

Revisiting Lee, Kim, & Yoo Authenticated Key Agreement Protocol

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Abstract

In recent issue of Journal of Applied Mathematics and Computation (2005), Lee, Kim, & Yoo revealed an attack on Hsu, Wu, & Wu (2003) authenticated key agreement protocol, and then presented an improved protocol. However, Lee, Kim, & Yoo (2005) present only heuristic argument with no formal proof of security. In this work, we revealed previously unpublished flaw in the protocol. We may speculate that such errors could have been found by protocol designers if proofs of security were to be constructed, and hope this work will encourage future protocol designers to provide proofs of security. We conclude with a countermeasure due to Choo, Boyd, & Hitchcock (2005).

Keywords: Key agreement protocols, provable security, password-based protocols

1 Introduction

With the velocity of technological advances in today's globalising electronic commerce landscape, cryptographic protocols are the *sine qua non* of many diverse secure electronic commerce applications. Although technology advances have brought us many conveniences and benefits, they have also resulted in the erosion of many assumptions about the design of cryptographic protocols, which began in the 1970s. As a result, the environment for cryptographic protocols has changed drastically over the years. One thing that does not change with time is that the design of cryptographic protocols is still notoriously hard. The difficulties associated in obtaining a high level of assurance in the security of almost any new or even existing protocols are well illustrated with examples of errors found in many such protocols years after they were published [1, 2, 3, 4, 10, 18, 19, 20, 22, 23, 26, 28, 37, 38, 40, 41, 42, 43, 44].

The many flaws discovered in published protocols for key establishment and authentication over many years, have promoted the use of formal models (i.e., the com-

puter security approach [27, 34, 35]) and rigorous security proofs (i.e., the computational complexity approach [5, 6, 7, 8, 9, 12, 13, 14, 15, 39]). The computer security approach concentrates on designing tools to formally verify the security of cryptographic protocols while the computational complexity approach concentrates on designing provably secure protocols.

1.1 Computer Security Approach

Emphasis in the computer security approach is placed on automated machine specification and analysis (e.g., model checking and theorem proving). The Dolev & Yao [25] adversarial model is the de-facto model used in formal specifications, where cryptographic operations are often used in a “black box” fashion ignoring the various cryptographic properties, resulting in possible loss of partial information. One of the main obstacles in this automated approach is the undecidability and intractability problems since the adversary can have an exponentially large set of possible actions (or combinations) which result in a state explosion [16]. Furthermore, protocols proven secure in such a manner could possibly be flawed (i.e., giving a false positive result – analogous to a Type II error in hypothesis testing). From a real world practicality perspective, it is debatable whether proofs of security in this manner carry significant weight in the real world, due to their idealistic model. However, the computer security approach should be credited for proving insecurities in protocols (i.e., finding both known and previously unknown flaws in protocols).

1.2 Computational Complexity Approach

On the other hand, the computational complexity approach adopts a deductive reasoning process (i.e., the logical process of deriving a conclusion from a known premise) whereby the emphasis is placed on a proven reduction from the problem of breaking the protocol to another problem believed to be hard. Since the initiative

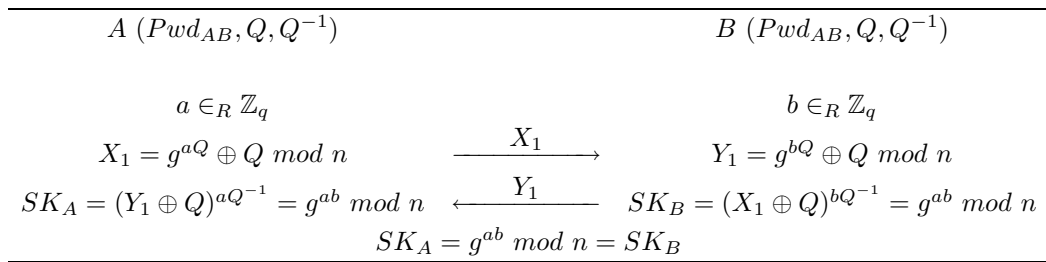


Figure 1: Lee, Kim, & Yoo (2005) authenticated key agreement protocol

of Bellare & Rogaway [6] who provided the first treatment of computational complexity to cryptographic protocol analysis, more than 100 protocols with accompanying computational proofs of security have been proposed in the literature [17]. Although these proofs provide a strong assurance for arguing about the security properties of the protocols, it is often difficult to obtain correct computational proofs of security. Furthermore, such proofs usually entail lengthy and complicated mathematical proofs, which are daunting to most reader as suggested by Koblitz & Menezes [29, 30]. A supporting example is the well-known example of OAEP mode for public key encryption [40]. Despite its popularity and inclusion in the SET electronic payment standard of MasterCard and Visa, a problem was found (and subsequently fixed in the case of RSA) years later. Difficulties in obtaining correct computational proofs of protocol security are evidenced by the breaking of provable-secure protocols after they were published. Despite these setbacks, proofs are invaluable tools for arguing about security and certainly are one very important tool in getting protocols right [18].

1.3 Case Study

In this work, we advocate the importance of proofs of protocol security and the proposal of any protocol should provide a rigorous proof of security as we argue that protocols without any computational proofs of security leads one to question the level of trust in the correctness in such protocols. We use the authenticated key agreement protocol of Lee, Kim, & Yoo [33] as a case study. We then demonstrated previously unknown flaw in the protocol.

1.4 Organization of Paper

The remainder of this paper is structured as follows: Section 2 describe the key agreement protocol of Lee, Kim, & Yoo [33] that will be used as case study. A previously unpublished attack on this protocol is revealed and a countermeasure is presented. Section 3 presents the conclusions.

2 Lee, Kim, & Yoo (2005) Authenticated Key Agreement Protocol

Figure 1 describes the key agreement protocol of Lee, Kim, & Yoo [33]. There are two communicating principals in the protocol, namely A and B . Both A and B are assumed to share a secret password, Pwd_{AB} , and integers, $Q \text{ mod } n$ and $Q^{-1} \text{ mod } n$, are computed in some predetermined manner from Pwd_{AB} . The system parameters are n and g , where n is a large prime and g is a generator of order $n - 1$ of $GF(n)$. In the protocol, the notation $a \in_R \mathbb{Z}_q$ denotes that a is randomly drawn from \mathbb{Z}_q .

At the end of the protocol execution, both A and B will share a common secret session key, $SK_A = g^{ab} \text{ mod } n = SK_B$.

2.1 A Reflection Attack

Figure 2 describes the execution of Lee, Kim, & Yoo (2005) authenticated key agreement protocol in the presence of a malicious adversary, \mathcal{A} . Let \mathcal{A}_U denotes the adversary impersonating some user, U .

At the end of the protocol execution shown in Figure 2, A has accepted two session keys, SK_A and $SK_{A(S2)}$, which A believes that both keys are shared with B in different sessions, as explained below:

- SK_A is being used in the session where A is the initiator and
- $SK_{A(S2)}$ is being used in the session (S2) where A is the responder.

We observe that both session keys accepted by A , SK_A and $SK_{A(S2)}$, are of the same value, as shown below:

$$\begin{aligned}
 SK_A &= (X_1 \oplus Q)^{as_2Q^{-1}} \\
 &= g^{aas_2} \text{ mod } n \\
 SK_{A(S2)} &= (X_2 \oplus Q)^{aQ^{-1}} \\
 &= g^{aas_2} \text{ mod } n \\
 &= SK_A.
 \end{aligned}$$

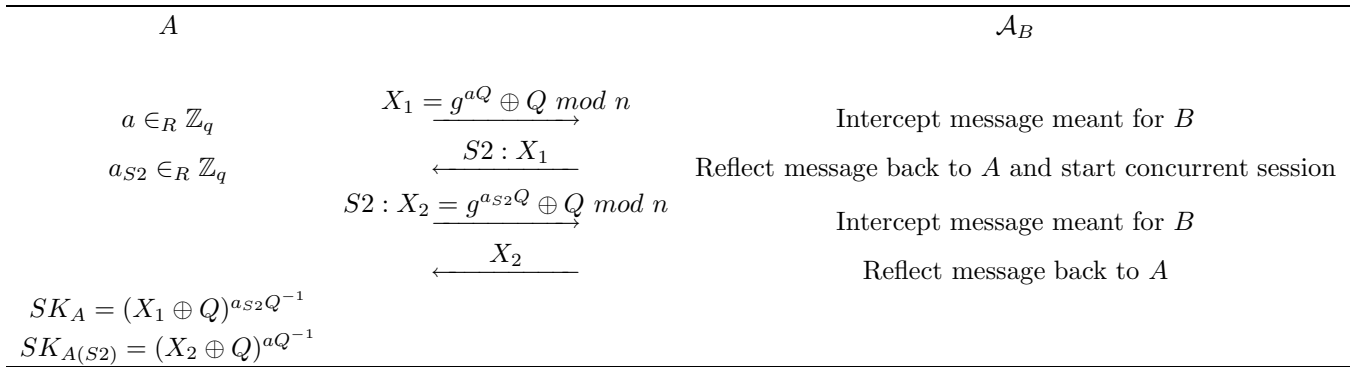


Figure 2: Execution of Lee, Kim, & Yoo (2005) authenticated key agreement protocol in the presence of a malicious adversary

However, B is unaware of any of these sessions, and the adversary, \mathcal{A} , is able to trivially expose any of this key to obtain the other fresh session key. Such an attack is known as a *reflection attack* and is realistic in the real world, as some party might want to establish a secure channel with itself (e.g., a mobile user that communicates to its desktop computer, while both the mobile device and the desktop have the same identity in the form of the same digital certificate) as described by Krawczyk [32].

The countermeasures are well studied and we may adopt the same approach by Choo, Boyd, & Hitchcock [21], who suggest that

- Including the identities of the participants and their roles in the key derivation function provides resilience against unknown key share attacks [11, Chapter 5.1.2] and reflection attacks [31], and
- Including the transcripts in the key derivation function provides freshness and data origin authentication.

Hence, we propose to include the sender's and responder's identities and transcripts, \mathcal{T}_U (i.e., concatenation of all messages sent and received), in the key derivation function, which will (effectively) bind the session key to all messages sent and received by both A and B , as shown below:

$$\begin{aligned} SK_{A(Fixed)} &= \mathcal{H}(A||B||\mathcal{T}_A||((Y_1 \oplus Q)^{aQ^{-1}})) \\ SK_{B(Fixed)} &= \mathcal{H}(A||B||\mathcal{T}_B||((X_1 \oplus Q)^{bQ^{-1}})) \\ &= SK_{A(Fixed)}, \end{aligned}$$

where \mathcal{H} denotes a secure hash function [24, 36] and $||$ denotes the concatenation of messages.

Intuitively, the reflection attack outlined in Figure 2 is no longer valid, since

$$\begin{aligned} SK_{A(Fixed)} &= \mathcal{H}(A||B||\mathcal{T}_A||((X_1 \oplus Q)^{a_{S2}Q^{-1}})) \\ &= \mathcal{H}(A||B||\mathcal{T}_A||((g^{a_{S2}} \text{ mod } n))) \\ SK_{A(S2)(Fixed)} &= \mathcal{H}(B||A||\mathcal{T}_B||((X_2 \oplus Q)^{aQ^{-1}})) \\ &= \mathcal{H}(B||A||\mathcal{T}_B||((g^{a_{S2}} \text{ mod } n))) \\ &\neq SK_{A(Fixed)}. \end{aligned}$$

3 Conclusion

Through a detailed study of the authenticated key agreement protocol of Lee, Kim, & Yoo [33], we demonstrated previously unpublished flaw in the protocol where the latter does not have accompanying proof of security. Proofs are invaluable for arguing about security and certainly are one very important tool in getting protocols right [18]. Without proofs of security, protocol implementers cannot be assured about the security properties of protocols. Flaws in protocols discovered after they were published or implemented certainly will have a damaging effect on the trustworthiness and the credibility of key establishment protocols in the real world. As a result of this work, we would recommend that protocol designers provide proofs of security for their protocols, in order to assure protocol implementers about the security properties of protocols.

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