

Lecture 27: Signatures on Arbitrary-length Messages

Problem Statement

- Suppose we are given a $(\text{Gen}, \text{Sign}, \text{Ver})$ digital signature scheme for B -bit messages (i.e., messages in $\{0, 1\}^B$), for some fixed $B \in \mathbb{N}$. We shall refer to this signature scheme as the basic signature scheme
- Given this signature scheme $(\text{Gen}^*, \text{Sign}^*, \text{Ver}^*)$ for B -bit messages, construct a signature scheme for arbitrary-length messages (i.e., messages in $\{0, 1\}^*$)

First Attempt

- Given a message $m \in \{0, 1\}^*$, we use standard padding technique to make its length a multiple of B and, then, break it into B -bit blocks $(m_1, m_2, \dots, m_\alpha)$, where $m_1, m_2, \dots, m_\alpha \in \{0, 1\}^B$
- Our first strategy is to sign the blocks $m_1, m_2, \dots, m_\alpha$ using the basic signature scheme. Suppose the signatures of $m_1, m_2, \dots, m_\alpha$ are, respectively, $\sigma_1, \sigma_2, \dots, \sigma_\alpha$
- Our first attempt generates the signature of the message $m \equiv (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$

Vulnerability: Prefix Attacks

- Suppose we are given the signature of the message $m = (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$
- We can generate the signature of the message $m' = (m_1, m_2, \dots, m_i)$ as $\sigma' = (\sigma_1, \sigma_2, \dots, \sigma_i)$, for any $1 \leq i < \alpha$
- **Solution.** We need to tie the “number of the blocks” into the message being signed by the basic scheme

Second Attempt

- Given a message $m \in \{0, 1\}^*$, we use standard padding technique to make its length a multiple of $B/2$ and, then, break it into $B/2$ -bit blocks $(m_1, m_2, \dots, m_\alpha)$, where $m_1, m_2, \dots, m_\alpha \in \{0, 1\}^{B/2}$
- Our second strategy is to sign the blocks $(\alpha \| m_1), (\alpha \| m_2), \dots, (\alpha \| m_\alpha)$ using the basic signature scheme. We clarify that $(\alpha \| m_i)$ is the concatenation of (a) $B/2$ -bit representation of the number of total blocks α , and (b) the $B/2$ -bit message m_i . Suppose the signatures are, respectively, $\sigma_1, \sigma_2, \dots, \sigma_\alpha$
- Our second attempt generates the signature of the message $m \equiv (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$

Vulnerability: Permutation Attacks

- Suppose we are given the signature of the message $m = (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$
- We can generate the signature of the message $m' = (m_2, m_1, \dots, m_\alpha)$ as $\sigma' = (\sigma_2, \sigma_1, \dots, \sigma_\alpha)$
- In general, we can permute the message blocks of m and generate the signature of the permuted message
- **Solution.** We need to tie the “position of the message block” into the message being signed by the basic scheme

Third Attempt

- Given a message $m \in \{0, 1\}^*$, we use standard padding technique to make its length a multiple of $B/3$ and, then, break it into $B/3$ -bit blocks $(m_1, m_2, \dots, m_\alpha)$, where $m_1, m_2, \dots, m_\alpha \in \{0, 1\}^{B/3}$
- Our second strategy is to sign the blocks $(\alpha \| 1 \| m_1), (\alpha \| 2 \| m_2), \dots, (\alpha \| \alpha \| m_\alpha)$ using the basic signature scheme. We clarify that $(\alpha \| m_i)$ is the concatenation of (a) $B/3$ -bit representation of the number of total blocks α , (b) $B/3$ -bit representation of the position i , and (c) the $B/3$ -bit message m_i . Suppose the signatures are, respectively, $\sigma_1, \sigma_2, \dots, \sigma_\alpha$
- Our third attempt generates the signature of the message $m \equiv (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$

Vulnerability: Splicing Attacks

- Suppose we are given the signature of the message $m = (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$
- Suppose we are given the signature of another message (of the same number of blocks) $m' = (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma' = (\sigma'_1, \sigma'_2, \dots, \sigma'_\alpha)$
- We can generate the signature of the message $m'' = (m'_1, m_2, \dots, m_\alpha)$ as $\sigma'' = (\sigma'_1, \sigma_2, \dots, \sigma_\alpha)$
- In general, we can splice the blocks of m and m' and generate the message m'' and forge the signature on m''
- **Solution.** We need to “tie together all blocks of a particular message” into the message being signed by the basic scheme

Fourth Attempt

- Given a message $m \in \{0, 1\}^*$, we use standard padding technique to make its length a multiple of $B/4$ and, then, break it into $B/4$ -bit blocks $(m_1, m_2, \dots, m_\alpha)$, where $m_1, m_2, \dots, m_\alpha \in \{0, 1\}^{B/4}$
- Pick a random string $s \xleftarrow{\$} \{0, 1\}^{B/4}$
- Our second strategy is to sign the blocks $(\alpha \| 1 \| s \| m_1), (\alpha \| 2 \| s \| m_2), \dots, (\alpha \| \alpha \| s \| m_\alpha)$ using the basic signature scheme. We clarify that $(\alpha \| m_i)$ is the concatenation of (a) $B/4$ -bit representation of the number of total blocks α , (b) $B/4$ -bit representation of the position i , (c) the random bit string s , and (d) the $B/4$ -bit message m_i . Suppose the signatures are, respectively, $\sigma_1, \sigma_2, \dots, \sigma_\alpha$
- Our fourth attempt generates the signature of the message $m \equiv (m_1, m_2, \dots, m_\alpha)$ as the signature $\sigma = (\sigma_1, \sigma_2, \dots, \sigma_\alpha)$.
- The idea is that all blocks of a message shall have the same random bit-string s . Furthermore, the bitstring corresponding to two messages shall be different with high probability (using the Birthday bound)

Security of the Fourth Attempt

- The fourth attempt ensures that prefix, permutation, and splicing attacks cannot forge signatures
- In fact, this scheme is secure against all forging strategies (not just the three forging strategies mentioned above). In a higher-level course, we can prove this stronger result

It is left as an exercise to write the algorithms $(\text{Gen}^*, \text{Sign}^*, \text{Ver}^*)$ using the algorithms $(\text{Gen}, \text{Sign}, \text{Ver})$