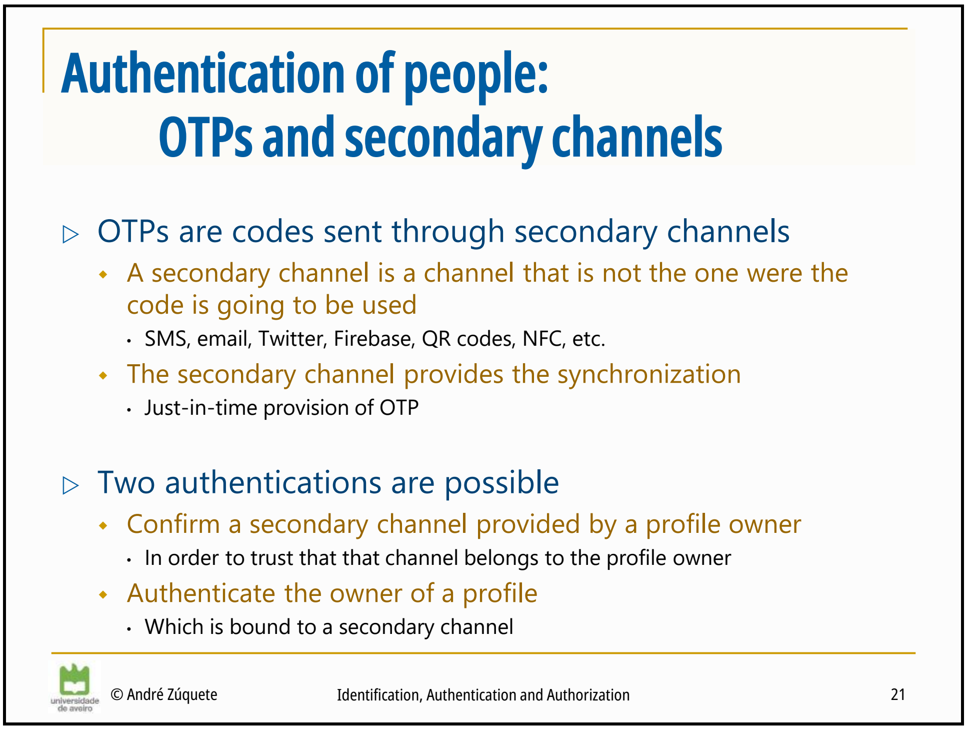
Authentication of people: Direct approach with OTPs

- One-time password (OTP)
  - Credential that can be used only once

- Advantage
  - OTPs can be eavesdropped
  - Eavesdroppers cannot impersonate the OTP owner
    - True for passive eavesdroppers
    - False for active attackers!

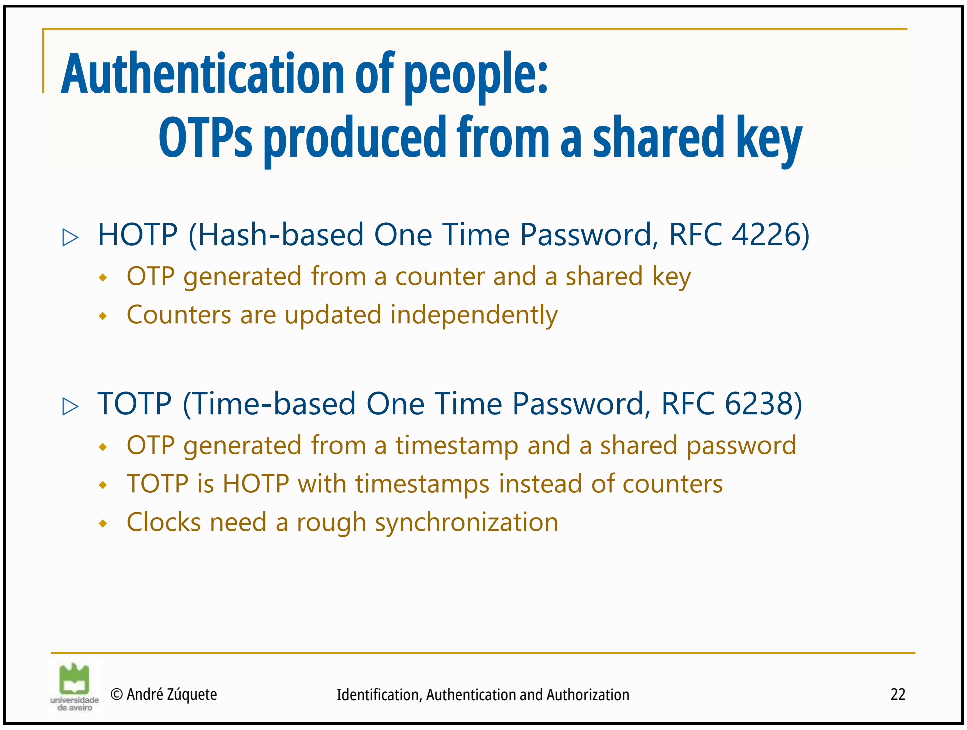
Authentication of people: Direct approach with OTPs

- Problems
  - Interactors need to know which password they should use at different occasions
    - Requires some form of synchronization
  - People may need to use extra resources to maintain or generate one-time passwords
    - Paper sheets
    - Computer programs
    - Special devices, etc.



Authentication of people: OTPs and secondary channels

- OTPs are codes sent through secondary channels
  - A secondary channel is a channel that is not the one were the code is going to be used
    - SMS, email, Twitter, Firebase, QR codes, NFC, etc.
  - The secondary channel provides the synchronization
    - Just-in-time provision of OTP
- Two authentications are possible
  - Confirm a secondary channel provided by a profile owner
    - In order to trust that that channel belongs to the profile owner
  - Authenticate the owner of a profile
    - Which is bound to a secondary channel



Authentication of people: OTPs produced from a shared key

- HOTP (Hash-based One Time Password, RFC 4226)
  - OTP generated from a counter and a shared key
  - Counters are updated independently
- TOTP (Time-based One Time Password, RFC 6238)
  - OTP generated from a timestamp and a shared password
  - TOTP is HOTP with timestamps instead of counters
  - Clocks need a rough synchronization

HOTP (HMAC-based one-time password, RFC 4226)

- Numeric OTP computed from shared key K and synchronized counter C
  - Hash key and counter
    - And increase counter
  - From hash, get a (floating) portion of 31 contiguous bits
    - Dynamic Binary Code (DBC)
  - Compute a *d*-long decimal number
    - d ≥ 6
- Issues
  - Counter synchronization upon a failure
    - If the authenticator keeps it after a failure, exhaustive search attacks are viable
    - If the authenticator always increments it, DoS attacks are possible
  - Acceptance windows
    - Mitigates minor desynchronizations, but decreases security

TOPT (Time-based one-time password, RFC 6238)

- HOTP with a counter derived from time
- $C_T = \left\lfloor \frac{T - T_0}{T_x} \right\rfloor$
  - T – initial time
  - T_0– initial time
  - T_x– time interval (default: 30 seconds)
- $\mathrm{TOTP}(K) = \mathrm{HOTP}(\, K, C_T)$

Token-based OTP generators: RSA SecurID

- ▷ Personal authentication token
  - Or software modules for handhelds (PDAs, smartphones, etc.)
- ▷ It generates a unique number at a fixed rate
  - Usually one per minute (or 30 seconds)
  - Bound to a person (User ID)
  - Unique number computed with:
    - A 64-bit key stored in the token
    - The actual timestamp
    - A proprietary digest algorithm (SecurID hash)
    - An extra PIN (only for some tokens)

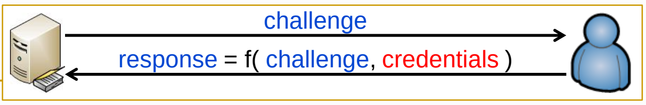
RSA SecurID

- ▷ OTP-based authentication
  - A user combines their User ID with the current token number

    OTP = User ID, Token Number
- ▷ An RSA ACE Server does the same and checks for match
  - It also knows the person’s key stored in the token
  - There must be a synchronization to tackle clock drifts
    - RSA Security Time Synchronization
- ▷ Robust against dictionary attacks
  - Keys are not selected by people

Challenge-response approach: Generic description

- ▷ The authenticator provides a challenge
- ▷ The entity being authenticated transforms the challenge
  - With its authentication credentials
- ▷ The result (response) is sent to the authenticator
- ▷ The authenticator checks the response
  - Produces a similar result and checks if they match
  - Transforms the result and checks if it matches the challenge or a related value



Challenge-response approach: Generic description

- ▷ Advantage
  - Authentication credentials are not exposed
- ▷ Problems
  - People may require means to compute responses
    - Hardware or software
  - The authenticator may have to have access to shared secrets
    - How can we prevent them from using the secrets elsewhere?
  - Offline dictionary attacks
    - Against recorded challenge-response dialogs
    - Can reveal secret credentials (passwords, keys)

Challenge-response protocols: selection of challenges

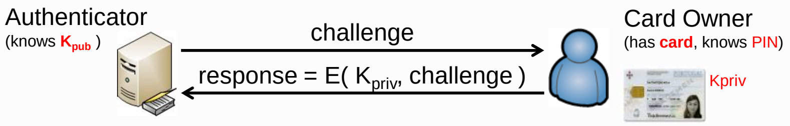
- ▷ Challenges cannot be repeated for the same entity
  - Same challenge → same response
  - An active attacker can impersonate a user using a previously recorded protocol run
- ▷ Challenges should be nonces
  - Nonce: number used only once
  - Stateful services can use counters
  - Stateless services can use (large) random numbers
  - Time can be used, but with caution
    - Because one cannot repeat a timestamp

Authentication of people: Challenge-response with smartcards

- ▷ Authentication credentials
  - The smartcard
    - e.g. Citizen Card
  - The private key stored in the smartcard
  - The PIN to unlock the private key
- ▷ The authenticator knows
  - The corresponding public key
  - Or some personal identifier
    - Which can be related with a public key through a (verifiable) certificate

PORTUGAL
SPECIMEN
PORTUGAL
SPECIMEN
I<PRT00000000<<0<ZZ4<<<<<<<<<<2
8108108F1201158PRT<<<<<<<<<<<1
AVILA<<PAULA<ANDREIA<CONCEICAO

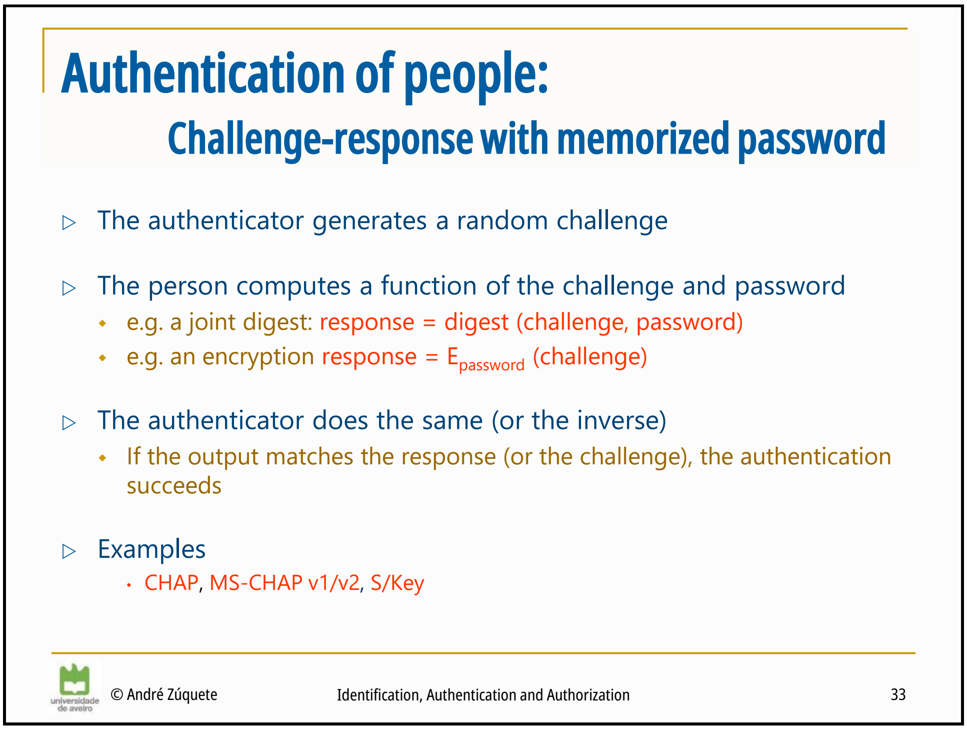
Authentication of people: Challenge-response with smartcards



- ▷ Signature-based protocol
  - The authenticator generates a random challenge
    - Or a value not used before
  - The card owner ciphers the challenge with their private key
    - PIN-protected
  - The authenticator decrypts the result with the public key
    - If the output matches the challenge, the authentication succeeds
- ▷ Encryption-based protocol
  - Possible when private key decryption is available

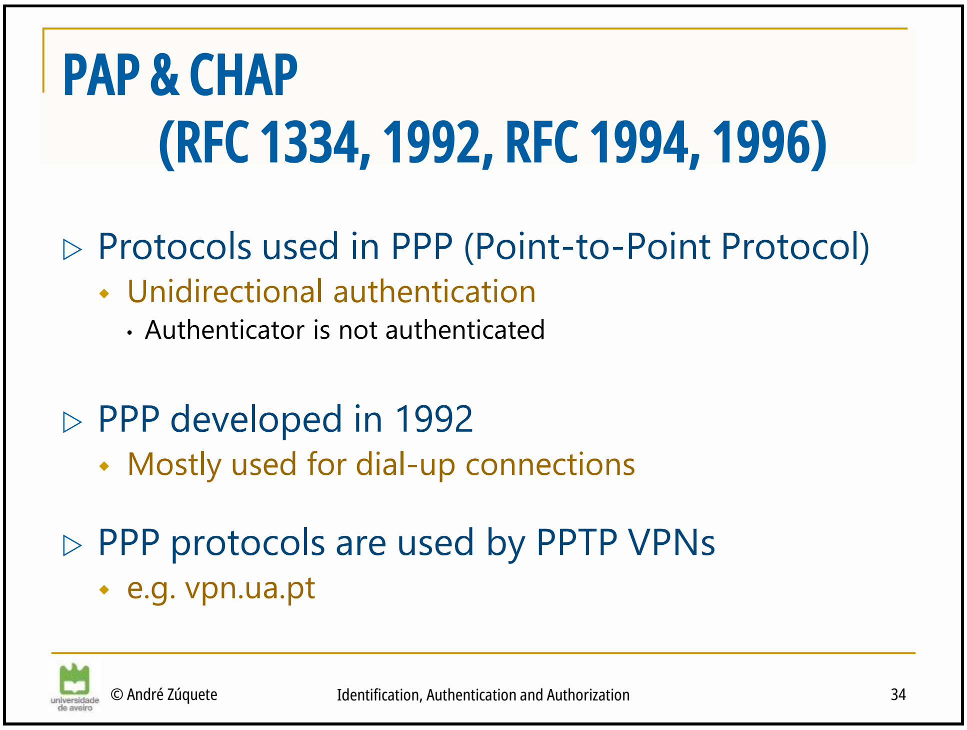
Authentication of people: Challenge-response with memorized password

- ▷ Authentication credentials
  - Passwords selected by people
- ▷ The authenticator knows
  - All the registered passwords; or
  - A transformation of each password
    - Preferable option
    - Preferably combined with some local value (salt)
    - Preferable using a tunable function (e.g. iterations)



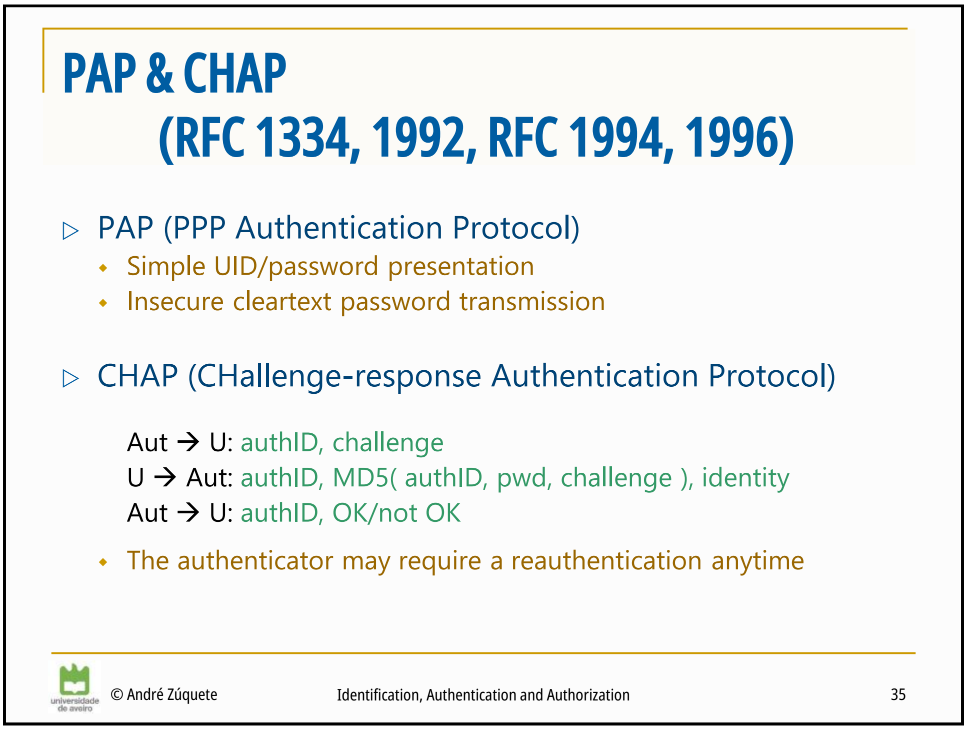
Authentication of people:
Challenge-response with memorized password

- ▷ The authenticator generates a random challenge
- ▷ The person computes a function of the challenge and password
  - e.g. a joint digest: response = digest (challenge, password)
  - e.g. an encryption response = $E_{password}$ (challenge)
- ▷ The authenticator does the same (or the inverse)
  - If the output matches the response (or the challenge), the authentication succeeds
- ▷ Examples
  - CHAP, MS-CHAP v1/v2, S/Key



PAP & CHAP
(RFC 1334, 1992, RFC 1994, 1996)

- ▷ Protocols used in PPP (Point-to-Point Protocol)
  - Unidirectional authentication
    - Authenticator is not authenticated
- ▷ PPP developed in 1992
  - Mostly used for dial-up connections
- ▷ PPP protocols are used by PPTP VPNs
  - e.g. vpn.ua.pt



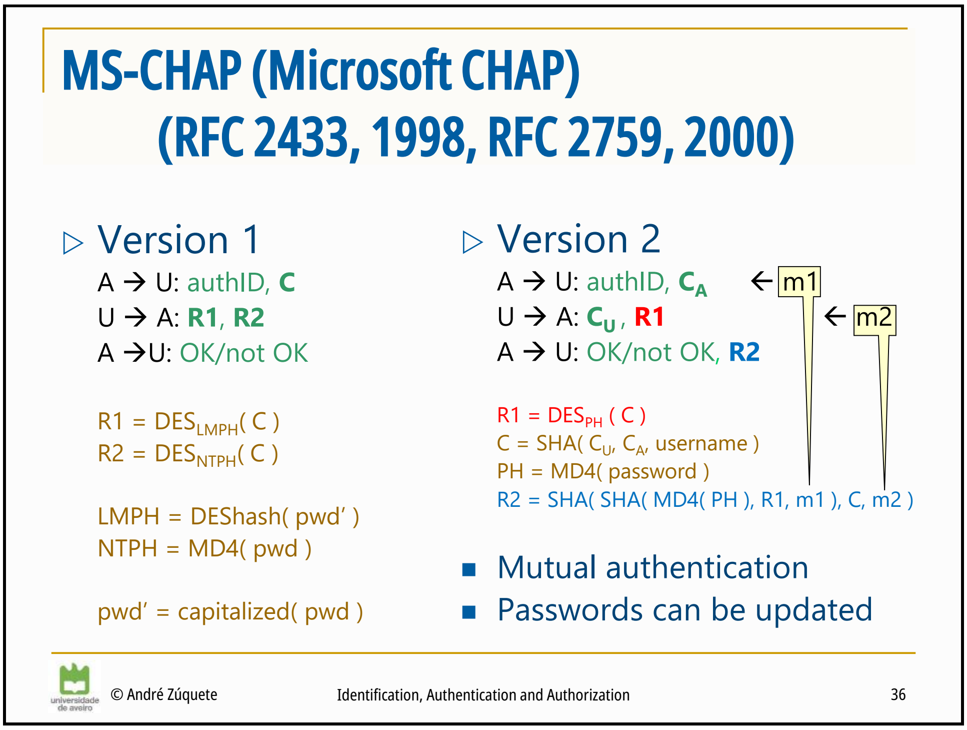
PAP & CHAP (RFC 1334, 1992, RFC 1994, 1996)

- PAP (PPP Authentication Protocol)
  - Simple UID/password presentation
  - Insecure cleartext password transmission

- CHAP (CHallenge-response Authentication Protocol)

  Aut → U: authID, challenge
  U → Aut: authID, MD5(authID, pwd, challenge), identity
  Aut → U: authID, OK/not OK

  - The authenticator may require a reauthentication anytime



MS-CHAP (Microsoft CHAP) (RFC 2433, 1998, RFC 2759, 2000)

- Version 1

  A → U: authID, **C**
  U → A: **R1**, **R2**
  A →U: OK/not OK

  R1 = DES_{LMPH}(C)
  R2 = DES_{NTPH}(C)

  LMPH = DEShash(pwd’)
  NTPH = MD4(pwd)

  pwd’ = capitalized(pwd)

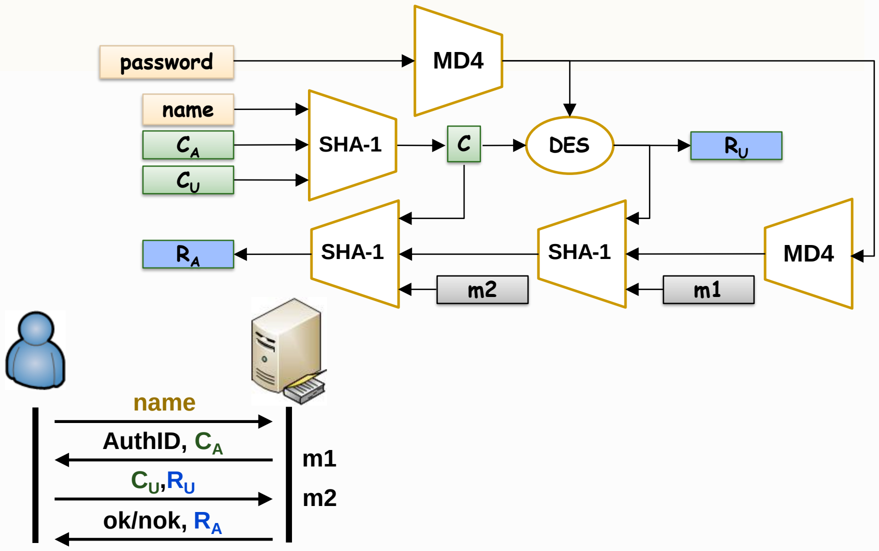
- Version 2

  A → U: authID, $\mathbf{C_A}$ ← m1
  U → A: $\mathbf{C_U}$, **R1** ← m2
  A → U: OK/not OK, **R2**

  R1 = DES_{PH} (C)
  C = SHA(C_U, C_A, username)
  PH = MD4(password)
  R2 = SHA(SHA(MD4(PH), R1, m1), C, m2)

- Mutual authentication
- Passwords can be updated

MS-CHAP v2

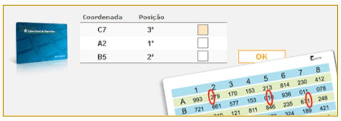


Authentication of people: Generation of OTPs with challenges

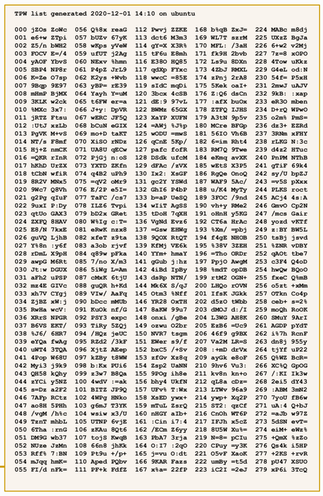
- OTPs can be produced from a challenge received
  - The fundamental protocol is password-based
    - But passwords are OTPs
  - OTPs are produced from a challenge
  - One can use several algorithms to handle OTPs

Authentication of people: OTPs selected from shared data

- ▷ Advantage:
  - Shared data can be random
  - No long-term short secrets to protect
- ▷ OTPs build from printed data
  - Example: online bank codes



- ▷ Selection of an OTP from a printed / saved list



```
TPW list generated 2020-12-01 14:10 on ubuntu

000 jZOs ZoWc  056 Q%8x reaG  112 Pwvj ZZKE  168 b%qB ZxJ=  224 MABc m8dj
001 e6+w ZTpi  057 bUZv 67yK  113 dct6 M3m3  169 WL7T szrM  225 UXzZ BgJa
002 Z5/n bWH2  058 wKps yVeW  114 gY=X X3R%  170 MFL: /3aH  226 6+w2 v2Mj
003 FOCV E=/4  059 ufUT j2Ag  115 tF6u E8mh  171 fk9H 2bvb  227 7z=8 xOPO
004 yAOF YbvS  060 NExv %hmn  116 E38O HQ85  172 Ls9u 8DXn  228 4Tow uKkz
005 SBP4 NP8r  061 P4pZ JrL9  117 qdXp FYxc  173 4ZbJ RMXL  229 G4eL od:N
006 K=Ze O7sp  062 K2ys +Wvb  118 wwcC =85E  174 zPnj 2rA8  230 54f= P5xH
007 9Bqp 9E97  063 yBP= rE39  119 sIdC mqDi  175 5Kek oaI+  231 2mwJ uAJV
008 mHmP BjMX  064 Yayh Y=uM  120 3bcx 4cSB  176 Z:Q6 dsCn  232 9kB: :xap
009 3KLK w2ck  065 t6FW er=a  121 dE:9 97vL  177 :afX buOx  233 eR3O mben
010 %MXc 3x7:  066 J+y: DpVR  122 BWMz 65GX  178 ZTFQ IJHS  234 D+rQ WPwO
011 jRTZ Ftsu  067 wERC JF5Q  123 XaYP XUFN  179 A3tN 9p5v  235 o2m% PmS=
012 :UtJ xzLb  068 bCuN eGIX  124 =AWj %J%p  180 MCre BFGp  236 dz3+ EZRd
013 PgVK M+vS  069 mo+D taKT  125 wODU =mwS  181 56IO Vh6B  237 3RNm xFHY
014 NT/s F8mf  070 XiSO rNDz  126 qCnE 5Kp/  182 6=im Rht4  238 rLKG N:3c
015 Hj+Z nmCK  071 UA8U qECw  127 pafc fofR  183 RM7Q 9Twe  239 d4z2 HTuc
016 =QKR rInR  072 PjGj n:oS  128 DSdk ufcM  184 eKmq avXK  240 PnPM NThB
017 hKhD UrZX  073 YXTD ZKfn  129 dFAc /zVX  185 wEtS X3P5  241 gTiF 69k4
018 tCbN wfiR  074 q4B2 uPh9  130 Ix2: XsGF  186 RgQe OnoQ  242 sy/U bpZJ
019 8R2V MNx5  075 =qV2 oMr9  131 gc2Y YSWd  187 WAF9 5Ac/  243 =v5S pXxx
020 9Wc7 Q8Vh  076 E/2P e5I=  132 GhI6 P4bP  188 u/K4 MyTy  244 PLKS roct
021 g2Pg qIuF  077 TaFC /cs7  133 b=aP UeSQ  189 3FOC /9nd  245 ACj4 4s:A
022 9uxI P:Dy  078 ILZ6 Tvpi  134 wIiT AgSS  190 vh+y RMe2  246 GmvO Cp2N
023 qtUo GAX3  079 bD2x GRet  135 tDoH 7qXH  191 oHnH y5KG  247 /mcs Gair
024 ZXFQ 8HAV  080 W%Ig c:T=  136 VgNd Evz6  192 CT6a HrAc  248 yozd vKTf
025 E8/N 7kxE  081 eRwK nzx8  137 =Gsw EHWg  193 %Xm/ =pbj  249 z:BY BW5L
026 guVQ LjhB  082 xfeT z9ta  138 9QOX RtQT  194 f4gE NHOB  250 tsBj jsvd
027 Y%8n :y6f  083 a3ob rjvf  139 KfMj VE6k  195 %38V 3ZEH  251 %ZNR vDBY
028 rDmL X9pH  084 q89w pFka  140 YYm+ hmaY  196 =Tho ORDr  252 qAOt tbe7
029 awpG M6Rt  085 7/no X/m3  141 gGub j:hz  197 PpjO AwgM  253 c3F4 Q4oD
030 Jt:w DGUX  086 5iWg L=Am  142 4iBd IpBy  198 %mdT opDB  254 hwQw BQoO
031 aFh2 uPSP  087 cMxK 6tjU  143 dsRp NTN/  199 rtM2 OGN+  255 fxeC Q%mB
032 mz4E GIVc  088 guQR h+Kd  144 Mk6X S/qJ  200 LHQo rOVN  256 o5zt +xMm
033 xh7V CYgj  089 VIw/ AaFq  145 Otm3 %Nff  201 IfsK JGkk  257 OTkn Co4p
034 ZjBZ xW:j  090 bDcc mMUb  146 YR28 OxTH  202 d5zO tWbb  258 ceb+ s=2%
035 RwHa wcV:  091 KuOk nf/G  147 8aKW 99u7  203 dMOJ d:/I  259 moQh RoOK
036 XRrS NPGR  092 PSY3 expc  148 onxi /gBe  204 L3WG AH8K  260 SMuY 9ArI
037 B6VS EKT/  093 TiRy 5ZQj  149 ozwu O2br  205 EzB6 =Uc9  261 AGDP pYdT
038 %J6/ 6HR7  094 /HQz jeUC  150 NVR7 tsgm  206 46f9 g9BX  262 i%7h RcnF
039 eYQa fwAg  095 RZd2 /3kF  151 EWer s9/f  207 Va2M LR=S  263 dn8j 955y
040 uWT4 3TQA  096 XjtZ AEep  152 bxC5 /+Sv  208 :+mD drVx  264 tjYf uP22
041 4Pop W68U  097 kZBy t8WW  153 zfGv Xz8q  209 ayGk e8oF  265 Q%WZ BcR=
042 Myi3 j9k9  098 b:Kx PUi6  154 Zsp2 UaNN  210 9hv6 Vu3:  266 XC%Q GpOG
043 QH58 kQhy  099 z3w7 B8Qa  155 9POg ih8e  211 kv8n kn+o  267 /:KI Ik3w
044 zYCi y5NZ  100 4wdV :=ak  156 bhy4 UkfN  212 qL8a cDz=  268 2ei5 dY43
045 s=Dz a2F2  101 BITZ JP9Q  157 UFv% T:Wx  213 LTWv 96a9  269 :ABM 3mN2
046 7AFp RCtz  102 4WPg HNko  158 XsED ywx+  214 ywp+ Xq2P  270 7yoU fB6w
047 ao8H 5PHh  103 g6mJ T3YK  159 mTuL ZsrQ  215 ST2: qzCf  271 uA:4 Q+bJ
048 /vgM /h%c  104 wsiw x3/U  160 nHGY aIb+  216 CnOh WT6P  272 =aJb w97Z
049 TznT mhbL  105 UTNP 6vjE  161 :Cin i7:4  217 IFJh x5cZ  273 5dSN evT=
050 6Tha :rnG  106 zKAu 8Qt6  162 /ECm Z6yy  218 8U5W Xu%=  274 eiM+ eWz%
051 DM9G wb37  107 tojS KwqB  163 PbA7 3rja  219 N=8= pCIu  275 +QmX %zZo
052 NUze JzMn  108 66n8 jhKk  164 O:I7 :2qO  220 CPuy =y3K  276 Qs4k i5HP
053 Rff% 7:BN  109 Pt9u +/p+  165 j=vu O:dt  221 O5vF XaoK  277 +2KS +rvR
054 mJqq hmK=  110 Aped PQbv  166 9KAR Fazs  222 umBy =t5d  278 pU47 XSUO
055 FI/d nFk=  111 PF+k FdfZ  167 x%a= 22fP  223 iC2I =2eJ  279 xP6i 3TcQ
```

S/Key (RFC 2289, 1998)

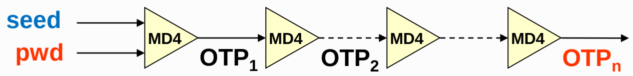
- ▷ Authentication credentials
  - A password (pwd)
- ▷ The authenticator knows
  - The last used one-time password (OTP)
  - The last used OTP index
    - Defines an order among consecutive OTPs
  - An seed value for the each person's OTPs
    - The seed is similar to a UNIX salt

S/Key setup

- The authenticator defines a random seed
- The person generates an initial OTP as:

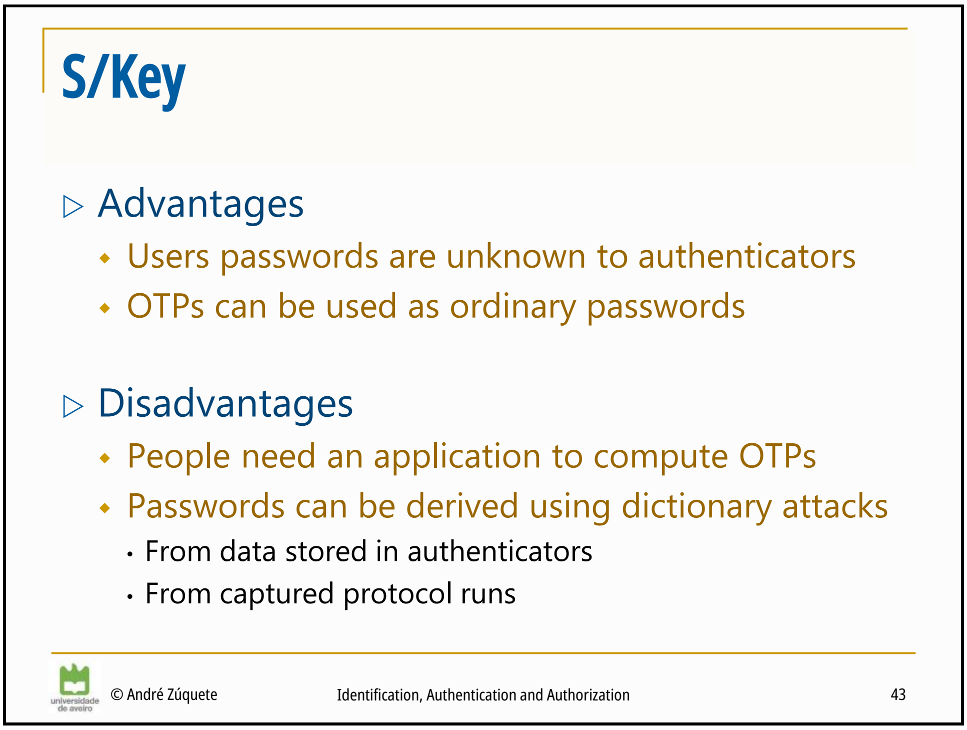
  $OTP_n = h^n$ (seed, pwd), where h = MD4

  - Some S/Key versions also use MD5 or SHA-1
- The authenticator stores seed, n and OTP_n as authentication credentials



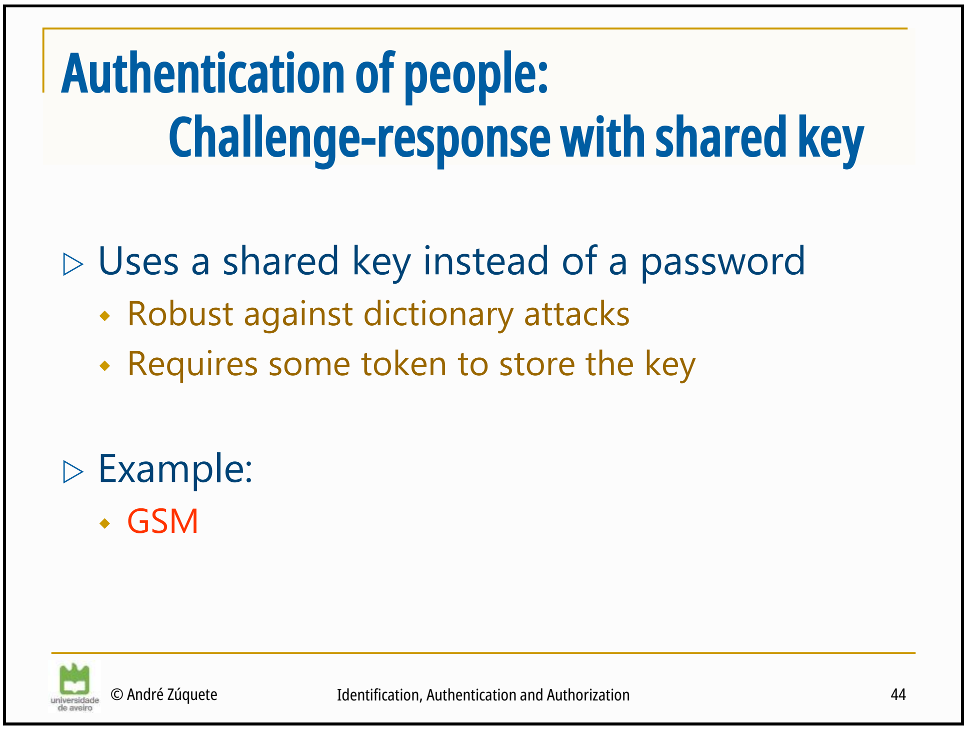
S/Key authentication protocol

- Authenticator sends seed & index of the person
  - They act as a challenge
- The person generates index-1 OTPs in a row
  - And selects the last one as result
  - result = $OPT_{index-1}$
- The authenticator computes h (result) and compares the result with the stored OPT_{index}
  - If they match, the authentication succeeds
  - Upon success, stores the recently used index & OTP
    - index-1 and $OPT_{index-1}$



S/Key

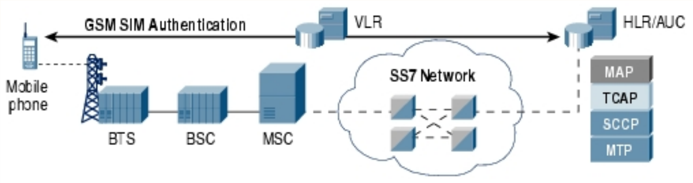
- ▷ Advantages
  - Users passwords are unknown to authenticators
  - OTPs can be used as ordinary passwords
- ▷ Disadvantages
  - People need an application to compute OTPs
  - Passwords can be derived using dictionary attacks
    - From data stored in authenticators
    - From captured protocol runs



Authentication of people: Challenge-response with shared key

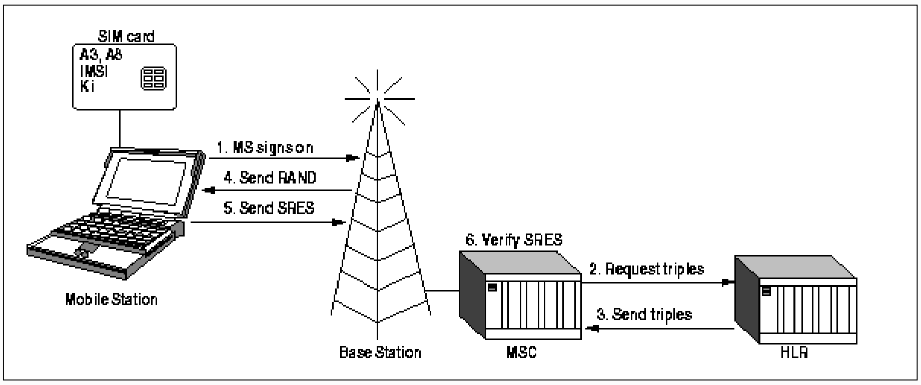
- ▷ Uses a shared key instead of a password
  - Robust against dictionary attacks
  - Requires some token to store the key
- ▷ Example:
  - GSM

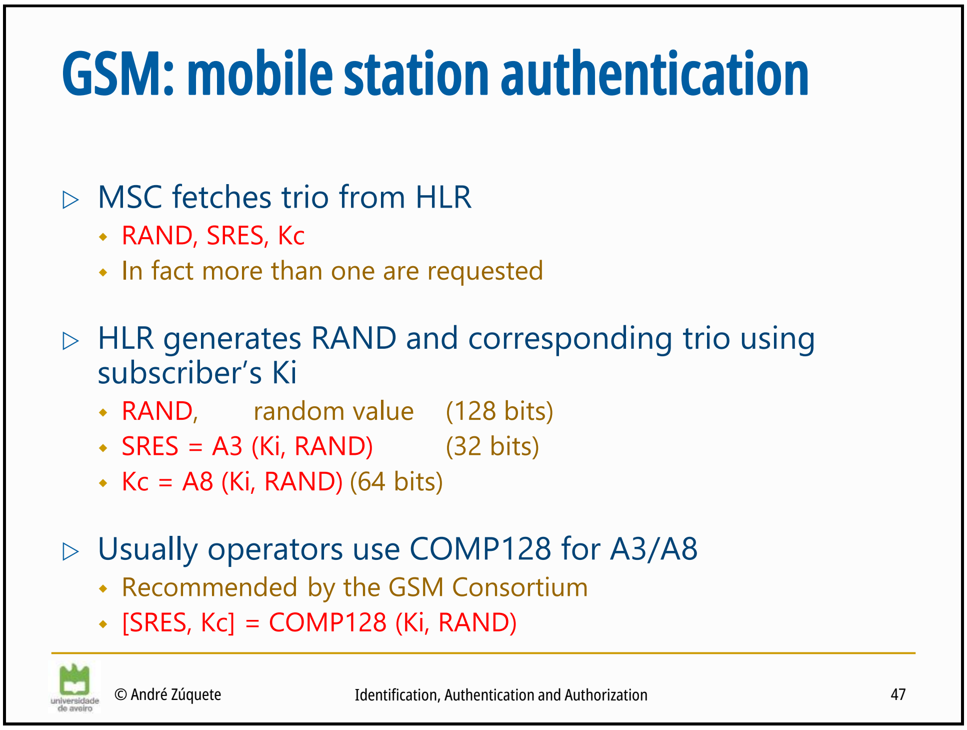
GSM: authentication architecture



- Based on a secret key shared between the HLR and the station
  - 128 Ki, stored in the station's SIM card
  - Can only be used after entering a PIN
- Algorithms (initially not public):
  - A3 for authentication
  - A8 for generating a session key
  - A5 for encrypting the communication
- A3 and A8 implemented by SIM card
  - Can be freely selected by the operator

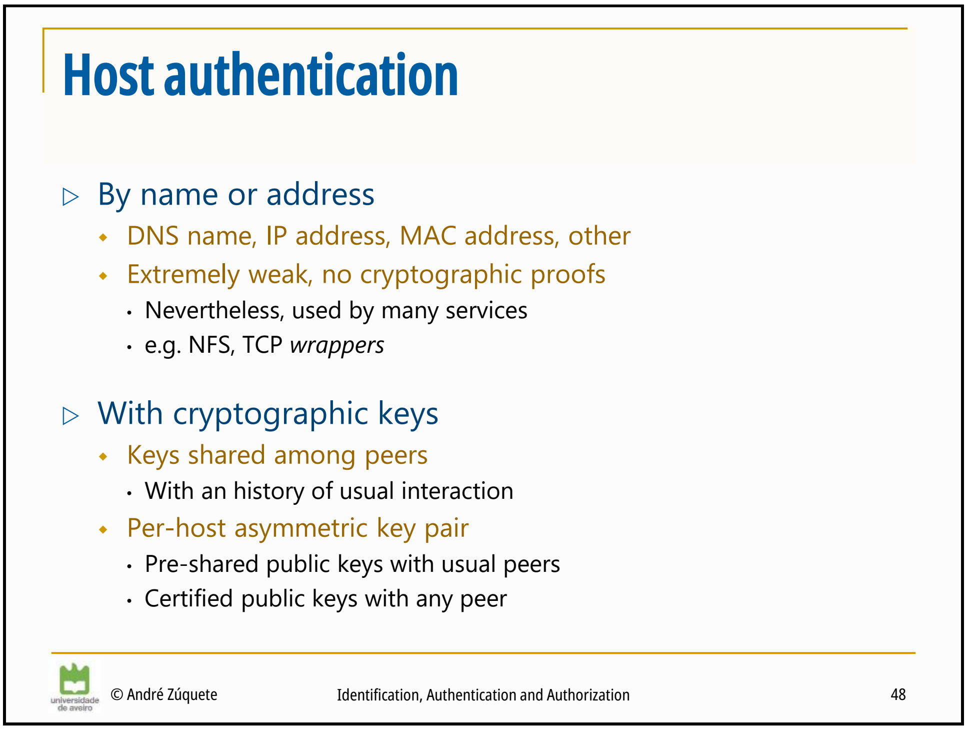
GSM: mobile station authentication





GSM: mobile station authentication

- MSC fetches trio from HLR
  - RAND, SRES, Kc
  - In fact more than one are requested
- HLR generates RAND and corresponding trio using subscriber's Ki
  - RAND,   random value   (128 bits)
  - SRES = A3 (Ki, RAND)   (32 bits)
  - Kc = A8 (Ki, RAND) (64 bits)
- Usually operators use COMP128 for A3/A8
  - Recommended by the GSM Consortium
  - [SRES, Kc] = COMP128 (Ki, RAND)



Host authentication

- By name or address
  - DNS name, IP address, MAC address, other
  - Extremely weak, no cryptographic proofs
    - Nevertheless, used by many services
    - e.g. NFS, TCP *wrappers*
- With cryptographic keys
  - Keys shared among peers
    - With an history of usual interaction
  - Per-host asymmetric key pair
    - Pre-shared public keys with usual peers
    - Certified public keys with any peer

Service / server authentication

- ▷ Host authentication
  - All co-located services/servers are indirectly authenticated
- ▷ Per-service/server credentials
  - Shared keys
    - When related with the authentication of people
    - The key shared with each person can be used to authenticate the service to that person
  - Per-service/server asymmetric key pair
    - Certified or not

TLS (Transport Layer Security, RFC 8446)

- ▷ Secure communication protocol over TCP/IP
  - Created upon SSL V3 (Secure Sockets Layer)
  - Manages per-application secure sessions over TCP/IP
    - Initially conceived for HTTP traffic
    - Actually used for other traffic types
- ▷ There is a similar version for UDP (DTLS, RFC 6347)
- ▷ Security mechanisms
  - Communication confidentiality and integrity
    - Key distribution
  - Authentication of communication endpoints
    - Servers (or, more frequently, services)
    - Client users
    - Both with asymmetric key pairs, typically with certified public keys

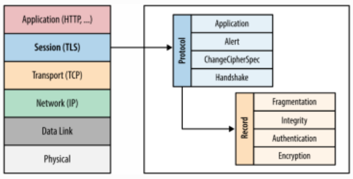
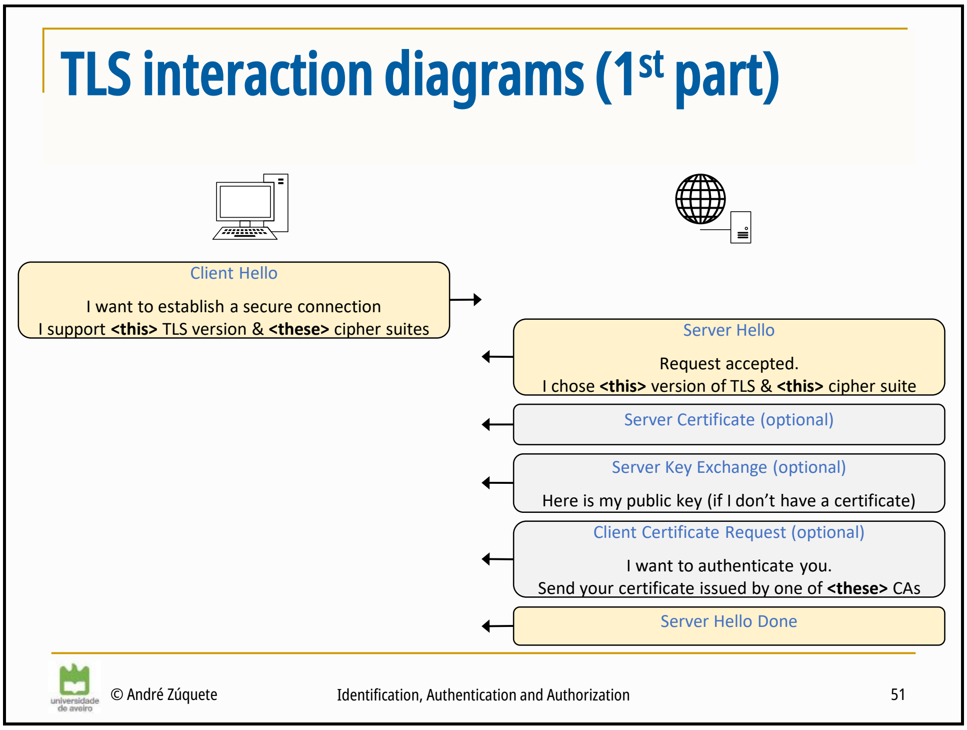


Image source: https://hpbn.co/transport-layer-security-tls/



TLS interaction diagrams (1st part)

Client Hello

I want to establish a secure connection
I support **<this>** TLS version & **<these>** cipher suites

Server Hello

Request accepted.
I chose **<this>** version of TLS & **<this>** cipher suite

Server Certificate (optional)

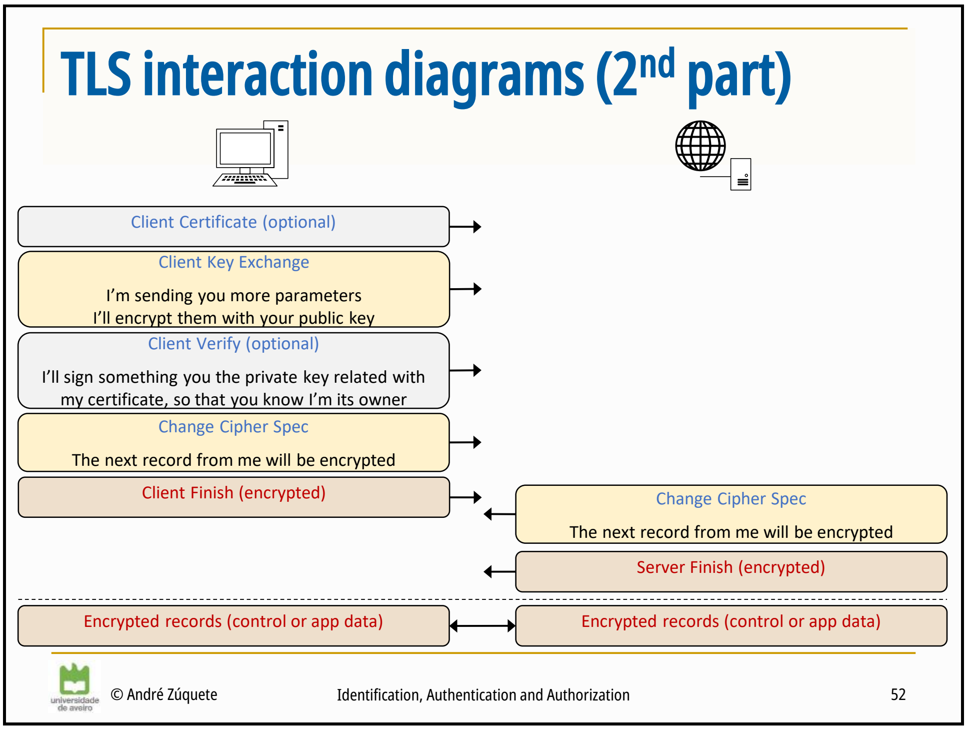
Server Key Exchange (optional)

Here is my public key (if I don't have a certificate)

Client Certificate Request (optional)

I want to authenticate you.
Send your certificate issued by one of **<these>** CAs

Server Hello Done



TLS interaction diagrams (2nd part)

Client Certificate (optional)

Client Key Exchange

I'm sending you more parameters
I'll encrypt them with your public key

Client Verify (optional)

I'll sign something you the private key related with my certificate, so that you know I'm its owner

Change Cipher Spec

The next record from me will be encrypted

Client Finish (encrypted)

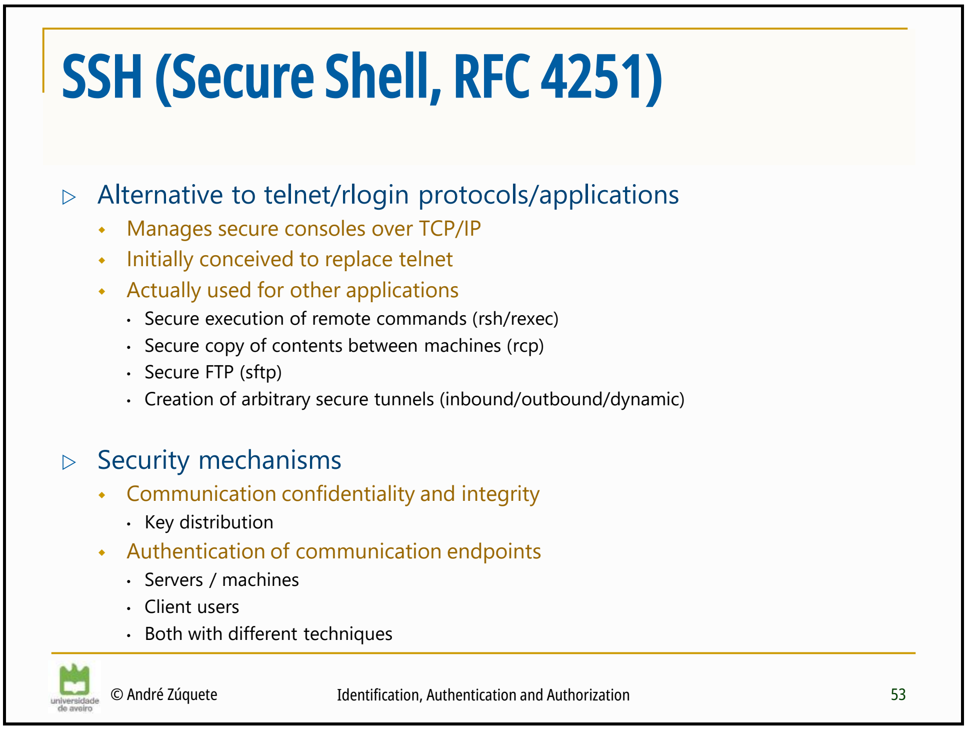
Change Cipher Spec

The next record from me will be encrypted

Server Finish (encrypted)

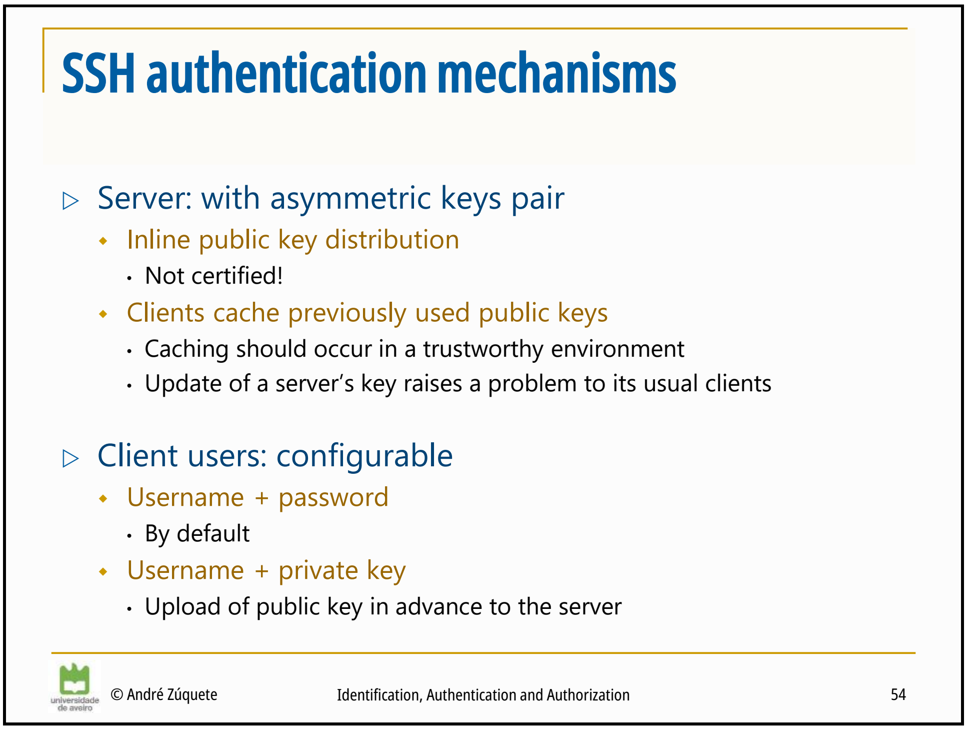
Encrypted records (control or app data)

Encrypted records (control or app data)



SSH (Secure Shell, RFC 4251)

- Alternative to telnet/rlogin protocols/applications
  - Manages secure consoles over TCP/IP
  - Initially conceived to replace telnet
  - Actually used for other applications
    - Secure execution of remote commands (rsh/rexec)
    - Secure copy of contents between machines (rcp)
    - Secure FTP (sftp)
    - Creation of arbitrary secure tunnels (inbound/outbound/dynamic)
- Security mechanisms
  - Communication confidentiality and integrity
    - Key distribution
  - Authentication of communication endpoints
    - Servers / machines
    - Client users
    - Both with different techniques



SSH authentication mechanisms

- Server: with asymmetric keys pair
  - Inline public key distribution
    - Not certified!
  - Clients cache previously used public keys
    - Caching should occur in a trustworthy environment
    - Update of a server’s key raises a problem to its usual clients
- Client users: configurable
  - Username + password
    - By default
  - Username + private key
    - Upload of public key in advance to the server

Single Sign-On (SSO)

- Unique, centralized authentication for a set of federated services
  - The identity of a client, upon authentication, is given to all federated services
  - The identity attributes given to each service may vary
  - The authenticator is called Identity Provider (IdP)
- Examples
  - SSO authentication @ UA
    - Performed by a central IdP (idp.ua.pt)
    - The identity attributes are securely conveyed to the service accessed by the user

Authentication metaprotocols

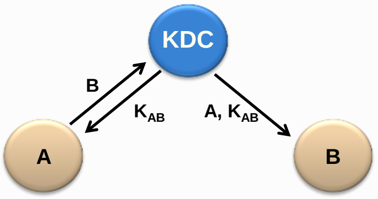
- Generic authentication protocols that encapsulate other authentication protocols
- Examples
  - EAP (Extensible Authentication Protocol)
    - Used in 802.1X (WiFi, enterprise mode)
    - e.g. PEAP (Protected EAP) and EAP-TLS run over EAP
  - ISAKMP(Internet Security Association and Key Management Protocol)
    - Formerly used in IPSec
    - e.g. IKE v1 (Internet Key Exchange) runs over ISAKMP

Authentication services

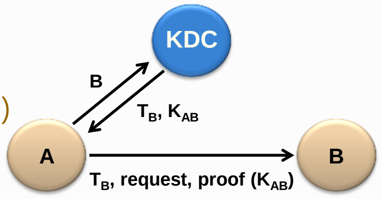
- ▷ Trusted third parties (TTP) used for authentication
  - But often combined with other related functionalities
- ▷ AAA services
  - Authentication, Authorization and Accounting
  - e.g. RADIUS

Key distribution services

- ▷ Services that distribute a shared key for authenticated entities
  - That key can then be used by those entities to protect their communication and ensure source authentication



- ▷ Examples
  - 802.1X (Wi-Fi, enterprise mode)
  - Kerberos


KDC
B
T_B, K_{AB}
A
B
T_B, request, proof (K_{AB})