CSE 3400/CSE 5850 - Introduction to Computer & Network Security
/ Introduction to Cybersecurity

Lecture 9
Shared Key Protocols – Part II

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Adapted from the Textbook Slides

Outline

- Handshake protocol extensions.
- Key distribution centers.
- Improving resilience to key exposure.

Handshake Protocol Extensions

Authenticated Request-Response Protocols

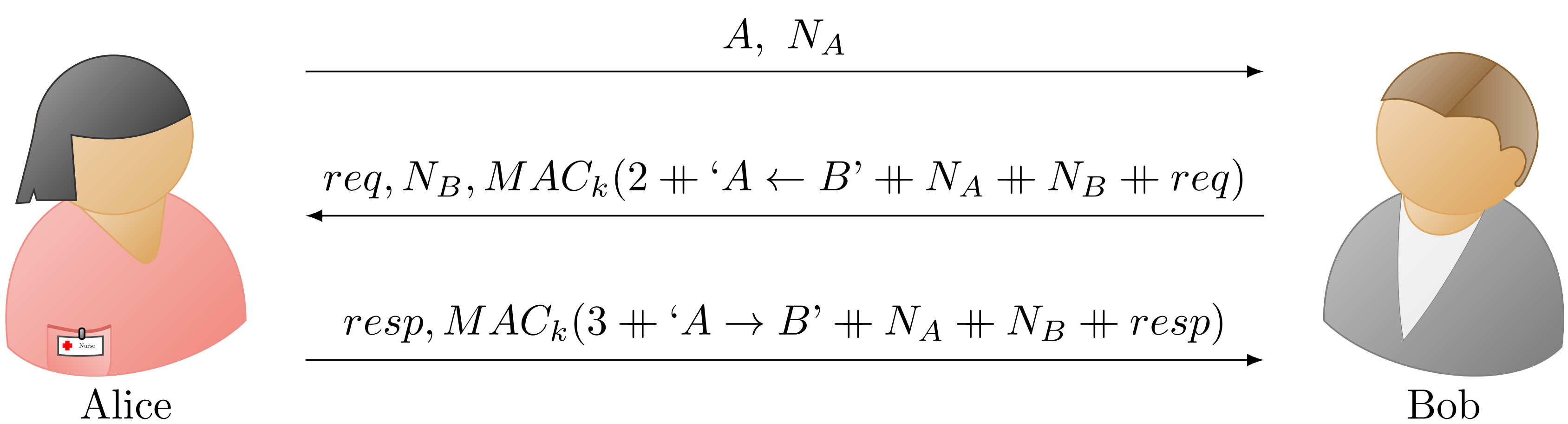
- Beside authenticating entities, these protocols authenticate the exchange of a request and a response between the entities.
- Required properties:
  - **Request authentication.**
    - The request was indeed sent by the peer.
  - **Response authentication**
    - The response was indeed sent by the peer.
  - **No replay.**
    - Every request/response was received at most the number of times it was sent by the peer.

Authenticated Request-Response Protocols

- Five variants:
  - 2PP-RR
  - 2RT-2PP
  - Counter-based-RR
  - Time-based-RR.
  - Key-exchange.

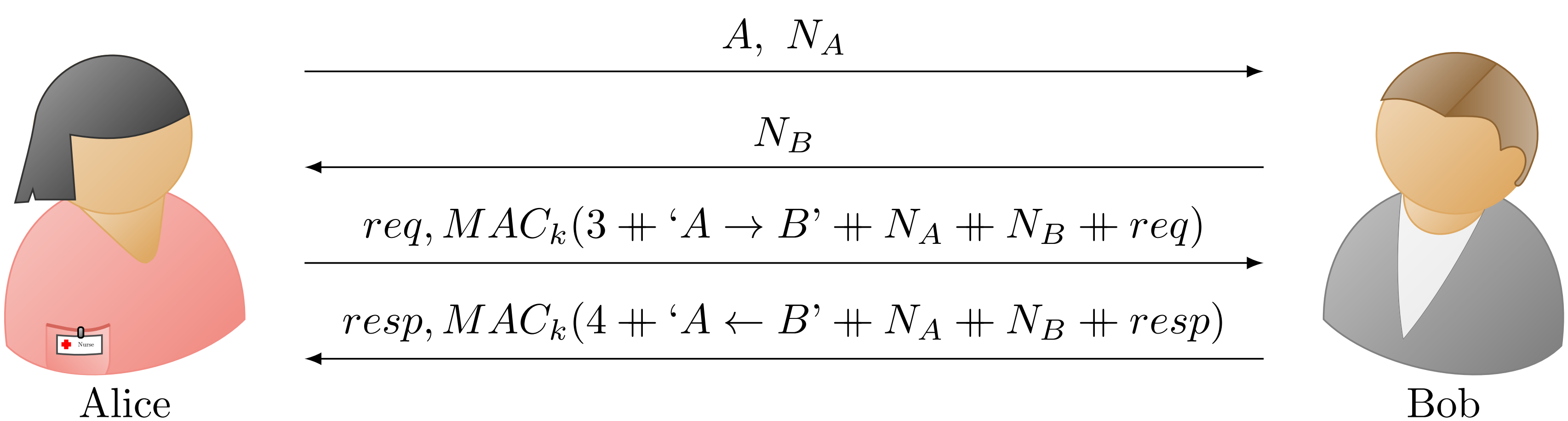
2PP-RR

- A three-flow nonce-based protocol.
- Significant drawback:
  - The request is sent by the responder and the initiator sends the response.
  - So initiator must wait for a request rather than sending it!!



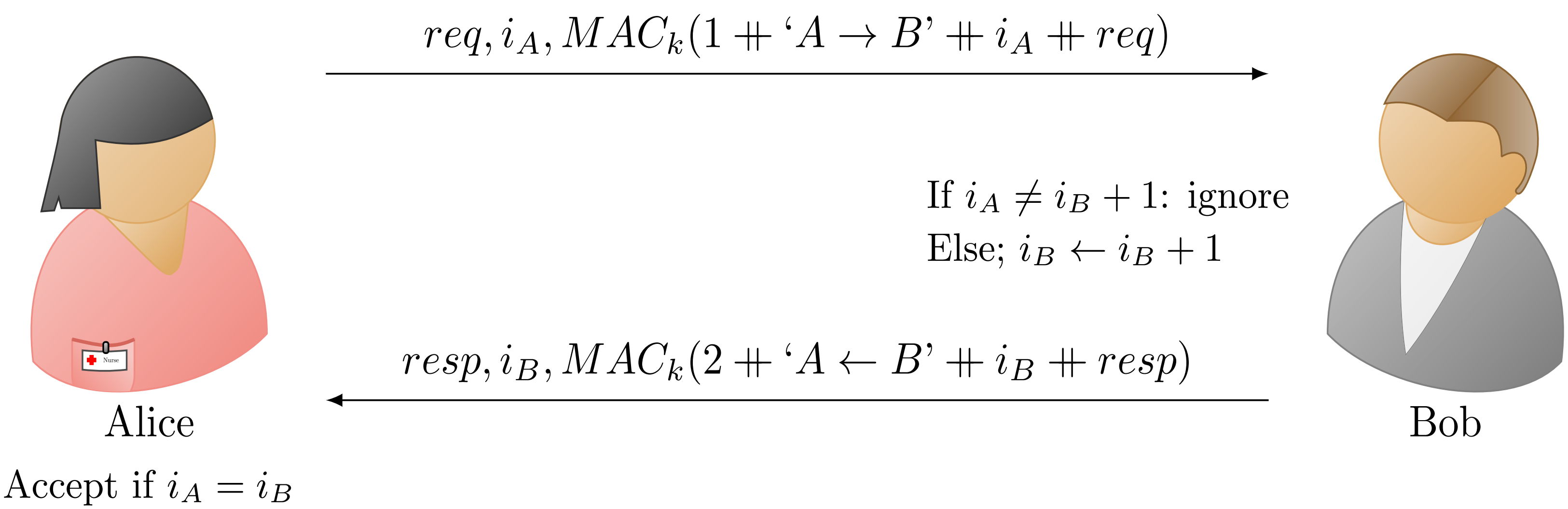
2RT-2PP

- A four-flow nonce-based protocol.
- Mainly fixes the drawback of 2PP-RR (see previous slide).



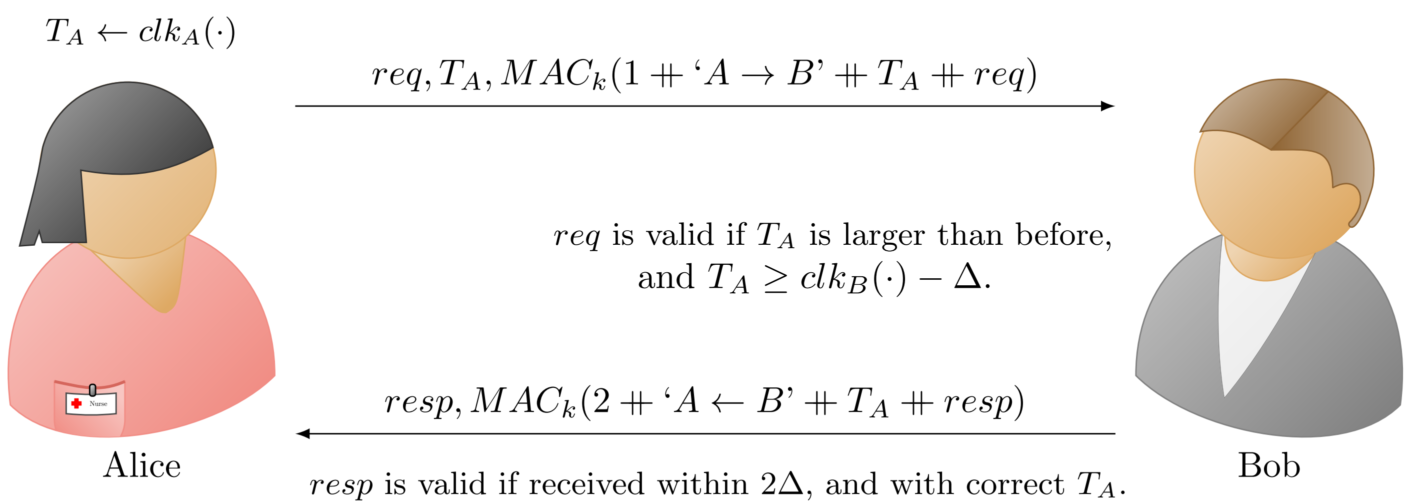
Counter-Based Authenticated RR

- **Simple stateful (counter) solution, requiring only one round:**
  - Unidirectional (run once for each direction if both are needed).
  - Parties maintain synchronized counter i of requests (and responses) to avoid replay attacks.
  - Recipient (e.g., Bob) validates counter received is $i + 1$
  - Both parties must remember counter



Time-Based Authenticated RR

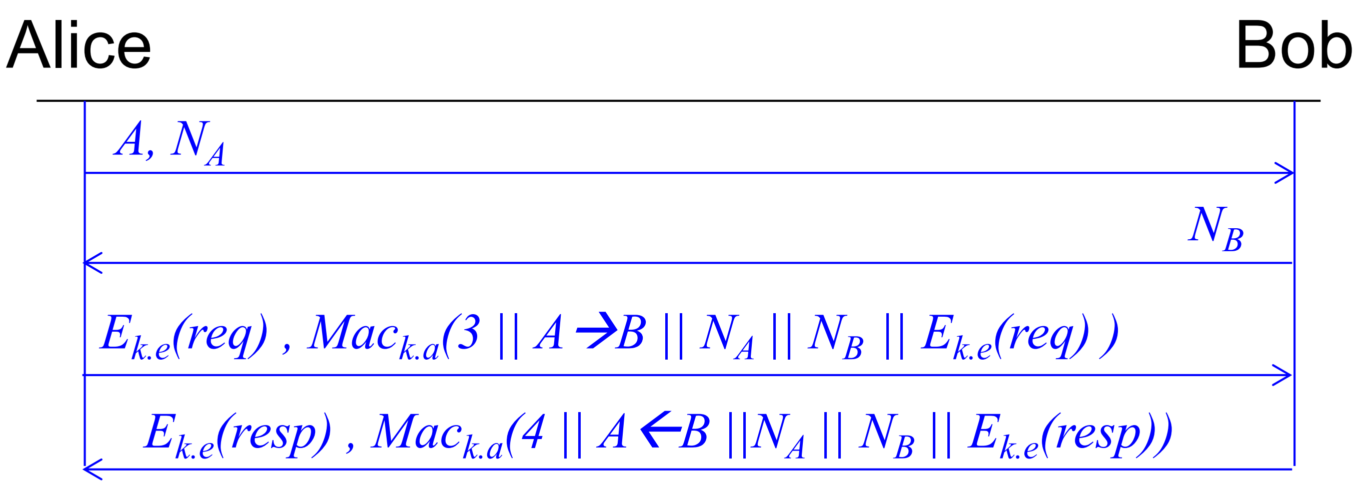
- **Simple stateful (time) solution, requiring only one round:**
  - Use local clocks T_A, T_B instead of counters with two assumptions: bounded delays and bounded clock skews.
  - Responder (Bob):
    - Rejects request if: $T_B > T_A + \Delta$ where $\Delta \equiv \Delta_{skew} + \Delta_{delay}$
    - Or if he received larger T_A already
    - Maintains last T_A received, until $T_A + \Delta$
  - Initiator (Alice) does not need **any** state, when can Bob discard his?



Remember T_A

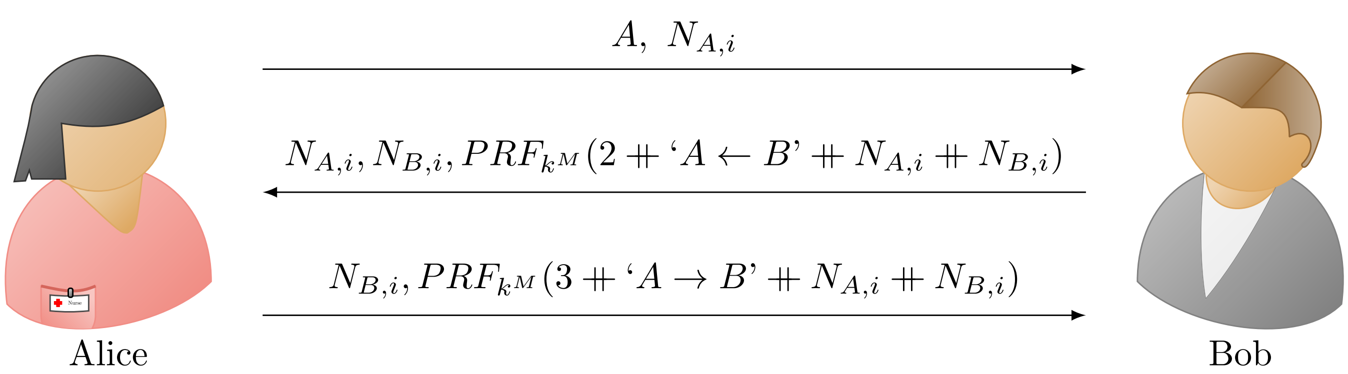
2RT-2PP with Confidentiality

- **Secure connection: authentication, freshness, secrecy**
  - Independent keys: for encryption $k.e$, for authentication: $k.a$
  - How can we derive them both from a single key k ?
    - $k.e=PRP_k(\text{"Encrypt"}), k.a=PRP_k(\text{"MAC"})$
  - Hmm… same key encrypts all messages, in all sessions ☹
- Can we improve security, by changing keys, e.g., between sessions ?



2PP Key Exchange Protocol

- Independent session keys, e.g. $k=PRF_{MK}(N_A,N_B)$
- Or, `directly' for authentication and for encryption:
  $k.e=PRF_{MK}(\text{“Encrypt”}, N_A,N_B)$, $k.a=PRF_{MK}(\text{“MAC”}, N_A,N_B)$
- Improves security:
  - Exposure of session key does not expose (long-term) ‘master key’ MK
  - And does not expose keys of other sessions
  - Limited amount of ciphertext exposed with each session key k
- Later: reduce risk also from exposure of Master Key MK



$k_i^S = PRF_{k^M}(N_{A,i} \mathbin{+\!\!+} N_{B,i})$ $\qquad$ $k_i^S = PRF_{k^M}(N_{A,i} \mathbin{+\!\!+} N_{B,i})$

A PRF is used instead of the MAC, is that ok?

Key Distribution Centers (KDCs)

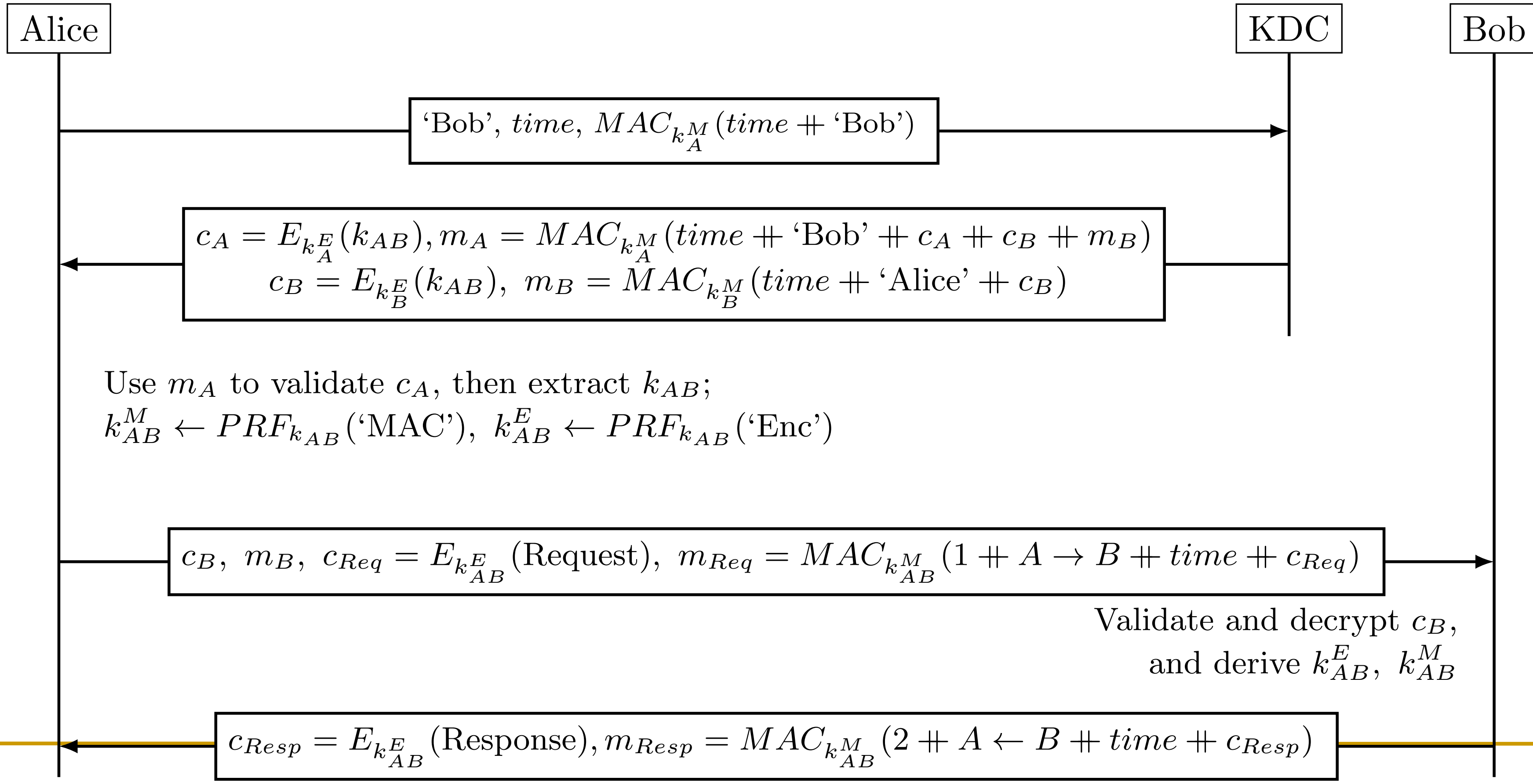
Establish a shared key between two or more entities, usually with the help of a trusted third party referred to as KDC

Key Distribution Center (KDC)

- Will focus on three party protocols; Alice, Bob, and KDC.
- KDC: shares keys with all parties (k_A, k_B…)
- Goal: help parties (A, B) establish k_{AB}
- We will study two protocols; simplified versions of:
  - The Kerberos protocol (secure) widely used in computer networks.
  - The GSM protocol (insecure) used by cellular networks.

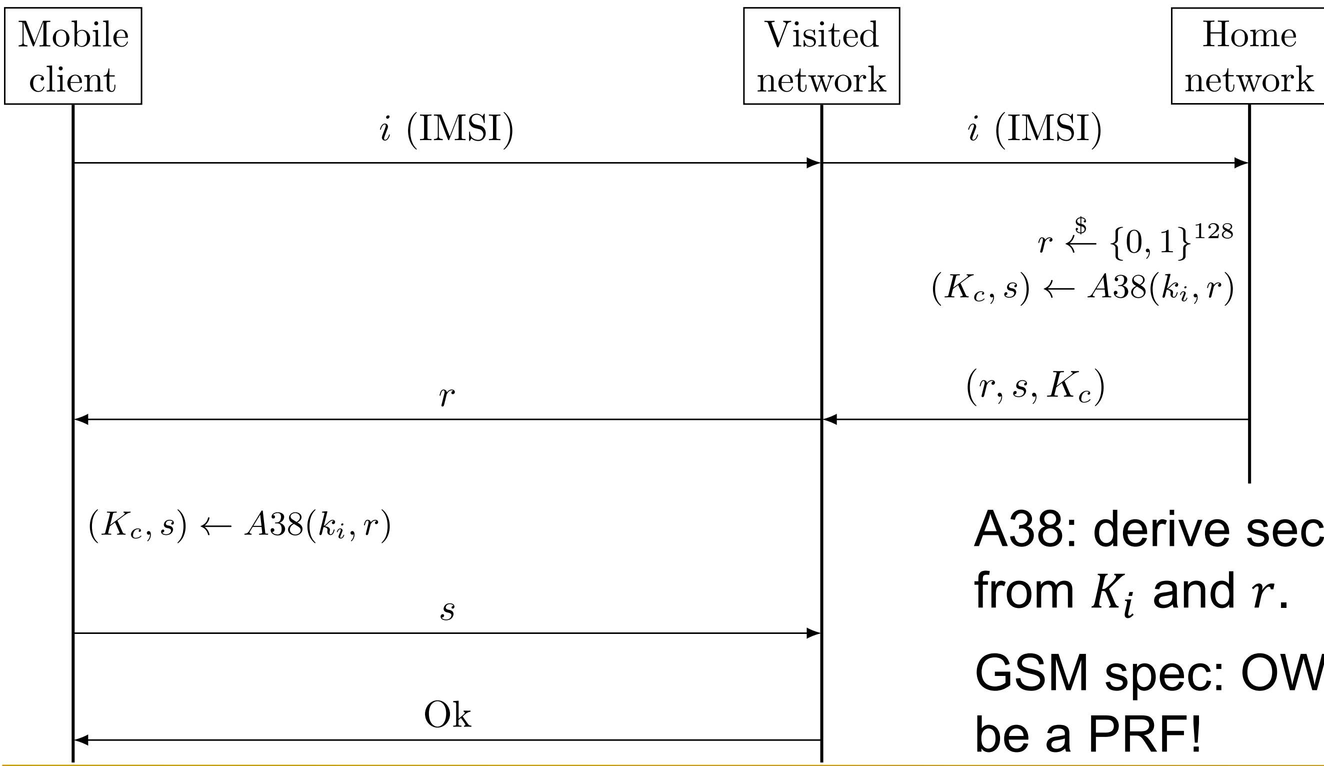
The Kerberos KDC Protocol

- KDC shares keys k_A^E (enc.), k_A^M (MAC) with Alice and k_B^E, k_B^M with Bob
- Goal: Alice and Bob share k_{AB}, then derive: k_{AB}^E, k_{AB}^M
- KDC performs access control as well; controlling whom Alice can contact.



The GSM Handshake Protocol

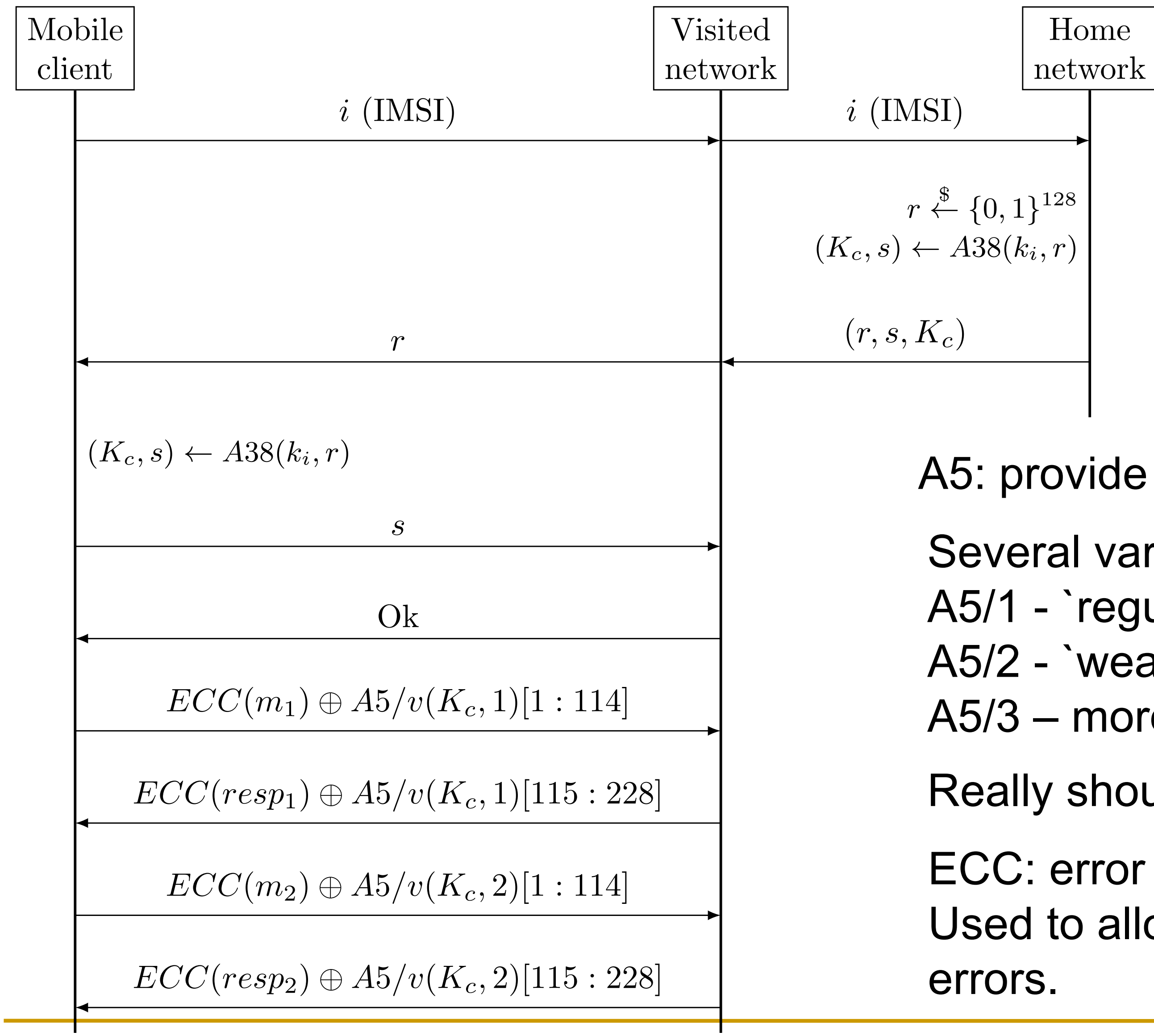
- Mobile client
  - Identified by i (IMSI: International Mobile Subscriber Identifier)
- Visited network (aka Base station); not fully trusted
- Home network; trusted, shares key k_i with client i



A38: derive secret, random K_c, s , from K_i and r.

GSM spec: OWF, but really should be a PRF!

Example – Sending two messages



Kc is the session key
s is called a secret authenticator

A5: provide 'pad' for encryption

Several variants:
A5/1 - `regular'
A5/2 - `weak'
A5/3 – more secure

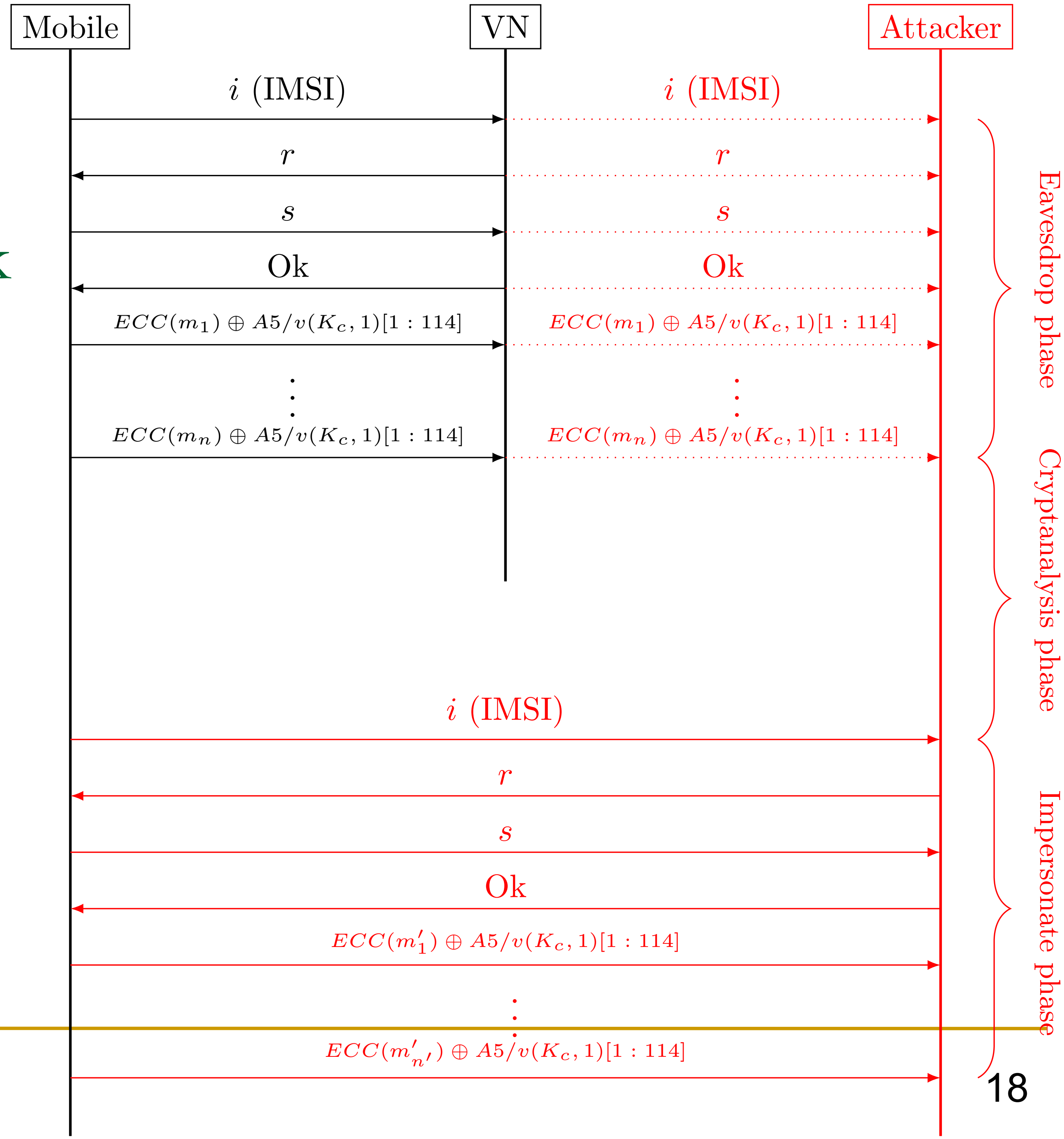
Really should be a PRF!

ECC: error correcting code. Used to allow recovery from errors.

Attacks on GSM

- We will explore two such attacks:
  - Visited network impersonation replay attack.
  - Ciphersuite downgrade attack.

Visited-network Impersonation Attack



Note: does NOT Impersonate **mobile,** only Visited network.

In the cryptanalysis phase, the attacker will try to obtain Kc based on the cyphertexts it collected in the eavesdropping phase (recall A5/1 and A5/2 are not secure)

GSM Ciphersuites Downgrade Attack

- A ciphersuite is the set of cryptographic schemes used in a protocol execution.
- Ciphersuite negotiation:
  - Mobile sends list of cipher-suites it supports
  - Visited-network selects best one that it also supports
- GSM encryption algorithms E_k:
  - A5/0: none, A5/1: broken, A5/2: useless (break with only 1sec), A5/3: ‘other’
- A MitM attacker may trick these parties to use a weak suite although the parties can support a stronger one.

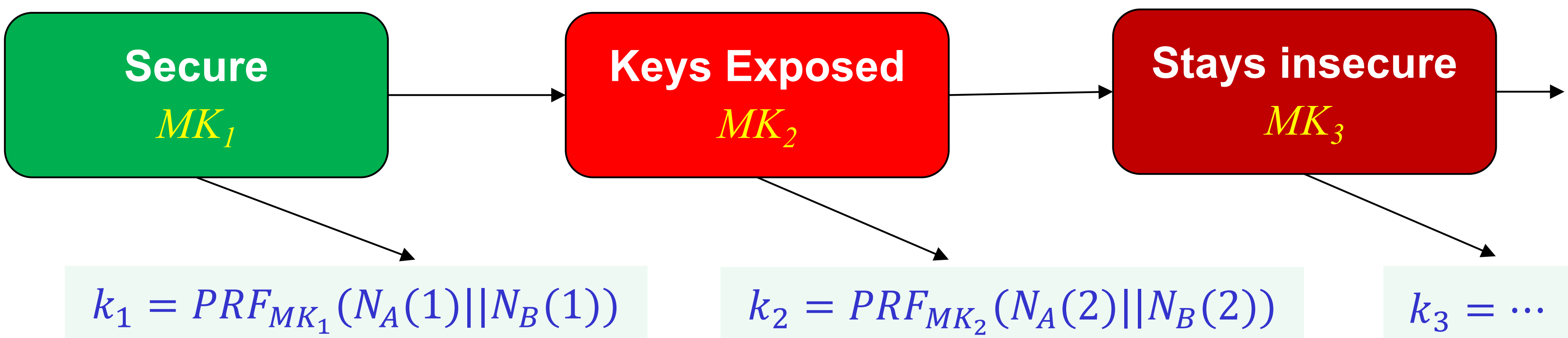
Cipher mode messages, negotiation

- Mobile sends list of supported ciphers
- VN sends choice in: CIPHMOD**CMD**
  - **Cipher Mode Command**
- Mobile confirms by sending encrypted: CIPHMOD**COM: cipher mode complete**
  - If not received (in few msecs), VN disconnects
- VN Acks: CIPHMOD**OK: cipher mode Ok**
  - If not received, mobile resends CIPHMOD**COM**
- *Details in the textbook*

Improving Resiliency to Key Exposure

Forward Secrecy I

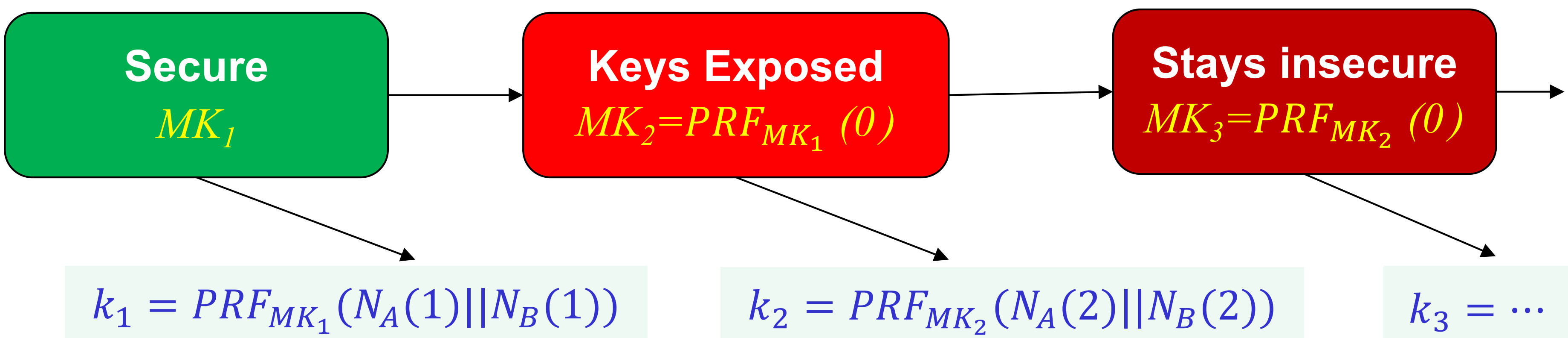
- **So far:** session key $k_i \nRightarrow k_j$ (expose no other keys)
  - And master key was fixed for all sessions
- Idea: we can do better!
  - Change the master key each session: $MK_1, MK_2, \ldots$
- Forward Secrecy (FS): <u>master</u> key $MK_i \nRightarrow k_j (j < i)$
  - I.e., MK_i (and k_i) don't expose keys, communication of <u>previous</u> sessions $(j < i)$



Forward Secrecy II

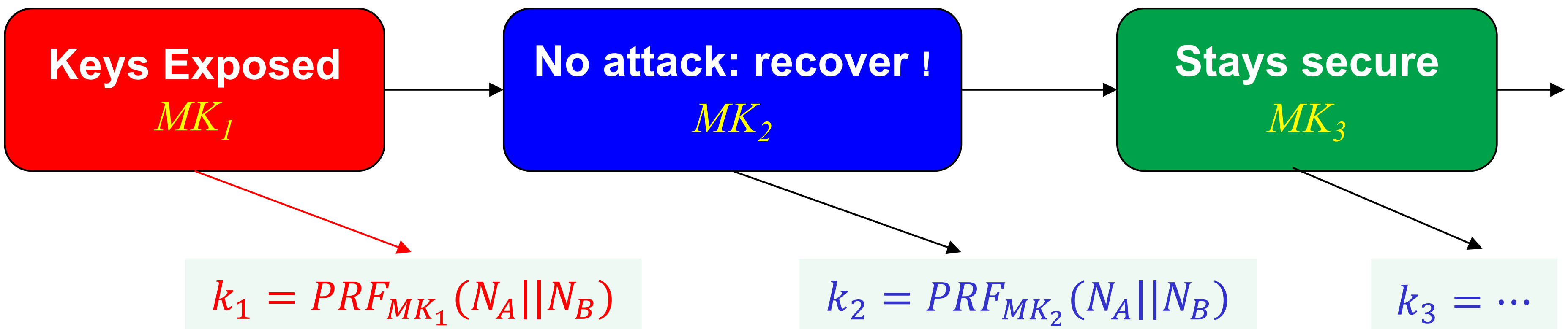
- **Forward Secrecy (FS)**: master key $MK_j \nRightarrow k_i (j > i)$
  - Session i is secret even if any state of later sessions is exposed.
  - Uni-directional: $MK_i \rightarrow MK_{i+1}$, but $MK_{i+1} \not\rightarrow MK_i$
  - **How?** Solution: PRF!

$$MK_i = PRF_{MK_{i-1}}(0)$$



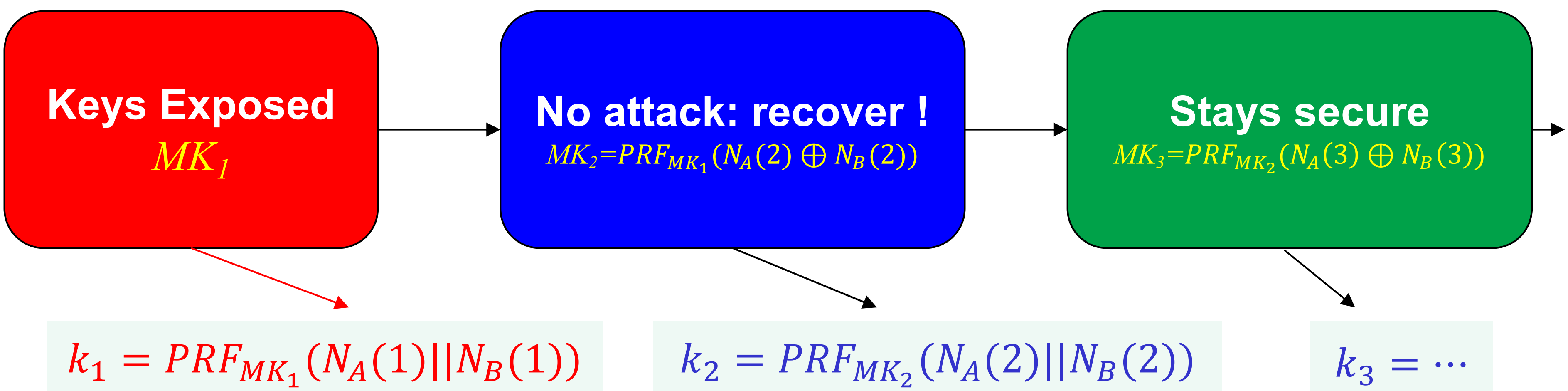
Recover Security

- Can we also **recover** security?
  - MK_{i_R-1} exposed, yet MK_{i_R}, $MK_{i_{R+1}}$ ... secure ?
  - Idea: assume **no attack** during 'recovery session' i_R



Recover Security (RS)

- Recover security: key setup protocols where a single session without eavesdropping or other attacks, suffices to recover security from previous key exposures.
- That is, session i is secure if it's keys are not given to attacker, and either session $i-1$ is secure, or there is no attack during session i
- How? The RS-Ratchet Protocol:
  - Let $N_A(i), N_B(i)$ denote session's i nonces
  - Then: $MK_i = PRF_{MK_{i-1}}(N_A(i) \oplus N_B(i))$



Covered Material From the Textbook

- Chapter 5
  - Sections 5.3 – 5.6 (except 5.6.3)

Thank You!