GSM Security Overview

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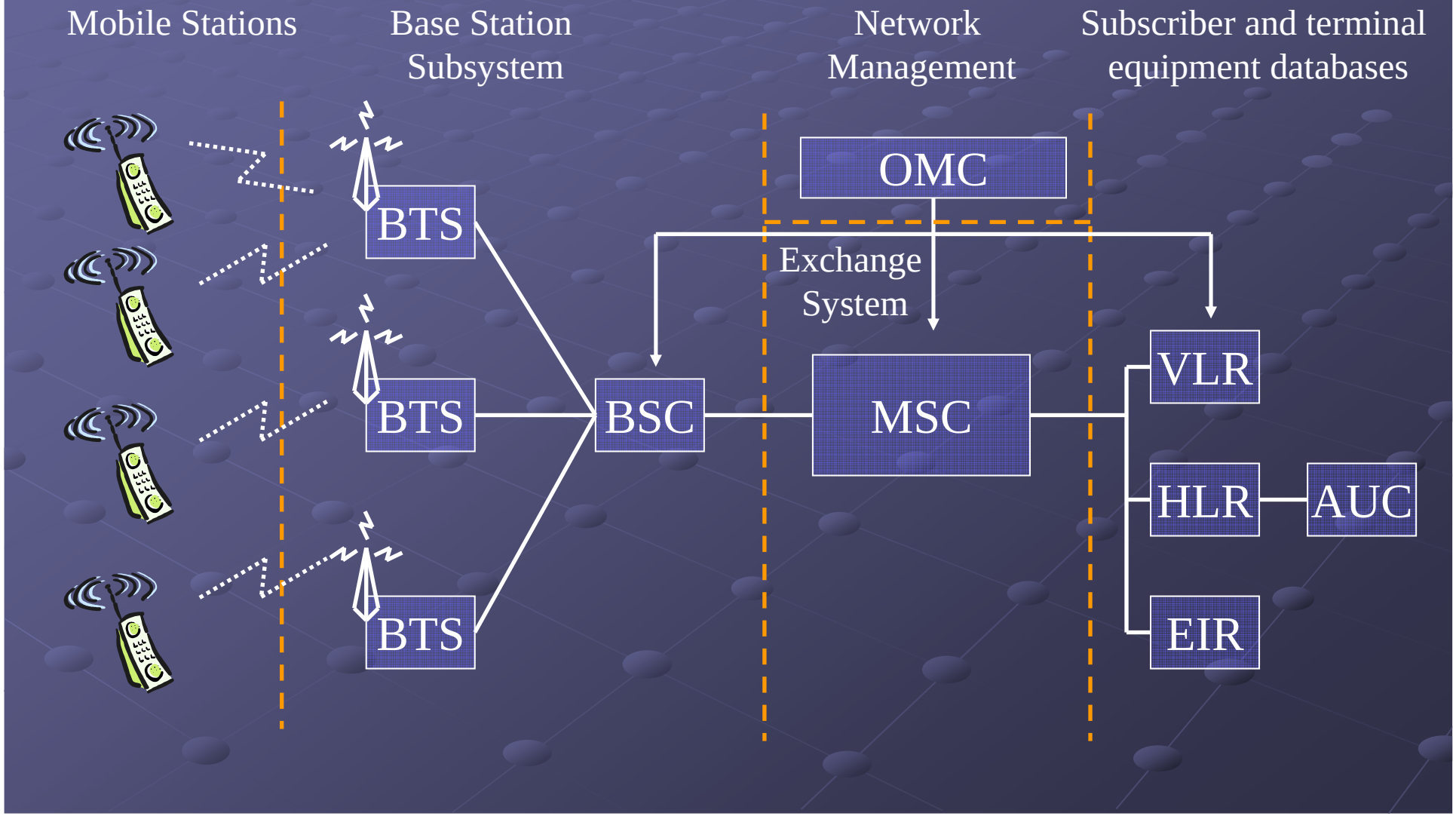
Agenda

- A5 Overview :
- Attack History on A5/1
- Rainbow Tables Attack on A5/1
- Data Collection and Frequency Hopping
- Third Generation Telephony Security
- Attack History on Kasumi

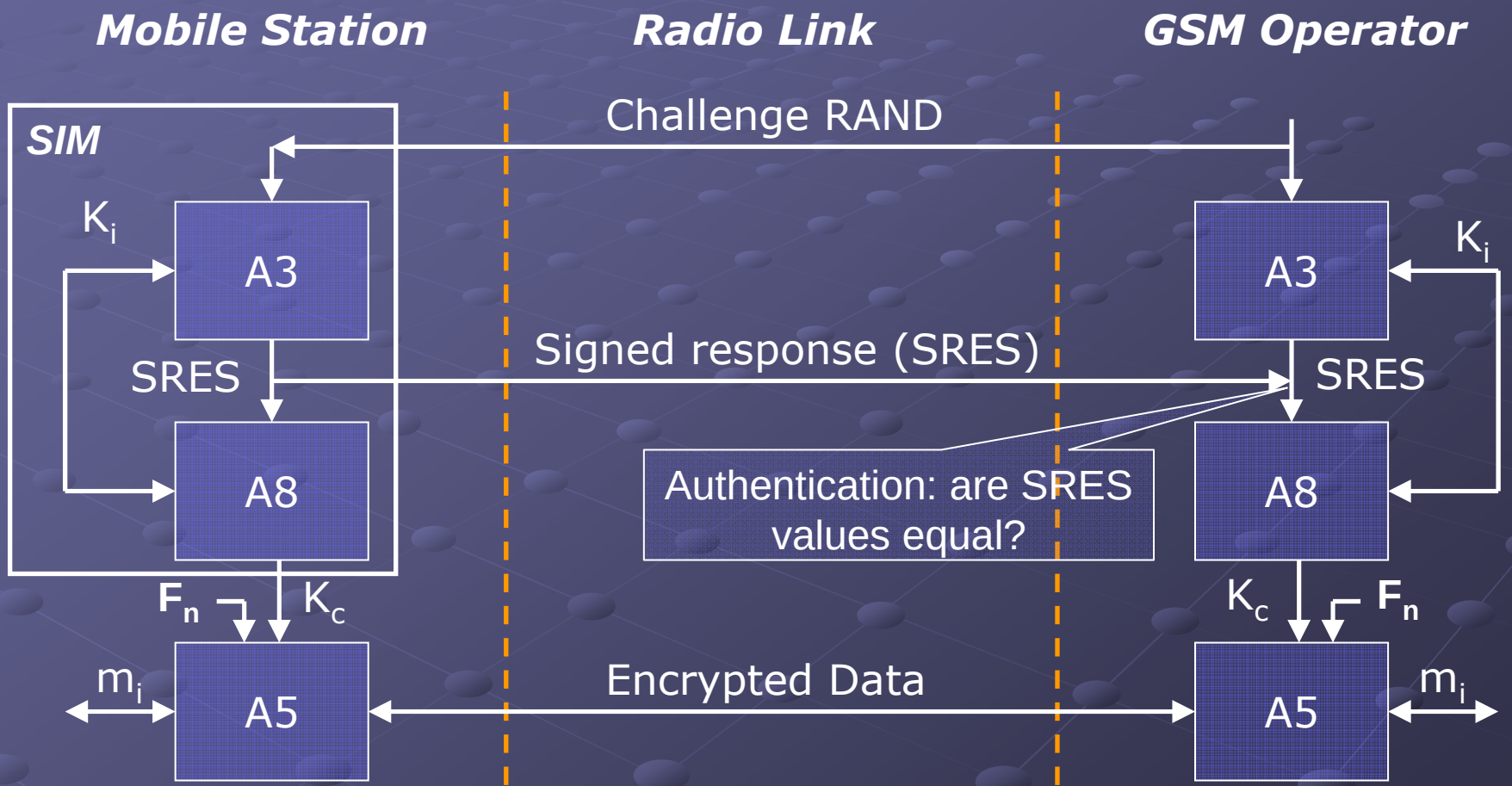
GSM is global and insecure

- 200+ countries
- 4 billion users!
- GSM encryption introduced in 1987
- Disclosed and shown insecure in 1994
- However, GSM is used in a growing number of sensitive applications:
  - Voice calls, obviously
  - SMS for banking
  - Seeding RFID/NFC secure elements for access control, payment and authentication
- GSM is constantly under attack

GSM Architecture



Authentication and Encryption Scheme



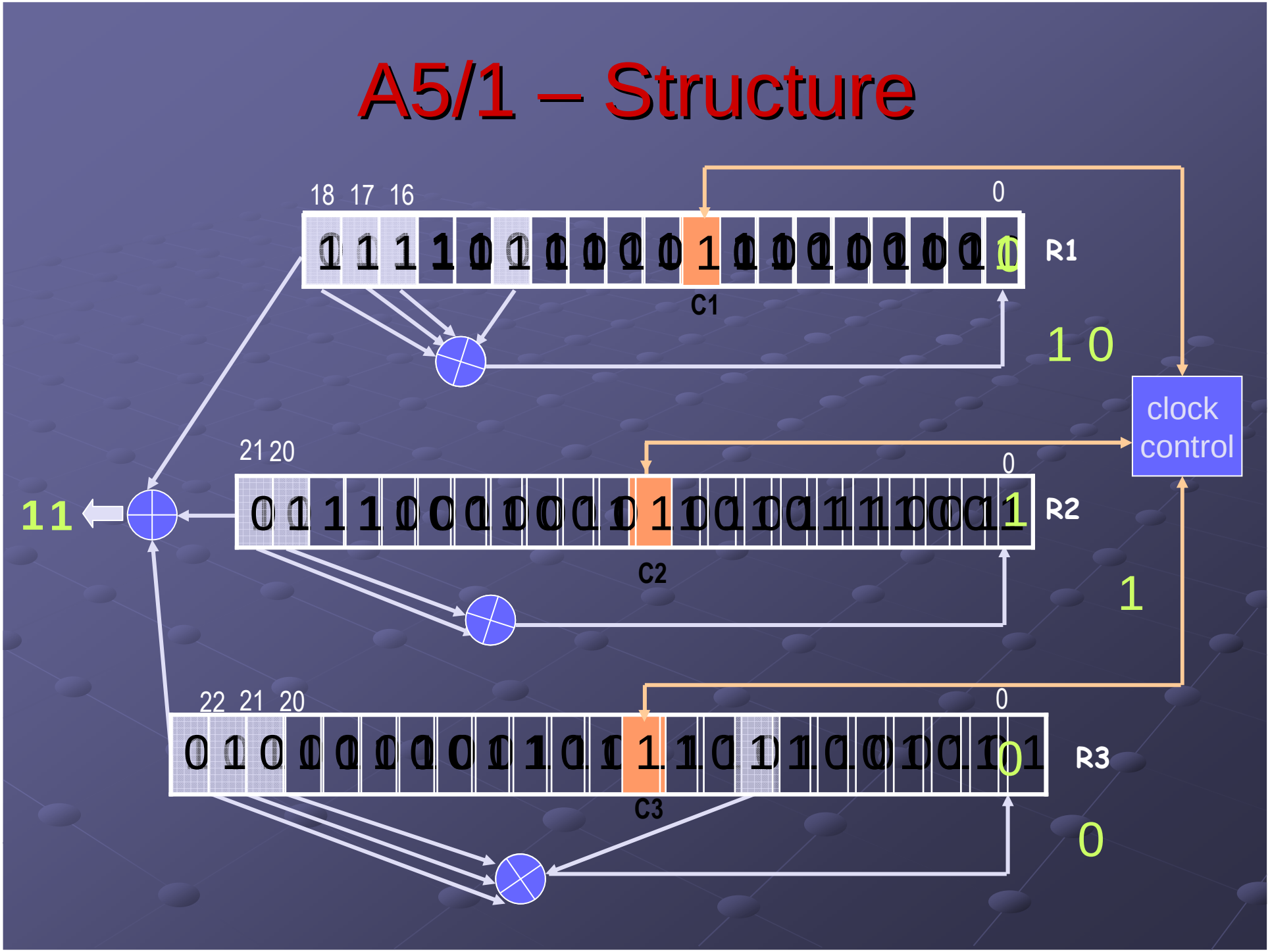
A5 – Encryption Algorithm

- A5 is a stream cipher
  - Implemented very efficiently on hardware
  - Consists of 3 LFSRs of 19,22,23 bits length
  - Registers are clocked in a stop/go fashion using the majority rule.
- Variants
  - A5/1 – the strong version
  - A5/2 – the weak version
  - A5/3
    - GSM Association Security Group and 3GPP design
    - Based on Kasumi algorithm used in 3G mobile systems

A5/1 – Operation

- All 3 registers set to zero
- 64 cycles (without the stop/go clock) :
  - Each bit of K_c (lsb to msb) is XOR'ed in parallel into the lsb's of the registers
- 22 cycles (without the stop/go clock) :
  - Each bit of F_n (lsb to msb) is XOR'ed in parallel into the lsb's of the registers
- 100 cycles with the stop/go clock control, discarding the output
- 228 cycles with the stop/go clock control which produce the output bit sequence.

A5/1 – Structure



Attack History

- 1991: First GSM implementation.
- 1997:
  - Golic presented an attack based on solving sets of linear equations.
  - Time complexity of 2^40.16
- 1999:
  - Alex Biryukov, Adi Shamir and David Wagner
  - Two minutes of intercepted call
  - The attack time was only 1 second.
  - 2^48 Steps
  - 300 GB of data
- 1999:
  - Eli Biham and Orr Dunkelman
  - total work complexity of 2^39.91 A5/1 clockings
  - 2^20.8 given bits of known plaintext
  - 32 GB of data storage after a precomputation stage of 2^38

Attack History

- 2003:
  - Ekdahl and Johannson published an attack on the initialisation procedure
  - Using two to five minutes of conversation plaintext.
  - No preprocessing stage.
  - In 2004, Maximov et al. improved this attack
    - Less than one minute of computations
    - A few seconds of known conversation
  - in 2005, improved by Elad Barkan and Eli Biham

Rainbow Tables

- Presented
  - In 2009
  - The 2009 Black Hat security conference
  - By cryptographers Karsten Nohl and Sascha Krißler
  - Using look-up tables
  - 2TB hard disk
  - ATI GPU

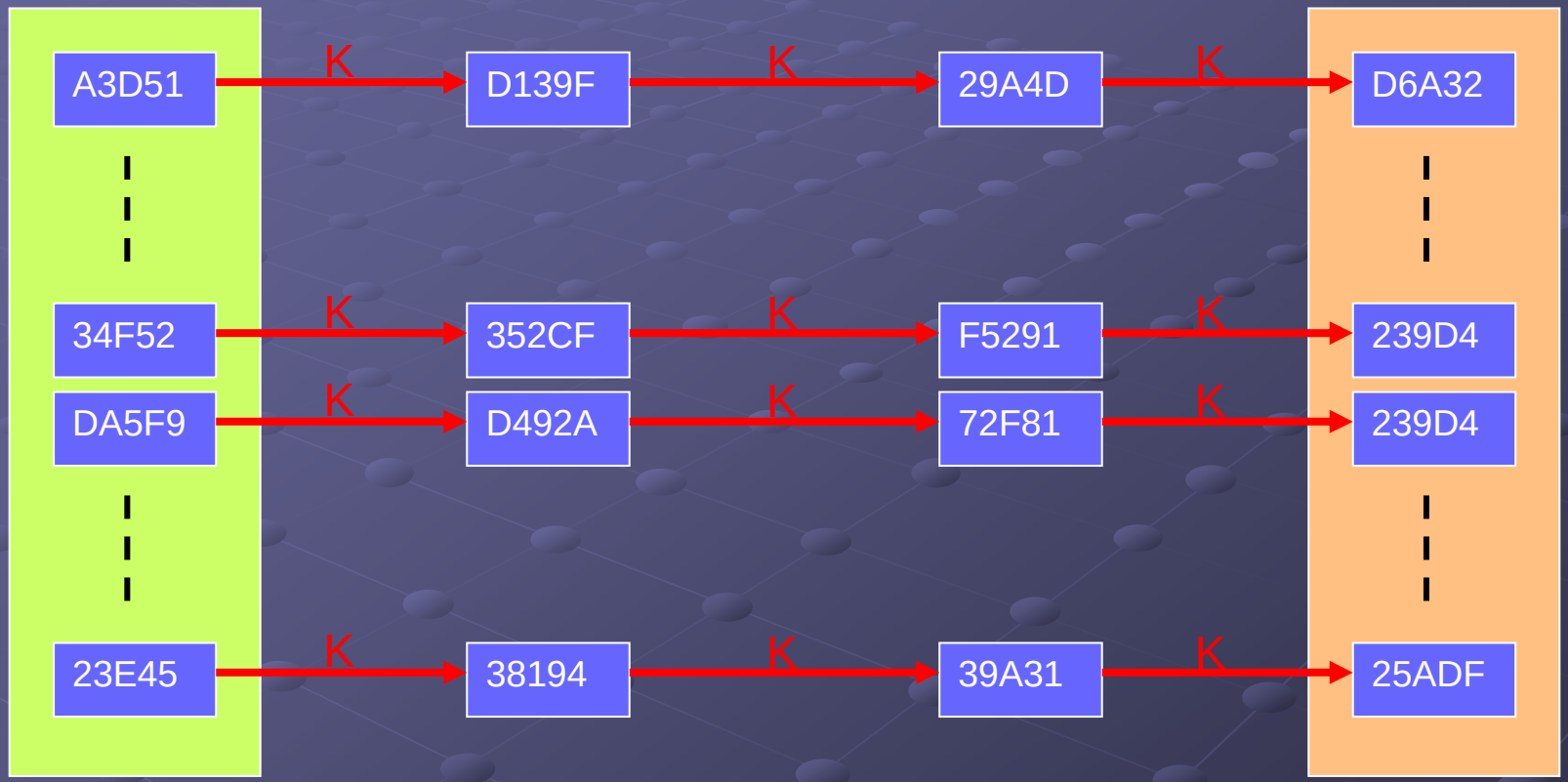
Code book attacks

- For ciphers with small keys, code books allow decryption
- Code book provides a mapping from known output to secret state

- An A5/1 code book is 128 Petabyte and takes 100,000+ years to be computed on a PC

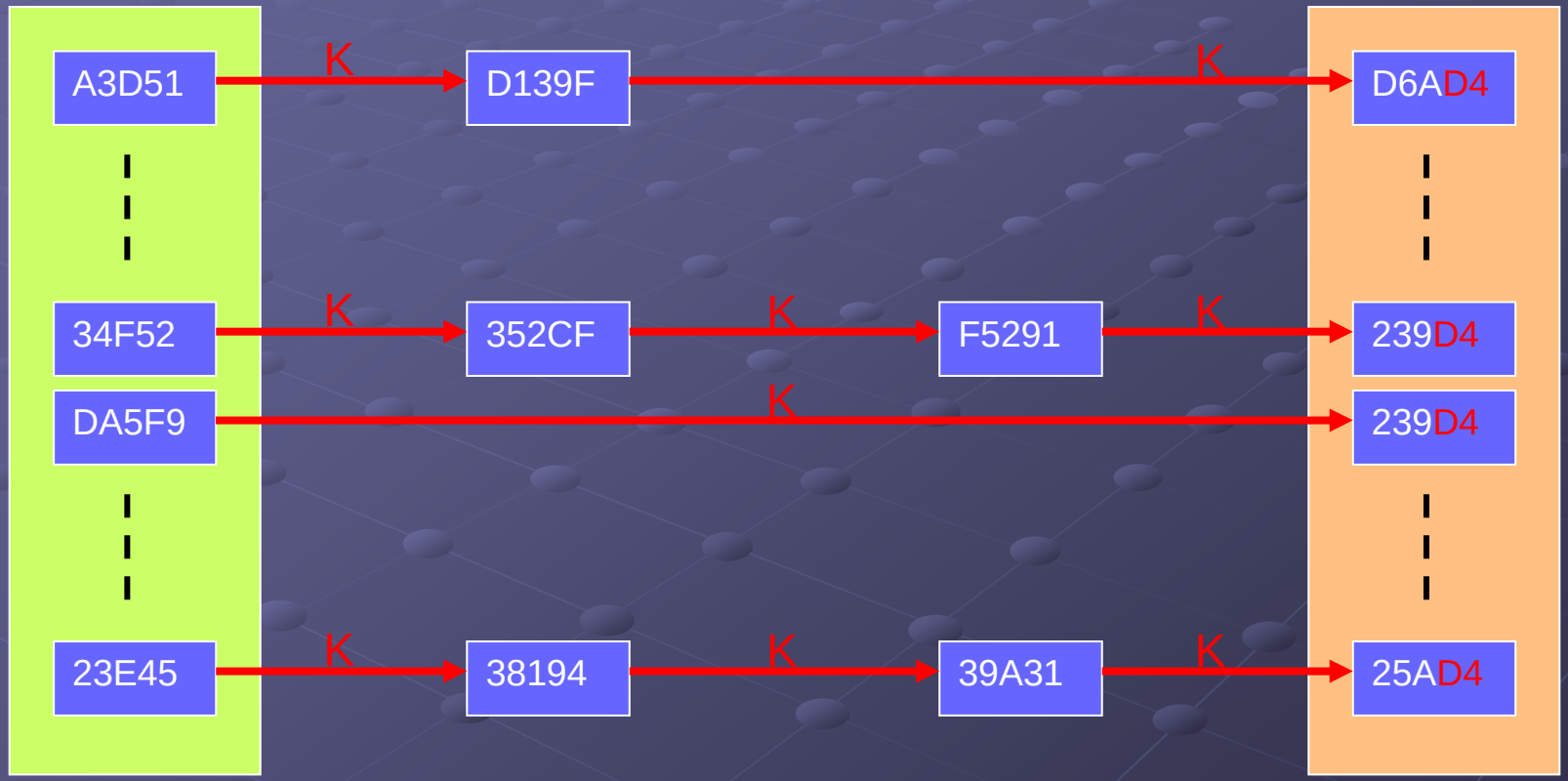
Secret state	Output
A52F8C02	52E91001
62B9320A	52E91002
C309ED0A	52E91003

Optimization 1: Chain



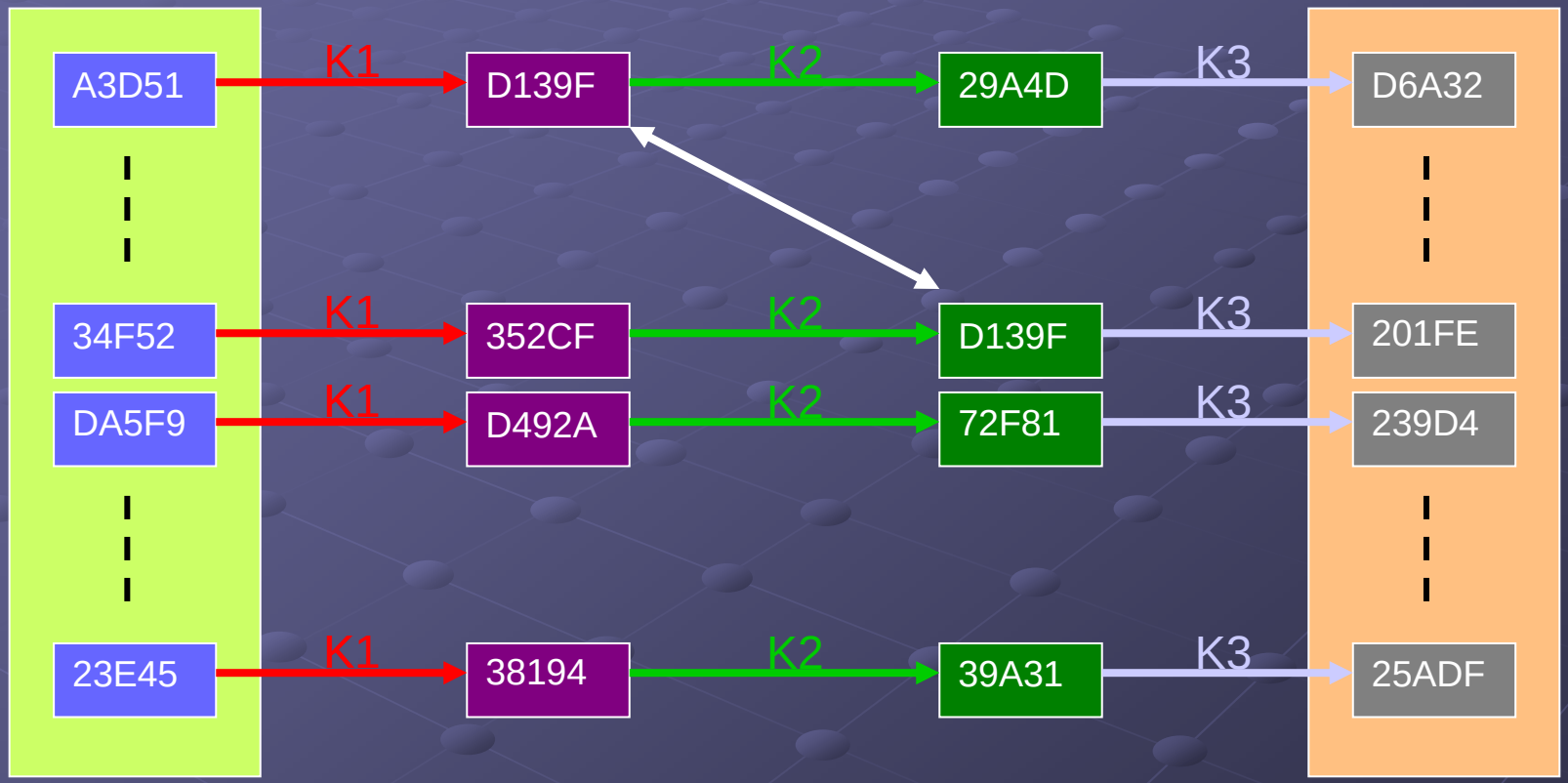
Longer chains := a) less storage, b) longer attack time

Optimization 2: Distinguishing points



Hard disk access only needed at distinguished points

Optimization 3: Rainbow tables

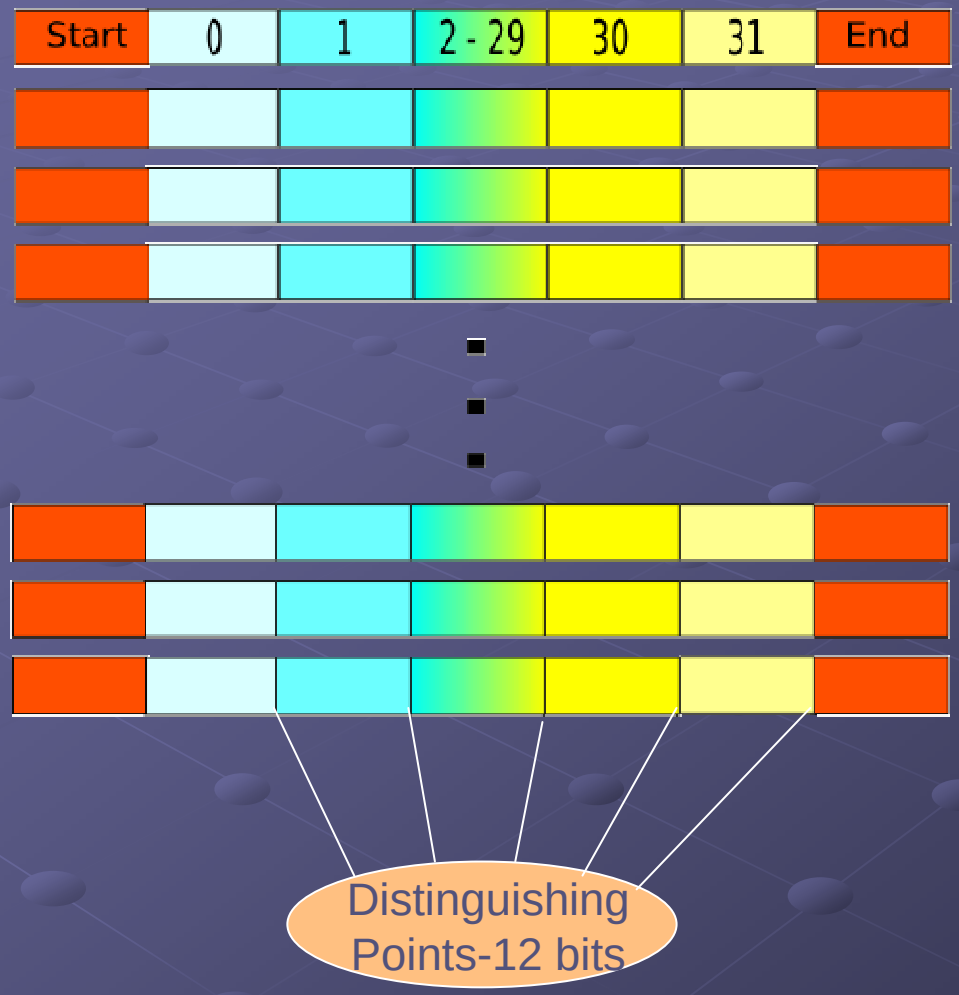


Rainbow tables have no mergers, but an exponentially higher attack time

Optimizations

- Original format: 2x64 bits for each chain
- Start values are 34 bits instead of 64 bit
- Tables are sorted by end values. Only the first values in each block are stored in full. Since neighboring values only differ in the last bits, a complete chain can be encoded in 52 to 72 bits.
- An average: 54 bits per chain
- Effectively compressing the tables by 42%
- 40 tables for a total of 2TB

Rainbow Tables



- 2^12 elements per color
- 2^5 color per chain
- 2^30 chains per table
- 2^8 tables

- In total, we have 2^54.6 Keys pre-calculated

Probability of Attack

- Our Tables cover 1/64 of key space
- 2 plaintext messages= 4 bursts= 4*114 bits
- We apply this attack on each 64 bits
- For each burst the probability of cracking:

$$1-(63/64)^{(114 - 64 + 1)} = 55.2\%$$

- Total probability: $1-(1-0.552)^4 = 95.97\%$

Key Cracking

- Given two encrypted known plaintext messages (ie. *Cipher mode complete* and a *System Information* message)
- The table set finds a secret key with almost 96% probability.
- The cracking takes about five seconds on two GPUs.
- Roughly 100,000 look-ups are required which fast SSD disks can provide within five seconds.

Data Collection

- *Cipher Mode Complete* message is available:
  - which is the first encrypted message in an encrypted transaction and usually contains the same data, mostly empty padding bytes
- *Cipher Mode Complete* message is not available:
  - the *System Information* messages also carry highly-predictable data that can be used for known plaintext where.

Frequency Hopping

- Hardware: **USRP2**

  - Capture 25 MHz of GSM spectrum
  - Typically enough for one operator
  - Need separate boards for up-and down-link

- Software: **OpenBTS**
  - Decode and record one GSM channel
  - Interpret control channel data

Third Generation Telephony Security

- **KASUMI:** Encryption Algorithm Used in Third Generation Telephony
- KASUMI is a block cipher
- It is used in **UMTS**, **GSM**, and **GPRS**
  - In **UMTS**, KASUMI is used in the confidentiality (f8) and integrity algorithms (f9) with names UEA1 and UIA1, respectively
  - In **GSM**, KASUMI is used in the **A5/3** key stream generator
  - in **GPRS,** It is used in the **GEA3** key stream generator.

Security of KASUMI

- In 2001, an impossible differential attack on six rounds of KASUMI was presented by Kühn

- In 2005, Eli Biham, Orr Dunkelman and Nathan Keller published a related-key rectangle (boomerang) attack on KASUMI that can break all 8 rounds faster than exhaustive search.
  - The attack requires 2^54.6 chosen plaintexts
  - The time complexity = 2^76.1 KASUMI encryptions

Attack on Kasumi

- Dunkelman, Keller, Shamir. Asiacrypt Rump session. **Dec. 2009**
- Data complexity: 2^26 plaintexts/ciphertexts
- Space complexity: 2^30 bytes (one gigabyte)
- Time complexity: 2^32
- Completely practical complexities
- Attack verified by actual software simulation

Thank You !