



EITA25 Computer Security (Datasäkerhet)
Mobility

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Mobility

- Wireless traffic is easy to eavesdrop
- Requires new security solutions
- **Mobile phones:** Network operator may not be same as service provider
- We will look at
 - GSM
 - UMTS, 3GPP, LTE
 - WLAN

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GSM - Introduction

- European standard, first deployed in 1991, still widely used
- Denoted 2G as it replaced NMT (1G)
- Security goals
 - Provide confidentiality for users – eavesdroppers cannot reconstruct messages
 - Provide anonymity for users – not possible to trace a user
 - Authenticate users – not possible to spoof an identity
- Security requirements
 - Complexity added by security should be as small as possible
 - » Bandwidth
 - » Error rate
 - » Overhead
 - Must be possible to use other networks in other countries

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Mobile Station

- Consists of mobile equipment (ME)
 - Physical device
 - IMEI – International Mobile Equipment Identity
- SIM card – Subscriber Identity Module, Smart card with identifiers, keys and algorithms
 - K_i – Subscriber Authentication Key (Long term key)
 - IMSI – International Mobile Subscriber Identity
 - TMSI – Temporary Mobile Subscriber Identity
 - PIN – Personal Identity Number protecting a SIM
 - LAI – Location Area Identity



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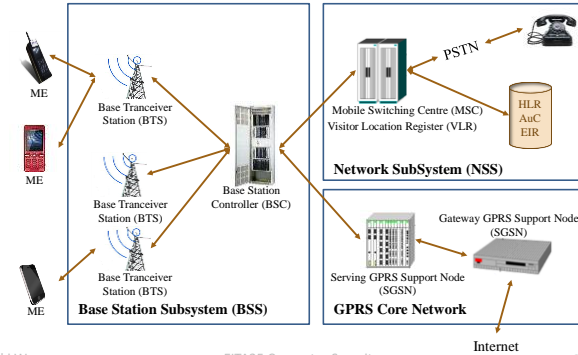


Some Important Parts of the Network

- HLR – Home Location Register
 - Stores information about every SIM card issued by the operator. SIM identified by IMSI.
 - Stores current location of SIM
 - Sends data to VLR/SGSN when SIM roams
- VLR – Visitor Location Register
 - Serves a base station
 - Stores IMSI and TMSI
 - Updates HLR with location
- AuC – Authentication Center
 - Manages authentication data for user
 - Stores K_i and algorithm ID (A3/A8)
 - Issues key for encryption
- EIR – Equipment Identity Register
 - Keeps a list of banned IMEI
 - Used to track stolen phones



GSM Architecture



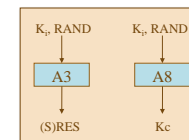
Subscriber Identity Protection

- If IMSI is always used for identification, then it is possible to **track subscribers**
 - Eavesdropping should not identify users
 - Network must identify users (someone has to pay the call)
- TMSI is used to identify a SIM
- Phone is switched on → IMSI is sent
 - SIM card receives a TMSI
 - All other times → TMSI is used
- VLR maps TMSI → IMSI
- New MSC → new TMSI

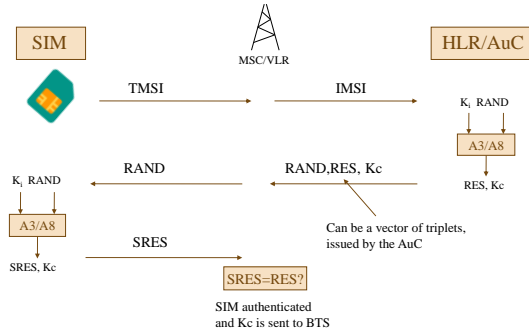


Authentication step

- K_i – subscriber identification key is stored in SIM and HLR/AuC
 - Size is 128 bits
- Goals
 1. Authenticate subscriber to network
 2. Create session key
- Algorithm A3 computes response in authentication step
- Algorithm A8 computes 64-bit session key
- RAND is 128 bits, generated by AuC
- (S)RES is 32 bits



Authentication Step



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A3/A8

- A3 and A8 are implemented on the SIM
- Can be network specific, but example algorithms were proposed (COMP128)
- Independent of hardware manufacturers
- COMP128 was very weak
 - Using Smart Card reader it was possible to get K_i
 - Possible to clone SIM cards
 - New versions were proposed

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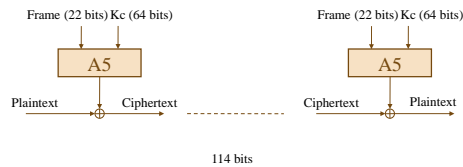
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Encryption

- Encryption algorithms
 - A5/1 - Strong version
 - A5/2 - Weak version
 - A5/3 - Strong version (introduced later and based on Kasumi used in 3G)
- Traffic only encrypted between mobile station and base station



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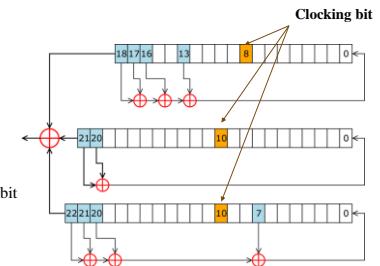
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A5/1

- Initialization: Load key and frame number by xoring them with bit 0
- Keystream generation: Register is clocked if clocking bit is majority bit



- Note the small state: Time-memory tradeoff feasible! (Some known plaintext is needed)

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Secrecy of algorithms

- Kerckhoffs' principle:

The secrecy of a message should only depend on the secret key!

- This well known principle from 1883 was ignored
- If the algorithm is not investigated by public/researchers before deployment, how can we know it is secure?
 - COMP128 leaked out – got broken
 - A5/1 leaked out – got broken
- Another problem with GSM: Only users are authenticated, the network is not
 - Fake basestations can trick phones to send IMSI and/or turn off encryption

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UMTS (3G)

- Developed by 3GPP (3rd generation partnership project)
 - Partners from Asia, Europe and North America
- First specification frozen 2000
- As far as we are concerned the architecture of UMTS is similar to the architecture of GSM
 - USIM – Universal subscriber identity module
 - Secret key K shared between USIM and HLR/AuC
- Goal of authentication step
 - Authenticate user
 - Create session key for encryption
 - **Authenticate network**
 - **Create session key for message authentication**
- Do not keep algorithms secret
- 128-bit session key

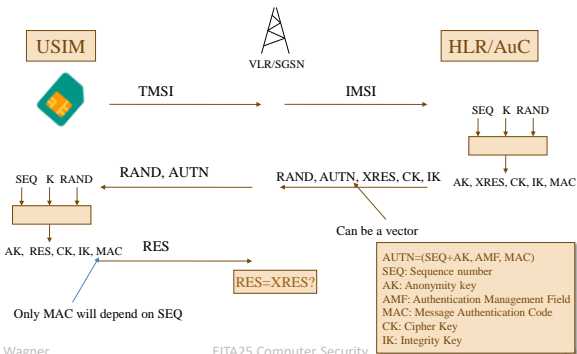
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Authentication and Key Agreement



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Functions used

- f0: Random number generator
- f1: Network authentication function. computes a MAC that is part of AUTN
- f2: User authentication function. Computes RES and XRES
- f3: Cipher key derivation function
- f4: Integrity key derivation function
- f5: Anonymity key derivation function. Used to hide sequence number
- f8: Stream cipher for session encryption
- f9: MAC for session integrity protection

f0 implemented in AuC
 f1-f5 are operator specific and implemented in USIM
 f8-f9 are mandatory for everyone and implemented in user equipment (phone)

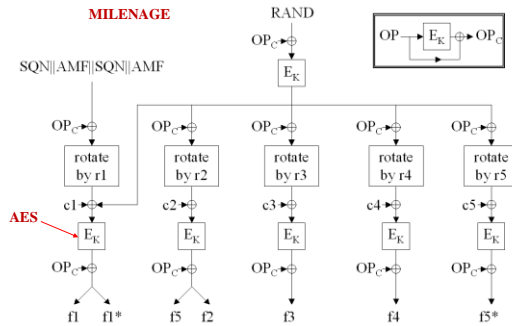
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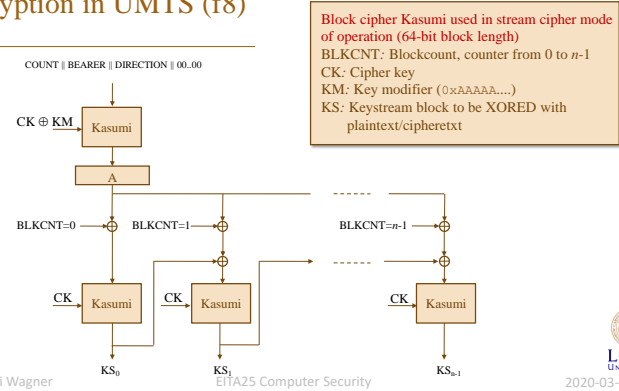
Functions computed in AuC and USIM



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Encryption in UMTS (f8)

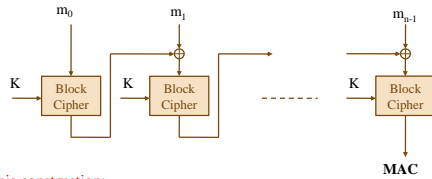


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Message Authentication, CBC-MAC

- CBC-MAC – Block cipher in CBC mode with last ciphertext as MAC value



Problem with this construction:

Get message/MAC pair of a one-block message (m,t)

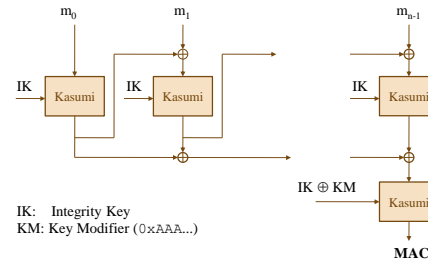
Then $m || m+t$ also has MAC t,
 $\rightarrow (m || m+t, t)$ is a valid pair

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MAC used in UMTS (f9)

- Only signalling data is authenticated
- CBC-MAC with output permutation and extra large state



IK: Integrity Key
 KM: Key Modifier (0xAAA...)

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LTE (4G)

- New generation, new features
- Quite different network, new names
 - Everything is packet switched
- Developed by 3GPP, constantly evolving with enhancements.
 - LTE is release 8 (2008)
 - LTE advanced is release 10 (2011)
 - LTE Advanced Pro is release 13 and 14 (2016)
 - 5G phases 1 and 2 are releases 15 and 16 (2019+), releases 17 and 18 (2021+)



3GPP Releases

Release Code	Name	Status	Start date	End date
Rel-18	Release 18	Open	2019-09-16	
Rel-17	Release 17	Open	2018-06-15	2021-09-17 (SA#93)
Rel-16	Release 16	Open	2017-03-22	2020-06-19 (SA#88)
Rel-15	Release 15	Frozen	2016-06-01	2019-06-07 (SA#84)
Rel-14	Release 14	Frozen	2014-09-17	2017-06-09 (SA#76)
Rel-13	Release 13	Frozen	2012-09-30	2016-03-11 (SA#71)
Rel-12	Release 12	Frozen	2011-06-26	2015-03-13 (SA#67)
Rel-11	Release 11	Frozen	2010-01-22	2013-03-06 (SA#59)
Rel-10	Release 10	Frozen	2009-01-20	2011-06-08 (SA#52)
Rel-9	Release 9	Frozen	2008-03-06	2010-03-25 (SA#47)
Rel-8	Release 8	Frozen	2006-01-23	2009-03-12 (SA#43)



Security in LTE

- Very similar authentication and key agreement as in UMTS
- AES has replaced Kasumi as confidentiality algorithm.
- New variant of Milenage proposed (based on SHA-3)
- Support for 256-bit symmetric keys
- Ericsson Research Security applied formal verification methods to prove security properties of several LTE methods (2014)



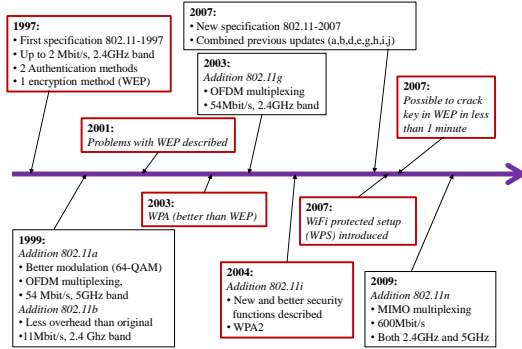
WLAN Security

- IEEE 802.11
- Security Requirements
 1. Integrity
 2. Confidentiality
 3. Authentication
- Non-cryptographic access control
 - Hide SSID – Users will have to know the SSID
 - Restrict access based on MAC address
- Cryptographic protection
 - WEP – Wired Equivalent Privacy
 - WPA – WiFi Protected Access
 - WPA2 – WiFi Protected Access 2
 - WPA3 introduced 2018
- **Specifications are (still) not publically analyzed before they are released!**

Both are more or less worthless!



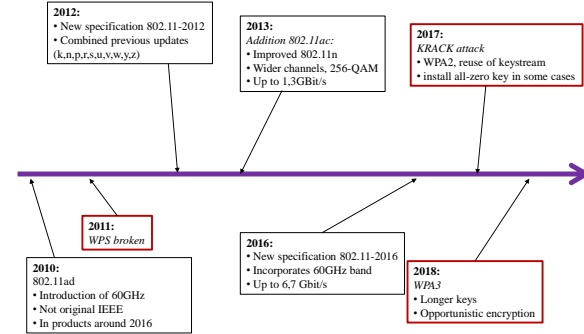
802.11 timeline



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802.11 timeline



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WEP encryption

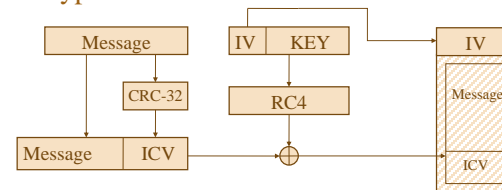
Three design goals:

- integrity
- confidentiality
- authentication

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WEP encryption



- Integrity Check Value (ICV) based on linear cyclic redundancy check
- Encryption uses stream cipher RC4
- Size of IV is 24 bits
- Size of key is 40 or 104 bits
- **Source of confusion:** 64-bit WEP uses 40-bit keys and 128-bit WEP uses 104 bit keys

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Weakness of CRC-32

- Message is divided by a degree 32 polynomial with coefficients in GF(2)
- Remainder is ICV
- Linear function – protects only against *accidental* changes if encryption is “xor plaintext with keystream”
- Assume we want to add (xor) Δ to plaintext.
 - Compute $\delta = \text{CRC-32}(\Delta)$
 - Add $(\Delta \parallel \delta)$ to ciphertext

$$\begin{aligned} (M \parallel \text{CRC-32}(M)) \oplus \text{RC4}(K) \oplus (\Delta \parallel \delta) &= (M \oplus \Delta \parallel \text{CRC-32}(M) \oplus \delta) \oplus \text{RC4}(K) \\ &= (M \oplus \Delta \parallel \text{CRC-32}(M \oplus \Delta)) \oplus \text{RC4}(K) \end{aligned}$$

- We still have a valid message \rightarrow no integrity protection



WEP encryption

Three design goals:

- ~~integrity~~
- confidentiality
- authentication



Weakness in encryption

- IV is only 24 bits. After 2^{24} frames the IV will repeat.
- If the key is not changed the keystream will repeat

$$C \oplus C' = \text{RC4}(\text{IV} \parallel K) \oplus P \oplus \text{RC4}(\text{IV} \parallel K) \oplus P' = P \oplus P'$$

- **Much worse problem:** RC4 does not define how to use IV so it was decided to concatenate the IV with key!
- It is possible to recover the key very fast using this setup
- It does not matter if it is 40 or 108 bit key, it is still easy to break
- No defense against replay attacks
 - Makes it easy to gather lots of encrypted data



WEP encryption

Three design goals:

- ~~integrity~~
- ~~confidentiality~~
- authentication



RC4

- Probably the most well known (and simplest) stream cipher
- Designed 1987 but kept secret, leaked out 1994
- Also referred to as ARC4 and ARCFOUR since the name RC4 is a trademark
- Many weaknesses have been found
- In SSL/TLS there is no IV in RC4. One stream is used for each key
 - But there are other problems that makes it unsuitable

$KSA(K[0..l-1])$ Initialization: For $i = 0 \dots N - 1$ $S[i] = i$ $j = 0$ Scrambling: For $i = 0 \dots N - 1$ $j = j + S[i] + K[i \bmod l]$ Swap($S[i], S[j]$)	$PRGA(K)$ Initialization: $i = 0$ $j = 0$ $S = KSA(K)$ Generation loop: $i = i + 1$ $j = j + S[i]$ Swap($S[i], S[j]$) Output $\pi = S[S[i] + S[j]]$
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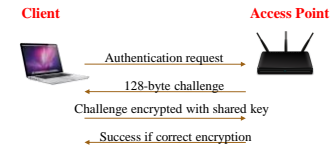
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Authentication in WEP

- Open system authentication
 - Same as no authentication
 - Client sends identity to authenticator
 - Authenticator sends association message back
- Shared key authentication
 - Prove that you have the key (password)
 - Challenge response protocol using shared WEP key



Attack: Save *keystream* = *challenge* @ *response* for an IV. Use same *keystream* for any new challenge and use same IV.

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WEP encryption

Three design goals:

- **integrity**
- **confidentiality**
- **authentication**

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WPA, WPA2 and WPA3

- Wi-Fi protected Access
- First version (WPA) started to appear in APs around 2003
 - Designed to quickly fix the problems in WEP
 - Important that the same hardware could be used
 - » only a software update was necessary
 - Based on 802.11i, but only a draft of it
 - Much stronger than WEP
 - » Better authentication
 - » Avoiding confidentiality and integrity problems in WEP
- Full implementation of 802.11i, using AES is called WPA2
- WPA3 announced in 2018

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802.11i Authentication

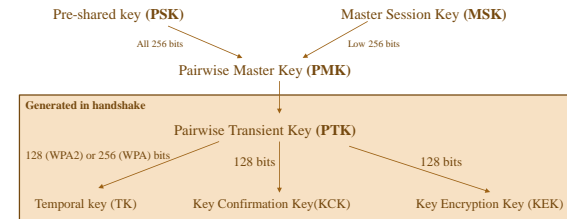
- Can use a specific server for EAP authentication
 - Supports several methods for authentication
 - More on this in the course "Advanced Computer Security"
 - Authentication server constructs a **Master Session Key (MSK)**
- Can also use a pre-shared key (called WPA-PSK)
 - Still keys are different for each user and each handshake
 - The **pre-shared key (PSK)** is derived from the password
 - Function used is Password-Based Key Derivation Function 2 (PBKDF2)
 - Slow function → Key strengthening

$PSK = PBKDF2(PRF, password, salt, iterations, output\ size)$

- WPA uses PBKDF2(HMAC-SHA1, password, ssid, 4096, 256)

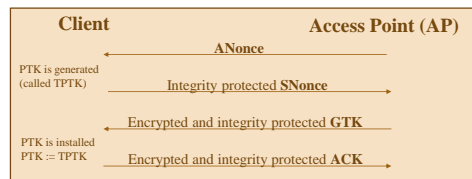
Keys in 802.11i

- A hierarchy of keys



AP also has a Group Master Key (GMK) used for broadcast messages

4-way handshake

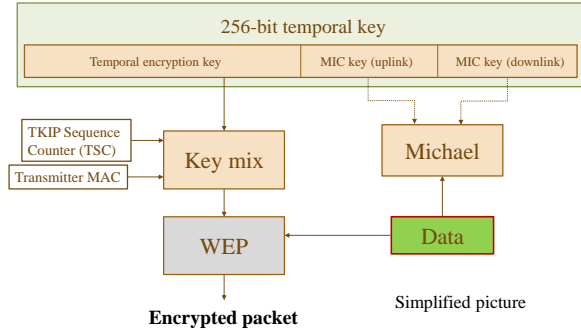


- PTK is hash of (PMK, MAC_{client} , MAC_{AP} , ANonce, SNonce)
 - Iterated SHA-1
 - Note that MAC here is *MAC address*
- Last two messages constructed such that *key confirmation* is provided
- Encryption and integrity protection in handshake uses KCK and KEK
- GTK is derived from GMK and updates every time someone leaves or enters the network

TKIP

- Temporal Key Integrity Protocol
- 256 bit temporal key divided into 128-bit encryption key and 2x64 bit integrity key (one for each direction)
- Message Integrity Code (MIC), Michael, is used
 - "MIC" removes "MAC" confusion in this context
- IV is increased to 48 bits and used as counter to prevent replay attacks
- New encryption key for every frame
 - Encryption key is mixed with counter
- WEP is still used
- Attacks on WEP are no longer possible

TKIP (WPA)



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CCMP (WPA2)

- Fully implementing 802.11i
- RC4 is replaced by AES in CCMP mode
 - AES used in counter mode
 - CBC-MAC based on AES instead of MIC
- Same 128-bit temporal key used for both encryption and MAC
 - Authenticated encryption
- Requires new hardware since completely new encryption algorithm is used

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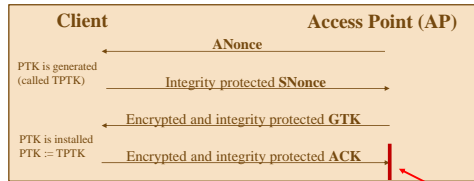
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KRACK Attack

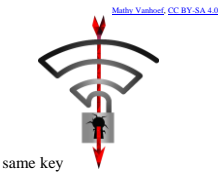
- October 2017
- Third step in 4-way handshake will install key in devices
- Force authenticator (AP) to replay message 3 → supplicant (client) reinstalls same key
 - Nonce is reset
 - Replay counter is reset
- Android 6.0: Zero key is installed

Details are very implementation dependent



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(Wired) KRACK Attack!

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Dragonblood Attack

- April 2019
- Serious design flaw in WPA3
- Allows attacker to perform
 - downgrade attacks
 - side-channel attacks
- **Problems:**
 - enables brute-forcing passphrase
 - DoS attacks on Wi-Fi base stations



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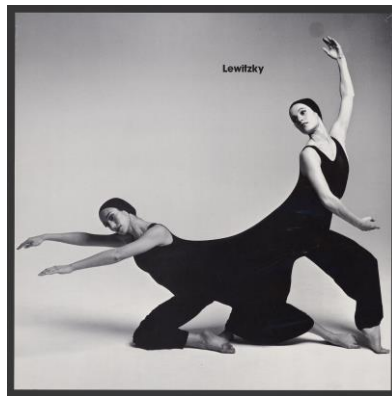
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Is wireless better?



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Stay connected

What's next?

- Optional Exam Friday 20/3, 14-19, MA:10F-H
 - For grade 4-5
- If you want more security courses
 - Web security HT1, 4 hp,
 - Advanced computer security, HT1, 7.5 hp
 - Advanced web security, HT2, 7.5 hp
 - Cryptology, HT2, 7.5 hp
 - Secure Systems Engineering, VT1, 7.5 hp

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