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# Comments on “ALAM: Anonymous Lightweight Authentication Mechanism for SDN Enabled Smart Homes”

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**ABSTRACT** Smart home is intended to be able to enhance home automation systems and achieves goals such as reducing operational costs and increasing comfort while providing security to mobile users. However, an attacker may attempt security attacks in smart home environments because he/she can inject, insert, intercept, delete, and modify transmitted messages over an insecure channel. Secure and lightweight authentication protocols are essential to ensure useful services in smart home environments. In 2020, Iqbal *et al.* presented an anonymous lightweight authentication protocol for software-defined networking (SDN) enabled smart home, called ALAM. They claimed that ALAM protocol could resist security threats, and also provide secure mutual authentication and user anonymity. This comment demonstrates that ALAM protocol is fragile to various attacks, including session key disclosure, impersonation, and man-in-the-middle attacks, and also their scheme cannot provide user anonymity and mutual authentication. We propose the essential security guidelines to overcome the security flaws of ALAM protocol.

**INDEX TERMS** Cryptanalysis, smart homes, key establishment, authentication, security protocol.

## I. INTRODUCTION

With the advances in wireless technologies and portable devices, users can access various services via mobile device in smart home environments. The smart home allows useful services for the mobile users, including humidity of the house, automatic checking of the temperature, controlling light bulbs, and so on. In general, the smart home comprises several indoor smart devices, gateways, users, and controllers. Mobile users are registered in the controller, and they can access various services. However, these services are susceptible to potential attacks because sensitive messages are exchanged via an insecure channel. If the data collected by smart devices is compromised, a malicious attacker can obtain the private information of users,

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including habits and daily routines in smart home, and also utilize the information for criminal purposes. Therefore, a secure and lightweight authentication protocol is essential to provide mobile users with useful services in smart home environments.

In 2020, Iqbal *et al.* [1] designed an anonymous lightweight authentication protocol to provide secure services in smart home environments. They claimed that ALAM protocol could withstand security threats, such as desynchronization and replay attacks, and also ensure user anonymity and mutual authentication. However, this comment paper demonstrates that ALAM protocol suffers from many security threats, including impersonation, session key disclosure and man-in-the-middle (MITM) attacks. Moreover, ALAM protocol cannot also provide user anonymity and mutual authentication. Thus, we propose the necessary guidelines to overcome the security flaws of ALAM scheme [1].

The rest of this comment paper is organized as follows. In Section II and III, we review Iqbal *et al.*'s protocol and then show cryptanalysis of Iqbal *et al.*'s protocol, respectively. Section IV proposes some guidelines to overcome the security shortcomings of Iqbal *et al.*'s protocol. Finally, Section V summarizes and concludes the work.

### A. ATTACKER MODEL

We present the widely-known Dolev-Yao (DY) model [2] to evaluate the security of ALAM protocol. The capabilities of an attacker in the DY model are as follows.

- Referring to DY model [2], a malicious adversary (*MA*) can replay, eavesdrop, modify, intercept, insert, and delete transmitted messages over an insecure channel.
- Software-defined networking (SDN) database modules and controllers are considered to be secure and cannot be compromised by *MA*. In other words, the controller's private key is not accessible to the *MA* [1].
- During a lost mobile device attack, *MA* obtains all secret credentials stored in mobile device by physical means, even if the mobile device has a certain degree of tamper resistance. Thus, *MA* can steal the legitimate user's mobile device and extract the secret credentials stored in memory by performing power analysis [3]–[5].
- After obtaining the secret credentials of the mobile device, *MA* may attempt various attacks such as "insider attack", "MITM attack", and "desynchronization attack", etc [6], [7].

### B. RESEARCH CONTRIBUTIONS AND MOTIVATION

The major goal of this comment paper is to identify the security flaws present in ALAM scheme. ALAM does not ensure the required security functionalities such as "session key disclosure attack", "MITM attack", "impersonation attack", "mutual authentication", and "user anonymity" in smart home environments. These facts motivated us to come up with the necessary security guidelines which can ensure security functionalities and overcome security threats and flaws that exist in smart home environments.

### II. REVIEW OF IQBAL ET AL.'S PROTOCOL

We review ALAM scheme [1] for a smart home environment. ALAM scheme consists of three phases: a) user registration, b) smart device registration and c) mutual authentication. The notations used in this comment are presented in Table 1.

#### A. USER REGISTRATION PHASE

The mobile users ( $MU_i$ ) must register with the SDN controller (*CT*) to receive smart home services. We show the user registration phase of ALAM protocol, and the detailed steps are as follows:

- **UR-1:**  $MU_i$  chooses user identity  $U_{ID}$ , and mobile identity  $M_{ID}$ . Then,  $MU_i$  sends  $\{U_{ID}, M_{ID}\}$  to *CT* via a secure channel.

TABLE 1. Notations.

Symbol	Description
$MU_i$	Mobile user
<i>CT</i>	Controller
$SD_i$	Smart device
$U_{ID}$	Identity of user
$M_{ID}$	Identity of mobile device
$C_c$	Counter of controller
$k_{uc}$	Shared secret key between controller and user
$C_n, U_n$	Random nonce of controller and user
<i>CSP</i>	Controller session parameter
<i>SID</i>	Session identifier
$SD_{ID}$	Identity of IoT smart device
<i>Auth.DB</i>	Database of authenticator manager
<i>Reg.DB</i>	Database of registration manager
$\Delta T$	Threshold difference in time
$E_K(), D_K()$	Encryption/decryption
$h()$	Hash function
$\oplus$	XOR operation

- **UR-2:** After getting message  $\{U_{ID}, M_{ID}\}$ , *CT* increases the value  $C_c$  and produces a transaction flow sequence number  $C_c = TF_{seq}$  using a shared secret key  $k_{uc}$ . After that, *CT* generates a random nonce  $C_n$  and computes  $CSP_{M_{ID}} = h(U_{ID} || M_{ID} || C_n)$  and  $SID_u = E_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$ . Then, *CT* sends  $\{SID_u, k_{uc}\}$  to the mobile user over a secure channel. Finally, *CT* sends  $\{SID_u, CSP_{M_{ID}}, k_{uc}, TF_{seq}\}$  to the *Reg.DB* and *Auth.DB*.
- **UR-3:** Upon getting message  $\{SID_u, k_{uc}\}$  from the *CT*,  $MU_i$  stores them in mobile memory.
- **UR-4:** After getting message  $\{SID_u, CSP_{M_{ID}}, k_{uc}, TF_{seq}\}$ , *Reg.DB* and *Auth.DB* also store them in secure database.

#### B. SMART DEVICE REGISTRATION PHASE

The smart device ( $SD_i$ ) must register with the SDN controller to ensure useful home services. We present the smart device registration phase of ALAM protocol, and the detailed steps are as below.

- **SR-1:**  $SD_i$  chooses smart device identity  $SD_{ID}$  and then sends  $\{SD_{ID}\}$  to the *CT* over a secure channel.
- **SR-2:** Upon getting message  $\{SD_{ID}\}$ , the *CT* generates controller identifier *CID* and random nonce  $C_m$ . *CT* then computes  $CSP_{SD_{ID}} = h(SD_{ID} || C_m)$  and  $SID_{SD_{ID}} = E_{k_c}(SD_{ID}, CSP_{SD_{ID}}, C_m)$ . After that, the *CT* sends  $\{SID_{SD_{ID}}, CID\}$  to the smart device  $SD_i$  over a secure channel. Finally, *CT* sends  $\{SID_{SD_{ID}}, CSP_{SD_{ID}}\}$  to the *Reg.DB* and *Auth.DB*.
- **SR-3:** After getting message  $\{SID_{SD_{ID}}, CID\}$  from the *CT*,  $SD_i$  stores them in memory.
- **SR-4:** Upon getting message  $\{SID_{SD_{ID}}, CSP_{SD_{ID}}\}$ , *Reg.DB* and *Auth.DB* also store them in their secure database.

#### C. MUTUAL AUTHENTICATION PHASE

In this phase, a mobile user  $MU_i$  requests authentication to the SDN controller to receive secure service. We describe

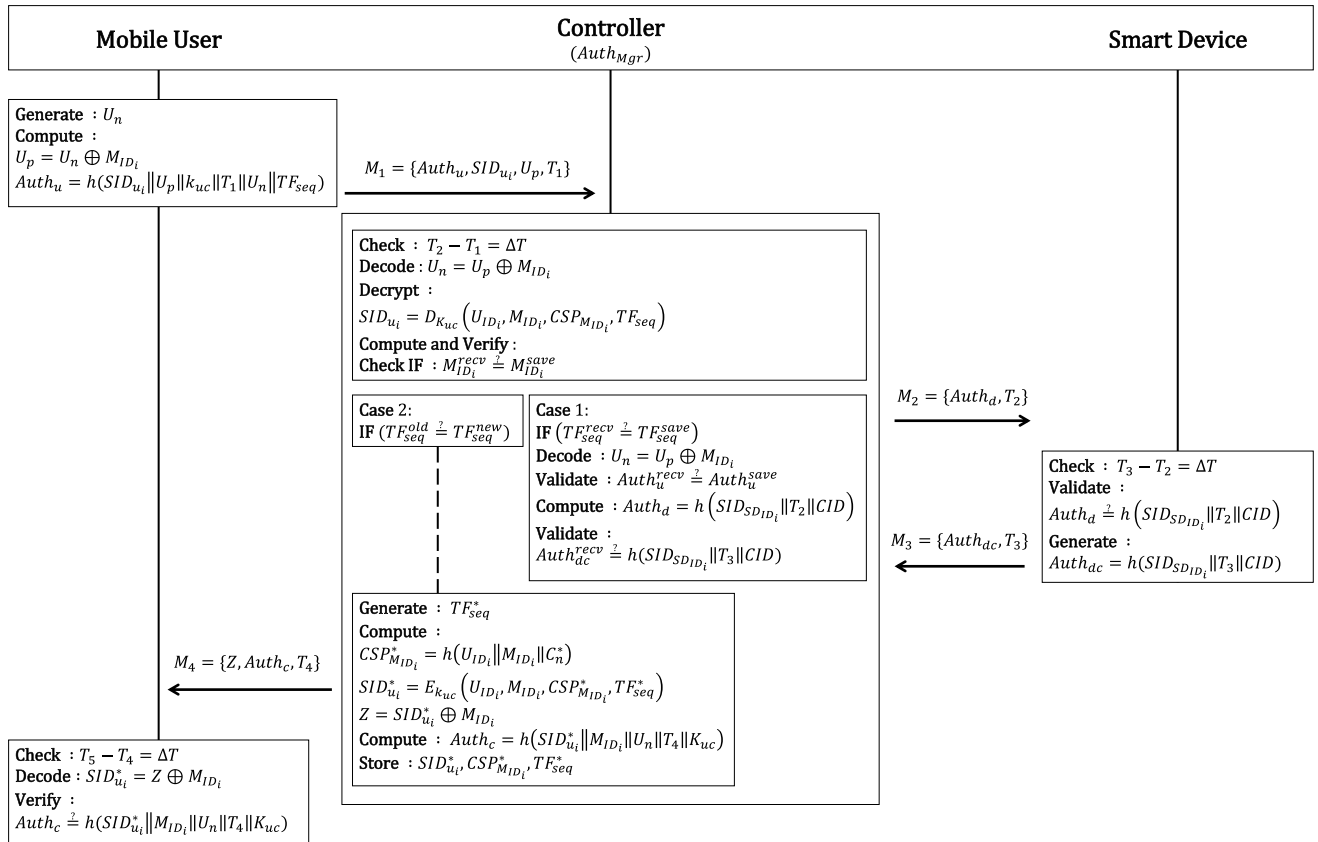


FIGURE 1. Mutual authentication phase of Iqbal et al.'s scheme.

the authentication phase of ALAM protocol as summarized in Fig. 1 and the detailed steps of this phase are as follows.

- **AP-1:**  $MU_i$  generates a random nonce  $U_n$  and a timestamp  $T_1$ , computes  $U_p = U_n \oplus M_{ID}$  and  $Auth_u = h(SID_u || U_p || k_{uc} || T_1 || U_n || TF_{seq})$ , and sends the message  $M_1 = \{Auth_u, SID_u, U_p, T_1\}$  to the  $CT$  over an insecure channel.
- **AP-2:** Upon getting the message  $M_1$ , the  $CT$  checks timestamp  $T_2 - T_1 = \Delta T$  and decodes  $U_n = U_p \oplus M_{ID}$ . The  $CT$  decrypts  $SID_u = D_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$  and checks  $M_{ID}^{recv} \stackrel{?}{=} M_{ID}^{save}$ . If it is valid,  $CT$  can come across two scenarios. In the following, we discuss the following two cases.

**Case 1.**

- **AP-3:** If  $TF_{seq}^{recv} \stackrel{?}{=} TF_{seq}^{save}$ ,  $MU_i$  will always be true in authentication request after registration and decodes  $U_n = U_p \oplus M_{ID}$ . Then,  $CT$  verifies  $Auth_u^{recv} \stackrel{?}{=} Auth_u^{save}$ . If it is valid,  $CT$  generates a timestamp  $T_2$  and computes  $Auth_d = h(SID_{SDID} || T_2 || CID)$ . After that,  $CT$  sends the message  $M_2 = \{Auth_d, T_2\}$  to the  $SD_i$  over an insecure channel.
- **AP-4:** Upon getting the message  $M_2$ ,  $SD_i$  checks  $T_3 - T_2 = \Delta T$  and computes  $Auth_d^* = h(SID_{SDID} || T_2 || CID)$ , and checks  $Auth_d^* \stackrel{?}{=} Auth_d$ . If it is correct,  $SD_i$  computes

$Auth_{dc} = h(SID_{SDID} || T_3 || CID)$  and sends the message  $M_3 = \{Auth_{dc}, T_3\}$  to the  $CT$  via an open channel.

- **AP-5:** Upon getting the message  $M_3$ ,  $CT$  computes  $Auth_{dc}^* = h(SID_{SDID} || T_3 || CID)$  and verifies  $Auth_{dc}^* \stackrel{?}{=} Auth_{dc}$ . If it is valid,  $SD_i$  is authenticated successfully.

**Case 2.**

- **AP-6:**  $CT$  either the received  $Auth_{dc}$  from the  $SD_i$  in  $M_3$  is checked or if the received  $TF_{seq}$  from the  $MU_i$  is old, whereas  $CT$  is waiting for new  $TF_{seq}^{new}$ . Then,  $CT$  verifies  $TF_{seq}^{old} \stackrel{?}{=} TF_{seq}^{new}$ . If it is valid,  $CT$  generates  $TF_{seq}^*$  and updates  $\{TF_{seq}\}$  with  $\{TF_{seq}^*\}$ , and stores both values in secure database. After that,  $CT$  generates a random nonce  $C_n^*$  and computes  $CSP_{M_{ID}}^* = h(U_{ID} || M_{ID} || C_n^*)$ .  $CT$  also chooses a timestamp  $T_4$  and generates  $SID_u^* = E_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}^*, TF_{seq}^*)$ ,  $SID_u^* \oplus M_{ID}$ , and  $Auth_c = h(SID_u^* || M_{ID} || U_n || T_4 || k_{uc})$ . Finally,  $CT$  sends the message  $M_4 = \{Auth_c, Z, T_4\}$  to the  $MU_i$  via insecure channel.
- **AP-7:** After getting the message  $M_4$ ,  $MU_i$  checks  $T_5 - T_4 = \Delta T$  and decrypts  $SID_u = D_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$ . Then,  $MU_i$  computes the session key  $SID_u^* = Z \oplus M_{ID}$ , the authentication message  $Auth_c^* = h(SID_u^* || M_{ID} || U_n || T_4 || k_{uc})$  and verifies  $Auth_c^* \stackrel{?}{=} Auth_c$ . If it is valid,  $MU_i$  is mutually authenticated successfully.

### III. CRYPTANALYSIS OF IQBAL *ET AL.*'S PROTOCOL

This comment paper is about "ALAM: Anonymous Lightweight Authentication Mechanism for SDN Enabled Smart Homes" that is presented by Iqbal *et al.* [1]. Iqbal *et al.* claimed that ALAM scheme could resist various attacks and also ensure user anonymity and mutual authentication. However, we demonstrate that ALAM scheme is vulnerable to "impersonation", "MITM", and "session key disclosure" attacks. Furthermore, we show that ALAM protocol fails to ensure "user anonymity" and "mutual authentication".

#### A. IMPERSONATION ATTACK

*MA* may attempt to impersonate legitimate user. Referring to Section I-A, *MA* can extract the secret credentials  $\{SID_u, k_{uc}\}$  stored in mobile device. Moreover, *MA* can replay, intercept, modify, eavesdrop, insert, and delete transmitted messages over an insecure channel. The detailed steps of this attack are as follows.

- **Step 1:** *MA* first calculates  $D_{k_{uc}}(SID_u) = (U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$  and  $U_n = U_p = M_{ID}$ . Then, *MA* generates a new random nonce  $A_n$ , and calculates  $U_{MA} = A_n \oplus M_{ID}$  and  $Auth_{MA} = h(SID_u || U_{MA} || k_{uc} || T_1 || A_n || TF_{seq})$ . After that, *MA* sends the message  $M_{MA1} = \{Auth_{MA}, SID_u, U_{MA}, T_1\}$  to the *CT* over an insecure channel.
- **Step 2:** After getting the message  $M_{MA1}$ , the *CT* checks the timestamp  $T_2 - T_1 = \Delta T$  and decodes  $A_n = U_{MA} \oplus M_{ID}$ . Then, *CT* decrypts  $SID_u = D_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$  and verifies  $M_{ID}^{recv} \stackrel{?}{=} M_{ID}^{save}$ . If it is correct, *CT* can come across two scenarios. Both situations are provided below.

##### Case 1.

- **Step 3:** If  $TF_{seq}^{recv} \stackrel{?}{=} TF_{seq}^{save}$ , the *CT* decodes  $A_n = U_{MA} \oplus M_{ID}$ . Then, *CT* verifies  $Auth_{MA}^{recv} \stackrel{?}{=} Auth_{MA}^{save}$ . If it is valid, *CT* generates a timestamp  $T_2$  and computes  $Auth_d = h(SID_{SD_{ID}} || T_2 || CID)$ . After that, *CT* sends  $M_2 = \{Auth_d, T_2\}$  to the *SD<sub>i</sub>* over an insecure channel.
- **Step 4:** Upon getting the message  $M_2$ , *SD<sub>i</sub>* checks  $T_3 - T_2 = \Delta T$  and computes  $Auth_d^* = h(SID_{SD_{ID}} || T_2 || CID)$ , and checks  $Auth_d^* \stackrel{?}{=} Auth_d$ . If it is correct, *SD<sub>i</sub>* computes  $Auth_{dc} = h(SID_{SD_{ID}} || T_3 || CID)$  and sends the message  $M_3 = \{Auth_{dc}, T_3\}$  to the *CT* via insecure channel.
- **Step 5:** After getting the message  $M_3$ , *CT* computes  $Auth_{dc}^* = h(SID_{SD_{ID}} || T_3 || CID)$  and verifies  $Auth_{dc}^* \stackrel{?}{=} Auth_{dc}$ . If it is correct, *SD<sub>i</sub>* is authenticated successfully.

##### Case 2.

- **Step 6:** *CT* verifies  $TF_{seq}^{old} \stackrel{?}{=} TF_{seq}^{new}$ . If it is valid, *CT* generates  $TF_{seq}^*$  and updates  $\{TF_{seq}\}$  with  $\{TF_{seq}^*\}$ , and stores both values in secure database. After that, *CT* generates a random nonce  $C_n^*$  and computes  $CSP_{M_{ID}}^* = h(U_{ID} || M_{ID} || C_n^*)$ . *CT* also chooses a timestamp  $T_4$  and generates  $SID_u^* = E_{k_{uc}}(U_{ID}, M_{ID}, CSP_{M_{ID}}^*, TF_{seq}^*)$ ,  $SID_u^* \oplus M_{ID}$ , and  $Auth_{cMA} = h(SID_u^* || M_{ID} || A_n || T_4$

$||k_{uc})$ . Finally, *CT* sends the message  $M_4 = \{Auth_{cMA}, Z, T_4\}$  to the *MU<sub>i</sub>* via public channel.

- **Step 7:** After getting the message  $M_4$ , *MA* checks  $T_5 - T_4 = \Delta T$  and computes session key  $SID_u^* = Z \oplus M_{ID}$ , authentication message  $Auth_{cMA}^* = h(SID_u^* || M_{ID} || A_n || T_4 || k_{uc})$ , and verifies  $Auth_{cMA}^* \stackrel{?}{=} Auth_{cMA}$ . If it is valid, *MA* is authenticated successfully.

Consequently, ALAM protocol is vulnerable to the impersonation attack, because *MA* can impersonate as a mobile user, and establish successfully a session key with the *CT* on behalf of the mobile user *MU<sub>i</sub>*.

#### B. SESSION KEY DISCLOSURE ATTACK

In Section III-A, this comment paper demonstrated that *MA* can impersonate a mobile user *MU<sub>i</sub>* and calculate a session key  $SID_u^* = Z \oplus M_{ID}$  as follows. Referring to Section I-A, *MA* can extract secret credentials stored in mobile device, and intercept the exchanged messages between *MU<sub>i</sub>*, *CT*, and *SD<sub>i</sub>* via an insecure channel. In addition, *MA* calculates  $D_{k_{uc}}(SID_u) = (U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$ , and  $U_n = U_p = M_{ID}$ . After getting message  $\{M_4\}$ , the *MA* computes the session key  $SID_u = Z \oplus M_{ID}$  and authentication message  $Auth_c^* = h(SID_u^* || M_{ID} || U_n || T_4 || k_{uc})$ . Consequently, ALAM protocol cannot withstand the session key disclosure attack because *MA* can generate  $SID_u = Z \oplus M_{ID}$  between *MU<sub>i</sub>* and *CT* successfully.

#### C. MITM ATTACK

ALAM scheme cannot withstand MITM attack, because *MA* can compute the authentication request message  $M_1$ . According to Section III-A, the *MA* computes  $D_{k_{uc}}(SID_u) = (U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$  and  $U_n = U_p = M_{ID}$ . After that, *MA* computes session key  $SID_u^* = Z \oplus M_{ID}$  and authentication message  $Auth_{cMA}^* = h(SID_u^* || M_{ID} || A_n || T_4 || k_{uc})$  successfully. Thus, ALAM scheme cannot resist to MITM attack.

#### D. USER ANONYMITY AND MUTUAL AUTHENTICATION

Iqbal *et al.* claimed that ALAM scheme ensures authentication between the *MU<sub>i</sub>*, *CT*, and *SD<sub>i</sub>*. However, referring to Section III-A and III-C, the *MA* can compute  $D_{k_{uc}}(SID_u) = (U_{ID}, M_{ID}, CSP_{M_{ID}}, TF_{seq})$ . Thus, *MA* can obtain the real identity  $U_{ID}$  and  $M_{ID}$  of the legitimate user and mobile device. Moreover, *MA* can compute the authentication request message  $M_1$  and response message  $M_4$  successfully. Thus, ALAM scheme cannot ensure user anonymity and mutual authentication.

### IV. GUIDELINES ON ATTACKS RESILIENCE

In ALAM scheme [1], the major security issue is that the shared secret (long-term) key is stored in mobile device without any cryptographic methods. Because of this problem, an adversary can extract and obtain secret credentials using power analysis. According to Section III, we proved that ALAM scheme is vulnerable to various attacks, including

"session key disclosure", "MITM", and "impersonation" attacks. In addition, their scheme fails to provide "user anonymity" and "mutual authentication". Thus, we propose the necessary guidelines to overcome the security flaws of ALAM scheme as also suggested in [8].

- **Guideline 1.** ALAM scheme adopts the two-factor authentication mechanism using the secret credentials and mobile device. However, referring to Section III, the *MA* is able to impersonate as a mobile user. Thus, ALAM should store the masked secret credentials with password and/or biometric using hash function and bitwise XOR operation to enhance the security level. This will increase the security level of the system.
- **Guideline 2.** In ALAM scheme, the mobile device can use the physical unclonable function (PUF) to prevent physical attacks. PUF-based authentication schemes can resist smart device physical capture attack because an attacker *MA* cannot access the PUF function even by stealing the smart device [9]–[11].
- **Guideline 3.** ALAM scheme may cause serious security problems in the future because the shared secret (long-term) key is not updated. Therefore, ALAM scheme should periodically update the shared secret (long-term) key to improve the security of the system.
- **Guideline 4.** All participants should securely encrypt and send messages using symmetric keys, because the attacker *MA* can modify, intercept, delete, and insert the exchanged messages during the mutual authentication phase.

It is worth to note that we do not claim that the guidelines suggested by us as a full-proof solution to the pointed-out drawback of ALAM scheme. However, it will definitely increase the complexity of the malicious adversary *MA*.

Iqbal *et al.* would have put best efforts to design a secure protocol for smart home applications. However, they would not have viewed their protocol from the point of view that we have analyzed and proved it. Thus, this comment paper will lead to the design of more secure and efficient authentication protocols for smart home applications.

## V. CONCLUSION

This comment paper refers to "ALAM: Anonymous Lightweight Authentication Mechanism for SDN Enabled Smart Homes" presented by Iqbal *et al.* We proved that their scheme is vulnerable to potential attacks such as "impersonation", "MITM", and "session key disclosure" attacks. Moreover, their scheme cannot also provide "user anonymity" and "mutual authentication" functionality requirements. After stealing secret credentials stored in mobile device, an adversary can compute the session key between a legitimate user and the controller. Thus, we presented some guidelines to enhance the security flaws of

ALAM protocol. Consequently, we can thwart the pointed out security problems not only in ALAM protocol, but we believe that these will be also helpful in other future authentication protocols.

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