Karsten Nohl, Chris Paget – 26C3, Berlin

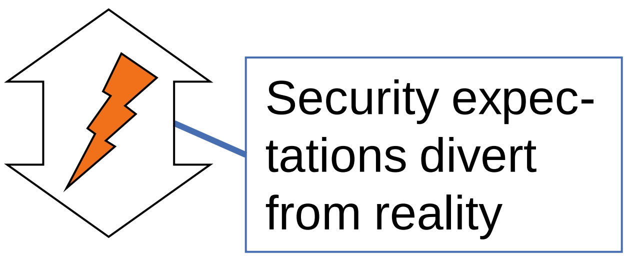
GSM – SRSLY?

H4RDW4RE

Summary:
GSM Encryption needs to be shown insecure

GSM is constantly under attack:

- A5/1 cipher shown insecure repeatedly
- Lack of network authentication allow MITM intercept (IMSI Catcher)



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

- To rectify the perception of GSM's security, we demon-strate its weaknesses
- The community has computed the cryptographic base for a public demons-tration of cracking GSM
- This presentation details motives, approach and next steps of the "A5/1 Security Project"

Source: H4RDW4RE

GSM is global, omnipresent and insecure

80% of mobile phone market

200+ countries

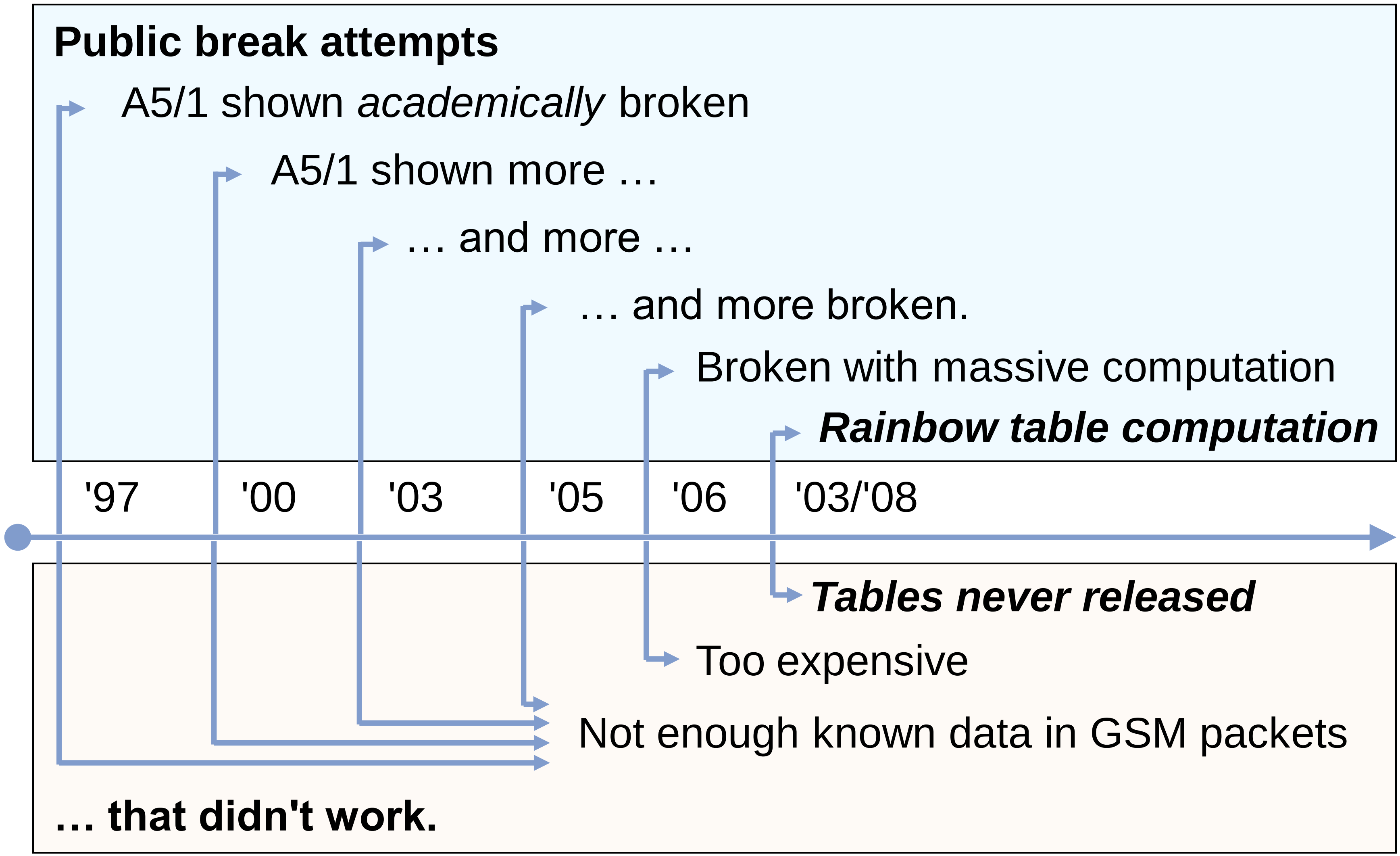
4 billion users!

GSM encryption introduced in 1987 …

… then disclosed and shown insecure in 1994

Source: Wikipedia, GSMA

We need to publicly demonstrate that GSM uses insufficient encryption



Source: H4RDW4RE

GSM encryption is constantly being broken, just not publicly

All public break attempts of A5/1 have failed so far

- Academic breaks of A5/1 cipher are not practical [EC1997, FSE2000, Crypto2003, SAC2005]
- Cracking tables computed in 2008 were never released

- 15 years of A5/1 research have not produced a proof of concept
- (until today)

Meanwhile …

… A5/1 is constantly being circumvented by intelligence, law enforcement, and criminals

Source: H4RDW4RE

Active and passive intercept is common as attack devices are readily available

Two flavors of attack devices

A

Active intercept:

- Phones connect through fake base station
- Easily spottable (but nobody is looking)

B

Passive key cracking:

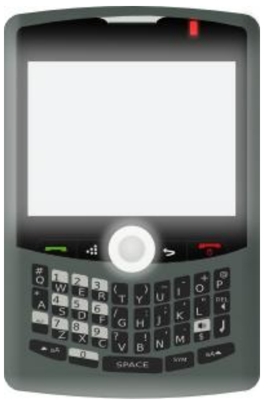
- Technically challenging
  - –Non-trivial RF setup
  - –Heavy pre-computation
- Allows hidden operation

This talk demonstrates that GSM intercept is practical to raise awareness

Source: H4RDW4RE, DeepSec GSM training

H4RDW4RE

IMSI catching routes calls through a fake base station



Advertise base station on beacon channel

IMSI: Subscriber Identity (~= username)
- Sort-of secret (replaced by TMSI asap)

MCC*: Mobile Country Code
- 262 for .de, 310-316 for USA

MNC*: Mobile Network Code
- Country-specific, usually a tuple with MCC
- 262-01 for T-Mobile Germany

Phones will connect to any base station with spoofed MNC/MCC
- If you claim it, they will come
- Strongest signal wins
- IMSI catching is detectable from phone, but no detect apps exists !
- Crypto is completely optional and set by the base station !!

* Full list of MNC/MCCs available on Wikipedia

Source: H4RDW4RE

H4RDW4RE

IMSI catcher could even be built from open source components

A Setup

- OpenBTS + USRP + 52MHz clock
  - Easy to set up, Asterisk is hardest part
  - On-board 64MHz clock is too unstable
- Software side is easy
  - ./configure && make
  - Libraries are the only difficulty

B Configure

- Set MCC/MNC to target network
- Find and use an open channel (ARFCN in GSM-ese)

C Collect, Decode

- Wireshark has a Built-in SIP analyzer
- Or: capture data on air with Airprobe and decode GSM packets

Source: H4RDW4RE

H4RDW4RE

The iPhone that wouldn't quit

What if we want to test and *not* "catch" IMSIs?

- Set MCC/MNC to 001-01 (Test/Test)
- Phones camp to strongest signal
  - Remove transmit antenna
  - Minimize transmit power
- GSM-900 in .eu overlaps ISM in USA
  - 902-928MHz is not a GSM band in the USA

Despite all of this we could not shake an iPhone 3G*…

* Other iPhones would not connect at all.

Source: H4RDW4RE

H4RDW4RE

Fun bugs exposed by OpenBTS

During testing, we saw bugs in OpenBTS and phones:

- Persistent MNO shortnames
  - Chinese student spoofed local MNO
  - Classmates connected
  - Network name of "OpenBTS", even after BTS was removed & phones hard rebooted!
- Open / Closed registration
  - Separate from SIP-level HLR auth
  - Supposed to send "not authorized" message
  - Instead sent "You've been stolen" message
  - Hard reboot required, maybe more

- Still many bugs in GSM stacks
- They are being found thanks to open source

Source: H4RDW4RE

H4RDW4RE

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Source: H4RDW4RE, DeepSec GSM training

H4RDW4RE

A5/1 is vulnerable to generic pre-computation attacks

Code book attacks

- For ciphers with small keys, code books allow decryption

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

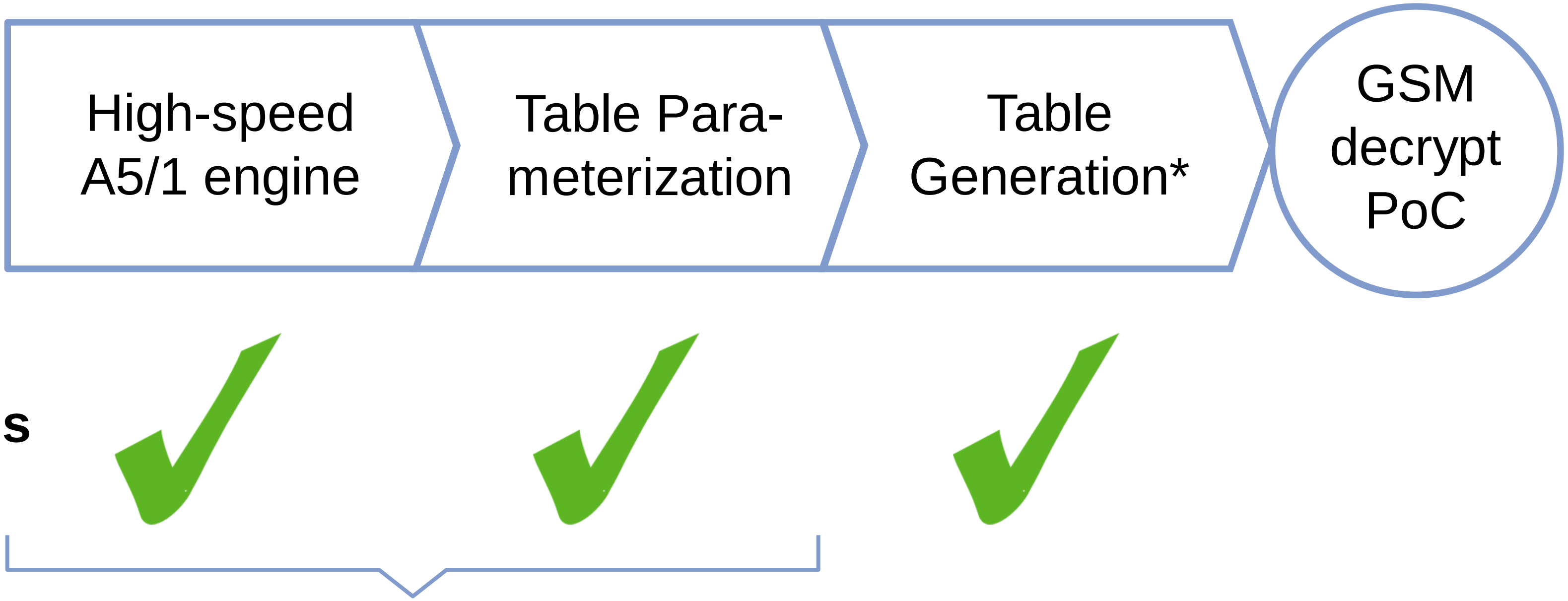
- Code book provides a mapping from known output to secret state
- An A5/1 code book is 128 Petabyte and takes 100,000+ years to be computed on a PC

> This talk revisits techniques for computing and storing a A5/1 code book efficiently

Source: H4RDW4RE

Groundwork for table generation is complete and released as open source

Status



Source and doc available:
reflextor.com/trac/a51

Tables seen on Bittorrent

* Community provided: fast graphics cards (NVidia or ATI) and Cell processors (Playstation)

Source: H4RDW4RE

Key requirement of code book generation is a fast A5/1 engine

Time on single threaded CPU:
100,000+ years

A Parallelization
- GPUs*: hundreds of threads
- FPGA: thousands of engines

B Algorithmic tweaks
- GPUs*: compute 4 bits at once
- FPGA: minimize critical path

C Implementation tweaks
- GPUs*: bitslicing

3 months on **40 CUDA nodes**

Latest speeds [chains/sec]
- Nvidia GTX280 – 500
- ATI HD5870 – 500
- PS3 Cell – 120

* NVidia CUDA and ATI Brook GPUs are supported

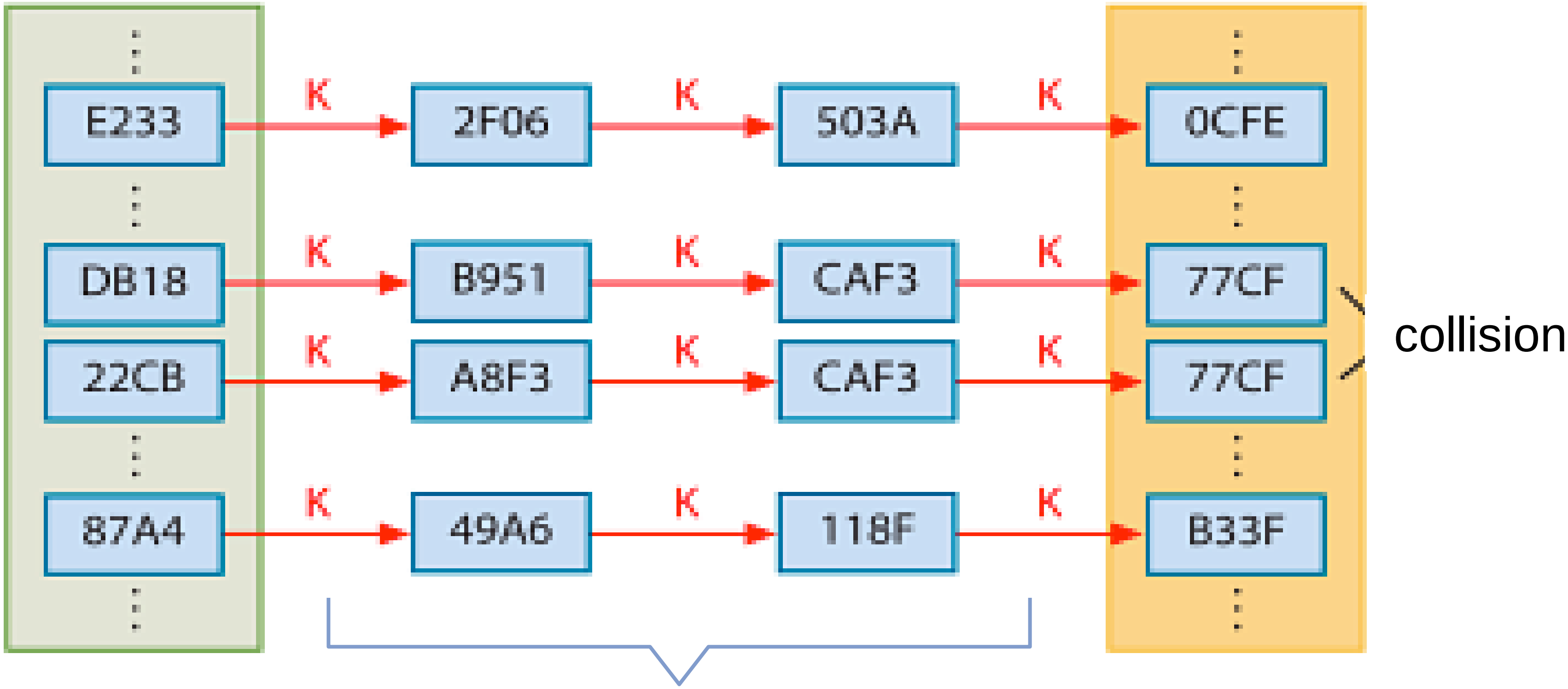
Source: H4RDW4RE

Cracking to be demonstrated on Wednesday

- The first tables started showing up on the congress FTPs and Bittorrents;
  - check *reflextor.com/trac/a51* for up-to-date details
- We want more!
  - Please sort your tables before uploading (tutorial on *reflextor.com/trac/a51*)
  - After the congress, keep sharing through Bittorrent

- We continue to collect tables until Tuesday evening
- Current state to be demonstrated in **workshop**
  - **Wednesday Dec 30, 13:00**, Large workshop room (A03)
  - Bring encrypted GSM sniffs you want to decrypt

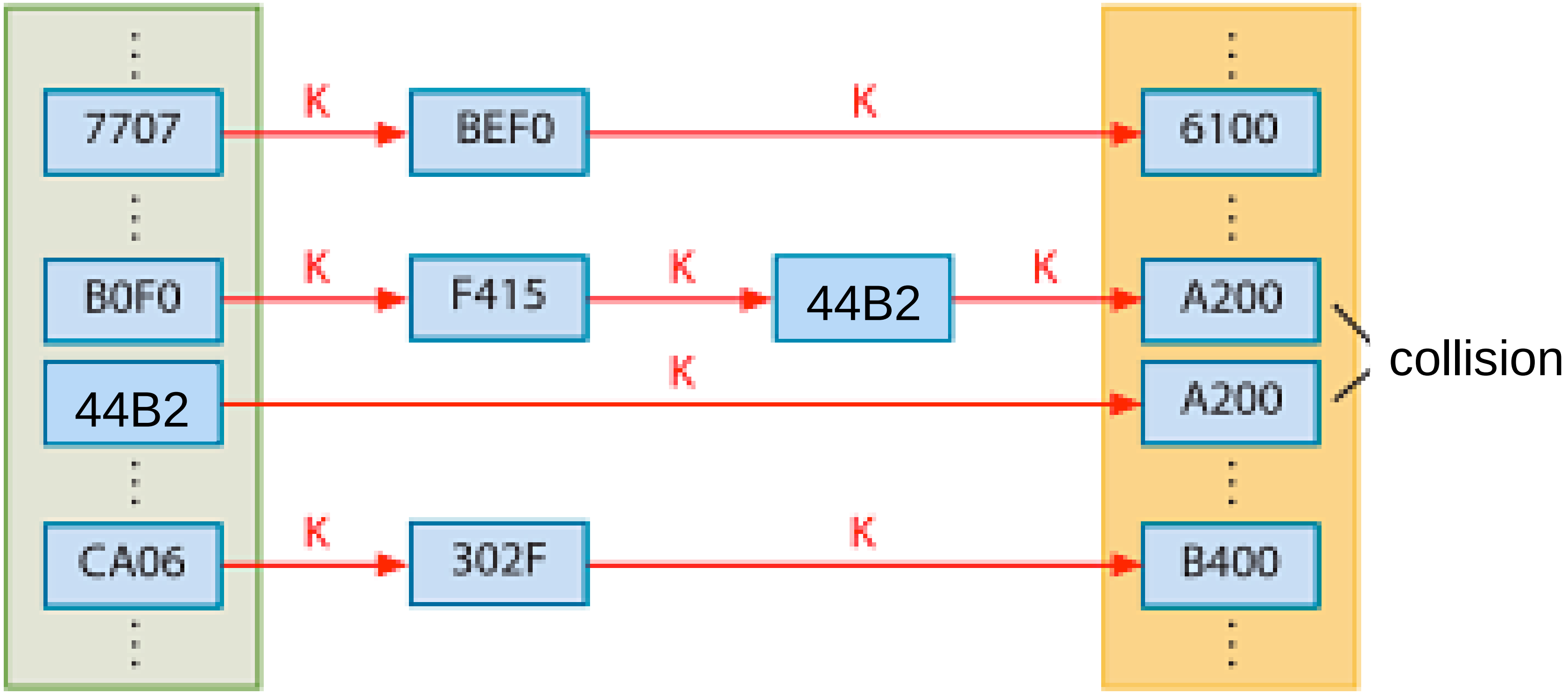
Pre-computation tables store the code book condensed



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

Source: H4RDW4RE, c't

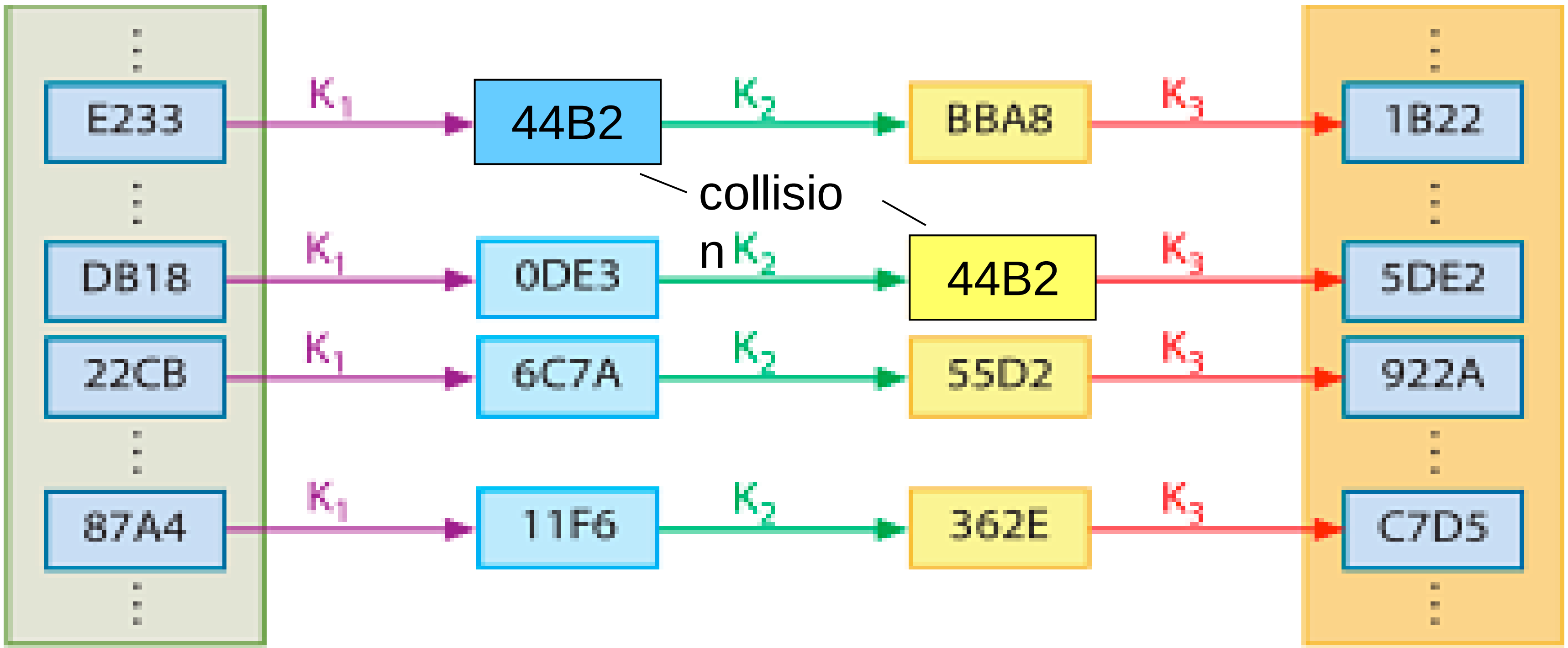
Distinguished point tables save hard disk lookups



Hard disk access only needed at distinguished points

Source: H4RDW4RE, c't

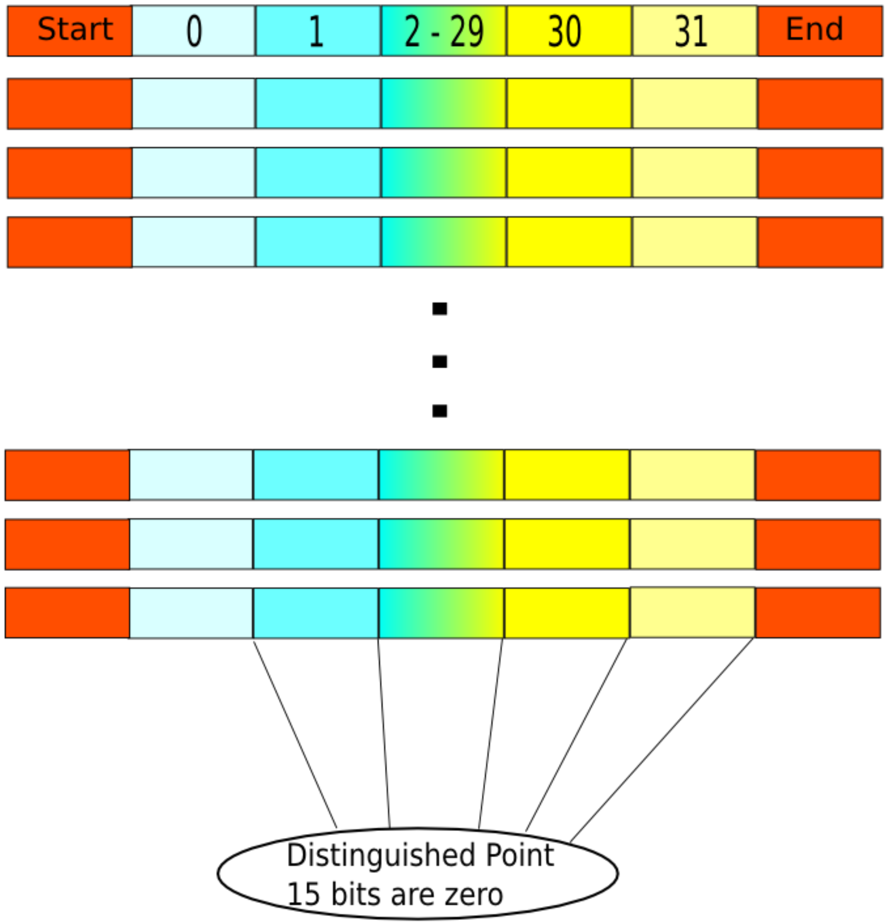
Rainbow tables mitigate collisions



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

Source: H4RDW4RE, c't

The combination of both table optimizations is optimal



Assumptions

- 2 TB total storage
- 99% success rate when collecting all available keystream*
- 50% success rate when only obvious keystream is used
- Near real-time decryption with distributed cracking network

The most resource efficient table for A5/1 is:

- 32 DP segments of length 2^{15}
- Merged into one rainbow
- 380 such tables with height $2^{28.5}$ needed

* Collecting all available key stream requires data from a registered phone

Source: H4RDW4RE

GSM discloses more known keystream than assumed in previous crack attempts

● Known Channel ○ Unknown Channel

	Frame with known or guessable plaintext	Assignment: Very early	Assignment: Early	Assignment: Late	Timing known through
Mobile termi-nated calls	1. Empty Ack after 'Assignment complete'	●	○	○	**"Stealing bits"**
	2. Empty Ack after 'Alerting'	○	○	○	
	3. 'Connect Acknowledge'	○	○	○	
	4. Idle filling on SDCCH (multiple frames)			●	
	5. System Information 5+6 (~1/sec)	◐	○	◐	
Network termi-nated calls	1. Empty Ack after 'Cipher mode complete'	●	●	●	**Counting frames**
	2. 'Call proceeding'	●	●	●	
	3. 'Alerting'	●	○	●	**"Stealing bits"**
	4. Idle filling (multiple frames)			●	
	5. 'Connect'	●	○	○	
	6. System Information 5+6 (~1/sec)	◐	○	◐	

Source: GSM Standards

Industry responds by creating a new challenge

"… the GSM **call has to be** identified and **recorded** from the radio interface. […] we strongly suspect **the team** developing the intercept approach **has underestimated its practical complexity**.

A hacker would need a <u>radio receiver system</u> and the **<u>signal processing software</u>** necessary to process the raw radio data." – GSMA, Aug.'09

These remaining components of an interceptor could be repurposed from open source projects

Source: GSMA press statement

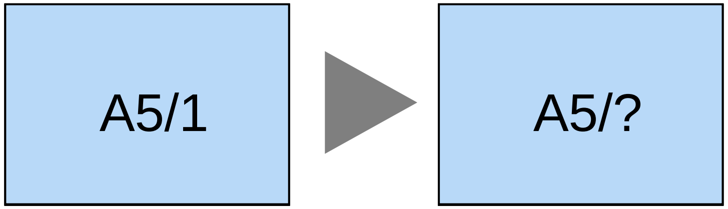
Hypothetically, an interceptor can be built from open source components

Compo-nent	**“Radio receiver system”**  – USRP2 –	**“Signal processing software”** **OpenBTS**
Current capabi-lities	▪ Capture 25 MHz of GSM spectrum – Typically enough for one operator – Need separate boards for up- and down-link	▪ Decode and record one GSM channel ▪ Interpret control channel data
Needed Improve-ments	▪ Decrease data rate (from 40MB/s) – Ability to detect active channels (energy detector) – Execute steps of decode chain in FPGA (Tune and Decimate) **Bottleneck: USRP programming**	▪ Decrypt A5/1 packets given the correct key (v.3.0?) ▪ Decode several channels (v.3.0)

Source: H4RDW4RE

GSM's security must be overhauled

Upgrading GSM's encryption function should be a mandatory security patch



However, replacing A5/1 with A5/3 may not be enough:

- **A** The A5/3 cipher "Kasumi" is academically broken
- **B** The same keys are used for A5/1 and A5/3 (weakest link security)

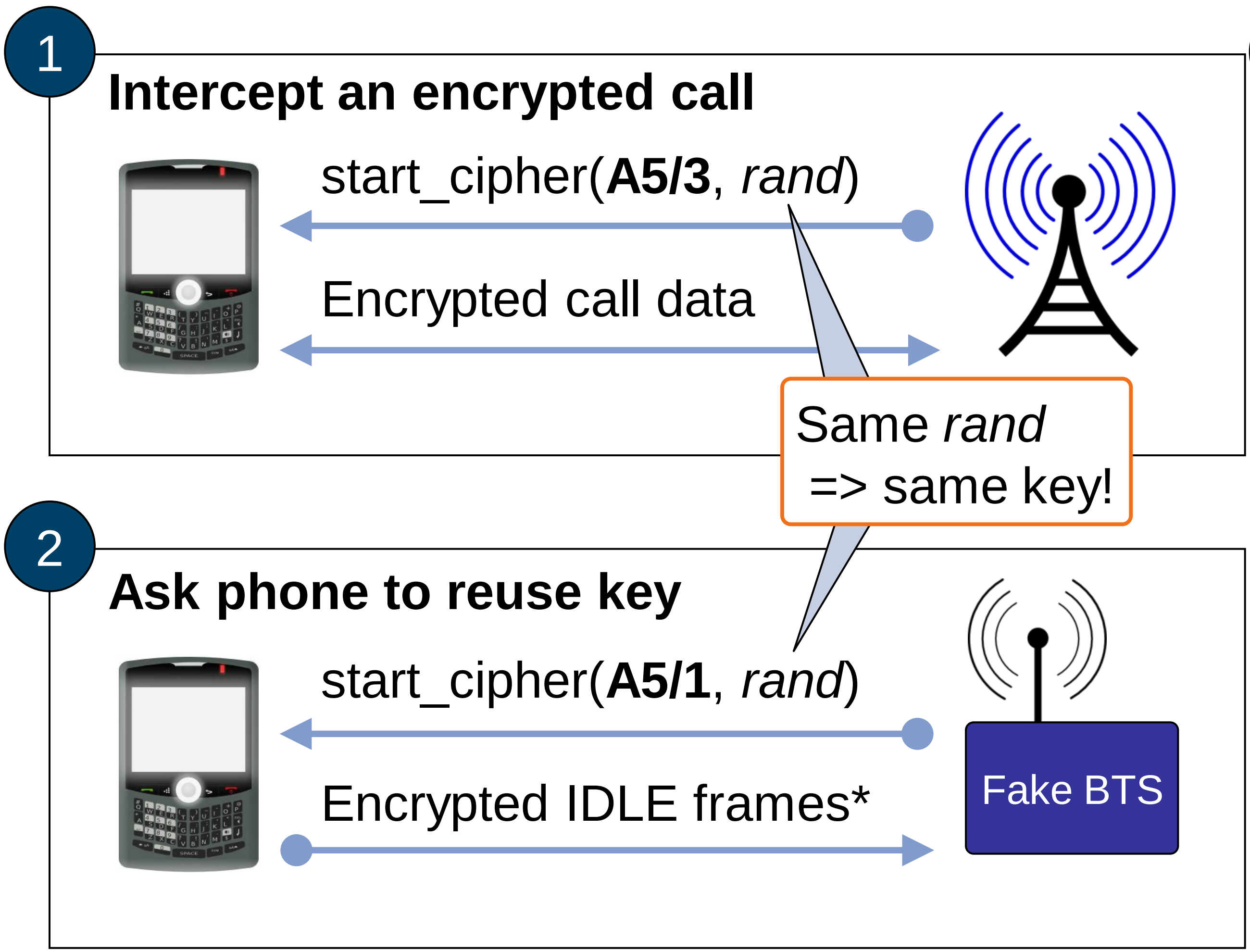
Source: H4RDW4RE

A Dunkelman, Keller, Shamir. Asiacrypt Rump session. **Dec. 2009**

Summary of the Attack on Kasumi:

- Data complexity: 2^{26} plaintexts/ciphertexts
- Space complexity: 2^{30} bytes (one gigabyte)
- Time complexity: 2^{32} (hardest part: ex search)
- Completely practical complexities
- Attack verified by actual software simulation

B A5/3 can be cracked in a semi-active attack



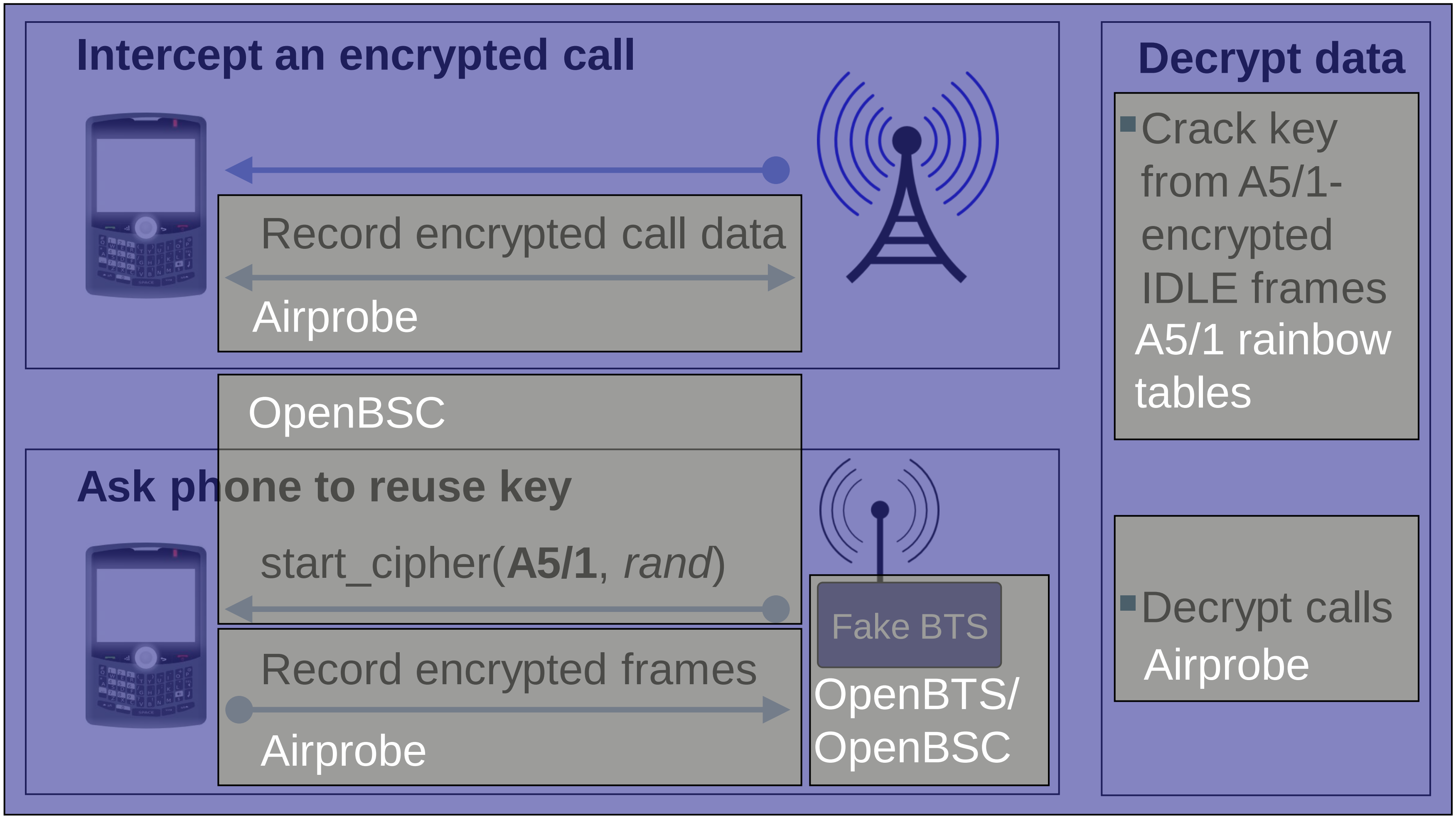
3 **Decrypt data**

- Decrypt call or SMS with key cracked from A5/1 trans-actions
- GSM cracker done ✓ (but not passive and not realtime)

* IDLE frames contain known plaintext

Source: H4RDW4RE

B All tools needed for the semi-active attack are openly available



* IDLE frames contain known plaintext

Source: H4RDW4RE

H4RDW4RE

A5/1 cracking is just the first step …

- Pre-computation framework build to be generic
  - Any cipher with small key space
  - Flexible table layout
  - Various back ends: CPU, CUDA, ATI, FPGA
- All tools released open source

- Please get involved
  - Port table generator to cipher in your projects
  - Find data to be decrypted (i.e., through programming the USRP's FPGA)

Source: H4RDW4RE

Questions?

Documentation, Source	reflextor.com/trac/a51
Mailing list	tinyurl.com/a51list
c't article	tinyurl.com/ct-rainbows

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Many thanks to Sascha Krißler, Frank A. Stevenson and David Burgess!