Modeling and Verifying AUPS Using CSP

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Outline

- Introduction
- Overview of AUPS
- Modeling AUPS
- Verification and Improvement
- Conclusion and Future Work

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Background

- **Authenticated Publish/Subscribe (AUPS)** is an IoT system based on the publish/subscribe scheme.
- It adopted the Attribute-based Access Control (ABAC) and encryption technology to ensure the security and privacy of the system.

Motivation

- AUPS was more efficient than the other existing secure solutions. Due to the superb characteristics of AUPS, it will attract a great amount of attention from industries.
- We formalize the architecture of AUPS Using CSP.
- We use PAT to verify some related properties, including **Deadlock Freedom**, **Data Availability**, **Data Leakage**, **Device Faking**, and **User Privacy Leakage**.

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Overview of AUPS

AUPS involves the following modules:

- **Device** collects data from environment and then publishes them to the NOS.
- **Networked Smart Object (NOS)** deals with the data received from devices.
- **Enforcement Framework (EF)** performs access control and manages the data encryption/decryption keys using a key table.
- **Keys Topics Manager (KTM)** generates the data encryption/decryption keys according to the services.
- **Broker** manages the subscriptions within the system.
- **User** subscribes to IoT services and gets the data from servers.

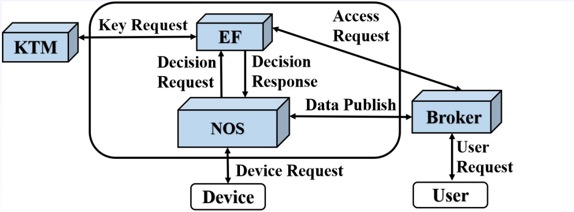


Figure 1: Architecture of AUPS

Overview of AUPS

- Overview of device publishing data:

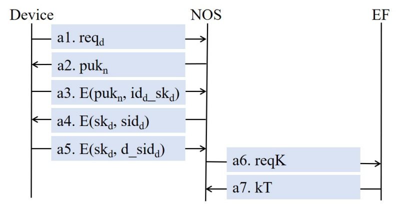
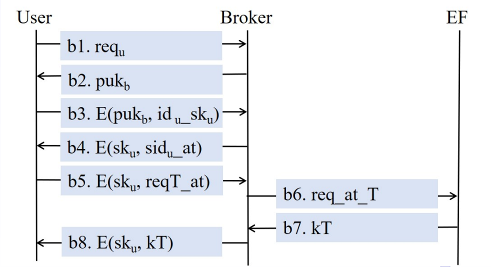


Figure 2: Overview of publishing data

- Overview of user getting data:



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Modeling AUPS

Overview of the Model

$$System_0 =_{df} Broker \| User \| EF \| ProcessE \| KTM \| Device \| NOS \| Clock$$

$$System =_{df} System_0 [| INTRUDER\_PATH |] Intruder$$

- *Broker*, *User*, *EF*, *Device*, *NOS* and *KTM* are processes describing the behavior of the broker, user, EF, device, NOS and KTM respectively.
- *ProcessE* denotes the internal processing procedures of the EF.
- The process *Clock* is used to realize the synchronization of time.
- *Intruder* process represents the actions of intruders such as intercepting and faking the transmitted messages.

Modeling AUPS

User Modeling:

Process $User_0$ describes the behavior of the user without intruders.

$$
\begin{aligned}
User_0 =_{df}\ & ComUB!msg_{req}.U.B.req_u \rightarrow \\
& ComUB?msg_{key}.B.U.puk_b \rightarrow \\
& ComUB!msg_{req}.U.B.E(puk_b, id_u.sk_u) \rightarrow \\
& ComUB?msg_{inf}.B.U.E(sk_u, sid_u.at) \rightarrow \\
& \left(\begin{array}{l}
ComUB!msg_{req}.U.B.E(sk_u, reqT.at) \rightarrow \\
ComUB?msg_{key}.B.U.E(sk_u, kT) \rightarrow \\
\left(\begin{array}{l}
ComUB?msg_{data}.B.U.E(kT, d) \rightarrow \\
User_0 \lhd D(kT, E(kT, d)) \rhd (fail \rightarrow User_0) \\
\lhd D(sk_u, E(sk_u, kT)) \rhd (fail \rightarrow User_0)
\end{array}\right) \\
\lhd D(sk_u, E(sk_u, sid_u.at)) \rhd (fail \rightarrow User_0)
\end{array}\right)
\end{aligned}
$$

Modeling AUPS

User Modeling with Intruders:

$$
\begin{aligned}
User =_{df} User_0[[\\
& ComUB!\{|ComUB|\} \leftarrow ComUB!\{|ComUB|\}, \\
& ComUB!\{|ComUB|\} \leftarrow FakeUB!\{|ComUB|\}, \\
& ComUB?\{|ComUB|\} \leftarrow ComUB?\{|ComUB|\}, \\
& ComUB?\{|ComUB|\} \leftarrow FakeBU?\{|ComUB|\}]]
\end{aligned}
$$

- The first two lines mean that whenever $User_0$ transmits a message on the channel *ComUB*, *User* can transmit the same message on the channel *ComUB* or *FakeUB*.
- The same is true for the last two lines.

Modeling AUPS

Other Processes Modeling:

- The process *Broker* deals with the user's subscription request and forwards the data to the user.
- The process *Device* publishes the collected data to the NOS.
- The process *NOS* interacts with the devices to handle the publishment and data delivery.
- The process *EF* interacts with the broker and NOS to perform access control.
- The process *ProcessE* mainly deals with the key requests of entities.
- The process *Clock* serves to record the time and return the current time whenever the entities want it.

Modeling AUPS

Intruder Modeling:

$$
\begin{aligned}
& Intruder_0(F) \\
=_{df}\ & \Box_{m \in MSG_{out}} Fake.m \rightarrow Intruder_0(F \cup Info(m)) \\
& \Box \Box_{f \in Fact, f \notin F, F \mapsto f} Init\{dl = false\} \rightarrow Deduce.f.F \\
& \rightarrow \left(\begin{array}{l} (\ dl := true \rightarrow Intruder_0(F \cup \{f\})\ ) \\ \lhd (f == d)) \rhd \\ (\ dl := false \rightarrow Intruder_0(F \cup \{f\})\ ) \end{array} \right)
\end{aligned}
$$

- When intercepting a message m, the intruder adds Info(m) to its knowledge.
- Moreover, the intruder can deduce new facts from its knowledge via the channel DEDUCE and add them to its knowledge.
- If the intruder knows *info*(*m*), then it can pretend as a legal entity and fake the message *m*.

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Verification and Improvement

Property 1: Deadlock Freedom

- AUPS should not run into a deadlock state. We verify this property by means of a primitive in PAT.

$$\#assert\ System()\ deadlockfree;$$

Property 2: Data Availability

- The property means that a legal user should get the required data. The following assertion is used to check the property.

$$\#define\ \ Data\_Available\ \ data\_suc == true;$$
$$\#assert\ \ System()\ \ reaches\ \ Data\_Available;$$

Property 3: Data Leakage

- Data leakage can cause a bad effect to the system. We use a Boolean variable *dl* to verify the property, using the "always" operator [] in LTL. If the intruder obtains the data, we set the value of *dl* to *true*.

$$\#define \;\; Data\_Leak\_Success \;\; dl == true;$$
$$\#assert \;\; System() \; | = [] ! \;\; Data\_Leak\_Success;$$

Property 4: Device Faking

- The property means that the intruder can pretend to be a legal device without being recognized. We adopt a Boolean variable *df* to verify the property. If the intruder fakes as a legal device successfully, we set the value of *df* to *true*.

$$\#define\ \ Device\_Fake\_Success\ \ df == true;$$

$$\#assert\ \ System()\ \ |= []!\ \ Device\_Fake\_Success;$$

Property 5: User Privacy Leakage

- User privacy leakage may bring great security risks to users. Hence, we check whether the intruder can obtain the sensitive information of the user using the following assertion.

$$\#define\ \ User\_Privacy\_Leak\ \ pl == true;$$
$$\#assert\ \ System()\ \ |= []!\ \ User\_Privacy\_Leak;$$

Verification and Improvement

Verification Results

- *Property* 1 and *Property* 2 are valid. It indicates that the model will never get stuck in a deadlock state and the data can be transmitted to the legal user who subscribes to the service.
- *Property* 3, *Property* 4 and *Property* 5 are invalid. It shows that the model can cause data leakage, device faking and user privacy leakage.

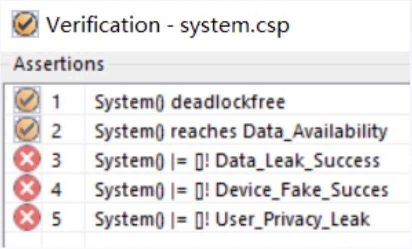

Figure 4: Verification results of the model

Verification and Improvement

Attack Analysis

$$A1.\ U \longrightarrow I : U.B.req_u$$
$$A2.\ I \longrightarrow B : U.B.req_u$$
$$A3.\ B \longrightarrow I : B.U.puk_b$$
$$A4.\ I \longrightarrow U : B.U.puk_i$$
$$A5.\ U \longrightarrow I : U.B.E(puk_i, sk_u.id_u)$$
$$A6.\ I \longrightarrow B : U.B.E(puk_b, sk_u.id_u)$$
$$A7.\ B \longrightarrow I : B.U.E(sk_u, sid_u.at)$$
$$A8.\ I \longrightarrow U : B.U.E(sk_u, sid_u.at)$$
$$A9.\ U \longrightarrow I : U.B.E(sk_u, at.T))$$
$$A10.\ I \longrightarrow B : U.B.E(sk_u, at.T))$$
$$A11.\ B \longrightarrow I : B.U.E(sk_u, kT)$$

- The intruder can obtain the data using kT.
- Similarly, the intruder can fake as the device to publish data, which leads to device faking.

We modify the message definitions of the model. MSG_{key} is replaced by the following MSG_{key2}.

$$MSG_{key2} = \{msg_{key2}.a.b.E(k_1, k.inf) \mid a, b \in Entity, k_1, k \in Key, inf \in Inf\}$$

The improved model is given as follows:

$$System_1 =_{df} Broker_1 \| User_1 \| EF \| ProcessE \| KTM \| Device_1 \| NOS_1 \| CA \| Clock$$

$$System =_{df} System_1 [| INTRUDER\_PATH |] Intruder$$

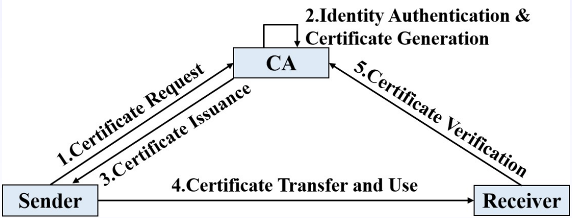

Figure 5: Flows of digital certificate

Verification and Improvement

Verification Result

Property 3, *Property* 4 and *Property* 5 are valid. It means that *Data Leakage*, *Device Faking* and *User Privacy Leakage* problems are solved now.

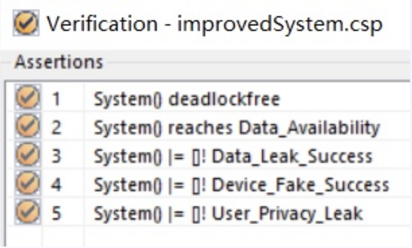

Figure 6: Verification results of the improved model

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Conclusion and Future Work

Conclusion

- We formalized AUPS using CSP.
- We verified five properties of AUPS model, including **deadlock freedom**, **data availability**, **data leakage**, **device faking** and **user privacy leakage**.

Future Work

- Study more security properties of AUPS using formal methods.
- Improve our model to handle more attacks.

Thank you!