King Fahd University of Petroleum & Minerals
Computer Engineering Dept

COE 543 – Mobile and Wireless Networks

Term 061

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Lecture Contents

1.

Main References

- K. Pahlavan and P. Krishnamurthy, A Unified Approach: Principles of Wireless Networks, Prentice Hall, 2002 – Section 6.4
- J. Wilkes, “Privacy and Authentication Needs for PCS,” IEEE Personal Communications, August 1995, pp. 11-15
- J. Williams, “The IEEE802.11b Security Problem, Part 1,” IT Professional, November-December 2001, pp. 91-95 (and the references therein)

Wireless Media

- RF is a shared media
  - Wireless communication is more susceptible to eaves dropping
- No privacy
- The presence of the communication request does not uniquely identify the originator
- Need for Privacy and Authentication

None Cryptographic Means

- Number Assigned Module (NAM) and Electronic Serial Number (ESN)
  - Used for authentication
- Using the > 900 MHz band
  - Outside the range of typical scanners
- Which is more secure FDMA, TDMA, or CDMA?
- None cryptographic methods usually do not provide the proper solution

http://www.philzimmermann.com/

Levels of Privacy

- Level 0: None – with no privacy enabled
  - Anyone with digital scanner can monitor calls
  - A “lack of privacy” indicator should be provided – a public trust issue
- Level 1: Equivalent to Wireline
  - Most people assume wireline calls are secure – eaves dropping can be detected – not as in wireless
  - Used for routine every day calls
  - Would take a year or so to break encryption – would require same effort to break every call
- Level 2: Commercially Secure
  - For proprietary info
  - Would take 10~25 yrs to break encryption – would require same effort to break every call
- Level 3: Military/Government Secure
  - None breakable?

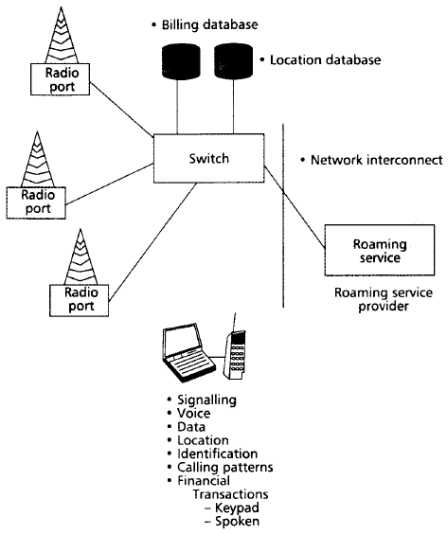
Privacy Requirements

- Privacy of Call Setup Information
  - Calling #, calling card #, type of service, etc.
- Privacy of Speech
  - Must be encoded and none interceptable
- Privacy of Data
  - Must be encoded and none interceptable
- Privacy of User Location
  - Location should not be disclosed – encrypting user id
  - Remember HLR and VLR have this info – must not be subject to attacks

Privacy Requirements – cont'd

- Privacy of User ID
  - User ID may be encrypted
  - Prevents analysis of calling patterns for this ID – VERY IMPORTANT
- Privacy of Calling Patterns
  - No info sent from mobile should allow traffic analysis
  - This info: calling #, frequency of use, caller identity
- Financial Transactions
  - Visa card # or bank transactions over the air!!
  - Securing the DTMF

Privacy Requirements



Theft Resistance Requirements

- Cryptographic design should make the reuse of stolen personal terminal difficult
  - Even if registered to a new legitimate account
- Clone Resistant Design
  - Mobile unique info must not be compromised
    - Over the air – eaves dropping
    - From the network – secure databases
    - From network interconnect – info passed between systems for security checking of roaming mobiles must have enough info to authenticate the mobile and not enough info to clone it!!
    - From users cloning their own mobiles

Theft Resistance Requirements – cont'd

- Installation Fraud
  - Cryptographic system must be designed to that installation cloning is reduced or eliminated
- Repair Fraud
- Unique User ID
  - Identify the correct person using the mobile for billing purposes
- Unique mobile ID
  - Different than user ID
  - Smart card or PCMCIA card containing all security info

Radio System Requirements

- Multipath Fading
  - Immune to sever burst errors
- Thermal Noise/Interference
  - The modulation scheme and the cryptographic system must be designed so that interference with shared users of the spectrum does not compromise the security of the system
- Jamming
  - Should work in the face of jamming – does not break
- Support for Handovers

Other Requirements

- Lifetime of ~20 years:
  - An algorithm that is secure today may be breakable in 5 to 10 years
- Physical Requirements:
  - Mass production
  - Exported and Imported
  - Minimal impact on handset size, weight, power consumption, etc.
  - Low-cost Level 1 implementation

Other Requirements – cont'd

- Law Enforcement Requirements
  - With the right court order, the law enforcement should be able to tap into the wireless calls
  - Over the air:
    - No encryption – easy
    - Breakable encryption
    - Strong encryption – problematic – need to obtain key
  - Wiretap at switch:
    - Preferred method – easiest

Network Security - Services

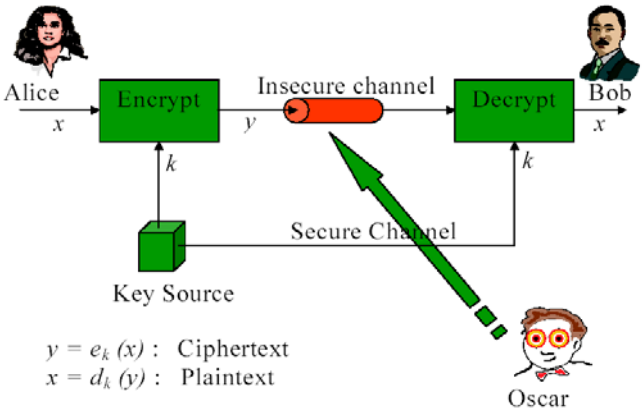
- (Def): Specific measures employing security mechanisms that combat security attacks on a network
- Include:
  - Confidentiality or Privacy: resistance to interception
  - Message Authentication: integrity of message and a guarantee that the sender is who he/she claims to be – Attacks: message modification or impersonation of sender
  - Nonrepudiation: service against denial by either party of creating or acknowledging a message – similar to digital signatures based on public key encryption – Attacks: fabrication
  - Access Control: only authorized entities can access – Attacks Masquerading
  - Availability: access to resources is not prevented by malicious entities (remember www.aljazeera.net!!) – Attacks: denial of service

Privacy

- Encryption
  - one way of providing most of the previously listed services
  - SHOULD be computationally secure – non breakable ideally
- Terms:
  - Message – plaintext or cleartext
  - Encoded version – ciphertext
  - Key – k
- Time and Cost to break the scheme should be significant relative to protected value
  - Should assume interceptor has access to plaintext-ciphertext pairs

Conventional Encryption Model

- Secret-Key Algorithm

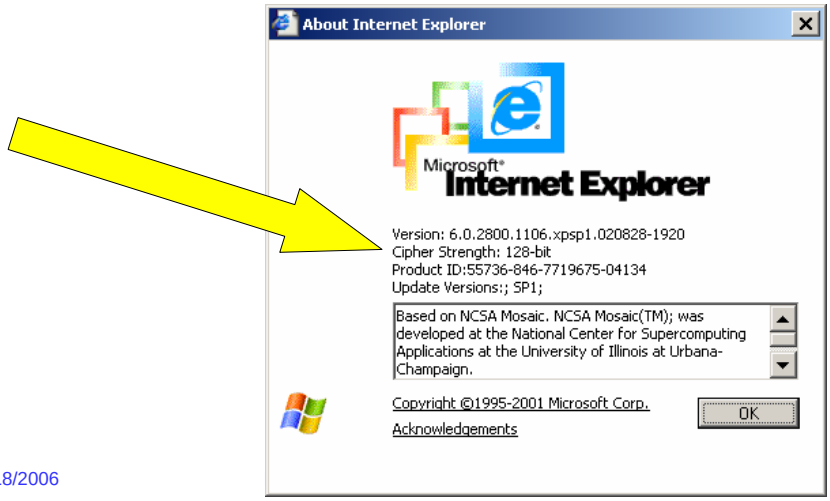


Secret Key Algorithms

- Example: Data Encryption Standard (DES)
- A symmetric key algorithm
  - Key used for encryption is the same as that used for decryption
- Two Principles:
  - Confusion ←→ scrambling of original data
  - Diffusion ←→ creating randomness – can not relate changes to plaintext to those of ciphertext
- Most secret-key algorithms are unbreakable except by brute-force
  - Key length of n bits → at least 2^{n-1} steps to break encryption – why?
- Main advantage – fast; appropriate for fast data streams
  - Compared to public-key algorithms

Date Encryption Standard (DES) – cont'd

- Usually a key size of 128 bits is recommended



http://www.laynetworks.com/des.htm
http://www.funet.fi/pub/crypt/mirrors/ftp.dsi.unimi.it/docs/des-how-to.txt
http://www.funet.fi/pub/crypt/mirrors/ftp.dsi.unimi.it/docs/des-how-to.txt

Example 6.20: Breaking DES

- DES is a block cipher: encrypts blocks of 64-bits of data using keys (56 bit long).
- Using brute force:
  - Use 500 MHz chip (each cost $20)
- How much time and money does it cost to break DES?

- **Solution:**
- Total # of keys = 2^{56} = $7.2X10^{16}$
  - On average half the keys will be tried ➔ 2^{55} keys
- If it takes one clock cycle to test every key ➔ time needed = 2^{55} / (500 X 10^6) /(60X60X24) = 834 days
- If 834 chips are used in parallel ➔ code can be broken in one day
- Cost = $20 X 834 = $16,680

http://www.laynetworks.com/des.htm
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Example 6.21: Moore's Law

- Processor or chip speed doubles every 18 months ➔ Strength of *any* encryption technique is weakened by time.
- DES algorithm using 112 bit keys can be broken in a day in 100 years from now!!

http://www.laynetworks.com/des.htm
http://www.funet.fi/pub/crypt/mirrors/ftp.dsi.unimi.it/docs/des-how-to.txt

Example 6.21: Key Sizes

- IEEE802.11 – Wired-equivalent privacy (WEP): 40-bit key
- IS-136 – 64-bit key – more secure but still considered weak

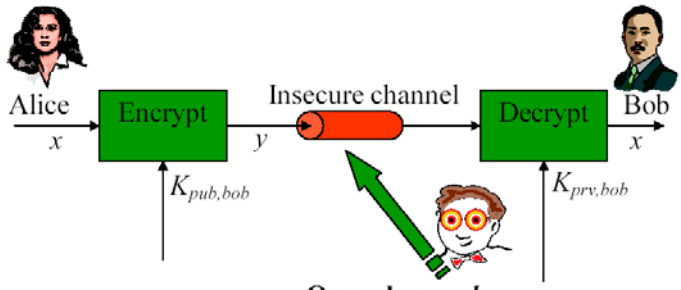
Public-key Algorithms

- Every pair of users have to have a key
  - A network of N users require the distribution of N(N-1)/2 keys!
  - Large and impractical for large N
- Key distribution schemes:
  - E.g: Needham-Schroeder – Kerberos
  - Involves several handshaking steps – start with a shared *master key*
- Concept introduced by Diffie and Hellman in 1977

Exploring Diffie-Hellman Encryption
Posted on Friday, August 16, 2002 by Jack Dennon
http://www.linuxjournal.com/article.php?sid=6131

Public-key Algorithms – cont'd

- It is extremely easy to compute $y = f(k_{pub}, x)$
- Given k_{pub}, and y, it is computationally not feasible to determine $x = f^{-1}(k_{pub}, y)$
- With a knowledge of k_{prv} that is related to k_{pub}, it is easy to determine $x = f^{-1}(k_{prv}, y)$



$y = e_{kpub}(x)$: Ciphertext
$x = d_{kprv}(y)$: Plaintext

Public-key Algorithms – cont'd

- *f(.)* ~ belongs to a group of functions referred to as a trapdoor one-way function - e.g:
  - Factorization:
    - It is easy to find 7 x 17 x 109 x 151 = 195, 821;
    - but it is quite difficult to split 30,616,693 into its prime number factors
  - Discrete logarithm:
    - It is easy to determine 2^{23} mod 109 is 77;
    - But it is difficult to find out u such that 2^{u} mod 109 is 68

- Since k_{pub} is available and the method is based on a mathematical structure ➔ need to be 3 to 15 times larger than the secret-key counter parts
- Elliptic Mathematics (refer to: http://world.std.com/~dpj/elliptic.html) provides a mean to use smaller keys with same level of security

Public-key Algorithms – Examples

- Rivest-Shamir-Adelman (RSA)
  - Employs integer factorization
  - Most popular
- Diffie-Hellman key-exchange
  - Based on discrete logarithm
  - Wireless networks
  - Used for key exchange for web transactions, e-commerce, IP security.
  - See appendix 6A for details
- Digital Signature Standard (DSS)
  - Based on discrete logarithms

Public-key Algorithms – Characteristics

- Computationally intensive
- Encryption rates quite small
- Rarely used for bulk data transfer
- Usually used to exchange a *session* key – to use a secret-key algorithm for later communications
  - Different session key each time!

Cost Equivalent Key Lengths (in Bits) of Various Encryption Schemes

Secret-key Algorithm	Elliptic Curve	RSA	Time to Break	Memory
56	112	430	Less than 5 mins	Trivial
80	160	760	600 months	4 Gb
96	192	1,020	3 million years	170 Gb
128	256	1,620	10^{16} years	120 Tb

Block vs. Stream Ciphers

- Block Ciphers – DES and Advanced Encryption Standard (AES)
  - Encrypt blocks of data at a time
  - Requires buffering and padding
- Stream Ciphers – no need for buffering
  - More suitable for a jitter-sensitive service
  - Usually a simple XOR operation is used
- Example:
  - IEEE802.11 employs the encryption algorithm RC-4 to generate a pseudorandom key stream using a 40-bit master key and an initial vector (IV)
  - Data is simply XORed with the key to create ciphertext

Message Authentication

- Involved:
  - Sender authentication
  - Message integrity
- This is accomplished using a message digest (MD) and a message authentication code (MAC)

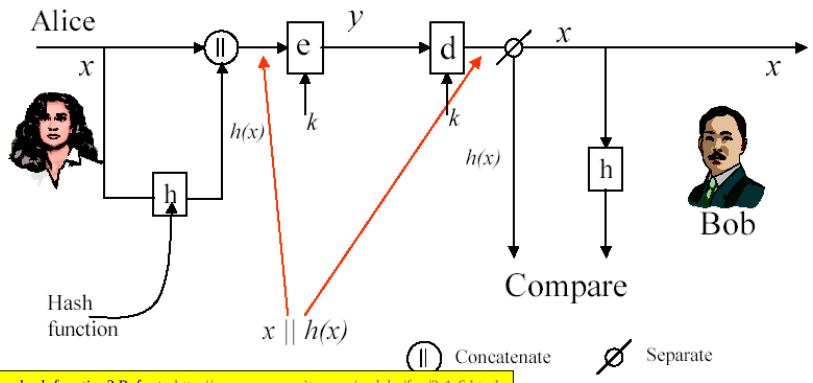
Message Authentication Code (MAC)

- MAC creates a fixed-length sequence of bits that depend on the message and the secret key
  - Not a function of message size
  - It is computationally infeasible to generate the MAC without the original message and key
- Message is then delivered (with the MAC) to destination
- Receiver computes MAC again based on received message
- New MAC is equal to old MAC IFF message was not tampered with (remember secret key is a secret!)

Message Digest (MD)

- MD depends only on the message x
- A hash function, h, is used to create the MD, h(x)
- The MD is appended to the message x ➔ x || h(x)
- The newly overall message x || h(x) is encrypted using the secret-key
- h(x) has to be sufficiently long
  - For a b bit h(x) ➔ a fake message with same h(x) can be generated in $2^{b/2}$ trails

Message Authentication with Hash Functions



What is a hash function? Refer to http://www.rsasecurity.com/rsalabs/faq/2-1-6.html
- some of the hash function properties:
- The input can be of any length.
- The output has a fixed length.
- $H(x)$ is relatively easy to compute for any given x.
- $H(x)$ is one-way.
- $H(x)$ is collision-free.

MD and HMAC C++ code

- From http://njet.org/doc/Doc/$24$24native/anvil/crypto.html
- **Message Digest (MD)** provides applications the functionality of a message digest algorithm, such as MD5 or SHA. Message digests are secure one-way hash functions that take arbitrary-sized data and output a fixed-length hash value.
- **Message Authentication Code (MAC)** Since everyone can generate the message digest, it may not be suitable for some security related applications. Because of this, Anvil+ also supports HMAC (rfc2104), which is a mechanism for message authentication using a (secret) key. So you can use a key with a hash algorithm to produce hashes that can only be verified using the same key.

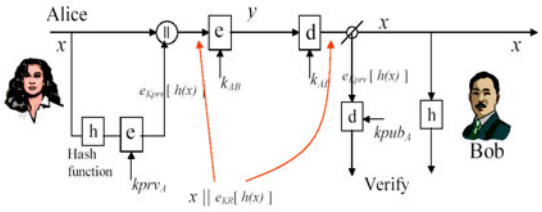
+ Anvil is a crypto library that can create message hash codes or checksums from any data. It is posted on the webpage listed above.

Digital Signatur

http://www.anu.edu.au/people/Roger.Clarke/DV/DigSig.html
http://www.youdzone.com/signature.html
http://computer.howstuffworks.com/question571.htm
http://www.rsasecurity.com/rsalabs/faq/2-2-2.html

- Def: a 'message digest' encrypted using the sender's private key
  - The receiver can verify the identity of the sender and the integrity of message by first decrypting the signature using the sender's public key – and then by reproducing the message digest and comparing it with the one received with message.

- What if a public key is not valid?
  - Use of Certificate Authority



Methods for Providing Security for Mobile Wide Area Networks

- MIN/ESN
- Shared Secret (Key) Data
- Security Triplets (Token Based)
- Public Key

MIN/ESN Authentication

- MIN = Mobile Identification Number (e.g. 10-digits)
- ESN = Electronic Serial Number (e.g. 32-bit)
- Data is shared between systems on bad MINs, ESNs, and MIN/ESN pairs
- When a roaming phone places a call, the bad list is checked, and then a message is sent to home system to validate the MIN/ESN (using SS7 on IS-41)

Shared Secret Data (SSD) Authentication

- Developed for TDMA systems (IS-54 and its derivatives)
- Utilizes a common authentication key in the mobile telephone and the network.
- When phone is placed in service a 64-bit A-key is entered into phone and network (HLR)
- From A-key two keys are derived: SSD-A and SSD-B – these are used to authenticate the phone and establish the voice privacy key
- Mobile is assigned a Temporary IMSI (TIMSI) when roaming into a foreign network – its identity (IMSI) is kept secret
- Mobile is authenticated by calculating AUTHR (an encrypted version of RAND sent by basestation) – encryption is done using SSD-A
- Mobile also possess a call-counter profile – every time the mobile makes a call, the counter is increments
  - A measure against cloning
- Procedures:
  - Shared Secret Key Registration
  - Shared Secret Key Global Challenge
  - Shared Secret Key Unique Challenge

All mobiles are assigned:
- ESN
- 15-digit International Mobile Subscriber Identity (IMSI)
- An A-key
- Plus other info

Token Based Authentication – GSM

- Triplets:
  - pseudorandom number RAND;
  - its corresponding response, SRES, generated by authentication algorithm;
  - Temporary encryption key, Kc, used for data, signaling and voice privacy
- Triplets are requested by the visitor system from the home system
  - Computed and stored in the mobile, home authentication centre and the visited VLR
- Procedure: MS sends registration request – network sends unique challenge – MS calculates challenge response and sends message back to network. VLR contains list of triplets – compares with response from MS
  - The just-used triplet is discarded
  - After all triplets are used – VLR query HLR for a new set
- Anonymity is handled using IMSI/TIMSI
- No call history counter for GSM – no clone detection is possible
- Subscriber Identity Module (SIM) – microprocessor-based secure system

Public-Key-Based Authentication

- Public-key method – two user keys are used
  - Public (USERPUB) for encrypting
  - Private (USERPRIV) for decrypting
- The network also has NETPUB and NETPRIV
- Used in PACS

Summary of Authentication Methods*

Air Interface	Type of Authentication				
	MIN/ESN	SSD	Token-Based	Public Key	Type of Voice Privacy Supported
AMPS	x	x			None
CDMA		x			Strong
GSM			x		Strong
PACS		x		x	Strong
PCS-2000		x	x		Strong
TDMA		x			Weak
W-CDMA		x			Strong

•From V. Garg and J Wilkes, Wireless And Personal Communications Systems, Printice Hall PTR, 1996 – chapter 10

Identification Schemes

- Need:
  - Access to an automatic teller machine
  - Logging on to a computer
  - Identifying a user of a cellular phone
  - Etc.
- Identification = entity authentication
  - A password or a pin compared to a securely stored hash value
  - Susceptible to replay attacks if transmitted over-the-air in an insecure manner
- Challenge-Response identification or Strong identification
  - Used in wireless networks

Identification Schemes – cont'd

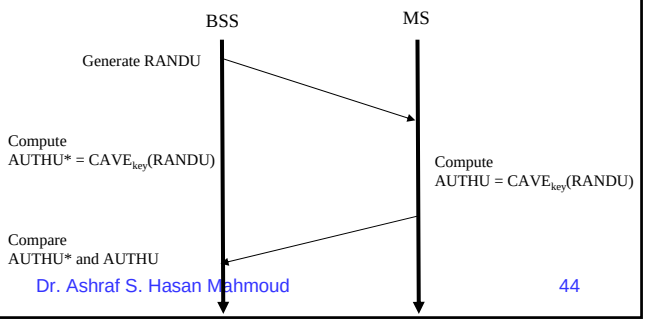
- A nonce: a value employed no more than once for the same purpose
  - Eliminates *replay* attacks

http://www.qualcomm.com.au/PublicationsDocs/AUUG99AuthSec.pdf

Identification Schemes – cont'd

Example: Challenge-Response mechanism in IS-41

1. Consider an IS-136 digital TDMA network
2. The network (BSS) generates a random # RANDU and sends it over the air to mobile
3. Mobile computes a value AUTHU using the encryption algorithm Cellular Authentication and Voice Encryption (CAVE)
4. AUTHU is sent to network and compared with a computed version at the network
5. If the two AUTHU match ➔ the mobile is authenticated – using IS-41 terminology



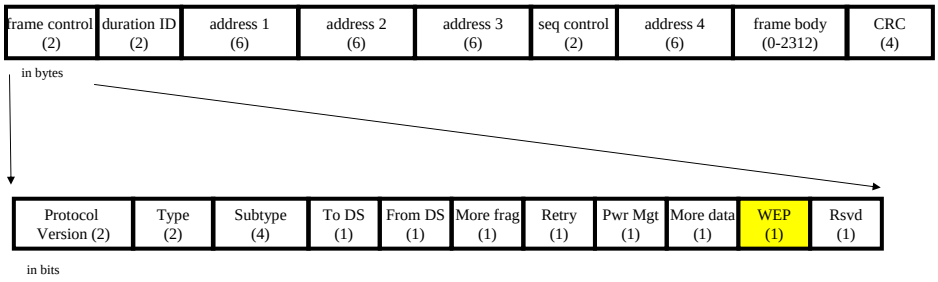
IEEE802.11 Security & Privacy

- Objectives:
  - To provide a wired equivalent privacy (WEP)
  - To protect against
    - Eavesdropping
    - Unauthorized access

1. http://www.cs.umd.edu/~waa/wireless.html and the references therein especially the following paper: "Your 802.11 network has no clothes,"
2. http://www.mobileinfo.com/Security/index.htm

MAC Frame Format

- General MAC frame format & Control Field
- WEP = 1 ➔ data bits are encrypted (refer to chapter 11 of Pahlavan)

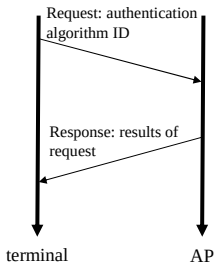


Authentication Schemes for IEEE802.11

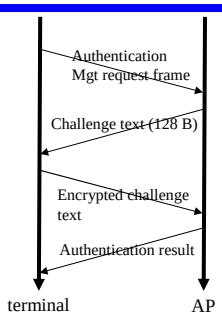
- Three schemes:
  1. Open system authentication
     - Default – uses SSID as a password to gain access
     - NULL Authentication function – authenticates anyone requesting authentication
     - Not secure
  2. Shared key authentication (WEP based)
     - 40-bits key
     - Not very secure
     - Standard does not specify key management or where to get this key from!!
     - Optional for IEEE802.11 (required to be Wi-Fi certified by WECA)
  3. Access Control List (MAC address filtering)
     - MAC address based
     - Not scalable – requires manual setting
- Not available for ad-hoc

http://www.cs.umd.edu/~waa/wireless.html (802.11 Security Vulnerabilities)
http://www.isaac.cs.berkeley.edu/isaac/wep-faq.html

Authentication Schemes for IEEE802.11



Open System Authentication



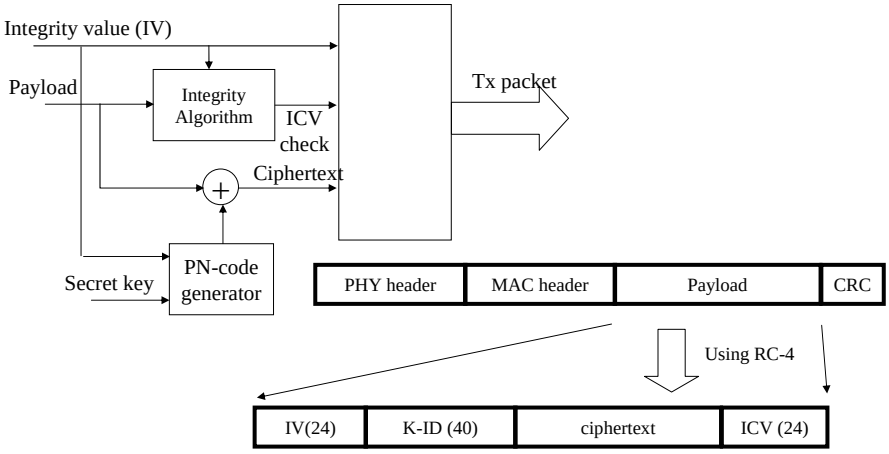
Shared-key Authentication

Challenge text: The challenge text is generated by using the WEP pseudo-random number generator (PRNG) with the "shared secret" and a random initialization vector (IV)
Challenge response: encrypted with WEP using the "shared secret" along with a new IV

Security Threats

- Theft of Hardware
  - Admin has to reprogram WEP keys
- Rogue Access Points
  - IEEE802.11b shared-key authentication is one way (i.e. AP authenticates mobile)
  - User can not authenticate AP ➔ rogue APs
- Per-packet encryption versus per-packet authentication ➔ to protect against spoofing and replay attacks
  - WEP keys may change frequently
  - Use per-session WEP keys

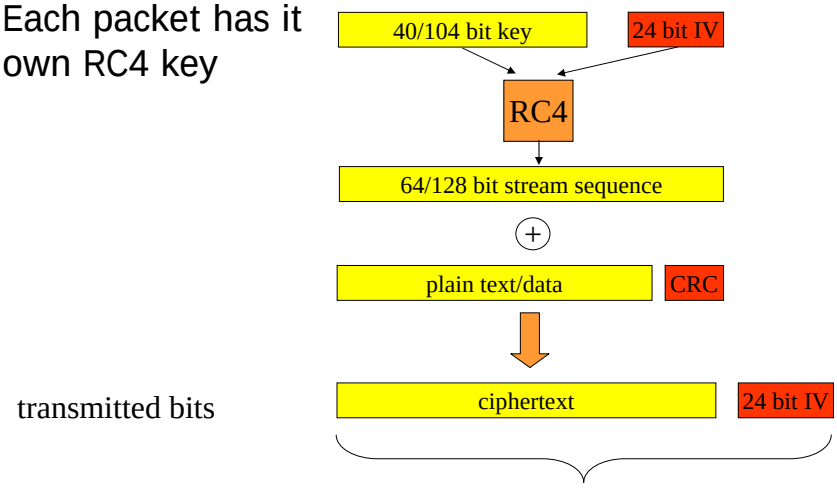
Privacy in IEEE802.11



Note that the IV and the key-ID are sent in the clear!
Same shared key for uplink and downlink

WEP Operation

- Each packet has it own RC4 key



Problems With WEP

- IV Collision: two packets using same IV ➔ one can deduce info about the two packets and then easily decrypt them (see Borisov, N. Goldberg, I. & Wagner, D. Intercepting Mobile Communications: The Insecurity of 802.11. http://www.isaac.cs.berkeley.edu/isaac/wep-draft.pdf, August, 2001) – the 24-bit IV will repeat in about 5 hours for an 11 Mbps WLAN with 1500 B maximum frame size
- Plaintext Attacks: Getting the user to transmit a known plaintext– the attacker than then infer the remaining XORed plain text. It is possible to expect what the plaintext should look like (for example structured IP/TCP header info), and then use the info to recover the rest of the plaintext or packet

RC4 Encryption (Stream Cipher)

- *Reasonable* strong:
  - A brute force attack on this algorithm is difficult since every frame is sent with a different IV
  - IV restarts the pseudo random number generator (PRNG) for each frame
- Self-Synchronizing:
  - Even if some intermediate frames are lost, the WEP algorithm resynchronizes at each frame

Encryption Keys

- Window of four keys
  - Can be manually configured – up to four keys
  - Each is 40 bits (5 ascii or 10 hex digits)
  - For all network
- Key-mapping table
  - Each unique MAC address has separate keys – one per device
  - Need to be configured manually
  - Most secure