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Lecture 3

Wireless Internet-oriented Infrastructures and Protocols

Mobile Business I (WS 2023/24)

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Guiding Question of this Lecture

Why did Wireless LAN not succeed over GSM and UMTS?

Overview

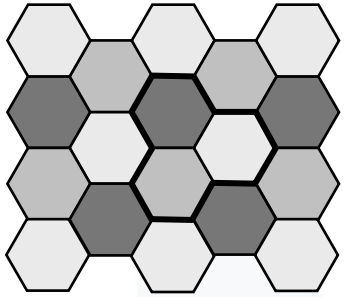
- Wireless LAN
  - Basics
  - Components and Infrastructure Types
  - State-of-the art Encryption
  - Mobility and Roaming
- Mobile IP – Mobility support for TCP/IP
- IP-based Radio Access Networks

Wireless LAN Basics
General

- Wireless communication based on radio as transport medium
- Cell based architecture
- Extension to a (wire based) LAN
- One cell serves an area in which PCs, laptops, and other connected devices can move freely.
- The term "Wi-Fi“ is
  - used in general English as synonym for a Wireless Local Area Network (WLAN),
  - a trademark owned by the *Wi-Fi Alliance*, a trade association promoting Wi-Fi technology.

Wireless LAN Basics
Radio Cell

- The basic module of a Wireless LAN is a so-called radio cell.
- A radio cell covers a circular area that PCs or laptops and other connected devices are able to use.



- A WLAN radio cell can be an add-on for already existing cable-based networks.

Wireless LAN Basics
Beacon Frame

- The Access Point is transferring a periodical beacon. A beacon communicates the Service Set Identifier (SSID) and other important operational parameters (channel, …)
- A Wireless LAN client sends a probe request. The Access Point answers with a probe response. If there is an agreement, the Wireless LAN client starts the communication over the Access Point.
- A more detailed description of beacon frames can be found in [Sauter2008].

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Wireless LAN Basics
802.11 Standard

Standard	Description
802.11	Protocol for transmission methods for wireless networks, defined in 1997 for **2 MBit/s** at 2,4 GHz
802.11a	Wireless LAN **up to 54 MBit/s** at 5 GHz
802.11b	Wireless LAN **up to 11 MBit/s** at 2,4 GHz
802.11f	Roaming between access points of different manufacturers (published in 2003 and withdrawn by IEEE in 2006) [IEEE2010]
802.11g	Wireless LAN **up to 54 MBit/s** at 2,4 GHz
802.11i	Extended security features: AES, 802.1x, TKIP
802.11n	Wireless LAN **up to 450 MBit/s** when using 3 spatial streams (3x 150 Mbit/s) at 2,4 GHz or 5 GHz *)
802.11r	Fast Roaming/Fast BSS Transition
802.11ac	Wireless LAN using 3 spatial streams at 5 GHz: **Up to 1.3 GBit/s** (3x 433 Mbit/s) or even **up to 2.6 GBit/s** (3x 867 Mbit/s, part of *802.11ac Wave2*) *) **)
802.11ad	Wireless LAN at 60 GHz: **Up to 7 GBit/s**
802.11ah	Wi-Fi HaLow for Smart Home and connected devices (900 MHz, increased distance, ~1km)
802.11aj	A derivative of 802.11ad for use in the 45 GHz unlicensed spectrum in some regions of the world (specifically China)
802.11ax	New Standard operating in the existing 2.4 GHz and 5 GHz spectrums but incorporating additional bands between 1 and 7 GHz. Achieved 4x increase to user throughput.
802.11ay	Upcoming Standard extending 802.11ad by defining a new physical layer for 802.11 networks to operate in the **60 GHz** spectrum
802.11ba	Amendment of IEEE 802.11 enabling energy efficient operation for data reception without increasing latency
802.11be	Potential next amendment likely be designated Wi-Fi 7 building upon 802.11ax

*) 802.11n and 802.11ac data rates depend on the number of antennas and spatial streams (“parallele räumliche Inhaltsströme”) supported by the hardware. 802.11ac devices often support 3 streams at most. 802.11n specifies a maximum of 4 streams, 802.11ac a maximum of 8 streams.

**) 802.11ac is a 5 GHz-only standard, so dual-band access points and clients will probably continue to use 802.11n at 2.4 GHz in parallel.

[IEEE] [Sauter 2008]

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Wireless LAN Basics
802.11 Standard In Process

Standard	Description
802.11be	Extremely High Throughput
802.11bf	WLAN Sensing
802.11bh	Randomized and Changing MAC Addresses
802.11me	802.11 Accumulated Maintenance Changes
802.11bi	Enhanced Data Privacy
802.11bk	320 MHz Positioning

[IEEE]

Wireless LAN Basics
Bandwidth Volatility

- Wireless LAN bandwidth depends on the **chosen standard**, the **distance** between client and access point, and the construction and quantity of **walls**.

Bandwidth 802.11b	Outside	Inside (Office)	Inside (House)
11 Mbps	~ 160 m	~ 50 m	< 20 m or max. 1 wall
5.5 Mbps	~ 270 m	~ 70 m	< 30 m or max. 2 walls
2 Mbps	~ 400 m	~ 90 m	< 40 m or max. 3 walls
1 Mbps	~ 550 m	~ 115 m	< 50 m or max. 4 walls

[Lanz 2003]

- **802.11b** uses the **2.4 GHz frequency band**. Reach depends even more on local circumstances when using newer IEEE standards together with **5 GHz frequency band**.

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Wireless LAN Components

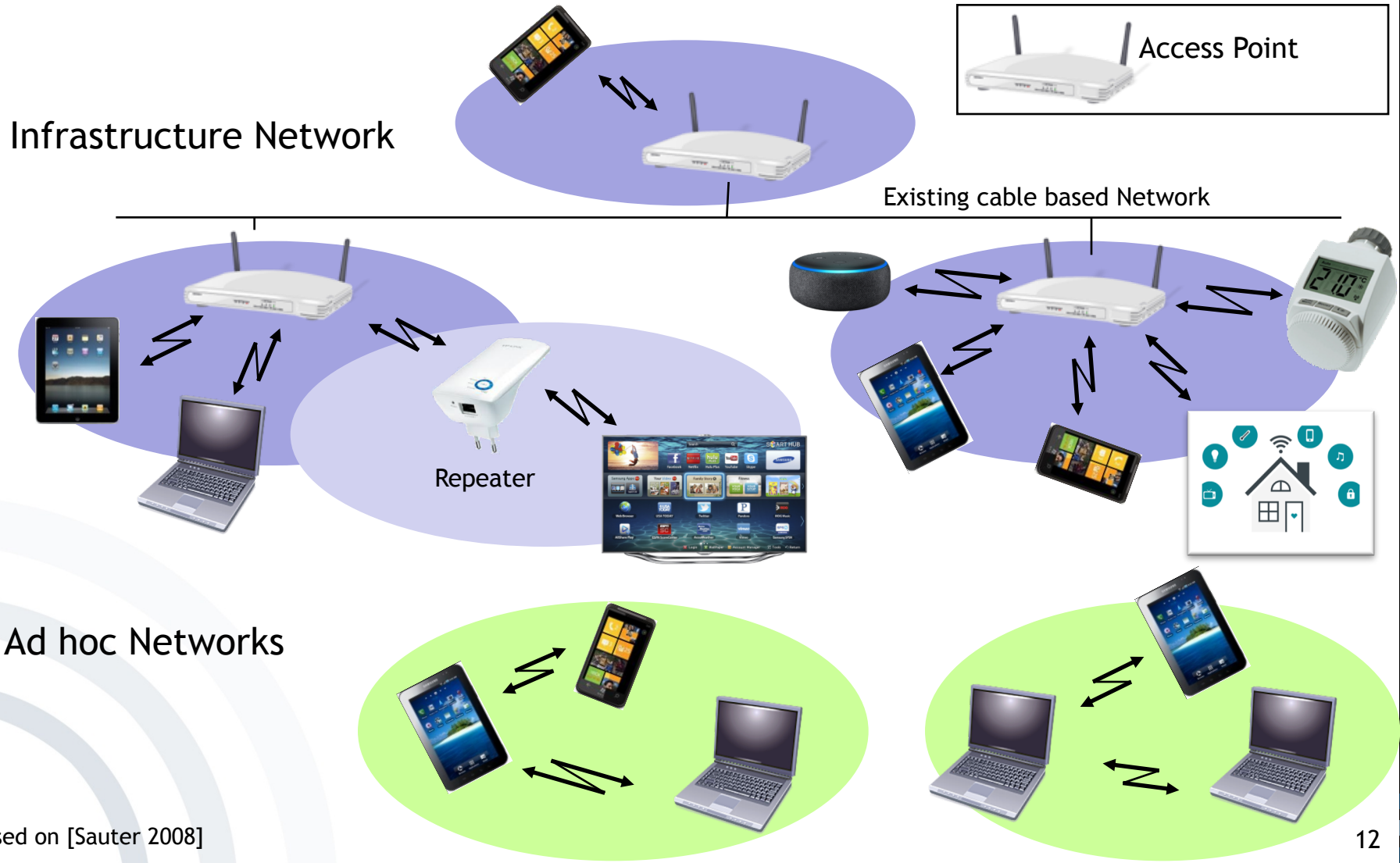
- Components (802.11b)
  - Access Point (AP)

    Sender and receiver station that allows the connecting of many stations

  - Stations

    End-systems that establish a wireless connection e.g. by using an Access Point (e.g. a notebook with built-in Wireless LAN)

Wireless LAN Infrastructure Types



Based on [Sauter 2008]

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Wireless LAN
State-of-the art Encryption

- There are numerous methods for Wireless LAN encryption.
- We are only looking at methods that use a pre-shared key (PSK).
- WEP encryption methods are outdated and hence insecure:
  - Wired Equivalent Privacy (WEP) 64-bit
  - Wired Equivalent Privacy (WEP) 128-bit
- WEP 128-bit can be by-passed within minutes. [Heise 2007]

PSK

Wireless LAN State-of-the art Encryption

- **Wi-Fi Protected Access (WPA)** was developed by the Wi-Fi Alliance. [Wi-Fi 2010]

- There are two versions of **Wi-Fi Protected Access,** WPA and WPA2:
  - **WPA** includes most of the 802.11i standard, but is **outdated and insecure** as it has various weaknesses:
    - Vulnerability to dictionary attacks when using a weak PSK
    - Other weaknesses inherited from earlier standards [ArsT 2008]
  - **WPA2** includes **802.11i** to its full extent and also the Advanced Encryption Standard (AES).

WPA-PSK

Key Reinstallation Attacks (KRACKs) against WPA2

- The attack is mainly against the ***4-way handshake*** of the WPA2 protocol.
- The 4-way handshake protocol is mathematically proven, but it only assures the negotiated key remains secret, and that handshake messages cannot be forged.
- The attack doesn't leak the encryption key, but sensitive information (usernames, passwords, …) can be stolen.
- Discovered by Mathy Vanhoef – a post-doctoral researcher at *KU Leuven*
- *Background material and video on the attack via* https://www.krackattacks.com

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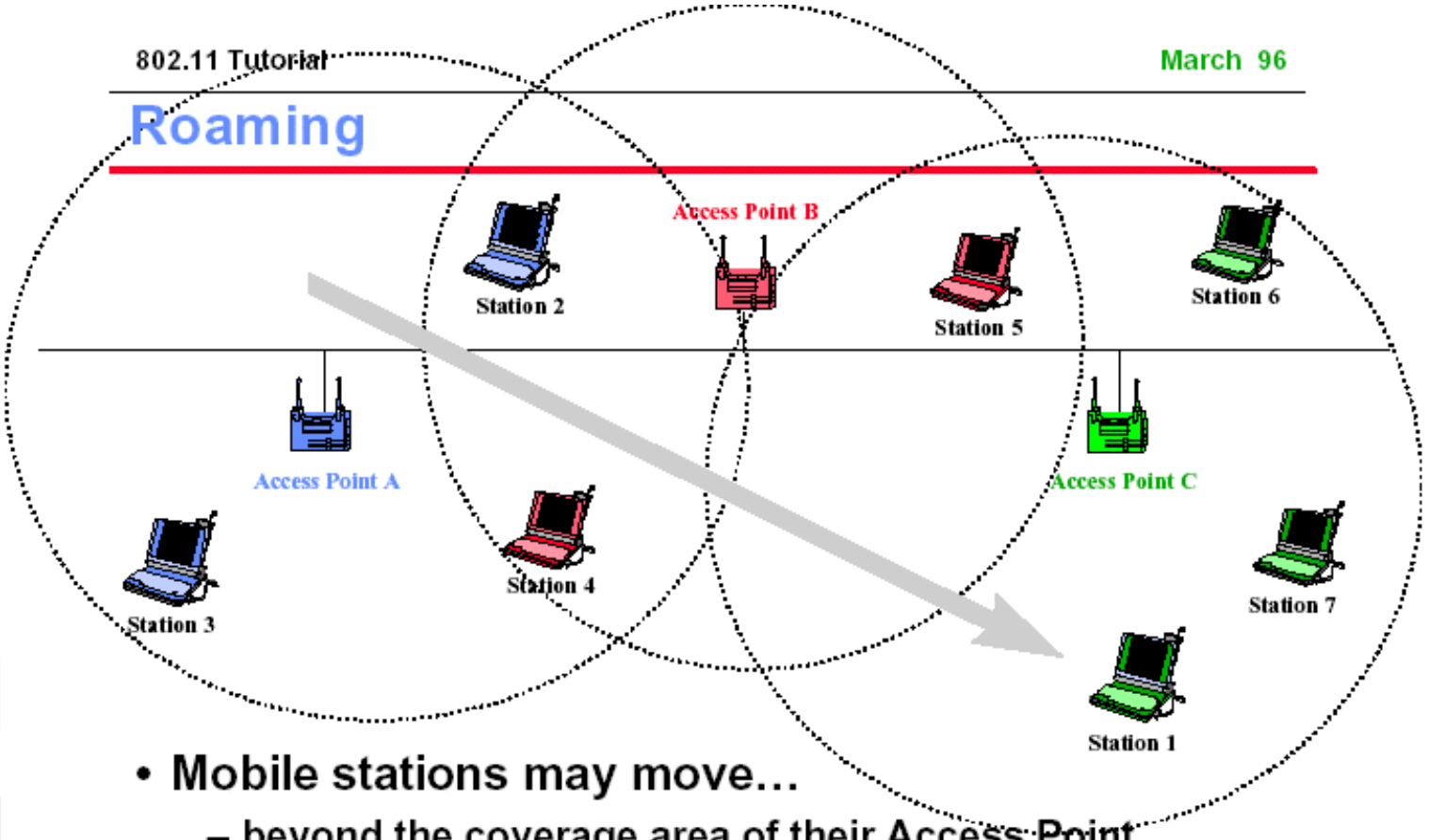
Restrictions of WLAN Mobility

- No existing standard for “handover” or “roaming” between:
  - Access points (AP)
  - Different providers of APs
- Change of AP leads to
  - Connection interrupt
  - New connection/authentication
- Non-uniform accounting / user administration

→ Some of the reasons why WLAN will not replace mobile communication networks

Wireless LAN Mobility Problems



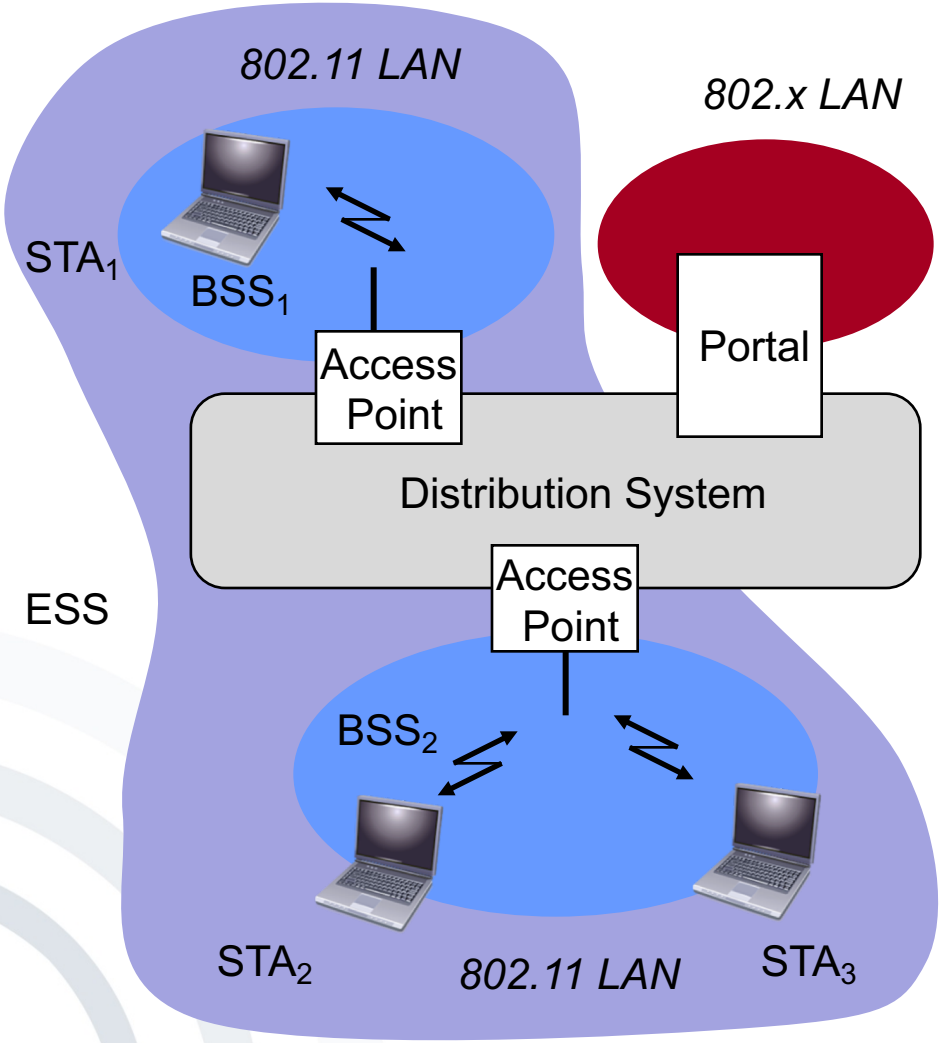
- Mobile stations may move…
  - beyond the coverage area of their Access Point
  - but within range of another Access Point
- Reassociation allows station to continue operation

[IEEE 1996]

Wireless LAN “Roaming”

- Approaches to perform “roaming”
  - By a combination of several access points a so-called distribution system is growing.
  - Every access point covers one radio cell.
  - Upon leaving a radio cell the station starts scanning for other existing access points (which may use the same SSID, but a different transmission channel) and tries to connect.
  - Following the connection to a new access point the distribution system and the access point that was used before will be informed.

Wireless LAN “Roaming”



Station (STA)

- Computer with access to the wireless medium and radio connect to the AP

Basic Service Set (BSS)

- Group of stations, which use the same radio frequency

Access Point

- Station which is integrated into the radio as well as the fixed local area network (distribution system)

Portal

- Transfer into another network

Distribution systems

- Connection of different cells for building a larger network (ESS: Extended Service Set)

Wireless LAN Mobility
Fast BSS Transition (802.11r)

- **BSS = Basic Service Set.**
  A *Basic Service Set (BSS)* is one Wireless LAN access point + all associated stations.
- The client decides which access point to (re)connect to in case the connection to the previous access point is lost (e.g. due to the client moving out of range).
- Wireless security protocols induce interruptions of several seconds during necessary reconnection (problem when using Voice-over-IP telephony connections!).
- Since 2008 a standard for "roaming" between Wireless LAN access points is available:
  IEEE 802.11r = fast roaming and fast BSS transition
  - As of February 2013, no Intel devices support the 802.11r standard. [Intel 2013]
  - For Apple devices iOS 6 introduced support for 802.11r (optimized client roaming on enterprise Wi-Fi networks). [Apple 2012]

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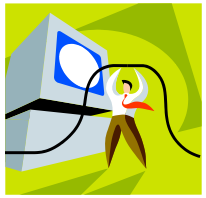
Mobile IP
Mobility with TCP/IP

The situation today:

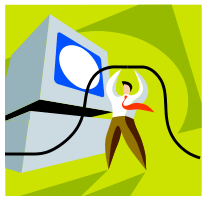
- Separate IP addresses in the office and at home
- DHCP – dynamic IP address assignment
- Dial-up with dynamic IP addresses
  - Continuous accessibility via one IP address is not guaranteed.
  - Connection interruptions during access point switches

Mobile IP
Routing in TCP/IP

Partner B
IP address, e.g.
61.9.193.200



Router



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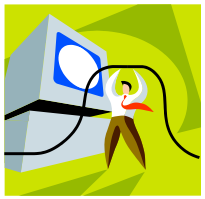

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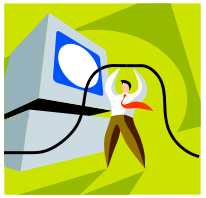


Router

Partner A
IP address,
e.g. 141.2.74.211

- Routing takes place from Partner A node to Partner B node and in reverse direction.
- Both nodes have their own address.
- The route follows the addresses.
- Routing of data packets by routers

Mobile IP
Addressing of Mobile Devices

Standards

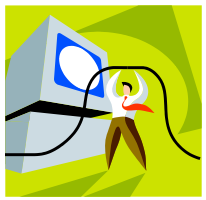
- Internet Engineering Task Force (IETF)
  www.ietf.org
- RFC 2002: IP Mobility Support
- RFC 2977: Mobile IP Authentication, Authorization, and Accounting Requirements

Mobile IP
Mobility problem

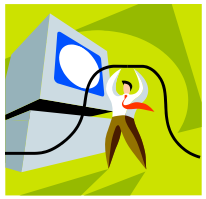
Old IP address (Partner B)

Partner B changes network

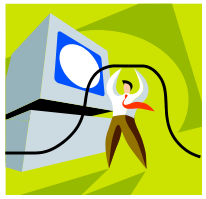
New IP address
(Partner B)



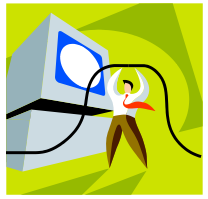
Router



Router



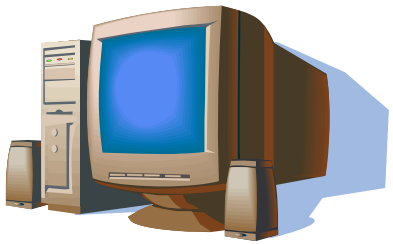
Router



Router

Partner A

Mobile IP
Mobility solution - Layer 3

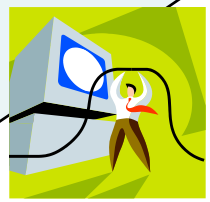


Redirection (“Tunneling“) via home address to mobile device

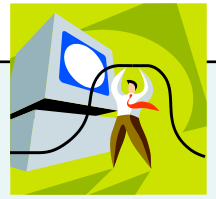
Home address (Partner B)

New IP address (Partner B)

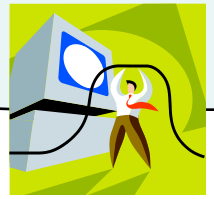
Router



Router



Router



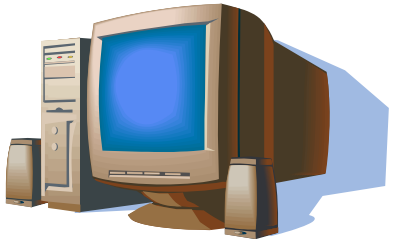
Router

Partner A

Mobile IP
Mobility solution - Layer 3

- **But** redirection implies
  - A longer route than before
  - Higher runtime
  - Avoidable usage of resources

Mobile IP
Mobility solution - Binding Update



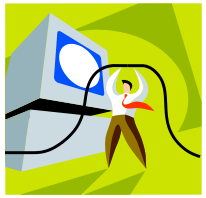
Redirection of the first package
via home address
to the mobile device

New
IP address
(Partner B)

Home address
(Partner B)

New route
with remaining
packets

Binding
Update
1st packet



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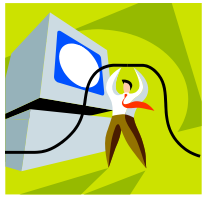

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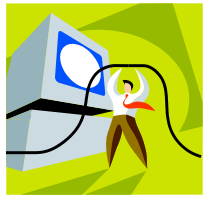

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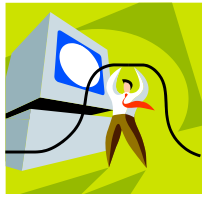

Router

Partner A

Security for Mobile IP

- Possible attack with illegitimate binding update: **Capture the route** and redirect the TCP/IP session.

  ➲ **Therefore, authentication** of Binding Update (BU) messages and address check is required.

- In addition, **observation** of user movements through their Binding Updates!

  ➲ Anonymous communication-channels are necessary to protect privacy.

Domain Names and Mobile IP

- In the **Domain Name System** a domain-name belongs to a fixed IP address (e.g. www.m-lehrstuhl.de = 141.2.66.180).
  - **Changing** these addresses requires an update-time of several hours ➲ this is no usable solution.
- **Better solution: Dynamic DNS**
  - Modification time: 15 minutes
  - Problem: applications resolve a name just once and do not query possible address changes thereafter.

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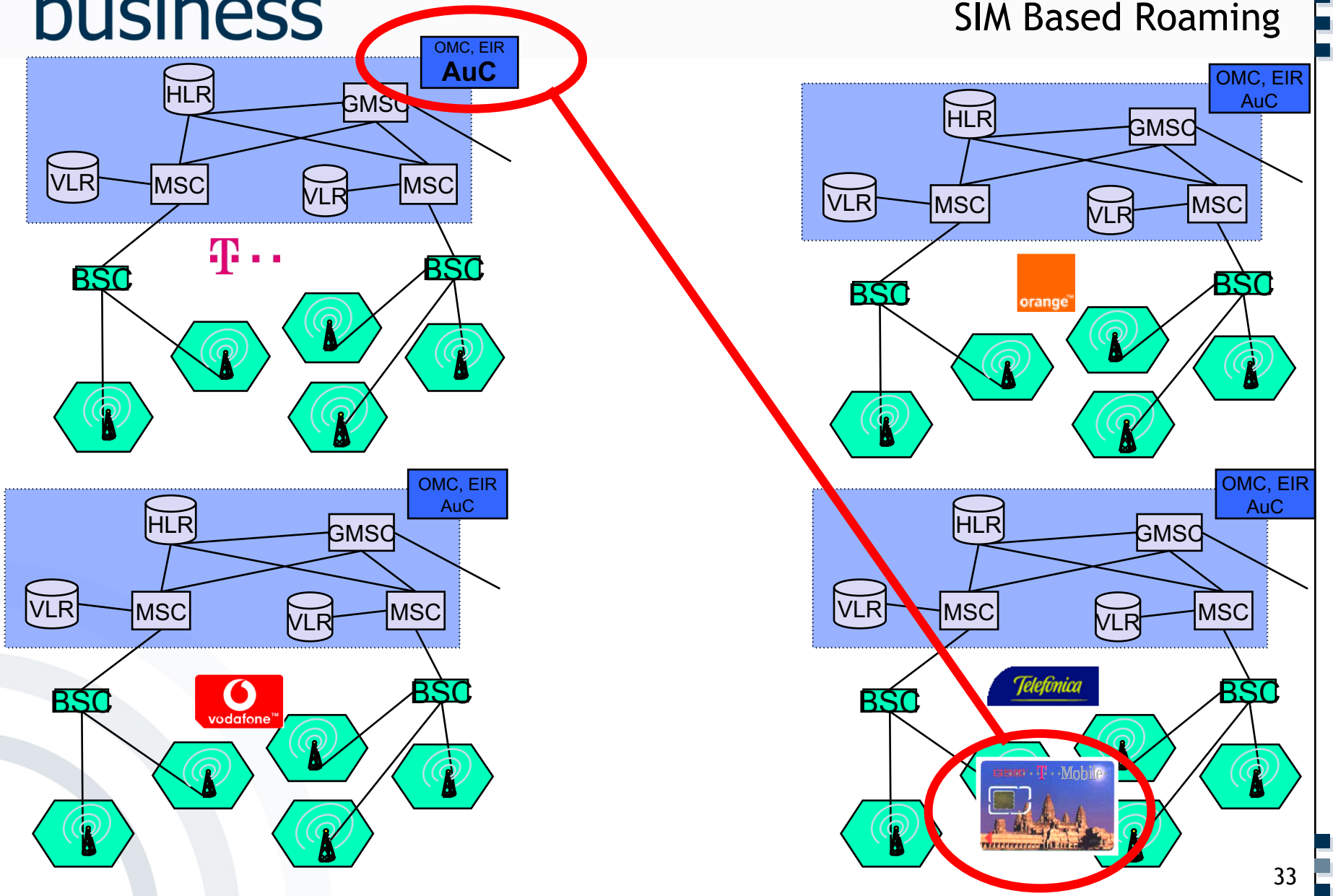
Roaming

SIM Based Roaming



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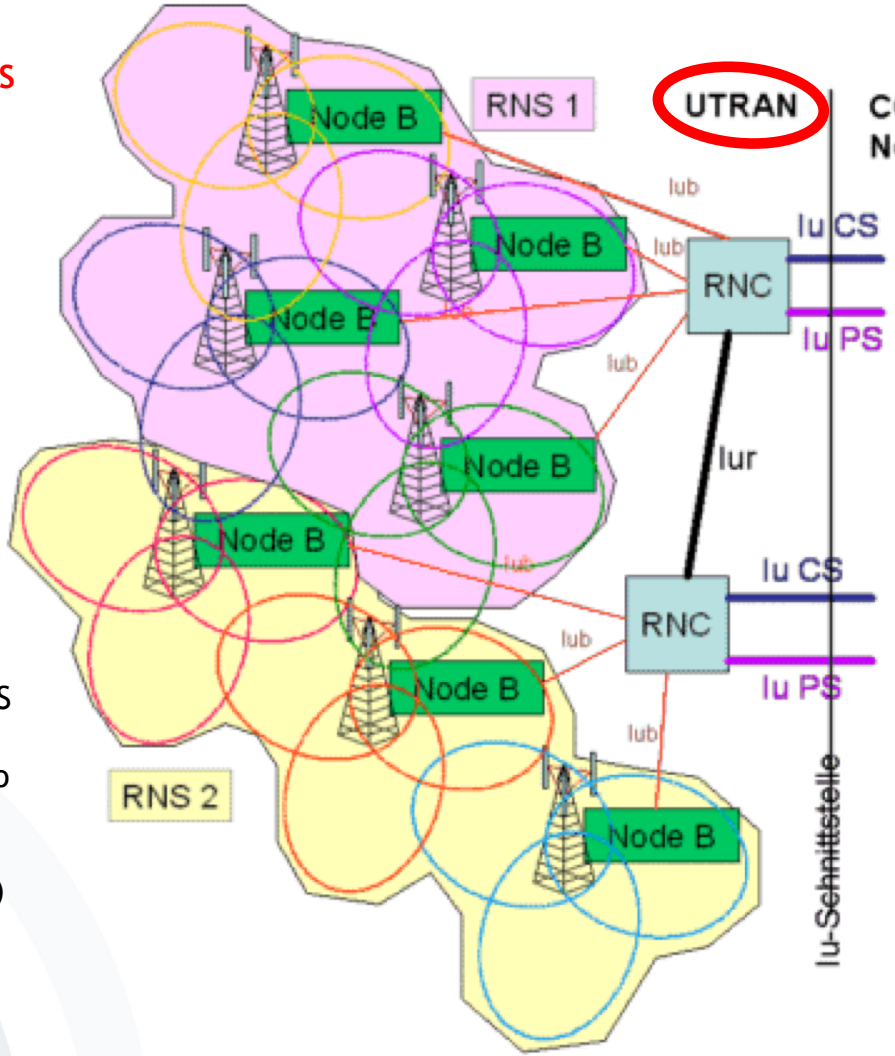
UMTS (3G) System Architecture

- ***UTRAN:*** **UMTS Terrestrial Radio Access Network**
- ***RNS:*** Radio Network Subsystem
- ***RNC:*** Radio Network Controller (controls the Node Bs)
- ***Node B:*** UMTS base stations (equivalent to base transceiver stations (BTS) in GSM



UMTS Core network
- is not shown here in detail
- UMTS Core network corresponds to Network- & Switching Subsystem (NSS) in GSM

Source: UMTSlink.at (2011)

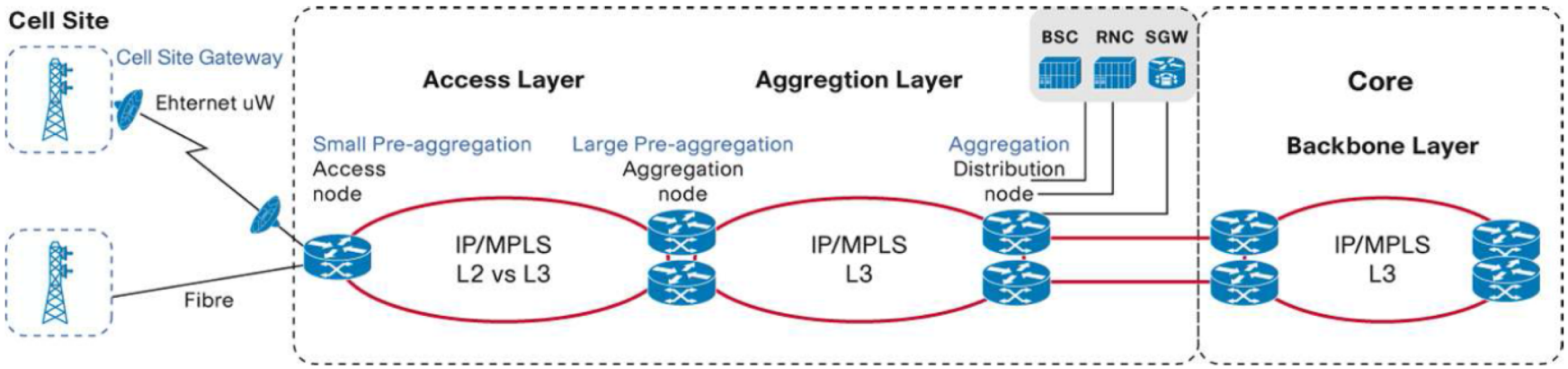
Radio Access Networks (RAN)

- Part of a mobile telecommunication system
- Provides connection between device (phone, computer, or machine) and core network
- Implements certain radio access technologies, e.g. GSM or 3G
- Examples of radio access network types are:
  - **GRAN:** GSM radio access network
  - **GERAN:** essentially the same as GRAN but specifying the inclusion of EDGE packet radio services
  - **UTRAN:** UMTS radio access network
  - **E-UTRAN:** Long Term Evolution (LTE) high speed, low latency radio access network
  - **C-RAN**: Centralized or Cloud-based radio access network
  - **VRAN**: Virtualized RAN
  - **ORAN**: Open Radio Access Network (Open RAN)
- Some handsets have capability to be simultaneously connected to multiple RANs (dual-mode handsets).

[Wiki 2014]

IP-based Radio Access Networks (IP RAN)

- All different backhaul technologies may be collapsed onto a single IP/MPLS network (MPLS = Multiprotocol Label Switching) → End-to-end IP approach
- Support for legacy services and reduced cost per bit
- 2G, 3G, and 4G radio technologies transparently supported
- Cost savings possible due to alternative transport media (such as Ethernet and DSL)



[Cisco 2011] [Cisco 2014]

IP-based Telephony

- LTE networks are **IP-based systems** (all-IP networks)
  - Voice calls in GSM and 3G (UMTS) are **circuit-switched**.
  - Only **packet-switched** communication is supported in LTE networks – no circuit-switched connections/calls/telephony!

- Five different approaches to provide telephony services in Long Term Evolution networks:
  - **CSFB (Circuit Switched Fallback)**
  - **VoLGA** (Voice over LTE via GAN – Generic Access Network)
  - **VoLTE (Voice Over LTE)** based on the IP Multimedia Subsystem (IMS) network.
  - **SVLTE** (Simultaneous Voice and LTE, handset-based approach)
  - Usage of Over The Top contents (OTT) (e.g. Skype) – not actively marketed by mobile operators

Literature (1)

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PSK
Pre-shared key

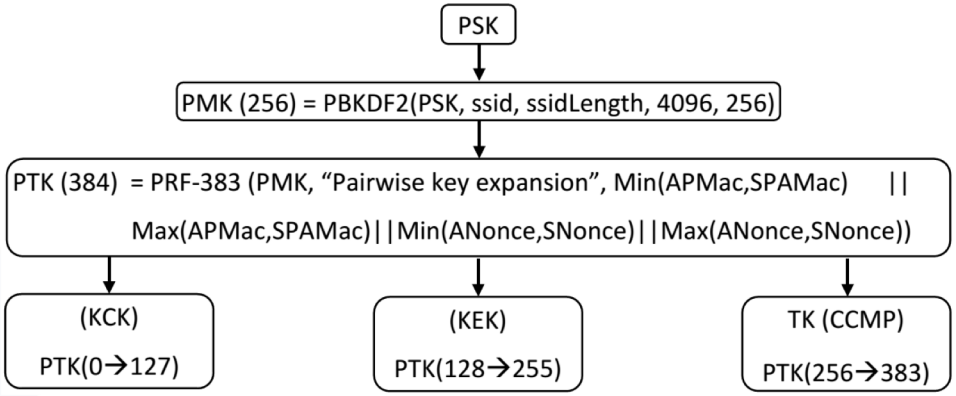
- The pre-shared key **method** of authentication enables a remote host to authenticate itself by providing a secret key, which is known to both hosts. This key is pre-configured by the administrator, and is used along with the Diffie-Hellman shared secret to derive cryptographic keys used to protect and authenticate data that flows during the phase 1 negotiation.
- **The pre-shared key** is a shared secret between the two IKE peers, and any host that does not know the shared key cannot enter into negotiation. IKE maintains a list of all the remote hosts that are authorized to negotiate. This list contains the identity of the remote host and the pre-shared key known to that host. [IBM2021]

The WPA2-PSK four-way hand- shaking procedure starts when the wireless client passes the authentication and the association states.

Back

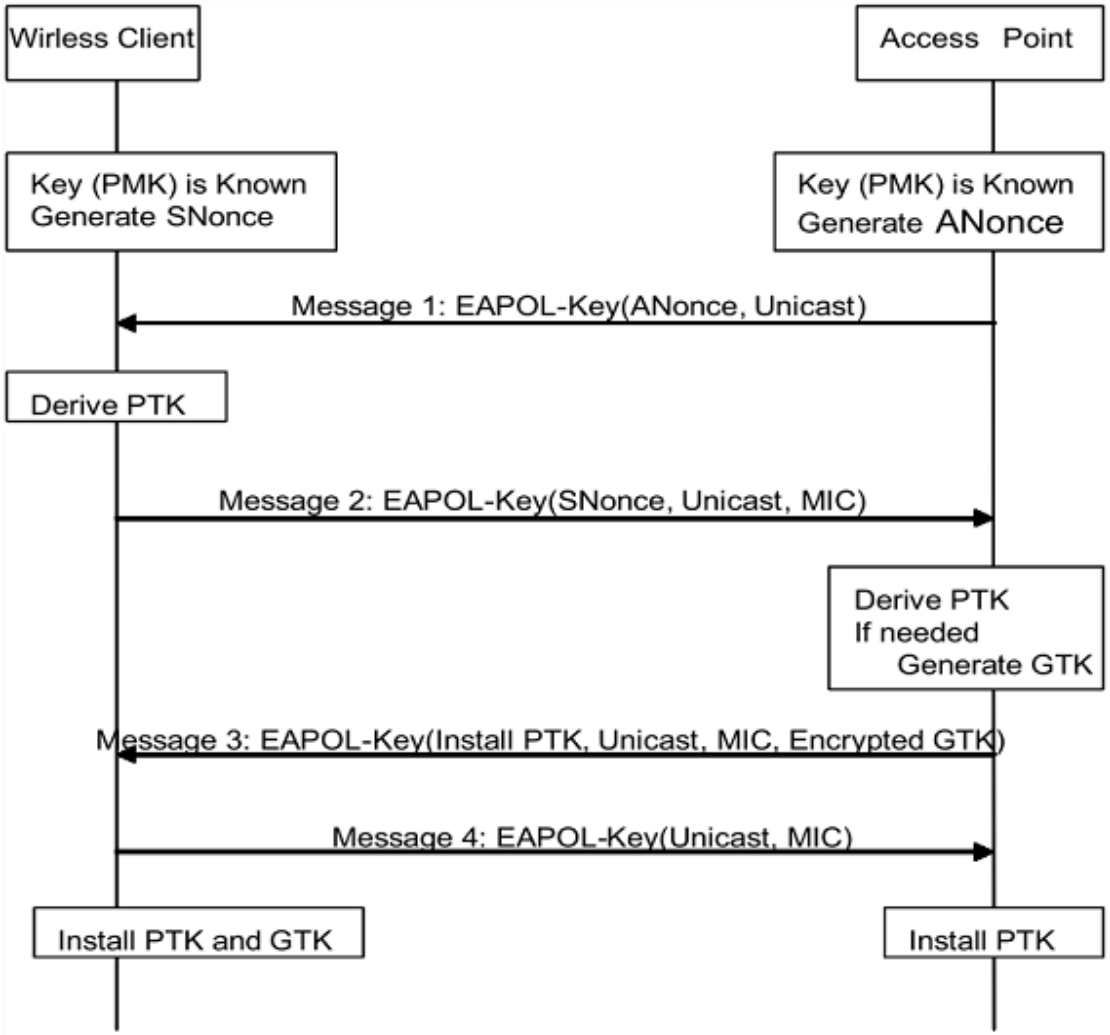
WPA2-PSK key generation

- WPA2-PSK protocol, essentials and methods:
  1. **PSK:** Pre-shared key (PSK) is derived from the pass-phrase that was entered manually on both the wireless client and the AP. The pass-phrase length is 8 to 63 characters.
  2. **PMK:** Using a Password-Based Key Derivation Function 2 (PBKDF2), the pass-phrase, SSID and SSID length are hashed 4096 times to produce a 256-bit Pair Master Key (PMK) as shown in Figure.
  3. **PTK:** PMK, the phrase "Pairwise key expansion", AP's MAC address and the wireless client's MAC address, a random number generated by the AP (ANonce) and a random number generated by the wireless client (SNonce) will be fed to a pseudo-random function (PRF) to produce Pair Temporary Key (PTK).
  4. **Triple essential keys** (**KCK**: Key Confirmation Key, **KEK**: Key Encryption Key, **TK**: Temporal key)



Back

WPA2-PSK Handshake Protocol



Back