Cross-Browser Payment Initiation Attack

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Introduction

This document is based on a security threat analysis of several PSD2 API standards conducted by OpenID Foundation’s Financial-grade API (FAPI) Working Group (https://openid.net/wg/fapi/).

It describes a possible attack on payment flows utilizing a browser-based redirect flow to authenticate the user and gather her consent to initiate the payment.

Idea: Bob (B) wants to make Alice (A) pay for the goods he ordered at the web site of some merchant (M).

Vulnerable API Designs

Payment flows that follow the following basic scheme are vulnerable to the attack:

1. The merchant is a PSD2 TPP and offers PSD2 Payment Initiation as payment method.
2. For payment, the user is redirected from the merchant to her bank.
3. The URL to which she is redirected designates (directly or indirectly, e.g., by referring to a payment resource) the intended receiver of the payment, the amount and currency to be transferred, and the purpose/reference of the payment.
4. At this URL, the user is prompted to authenticate to the bank and provide her consent to the transaction.
5. The actual transfer of funds is performed in the same step before redirecting the user agent back to the merchant.

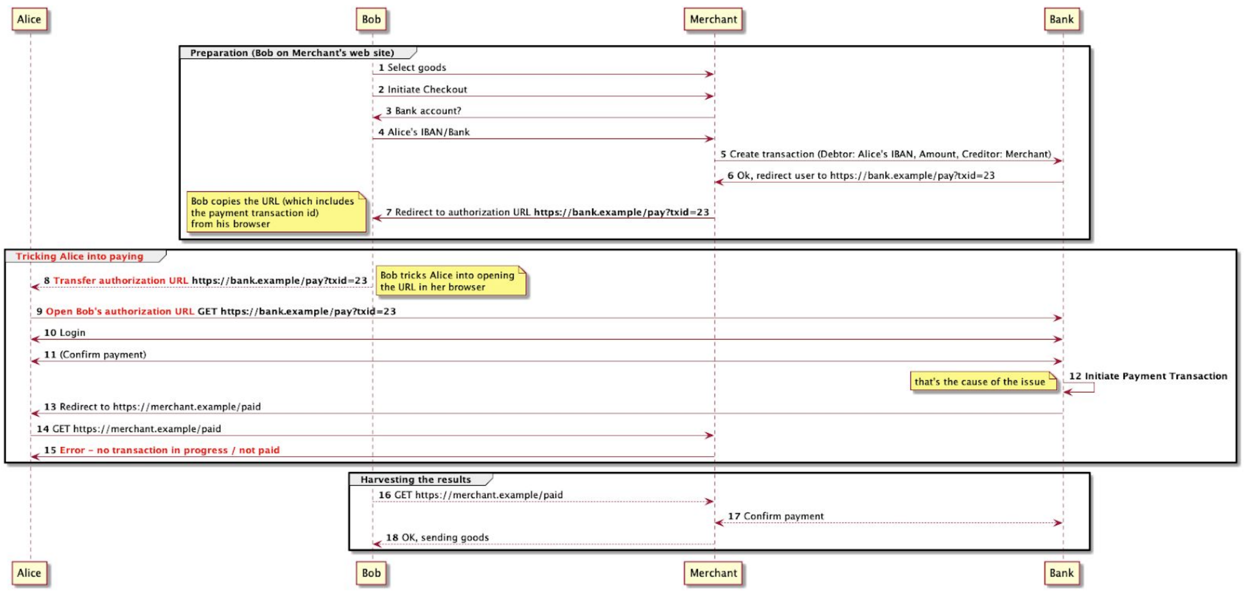
As can be seen from the attack below, the fact that the transfer of funds is performed before redirecting the user agent back to the merchant is what makes the API design vulnerable: There is no check that the flow was started in the same user agent in which the authentication and payment were performed.

Prerequisites

1. Alice needs to be expecting some kind of payment flow, for example, because she is shopping for some goods.
2. Bob needs to know **when** Alice expects to do this payment. It suffices if Bob learns when Alice opens the payment page at the merchant or the authentication URI of the bank. There are several possibilities how Bob can achieve this:
    a. Bob controls advertisement or tracking scripts in the merchant's web site. (Note: Even if these are **sandboxed in an iframe**, these kinds of scripts often learn the visited URL since this is important for tracking.)
    b. Bob might be able to use leaked information from the merchant web site, for example via CSRF or inadvertently exposed state information.
    c. If Bob can read the network traffic, he can, even if the traffic is protected by TLS, often read the domain of the visited web site (SNI header) or correlate IP addresses and packet sizes with the visited web site.
3. Bob needs to be able to open a URL chosen by him in Alice's browser. There are many different mechanisms through which Bob can achieve this and is hard to foresee which ones would be used in a real attack. Some options are: Alice visits Bob's website, Bob controls an advertisement script, or Bob sends an email to Alice.
4. Depending on the details of the payment interface, Bob might need to know some information about Alice; for example, the bank (to start the payment with the correct bank) or the IBAN of Alice's account (if the IBAN is required for starting the payment

flow). If needed, he might learn this from social engineering, data leakage on a web site, etc.

The Attack



Preparation (Bob on Merchant's web site)

Message #1 Bob selects a product at a merchant web site.

Message #2 Bob initiates the checkout.

Message #3 The merchant asks Bob for his bank account.

Message #4 Bob enters Alice's Bank Id or IBAN.

Messages #5 & #6 The merchant sets up a new payment initiation transaction with the Merchant's IBAN as the creditor account and the price of the shopping cart as amount. Depending on the API design, it might be required to set Alice's IBAN as the debtor
The bank responds with an URL the merchant needs to redirect the user's browser to in order to authenticate and authorize the payment (payment authorization URL).

Message #7 The merchant redirects the browser to the bank. Bob copies the URL (which includes data identifying the payment initiation transaction).

Tricking Alice into paying

Message #8 & #9 Bob tricks Alice into opening this URL in her browser (see Prerequisites).

Message #10 Alice logs into her bank.

Message #11 Alice confirms the payment initiation using a SCA (SCA is potentially omitted if the merchant is on the exemption list or the amount is below a certain limit).

Message #12 The bank initiates the payment.

Message #13 & #14 The bank redirects the browser back to the merchant's after pay landing page (in Alice's browser)

Message #15 The merchant site does not know anything about an ongoing checkout since there are no cookies in Alice's browser. It shows an error. Alice is confused[1].

Harvesting the results[2]

Message #16 Bob waited for some time and then directs his browser to the merchant's after pay landing page (in his browser).

Message #17 The merchant recognizes the checkout (based on the browser cookies), queries the status of the payment with the bank and confirms the successful payment to Bob.

Message #18 The merchant delivers the goods to Bob.

The Vulnerability in Detail

The reasons for this vulnerability are

- the **lack of binding between the browser** which **initiated payment transaction** (Bob's browser) and the **browser where the transaction was authorized** (Alice's browser) and
- the fact **the transaction is automatically initiated** when the user authorized it (Message #12) before such a lack of binding could be detected.

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[1] Depending on the exact method chosen to open the window, Bob might be able to close the window of Alice's browser in which the merchant website would be opened, e.g., because Bob controls the top-level window.

[2] Bob might repeat the steps listed next in order to get a precise timing for closing that window.

This allows the attacker to prepare a transaction and remotely trick the victim into executing it. Since the attacker has all the details, it can benefit from the successful execution. That’s why this kind of attack is typically referred to as “session fixation” (see https://en.wikipedia.org/wiki/Session_fixation)[3].

The Strong Customer Authentication (SCA)/Dynamic Linking is the only line of defense in the design described above. This means it’s Alice’s responsibility to recognize the attack and stop it by refusing to perform the respective SCA[4]. Since the attacker will most likely synchronize his attack with a payment process Alice is expecting makes it even harder.

The situation is getting even worse, if the particular transaction is subject to an exemption, e.g. because Alice whitelisted the respective merchant. In this case even the SCA line of the defense disappears leaving Alice unprotected.

As a result, the design described above puts a huge burden on the shoulders of the average PSU while there exist ways to mitigate this kind of attack on the protocol level without the need to rely on the user as shown in the following section.

[3] This attack would also work for account information services. In this case, the attacker sets up a transaction (or consent request), which is then upgraded (authorized) by the victim. The attacker then (through the TPP) just uses the handle to the transaction (or consent resource) to access the account information.

[4] Neither the TPP nor the ASPSP will directly know Alice refused to perform SCA because it recognized an attempt to attack her, which means it’s very hard to chase and stop the attacker effectively.

Mitigation (General Approach)

The attack can be mitigated by generating and issuing a token in the browser-based authorization process, which is required to complete the transaction. Since the attacker does not control Alice's device, he is unable to get access to this token. Moreover, a check to verify the transaction's binding to the particular browser is introduced.

Applying this pattern to the payment flow means:

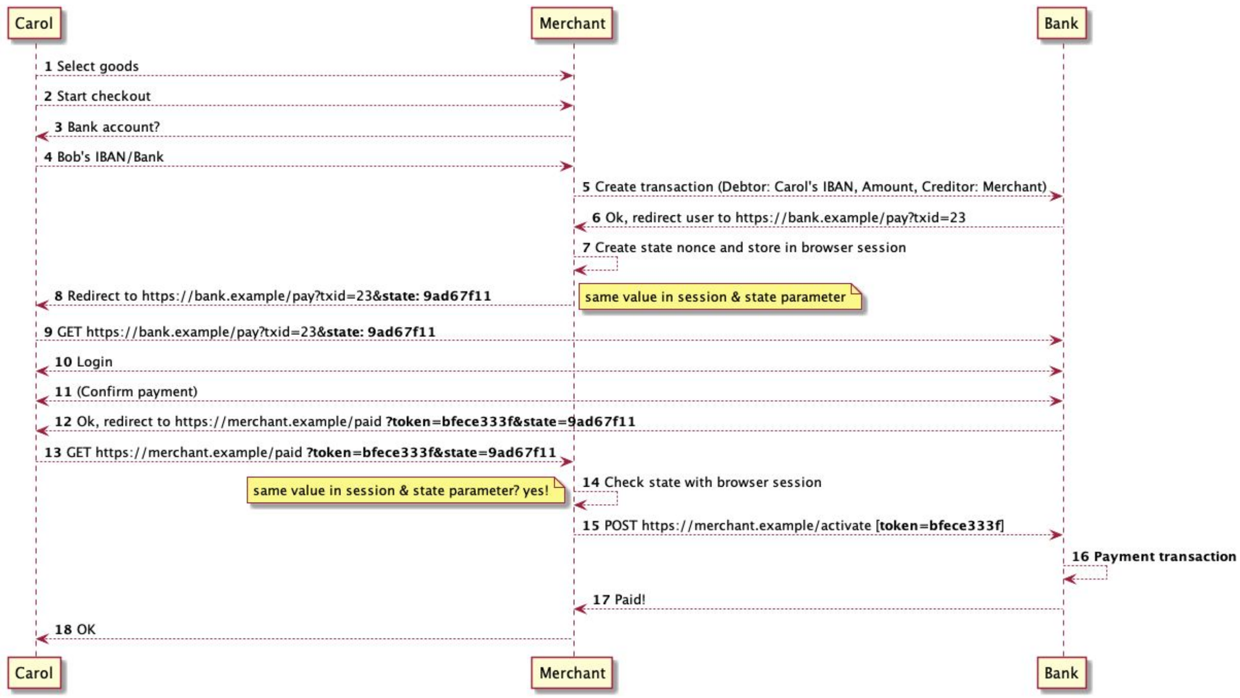
- The bank does not initiate the payment in the authorization process.
- The authorization process sends the browser back to the merchant site and the redirect includes a freshly generated token associated with the current transaction.
- The merchant uses this token to activate the payment initiation using an API call exposed by the bank.

BEFORE the merchant triggers the payment initiation, it MUST check whether the authorization response it just received belongs to an authorization request that was sent from the current browser (BROWSER BINDING!).

The solutions to implement this binding are protocol specific. In OAuth 2.0, for example, the merchant would add a nonce as the state parameter to the authorization request and bind it to the user's browser session. In the redirection back, the same parameter is added again by the bank. The merchant could then check that the state parameter matches the state value stored in the cookie.

Modified Payment Flow (good case)

The following sequence diagram shows the modified payment flow in a good case (no attack is performed):



There are two important additions:

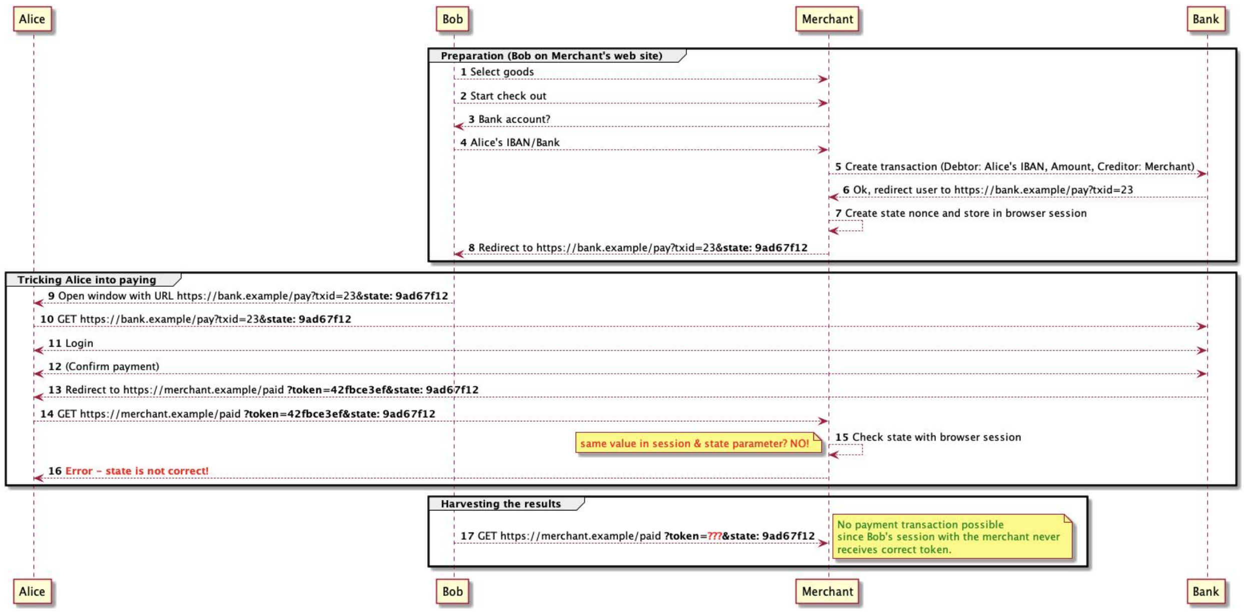
(1) Browser Binding
In messages #7 & #8 the merchant establishes a nonce that is stored in the browser session and sent to the bank, which links this transaction to the particular browser session.

In message #14, the merchant compares the state values in the session to the value of the state response parameter. Since it is the same value, this transaction was initiated in the same browser and the process can continue.

(2) Token for Payment Initiation
After this check (which only can take place at the merchant!), the merchant now uses the token issued by the bank to initiate the payment.

Modified Payment Flow (Attack)

The following diagram shows how an attempt by Bob to trick Alice into paying his goods is detected and prevented.



If Bob forwards the authorization URL to Alice, as in the attack above, then Alice would be redirected and the token would be received by the merchant but it **will be received in Alice's session with the merchant**. At this point, the CSRF protection by the merchant will detect and prevent the attack. The merchant will therefore not start the payment activation.

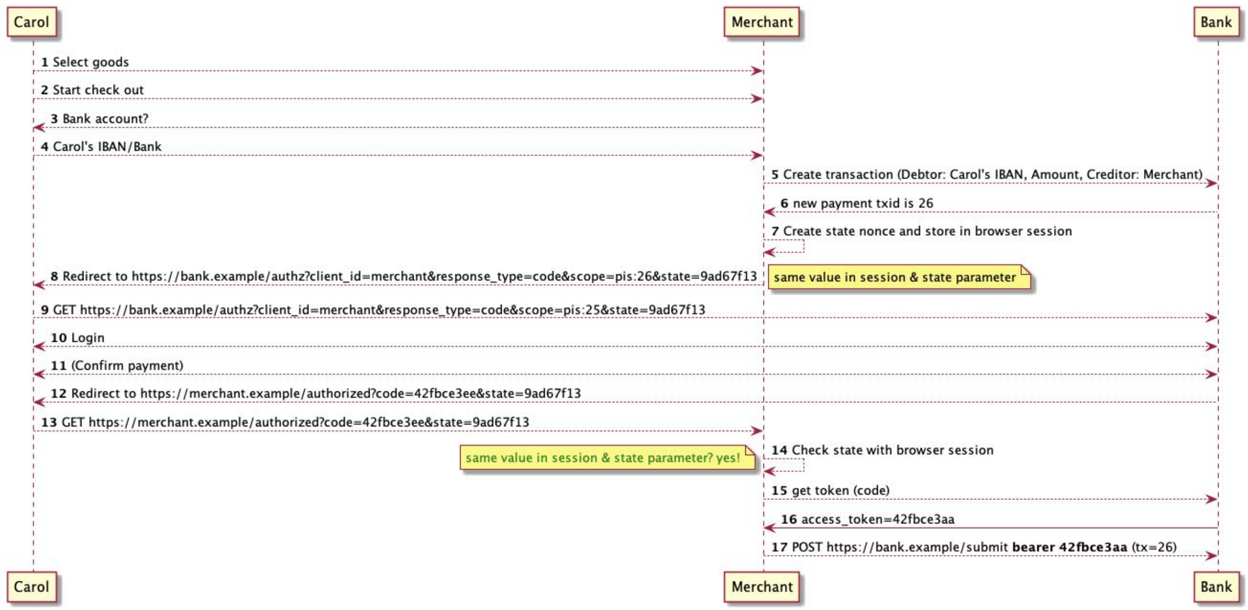
Bob will not be able to forward Alice's session to the merchant since he does not see the token. Bob will not be able to activate his payment using Alice's account.

Note: The security of this solution depends on the secrecy of the token. For example, if the URL containing the token leaks to the attacker, the mechanism does not provide additional security. Such a leakage can happen, for example, through referrer headers set by the browser, the browser history, log files of browsers, proxy servers, and operating systems, and, on mobile operating systems, during communication between apps.

Mitigation using OAuth 2.0

The mitigation above and mitigations against other attacks are already contained in the authorization code grant type defined by the OAuth 2.0 authorization framework (https://tools.ietf.org/html/rfc6749#section-4.1). With minor changes, the flow above can be adapted for OAuth.

The payment initiation flow using OAuth 2.0 is shown in the following sequence diagram.



It looks similar to the flow shown before, except for the following changes:

- It uses the standard OAuth parameters in the authorization request (messages #8 & #9). The payment transaction id is encoded in the so-called “scope” parameter.
- Instead of returning the token to the merchant in the authorization response (messages #12 & #13), the bank only returns a so-called *authorization code*, a one-time use token chosen by the bank and bound to the identity (client_id) of the merchant. The authorization response also contains the “state” parameter as sent in the authorization response.
- The merchant then sends a request to the bank containing the authorization code (message #15). This request is authenticated using the credentials the merchant had set up with the bank (e.g. TLS Client Authentication using X.509 certificates). Only after checking the authorization code and its binding to the merchant’s client_id, the bank sends the access token to the merchant in the response (message #16).
- The merchant then sends the access token with the request to submit the actual payment to the bank’s payment initiation API (message #17).

This solution is compatible to existing implementations of OAuth 2.0. The security of the OAuth protocol has been analyzed in detail and existing security recommendations can be applied.

Note: https://tools.ietf.org/html/draft-ietf-oauth-security-topics-10#section-2.1 gives the the full set of recommendations how to protect Redirect-Based Flows using OAuth 2.0.

In addition the OpenID Foundation has published a [financial-grade security profile of OAuth 2.0](#) which includes these best practices and additional security mechanisms.

Acknowledgement

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