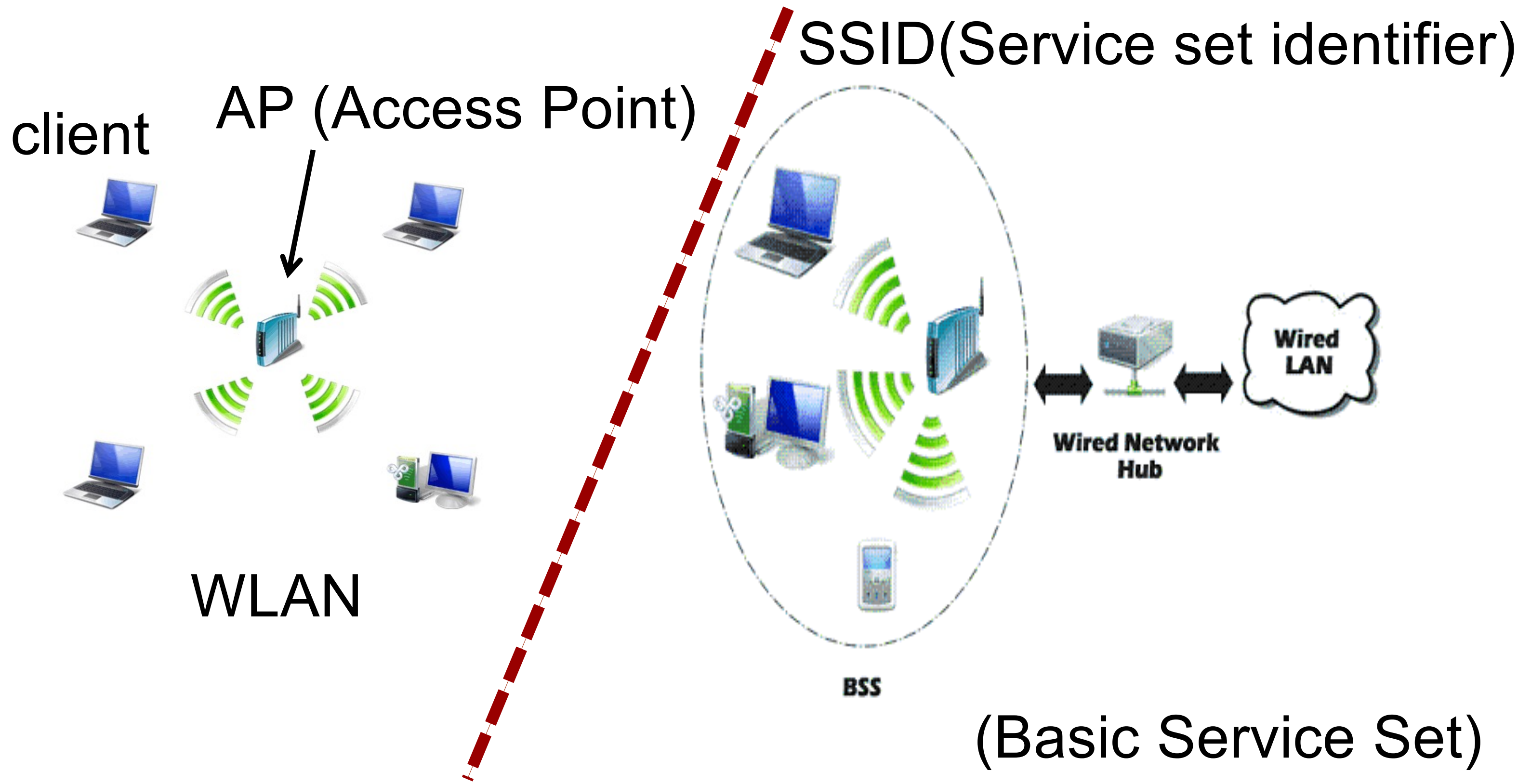
Wireless Security: WEP and GSM

Wireless Local Area Network (WLAN)



WLAN security standards

- **WEP**: Wired Equivalent Privacy (introduced in 1999)
  - Original 802.11 standard for WLAN
  - Can be broken within a few minutes

- **WPA**: Wi-Fi Protected Access (2003)
  - Draft 802.11i standard
  - Based on the same hardware for WEP

- **WPA2**: Wi-Fi Protected Access II (2004)
  - Full 802.11i standard
  - Requires more powerful hardware

- **WPA3**: Wi-Fi Protected Access III (2018)

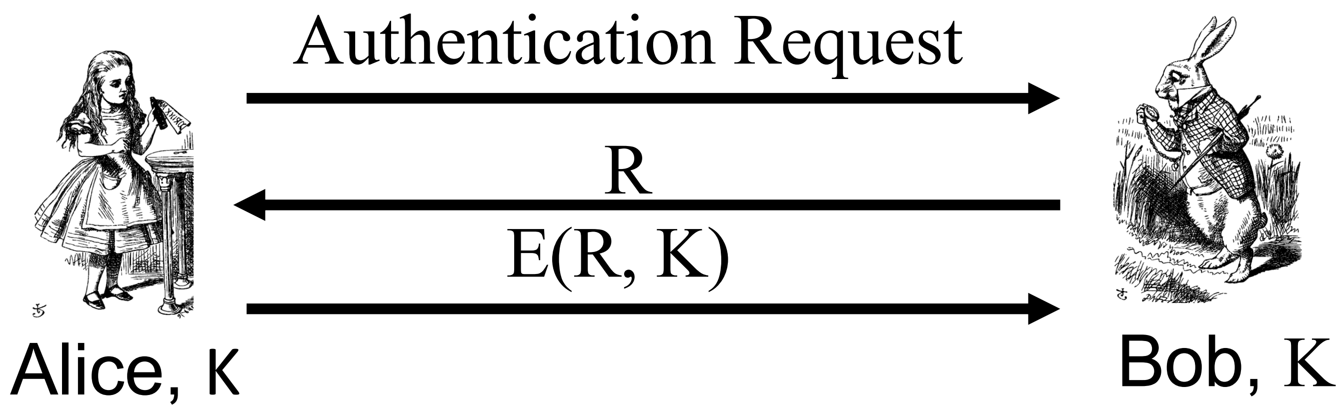
WEP

- WEP — Wired Equivalent Privacy
- The stated goal of WEP was to **make wireless LAN as secure as a wired LAN**
- According to Tanenbaum:
  - "The 802.11 standard prescribes a **data link-level** security protocol called WEP (Wired Equivalent Privacy), which is designed to <u>make the security of a wireless LAN as good as that of a wired LAN</u>. Since the default for a wired LAN is no security at all, this goal is easy to achieve, and WEP achieves it as we shall see."

WEP router

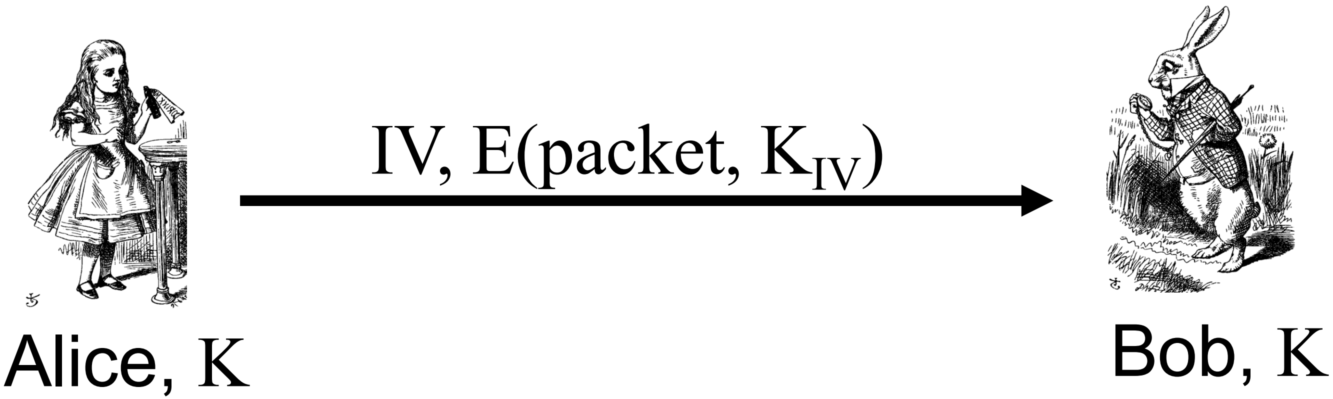
NAME of your router
ESSID: 62064
Model
Actiontec MI424-WR Rev. F
WEP KEY: A7A01F51DE
PASSWORD
WPS PIN: 26022475
LISTED
I.T.E.
E212044
WAN MAC: 0026626B4351
FOR HOME OR OFFICE USE
FCC ID: LNQMI424WRF
Made in China
Shipped Firmware Version: 20.12.2.4
CSJF0273101815

WEP Authentication



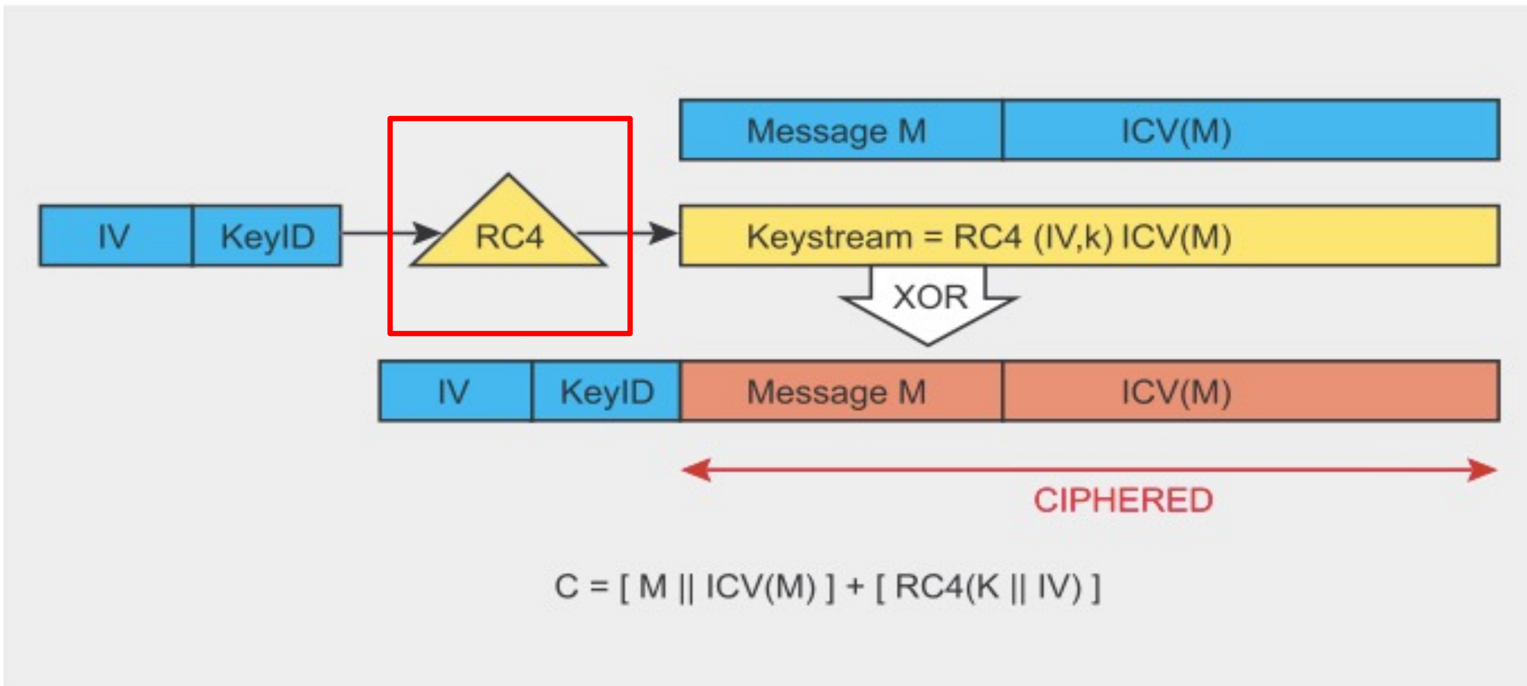
- Bob is ***wireless access point***
- Key K shared by access point and **all users**
    - Key K seldom (if ever) changes

WEP Encryption

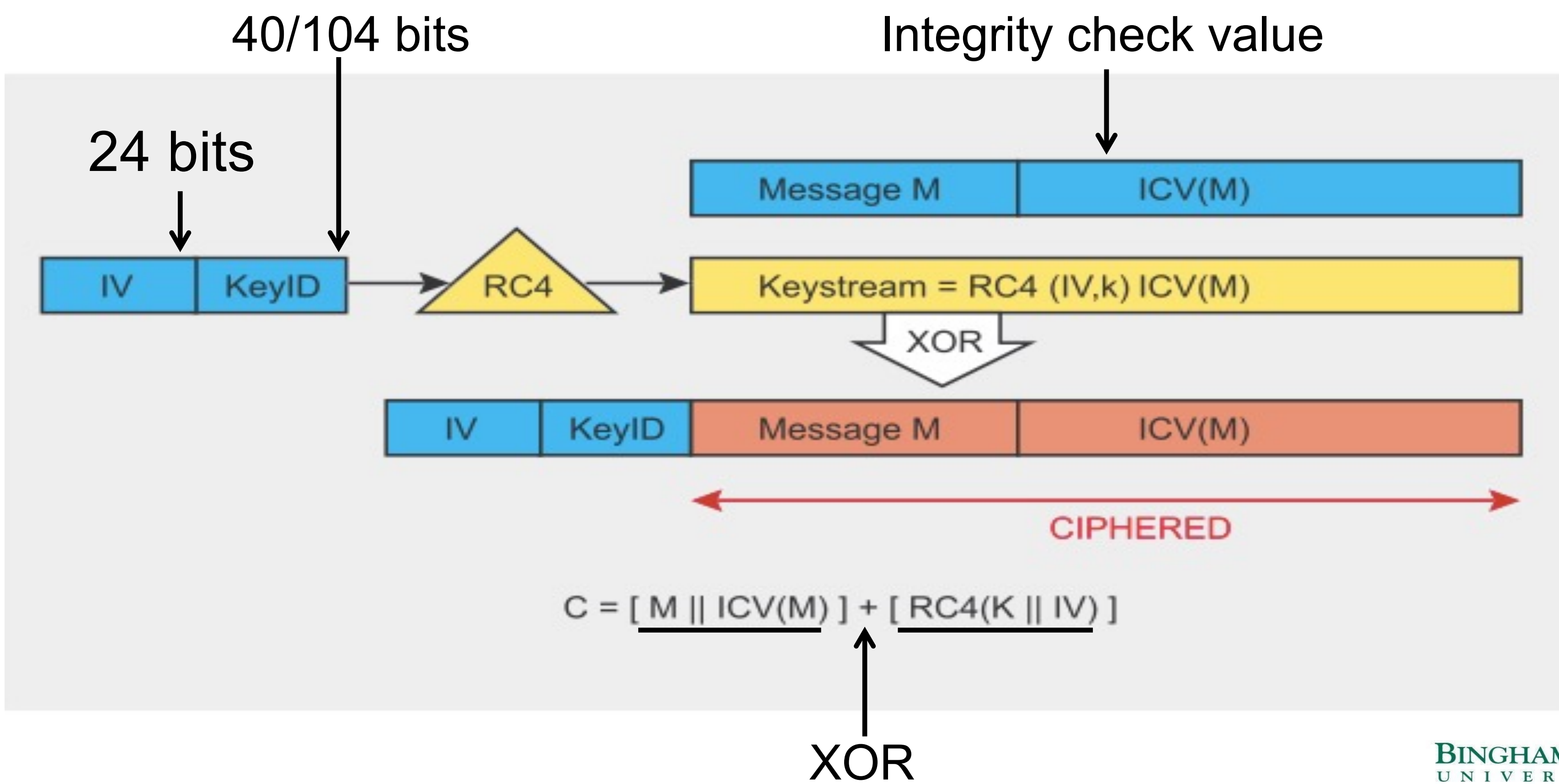


- $K_{IV} = (IV, K)$
  - Encrypted using RC4 stream cipher
  - RC4 key is K with 3-byte IV pre-pended
- Note that the IV is known to Trudy
- Goal: Encrypt packets with distinct keys

WEP Encryption



WEP Encryption



WEP Issues

- WEP uses RC4 cipher for confidentiality
  - RC4 is considered a strong cipher
  - But WEP introduces a subtle flaw…
  - …making cryptanalytic attacks feasible
- WEP uses **CRC** (Circular Redundancy Check) for "integrity"
  - Should have used a MAC or HMAC instead
  - CRC is for error detection, not crypto integrity
  - Everyone in security knows **NOT** to use CRC for this…

(1) WEP Integrity Problems

- WEP "integrity" gives no crypto integrity
  - CRC is linear, so is stream cipher (XOR)
  - Trudy can change **ciphertext and CRC** so that checksum remains correct
  - Then Trudy's introduced errors go undetected
  - Requires no knowledge of the plaintext!
- CRC does ***not*** provide a cryptographic integrity check
  - CRC designed to detect random errors
  - Not able to detect intelligent changes

More WEP Integrity Issues

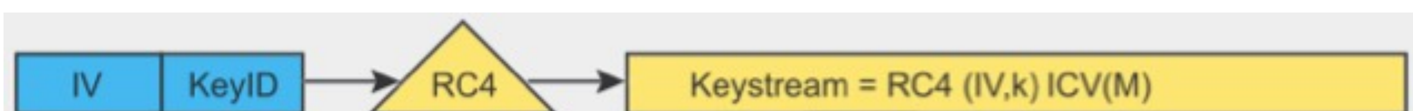
- Suppose Trudy knows destination IP
- Then Trudy also knows keystream used to encrypt IP address, since…
  - … **C** = destination IP address ⊕ **keystream**
- Then Trudy can replace **C** with…
  - … **C′** = Trudy's IP address ⊕ **keystream**
  - **How?**
- And change the CRC so no error detected!
  - Then what happens??
- Moral: Big problem when integrity fails

(2) WEP confidentiality issue: WEP Key Repeat

- Recall WEP uses a long-term secret key: K
- RC4 is a stream cipher, so each packet must be encrypted using a different key
  - Initialization Vector (IV) sent with packet
  - Sent in the clear, that is, IV is **not** secret
- Actual RC4 key for packet is (IV, K)
  - That is, IV is **pre-pended** to long-term key K

WEP IV Issues

- WEP uses 24-bit (3 byte) IV
  - Each packet gets a new IV
  - Key: IV pre-pended to long-term key, K
- Long term key K seldom changes
- If long-term key and IV are the same, then the same keystream is used
  - This really bad!
  - Why?



WEP IV Issues

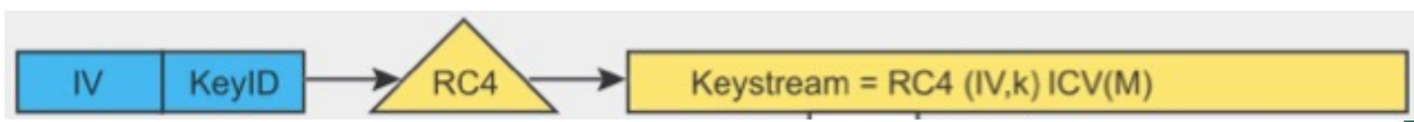
- Assume 1500 byte packets, 11 Mbps link
- Suppose IVs generated in sequence
  - Since $1500 \cdot 8/(11 \cdot 10^6) \cdot 2^{24} = 18{,}000$ seconds…
  - …an IV must repeat in about 5 hours
- Again, repeated IV (with same K) is bad!

(3) WEP : Another Active Attack

- Suppose Trudy can **insert traffic** and **observe corresponding ciphertext**
  - Then she knows the keystream for some IV
  - She can decrypt any packet(s) that uses that IV
- If Trudy does this many times, she can then decrypt data for lots of IVs
  - Remember, IV is sent in the clear

(4) Cryptanalytic Attack

- 3-byte IV pre-pended to key
- Denote the RC4 key **bytes**…
  - …as $K_0, K_1, K_2, K_3, K_4, K_5, \ldots$
  - Where $IV = (K_0, K_1, K_2)$, which Trudy knows
  - Trudy wants to find $K = (K_3, K_4, K_5, \ldots)$
- FMS attack
  - Designed by Fluhrer, Mantin and Shamir
  - With **certain IVs**, an attacker knowing **the first byte of the keystream** and **the first m bytes of the key** can derive the **(m+1)-th** byte of the key



WEP Conclusions

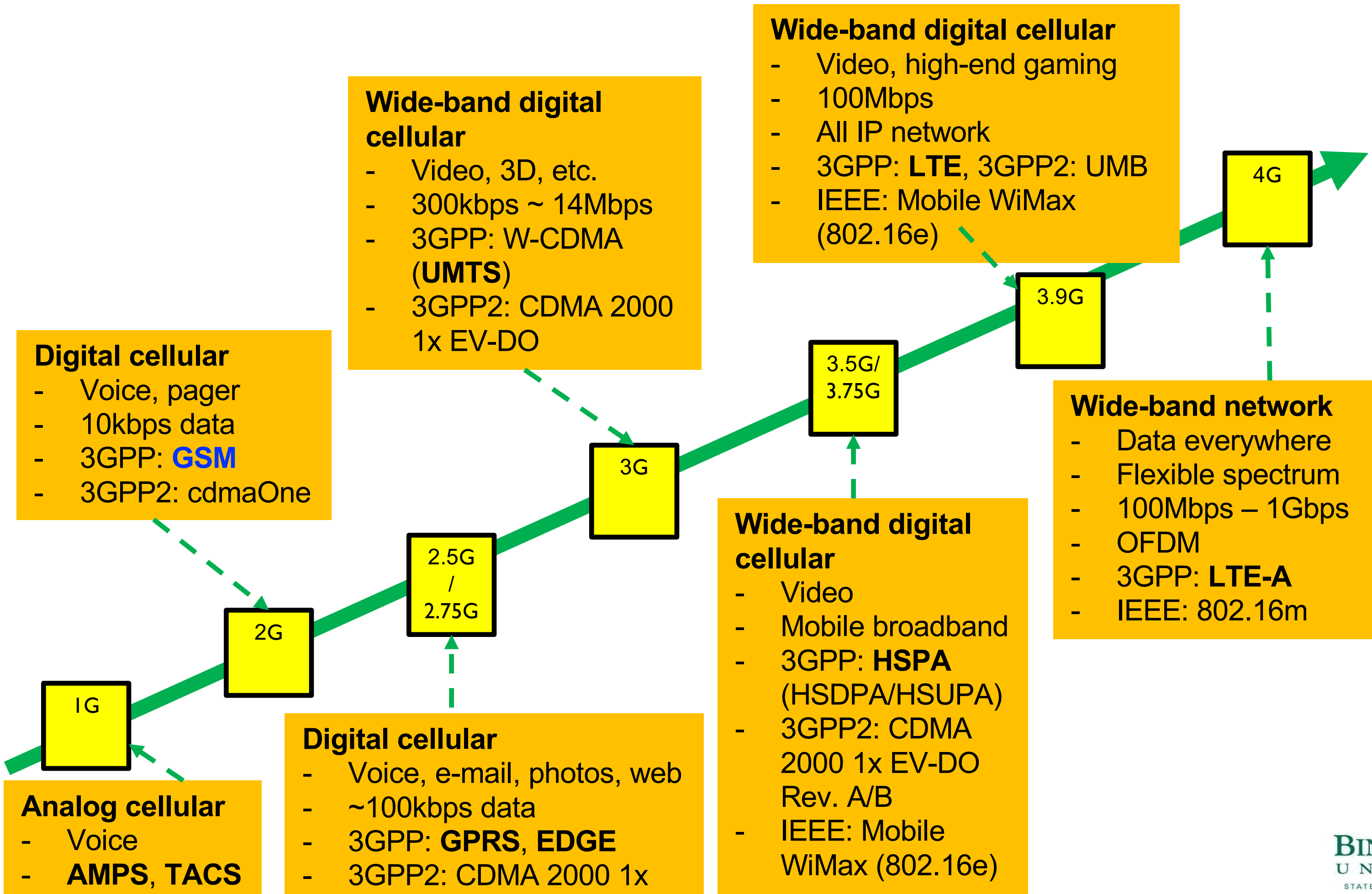
- Many attacks are practical
  - AirSnort
  - AirCrack
  - WepLab
  - …

Crack 128-bit WEP key in less than 10 minutes

- Attacks have been used to recover keys and break real WEP traffic
- How to prevent WEP attacks?
  - Don’t use WEP
  - Good alternatives: WPA, WPA2, etc.

GSM (In)Security

Evolution of cellular communications standards



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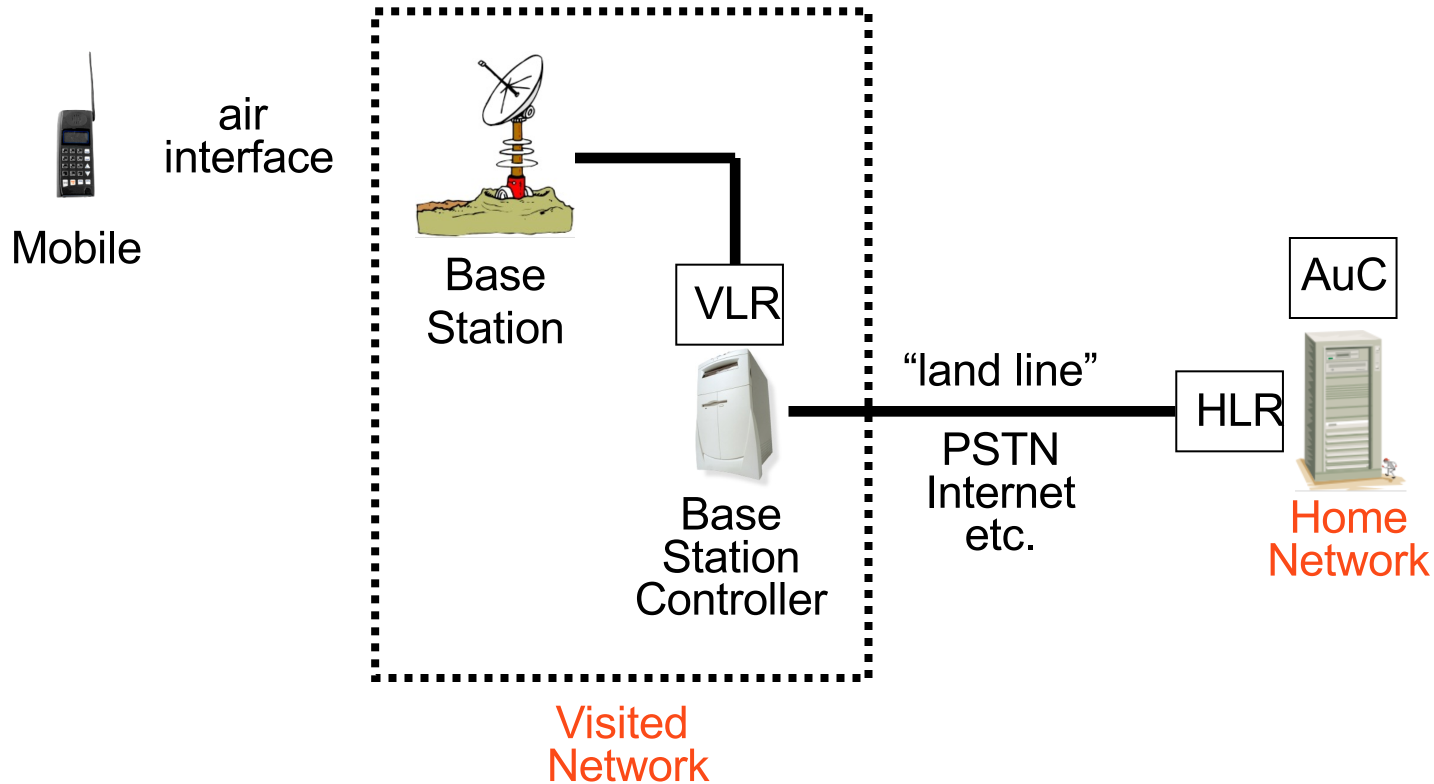
Cell Phones

- First generation cell phones
  - Brick-sized, analog, few standards
  - Little or ***no*** security, and susceptible to **cloning**
- Second generation cell phones: **GSM**
  - Began in 1982 as "*Groupe Spécial Mobile*"
  - Now, Global System for Mobile Communications
- Third generation: UMTS (Universal Mobile Telecommunications System)
- 4^{th} gen (LTE)
- 5^{th} gen, …

GSM System Overview



GSM System Components

- Mobile phone
  - Contains SIM (Subscriber Identity Module)
- SIM is the **security module**
  - **IMSI (International Mobile Subscriber ID)**
  - **User key: K_i (128 bits)**
  - **Tamper resistant (smart card)**
  - **PIN activated (usually not used)**

GSM System Components

- **Visited network** — network where mobile is currently located
  - Base station — one "cell"
  - Base station controller — manages many cells
  - **VLR** (Visitor Location Register) — info on all visiting mobiles currently in the network
- **Home network** — "home" of the mobile
  - **HLR** (Home Location Register) — keeps track of most recent **location** of mobile
  - **AuC** (Authentication Center) — has **IMSI** and **Ki**

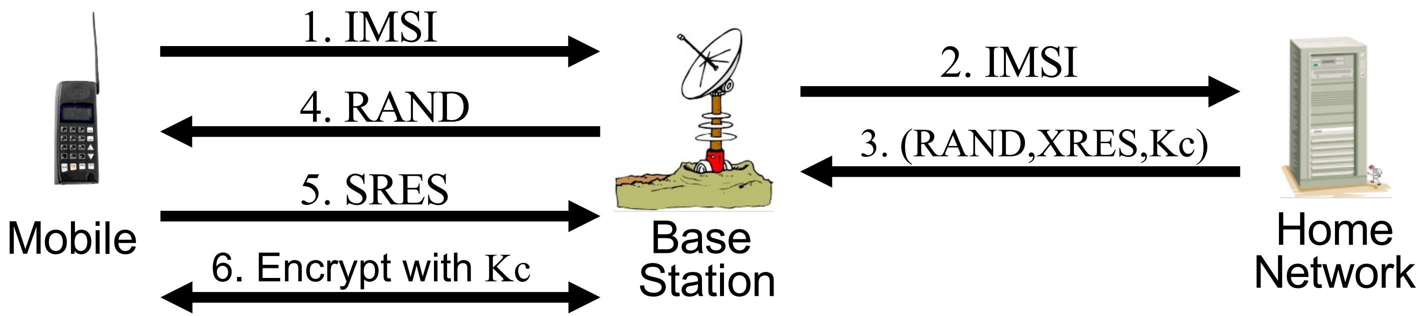
GSM Security Goals

- Primary design goals
  - **Make GSM as secure as ordinary telephone**
  - **Prevent phone cloning**
- Not designed to resist active attacks
  - At the time this seemed infeasible
  - Today such attacks are feasible…
- Designers considered biggest threats to be
  - Insecure billing
  - Other low-tech attacks

GSM Security Features

- **Anonymity**
  - Intercepted traffic does not identify user
  - Not so important to phone company
- **Authentication**
  - Necessary for proper billing
  - Very, very important to phone company!
- **Confidentiality**
  - Confidentiality of calls over the air interface
  - Not important to phone company
  - May be important for marketing

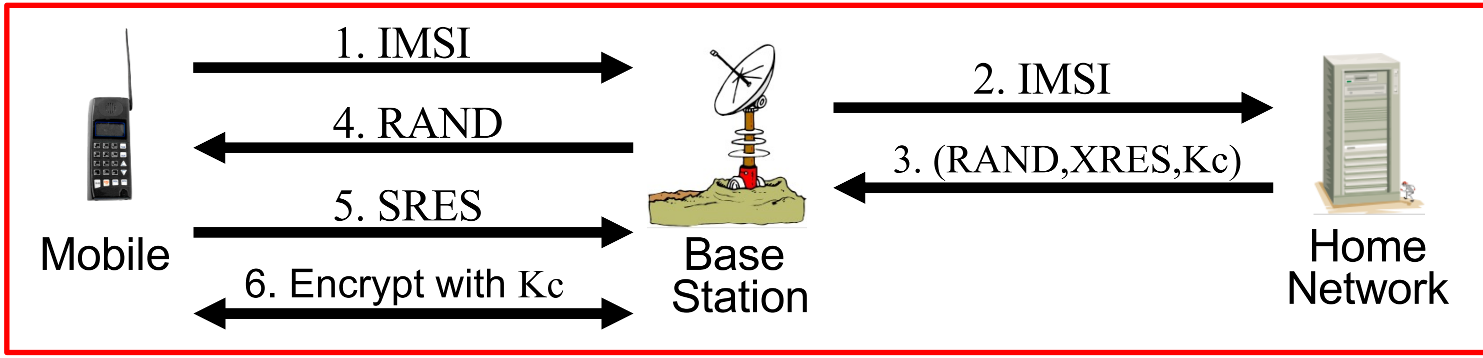
GSM Security Protocol



GSM: Anonymity

- IMSI used to initially identify caller
- Then TMSI (**Temporary** Mobile Subscriber ID) used
  - TMSI changed frequently
  - TMSI's encrypted when sent
- Not a strong form of anonymity
- But probably sufficient for most uses

GSM: Authentication

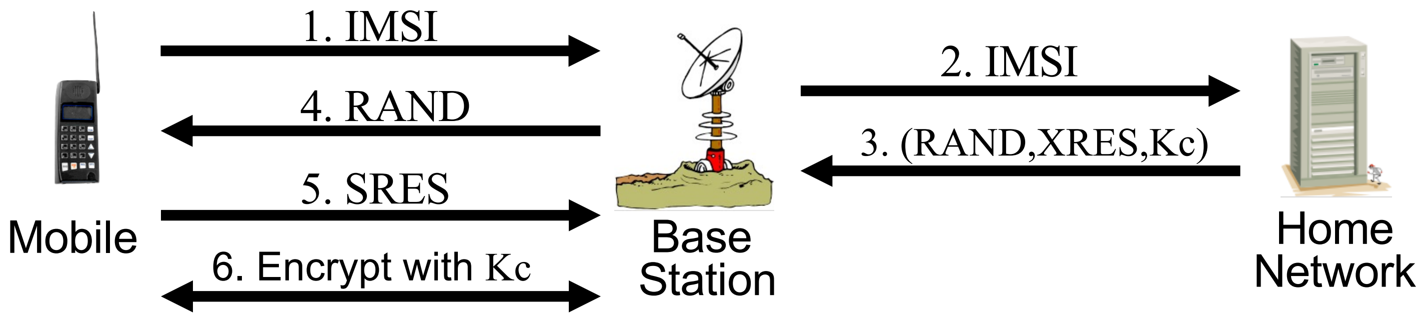


- Caller is authenticated to base station (not mutual)
- Authentication via **challenge-response**
  - Home network generates RAND and computes XRES = A3(RAND, Ki) where A3 is a hash function and Ki the mobile's 128 bit user key
  - Then (RAND, XRES) sent to base station
  - Base station sends **challenge** RAND to mobile
  - Mobile's **response** is SRES = A3(RAND, Ki)
  - Base station verifies SRES = XRES

GSM: Confidentiality

- Data encrypted with stream cipher
  - Error rate estimated at about 1/1000
- Encryption key Kc
  - Home network computes Kc = A8(RAND, Ki) where A8 is a hash
  - Then Kc sent to base station with (RAND, XRES)
  - Mobile computes Kc = A8(RAND, Ki)
  - Keystream generated from A5(Kc)
- **Note: Ki never leaves home network!**

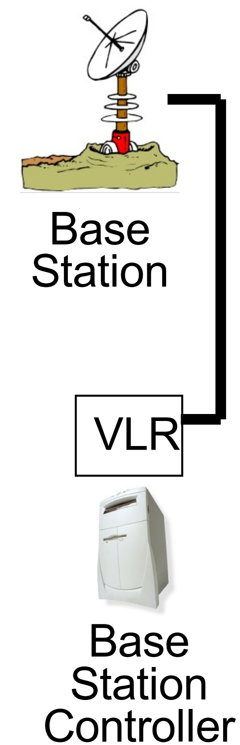
GSM Security



- SRES = XRES = A3(RAND, Ki), Kc = A8(RAND, Ki)
- **SRES and Kc must be uncorrelated**
  - Even though both are derived from RAND and Ki
- Must not be possible to deduce Ki from known RAND/SRES pairs (known plaintext attack)
- Must not be possible to deduce Ki from chosen RAND/SRES pairs (chosen plaintext attack)
  - With possession of SIM, attacker can choose RAND’s

GSM Insecurity – Crypto Flaws

- Hash used for A3/A8 is **COMP128**
  - Broken by 160,000 chosen plaintexts
  - With SIM, can get Ki in 2 to 10 hours
- Encryption between mobile and base station but **no encryption** from base station to base station controller
  - Often transmitted over microwave link
- Encryption algorithm A5/1
  - Feasible attacks on A5/1 are known

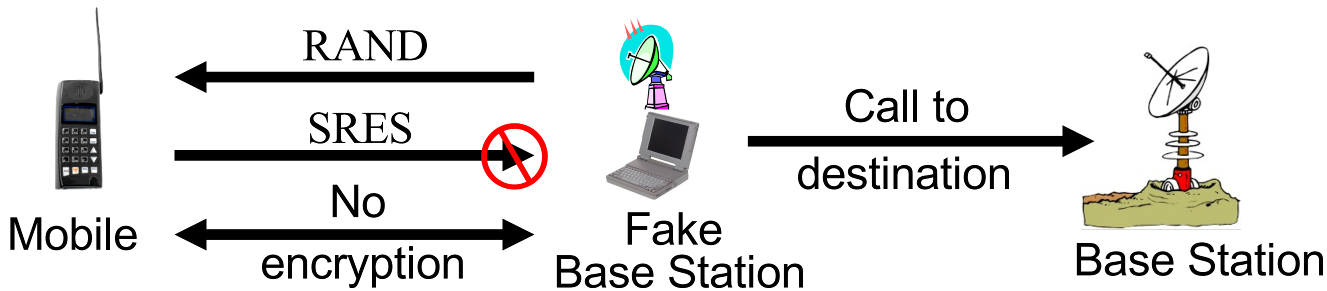


GSM Insecurity – SIM Card

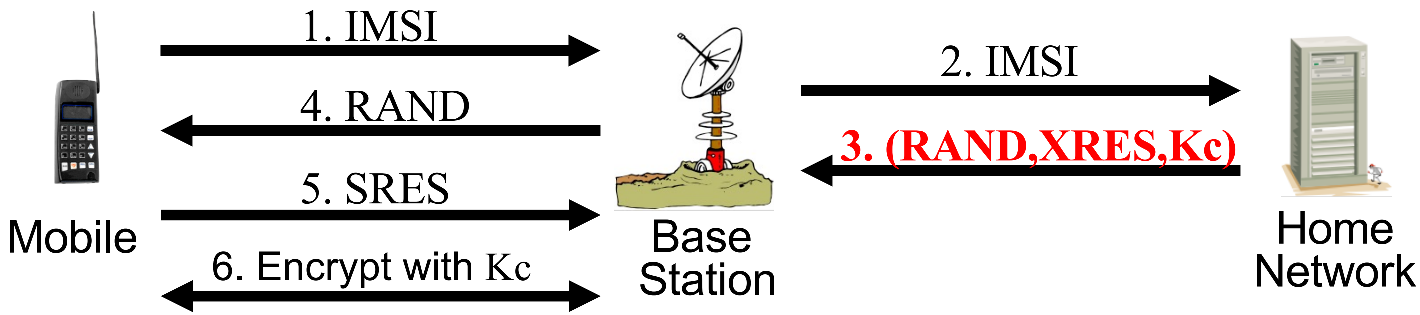
- Attacks on SIM card
  - **Optical Fault Induction** — could attack SIM with a flashbulb to recover Ki
  - **Partitioning Attacks** — using timing and power consumption, could recover Ki with only 8 adaptively chosen “plaintexts”

GSM Insecurity - Base Station

- **Fake base station** exploits two flaws
  - Encryption not automatic
  - Base station not authenticated



GSM Insecurity - Replay



- Can replay triple: (RAND, XRES, Kc)
  - One compromised triple gives attacker a key Kc that is valid forever
  - No replay protection here

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GSM Conclusion

- Did GSM achieve its goals?
  - Eliminate cloning? **Yes, as a practical matter**
  - Make air interface as secure as PSTN? **Perhaps…**
- But design goals were clearly too limited
- GSM insecurities — weak crypto, SIM issues, fake base station, replay, etc.
- GSM a (modest) security success?

Protocols Summary

- Generic authentication protocols
  - Protocols are subtle!
- SSH
- SSL
- IPSec
- Kerberos
- Wireless: GSM and WEP