Decoupled-IFTTT: Constraining Privilege in Trigger-Action Platforms for the Internet of Things

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Abstract—Trigger-Action platforms are an emerging class of web-based systems that enable users to create automation rules (or recipes) of the form, “If there is a smoke alarm, then turn off my oven.” These platforms stitch together various online services including Internet of Things devices, social networks, and productivity tools by obtaining OAuth tokens on behalf of users. Unfortunately, these platforms also introduce a long-term security risk: If they are compromised, the attacker can misuse the OAuth tokens belonging to millions of users to arbitrarily manipulate their devices and data. In this work, we first quantify the risk users face in the context of If-This-Then-That (IFTTT), a popular trigger-action platform that interfaces with 297 online services and provides over 200,000 recipes. We perform the first empirical analysis of the OAuth-based authorization model of IFTTT using semi-automated tools that we built to overcome the challenges of IFTTT’s closed source nature and of online service API inconsistencies. We find that 75% of IFTTT’s channels, an abstraction of online services, use overprivileged OAuth tokens, increasing risks in the event of a compromise. Even if the OAuth tokens were to be privileged correctly, IFTTT’s compromise will not prevent their misuse. Motivated by this empirical analysis, we design, build, and evaluate Decoupled-IFTTT (dIFTTT), the first trigger-action platform where users do not have to give it highly-privileged access to their online services. dIFTTT splits the logically monolithic IFTTT architecture into a cloud service that users do not trust, and a set of clients. A user only has to trust the client she installs. Our design pushes the notion of fine-grained OAuth tokens to its extreme and ensures that even if the cloud service is controlled by the attacker, it cannot misuse the OAuth tokens to invoke unauthorized actions. Using such fine-grained tokens would normally lead to a drastic increase in the number of OAuth permission prompts. dIFTTT avoids this increase by introducing the concept of a Transfer Token (XToken) and combining it with recipe-specific tokens. Our evaluation establishes that dIFTTT poses modest overhead: it adds less than 15ms of latency to recipe execution time, and reduces throughput by 2.5%.

I. INTRODUCTION

Trigger-Action platforms are a class of web-based systems that stitch together several online services to provide users the ability to set up automation rules. These platforms allow users to setup rules like, “If I post a picture to Instagram, save the picture to my Dropbox account.” The ease of use and functionality of such platforms have made them increasingly popular, and several of them (e.g., If-This-Then-That [5], Zapier [12], and Microsoft Flow [3]) are on the rise. Furthermore, with the rise in popularity of connected physical devices like smart locks and ovens, we observe that many trigger-action platforms have started adding automation support for physical devices, making it possible for users to set up rules like: “If there is a smoke alarm, then turn off my oven” [15]. These platforms have privileged access to a user’s online services and physical devices. If they are compromised, then attackers can arbitrarily manipulate data and devices belonging to a large number of users to cause damage.

We quantify the risk users face if a trigger-action platform is compromised by performing the first empirical analysis of IFTTT’s authorization model—a cloud-based closed source system that provides a trigger-action abstraction for end-users in the form of recipes. Running our example recipe above requires IFTTT to integrate with the smoke alarm (Nest) and the oven and obtain authorization to access them on the user’s behalf. It achieves this integration using its channel abstraction [5], through which IFTTT gains privileged access to the user’s accounts on online services that in turn provide access to the smoke alarm and the oven. IFTTT and online services decide the privilege using the popular OAuth protocol [23], [24], where IFTTT requests a certain amount of privilege using the scope parameter, and gains OAuth tokens if users grant privilege. Therefore, IFTTT contains OAuth tokens for all user online services in its logically monolithic architecture [4]. If IFTTT is compromised, then the attacker can misuse the tokens and arbitrarily manipulate data and devices. Furthermore, incorrect OAuth scoping can lead to overprivilege—either IFTTT channels may request broad scopes or the online services may only offer coarse-grained scopes. In either case, if IFTTT is compromised, the highly-privileged OAuth tokens will only increase the damage that attackers can cause.

We choose to study IFTTT for several reasons. First, it is a popular platform, supporting 297 channels as of April 14th, 2016, and offers more than 200,000 recipes, many created by end-users [36]. Second, its trigger-action programming abstraction is well-suited to many desirable home automation behaviors [37], and it supports 80 cyber-physical channels. Third, IFTTT is representative of a larger class of trigger-action platforms. Other systems such as Zapier [12] and Microsoft Flow [3] share the same design principles. Therefore, the results and lessons we learn from our empirical study of IFTTT are broadly applicable to the security design of other systems in this class.

Performing this empirical analysis is challenging for sev-
eral reasons. First, IFTTT is closed source—we cannot inspect source code or even binary code to determine what scopes the channels need or request. Second, many channels use a specific opaque `scope=ifttt` OAuth authorization URL parameter, defined by the online service for the channel, and that does not reveal the APIs that the channel can access. Third, there is no defined scope-to-API mapping in the OAuth specification, making it difficult to compute the set of online service APIs to which a scoped token gives access. Fourth, online services do not document their APIs in consistent ways and do not provide unit tests, making large scale testing difficult. We built a semi-automated measurement pipeline that overcame the above challenges to obtain tokens of the same privilege that IFTTT uses and then exhaustively tested online service APIs to compute a conservative lower bound on the overprivilege that IFTTT channels exhibit. Our results indicate that 75% of the channels examined have access to more operations than they need to support their triggers and actions.

The presence of such tokens makes IFTTT an attractive target for attackers and increases risks if it is compromised. For example, our empirical analysis shows that an attacker can reprogram Particle chips and delete Google Drive files with a single HTTP call (§III-D). Thus, users are taking a significant long-term risk in granting IFTTT highly-privileged access to their online data and devices.

We show that this risk can be avoided, while getting the benefits of a cloud-based trigger-action platform. We design, implement, and evaluate Decoupled-IFTTT (dIFTTT), the first decoupled trigger-action platform whose compromise does not permit an attacker to arbitrarily invoke functions in online services. dIFTTT achieves this property by introducing the notion of recipe-specific tokens. A recipe-specific token can only be used to execute the specified recipe. If a compromised cloud service attempts to use a token to invoke an action without a valid trigger, the online service will deny that request. Thus dIFTTT ensures that the cloud service: (1) can only invoke actions and triggers needed for the recipes it is executing; (2) can invoke actions only if it can prove to an action service that the corresponding trigger occurred in the past within a reasonable amount of time; and (3) cannot tamper with any trigger data passing through it undetected.

Unless carefully designed, recipe-specific tokens can lead to an increased number of OAuth permission prompts because users would have to login and approve an OAuth scope request every time they create a recipe. The challenge is to gain the security of recipe-specific tokens but maintain the current IFTTT experience where users login to channels only once during a setup phase. dIFTTT overcomes this challenge by introducing the concept of transfer tokens (XTokens). A client uses an XToken to automatically obtain a recipe-specific token, which it transmits to the cloud service for recipe execution.

dIFTTT requires the untrusted cloud service to prove to the invoked action service that a trigger has occurred within a reasonable amount of time in the past. As the cloud service can be compromised, a possible design is to have the trigger service communicate directly with the action service to verify the occurrence of a triggering event. However, this introduces an undesirable dependency between the action and trigger services. dIFTTT avoids that by using a lightweight cryptographic signature-based extension to the OAuth 2.0 protocol.

Our Contributions:

- We perform an empirical analysis of IFTTT’s authorization model to quantify the risk that users face in the event that it is compromised:
  - Based on an analysis of authorization sessions of 128 online services that IFTTT integrates with, we characterize: (1) the descriptiveness of OAuth scope requests (§II), and (2) the level of control these services provide to users when IFTTT requests scopes. Our analysis reveals that most online services (101/128) provide a good or acceptable explanation of the scopes being requested. Unfortunately, for many online services (122/128), a user is only given an all-or-nothing choice of accepting all scope requests or none at all. Therefore, for most online services, even though users are told what level of access is being requested, they are not provided the means to restrict the amount of privilege they grant to IFTTT.
  - We find that 107/128 channels use an opaque scope that the online service provides, such as `generic`, `null`, or `ifttt`. This can lead to overprivilege. Therefore, we perform an in-depth analysis of the overprivilege of all externally measurable IFTTT channels (69 of them) and obtain a conservative lower bound. We study all 941 APIs across 24 channels, including 16 higher-risk cyber-physical channels, and find that 18 channels including 10 cyber-physical channels have access to APIs that they do not need to implement their functionality. Our analysis covers 80.4% of all recipes involved in the set of 69 channels (§III-D). Examples of overprivileged channels include well-known services like Facebook, Twitter, and Google Drive and cyber-physical services like Particle, and MyFox Home Control. Using such overprivileged access, a potentially compromised IFTTT platform can reprogram a Particle chip’s firmware or delete files on Google Drive arbitrarily with a single single HTTP call.

- Motivated by this empirical analysis, we designed and implemented Decoupled-IFTTT, the first decoupled trigger-action platform where users do not have to trust the platform with highly-privileged access to their online services (§IV). dIFTTT splits the logically monolithic IFTTT architecture into an untrusted cloud service that executes recipes at scale, and a set of clients that help users create recipes in a secure manner. dIFTTT is based on cryptographic extensions to the OAuth protocol that only allow the cloud service to execute user recipes, even if it is attacker-controlled. Our design introduces techniques that enable trigger-action functionality without putting users at risk of attackers arbitrarily manipulating data and devices. Recipe-specific tokens also reduce the platform’s liability in the event of a compromise.
  - Our evaluation of dIFTTT shows that performance overhead is modest (§V). Each recipe requires less than 3.5KB additional storage space and imposes less than 7.5KB of transmission overhead per execution.
  - dIFTTT adds less than 15ms of latency to recipe execution time. For recipes on IFTTT, which typically send emails, SMSs, or invoke actions on physical devices or on online services over a network, we consider this
additional latency to be acceptable. dIFTTT reduces throughput by 2.5% for recipe execution.

Although dIFTTT requires online services to support recipe-specific tokens and to use cryptographic extensions to the OAuth 2.0 protocol, there are several options to help developers make the transition. One option that we followed in our implementation is to design a library that only requires adding a single annotation above HTTP methods in the server (§VI). Another option is to construct a trusted proxy for the online services (§VII). Furthermore, as these platforms are still emerging, our design gives system implementers an opportunity to construct secure trigger-action platforms from the ground up, and represents an important first step towards securing trigger-action platforms.

II. IF-THIS-THEN-THAT

IFTTT is a popular trigger-action platform that makes it easy for end-users to set up interactions between various online services and IoT devices to achieve useful automation. IFTTT works by communicating with the REST APIs that these services expose. Figure 1 shows the high-level IFTTT architecture. It has the following four architectural components:

- **Channel:** A channel represents part of an online service’s set of APIs on the IFTTT platform. Users connect channels to their IFTTT accounts—a process that involves user authorization. For example, a user with a Facebook account must authorize the IFTTT Facebook channel to communicate with the corresponding Facebook account. Channels communicate with online services using REST (Representational State Transfer) APIs operating over HTTP(S). These online services use the popular OAuth protocol to enforce authorization [23], [24]. Users must connect several such channels, before they can accomplish any useful work. Either IFTTT developers or service providers can implement channels. In the latter case, IFTTT exposes a separate API to channel writers to help them integrate their online service with IFTTT [2].

- **Trigger:** A channel may provide triggers, which are events that occur in the associated online service. “A file was uploaded to a cloud drive” or “smoke alarm is on” are examples of triggers.

- **Action:** A channel may also provide actions. An action is a function (or set of functions) that exists in the API of the online service. Examples of actions include “turning on or off a connected oven” or “sending an SMS.”

- **Recipe:** Recipes are at the core of the IFTTT user experience, and they are the core functionality that IFTTT enables. A recipe stitches together two channels to achieve useful automation. It has two pieces. The “If” piece represents a trigger or an event that occurs on an online service. The “Then” piece represents an action that should be executed on the online service. For example, “If there is a smoke alarm, then turn off my oven.” This recipe integrates the smoke alarm channel’s “alarm is on” trigger with the oven channel’s “turn off the oven” action. Although IFTTT only permits a single trigger and a single action in a recipe, other trigger-action platforms offer multiple triggers and actions in the same recipe.

There is a one-to-one correspondence between online services and IFTTT channels. For example, the Google Drive online service corresponds to the Google Drive IFTTT channel. IFTTT has 297 channels as of April 14th, 2016.

**Authorization Model.** Online services protect their REST APIs using authorization protocols. OAuth is a popular choice that enables an online service to provide third parties with secure delegated access to its APIs. IFTTT must obtain authorization to communicate with online services that its channels represent; and therefore it must follow the OAuth authorization workflow. Figure 2 shows the IFTTT authorization model. It has four steps.

First, a channel developer (IFTTT or the online service provider itself) must create a client application for the online service’s REST API. This client application represents an IFTTT channel on the online service. During the sign-up phase, the online service assigns a client ID and a secret that IFTTT uses during the authorization workflow.

Second, a user initiates a channel connection within the IFTTT administrative interface and this causes IFTTT to initiate the OAuth 2.0 authorization code flow—the recommended workflow for server-to-server authorization—that results in IFTTT requesting the corresponding online service for a short authorization code on behalf of the user. IFTTT passes a client identifier value, a redirect URI, and a scope value as part of the HTTP(S) request. The scope value represents the level of access IFTTT is requesting to operate a channel. This authorization request results in the user being presented with an OAuth permissions screen that explains the scope that IFTTT is requesting. As the OAuth protocol does not specify the design of the permissions screen, the screen design, scope explanations, and UI options to modify the requested scopes is at the discretion of the online service.

Third, assuming the user accepts the scope request, the
Service-to-Service Channel Signup
User-to-Service Authorization

Fig. 2: IFTTT’s authorization model has four phases. Channel developers create client applications for the online service that results in the online service assigning a client ID and secret to the application. Then, IFTTT initiates an authorization workflow. The OAuth 2.0 authorization code flow is a popular choice, and it results in IFTTT gaining a scoped bearer token that authorizes a channel to invoke APIs on an online service. Users are prompted to approve or deny scope requests during this process.

Although OAuth 2.0 is by far the most popular authorization protocol that IFTTT uses, there are online services that use OAuth 1.0a. This protocol does not have explicit scoping as part of the authorization workflow, but a similar concept is available when a client application signs up for the online service’s API. During the client application sign-up phase, the developer can choose scopes to enable. For example, Twitter uses OAuth 1.0a, and it provides a settings item that allows a developer to change the access level of the client application, and hence, change the scope of any tokens issued in the future.

A. Potential for Overprivilege

Ideally, IFTTT should be authorized with only enough privilege to run a given user’s set of recipes. Any access rights beyond what it requires to run a user’s recipes is overprivileged access. Based on the authorization model and IFTTT architecture discussion above, we observe the potential for two kinds of systemic overprivilege that stems from IFTTT’s design. We discuss them below.

Recipe-Channel Overprivilege. An IFTTT recipe only requires a single trigger and a single action. However, one channel can support multiple triggers and actions. Table I shows the set of triggers and actions for two example channels—Particle and Google Drive. Therefore, if a user adds a recipe that uses a subset of triggers and actions of the associated channels, all additional triggers and actions that the channel implements is overprivileged access. That is, IFTTT acquires the right to invoke online service APIs that it does not need for executing the recipes of a given user. This kind of overprivilege stems from the IFTTT design choice that channel authorization is not recipe-specific.

Channel-Online-Service Overprivilege. The second type of overprivilege we observe is related to the authorization between IFTTT and an online service. As discussed, IFTTT provides channels that have trigger and action functionality. Furthermore, IFTTT must request authorization to a set of online service APIs to implement a channel’s functionality. Ideally, the IFTTT channel should only have the authorization needed to implement its functionality. However, in practice, incorrect scoping can lead to IFTTT gaining authorization to access APIs it does not need to implement its trigger and action functionality. This can occur if the online service does not provide granular scopes, forcing IFTTT to request coarsely-grained overprivileged access. This can also occur if IFTTT incorrectly requests overprivileged access even if the online service provides fine-grained scopes.

B. Examples of Overprivilege

Here we show the potential for the two types of overprivilege discussed above using two case studies.

Particle. This is a DIY electronics platform that offers small form-factor chips with a microcontroller, memory, and an Internet connection. Particle supports writing custom firmware for its chips and exposes a REST API to make the chips remotely accessible. IFTTT supports the Particle channel. Table I shows the set of triggers and actions for this channel. If a user’s recipes do not use all the triggers and actions, then that channel exhibits recipe-channel overprivilege. Figure 2 shows the OAuth permissions screen a user sees while connecting the Particle channel to IFTTT. Clearly, the channel is requesting privilege to “reprogram” a Particle device. However, based on the triggers and actions from Table I the channel does not offer any such operation in recipes, and hence exhibits channel-online-service overprivilege. If IFTTT is compromised, an attacker can use this level of access to reprogram a chip even though there are no channel operations and no recipes that offer such functionality.

| Channel       | Triggers                                    | Actions                           |
|---------------|---------------------------------------------|-----------------------------------|
| Particle      | New event published. Monitor a variable.   | Publish an event.                 |
|               | Monitor a function result.                  | Call a function.                  |
|               | Monitor your device status.                 |                                   |
| Google Drive  | NONE                                        | Upload file from URL.             |
|               | Create a document.                         | Append to a document.             |
|               | Add row to spreadsheet                      |                                   |

TABLE I: Triggers and Actions for the Particle and Google Drive Channels.
Google Drive. This is a well-known online service that offers cloud storage for various types of files. Similar to Particle, if a user’s Google Drive recipes do not use all the triggers and actions of the corresponding IFTTT channel (see Table I), then that channel exhibits recipe-channel overprivilege. Figure 4 shows the OAuth permissions screen a user sees while connecting the Google Drive channel to IFTTT. The prompt indicates that IFTTT will be able to “View and manage the files in your Google Drive.” Based on Google Drive API documentation, this implies the ability to “Upload, download, update, and delete files in your Google Drive.” However, the Google Drive channel does not offer any triggers or actions that delete files. Thus we conclude that the IFTTT Google Drive channel exhibits channel-online-service overprivilege.

Therefore, based on these case studies, we observe the potential for overprivilege in terms of recipes operating with channels and in terms of channels interfacing with the online service APIs. We focus our empirical overprivilege analysis on these two types of overprivilege.

III. EMPIRICAL OVERPRIVILEGE ANALYSIS OF IFTTT

We studied 297 channels, covering 219,284 recipes and performed an in-depth overprivilege computation for 24 channels, including 16 cyber-physical channels, achieving a coverage of 80.4% of all recipes involved in a set of 69 channels that can be studied in-depth. Our findings are two-fold. First, based on an analysis of the triggers and actions supported by 297 channels, we found that on average, each channel has 3.5 triggers and 2 actions. As a recipe only needs one trigger and one action, if a user’s set of recipes do not use all channel triggers/actions, then there is overprivilege. Second, we find that 18 (out of 24) channels have access to online service APIs that they do not need to implement their trigger/action functionality. We present details on our dataset and how we constructed it, and we present our semi-automated overprivilege measurement pipeline, along with details on its output.

A. Dataset and Measurement Setup

There are two parts to our dataset: recipes and channels. We used the recipe dataset from Ur et al. [36] that contains 219,284 recipes (after filtering out recipes that refer to defunct channels), and we created our own dataset of 297 channels that consists of trigger and action details. We created this dataset of channels on April 14th, 2016. We also scraped the IFTTT website to download trigger and action details (description, input arguments) for all channels of the dataset.

Subsequently, we created a test IFTTT account and an account for each online service. We then manually connected each channel by following the OAuth workflow. We were able to connect 170 channels to our test IFTTT account, out of which, we recorded authorization sessions for 128 channels. An authorization session consists of two items: (1) The OAuth authorization URL that IFTTT uses to initiate authorization with the online service to receive a token, and (2) A screenshot of the OAuth permissions prompt. We were unable to connect or record authorization sessions for 169 channels due to the following reasons:

- Channels that are connected by default or do not require authorization: Channels such as SMS, weather, and ESPN that are not tied to any 3rd party user account fall in this category. We observed 40 such channels among 297 in our study. We exclude these channels from further analysis.
TABLE II: Channel connection status. We were able to record authorization session information for 43% of all channels in our dataset. 19% of channels require a physical device to be present during connection, 11% gain authorization through a mobile app’s native permission model, 19% of channels connect without requiring authorization, 3% sit behind a pay-wall and could not be connected, and 10% were either defunct or malfunctioning at the time of our analysis.

- **Channels that require specific physical devices for connection or are behind a pay-wall:** Channels such as Feedly and D-Link Siren that require either purchasing a physical device or purchasing a subscription to complete the connection to IFTTT fall in this category. We observed 67 such channels. To minimize the cost of our research project, we exclude them from further analysis. We note that we include channels with physical devices in our analysis if they could be connected to our test IFTTT account without a physical device being present. We also include the Alexa and SmartThings channels for which we purchased physical devices.

- **Channels that are mobile only and communicate only through IFTTT mobile app:** Channels such as iOS Contacts and Android Location that only operate on a mobile platform such as Android and iOS fall in this category. We observed 33 such channels. These channels rely on the permission architecture of the underlying mobile platform and do not use OAuth. Therefore, we exclude them from further analysis.

- **Defunct or Malfunctioning Channels:** Channels such as Home8 and iSmartAlarm that were either defunct or malfunctioning during the connection process fall in this category. We observe 29 such channels, which we exclude from further analysis.

Table II presents a breakdown of the connection status of our 297 channels. We focus the rest of our analysis on the 128 authorized channels, and their associated recipes.

### B. Initial Observations

We recorded authorization sessions (screenshot of OAuth permissions prompt and authorization URL) for 128 channels connected to our test IFTTT account. Based on this data, we make initial observations about: (1) Permission prompt descriptiveness and user control, and (2) OAuth token scopes.

- **OAuth permission prompts serve as potential control points for users to enforce fine-grained control over the privilege that third parties gain.** We analyzed whether the permission prompt screens in our dataset offer fine-grained control by manually interacting with the UI and checking for options to modify the requested privilege. Out of 128 channels we studied, the online services for 122 of those channels provide the user with an all-or-nothing choice (authorizing the channel or not), even though 106 of them have multiple triggers or actions. The online services of 2 channels (Evernote and LinkedIn) allow the user to select the time duration for the authorization, and only 4 online services (AT&T M2X, Facebook, Pushover, and SmartThings) provide fine-grained control over data or devices that were being shared with IFTTT.

- **OAuth permission prompts are an opportunity for online services to explain the privilege that third parties are requesting.** We analyzed whether online services in our dataset provide an adequate explanation of privilege by comparing the description of the channels triggers and actions with text in the prompt. Out of 128 channels, only 76 of the corresponding online services provide an adequate description of data that was being shared; 25 online services provide some description that is either vague or insufficient in explaining their function to the user; and 27 provide no information on data that was being shared with the user.

Based on these measurements, we conclude that even though online services provide some description of the privilege that third parties like IFTTT request, they do not offer the user control over those requests. This forces users to entrust IFTTT with highly-privileged access to their devices and data, thus increasing the risk they face if attackers compromise IFTTT.

Next, we computed the average and median number of triggers and actions for 297 channels. We find that channels have on average 3.5 triggers per channel (median = 2), and an average of 2 actions per channel (median = 1) with a long-tail distribution (See Appendix B for a graph). As an IFTTT recipe only uses a single trigger and a single action, most channels exhibit recipe-channel overprivilege. However, if users create recipes that involve all triggers and actions of all connected channels, then this type of overprivilege does not exist any more.

Finally, we determined the distribution of various OAuth protocol variants in use. Out the set of 128 connected and authorized channels, 113 online services that correspond to these channels use OAuth 2.0, making it the most popular variant (the remaining 8 use OAuth 1.0 and its variants, and we could not determine the protocol being used for 7 channels due to lack of information in the authorization sessions). Therefore, we drilled down and analyzed the OAuth 2.0 scopes being requested because they define the privilege an IFTTT channel requests from the online service (III).

Table III shows the breakdown of these scopes. Similar to what we observe based on OAuth permissions prompts, we see that 107 channels request a scope that is generic, null, or simply specified as “ifttt”—clearly coarse-grained privilege requests. Furthermore, due to IFTTT architecture, fault cannot clearly be placed on IFTTT or on the online services since a channel may be written by either IFTTT developers or the online service provider. If an online service provider only has coarse-grained tokens, then a channel only has the option to request overprivileged access, irrespective of whether IFTTT developers or the service provider creates the channel. We also observe that only 21 online services out of 128 offer fine-grained scoping. Table IV shows examples of fine-grained scopes for channels in our dataset.

A significant fraction of the channels we study use fairly
Table III: 83% of online services do not provide fine-grained scoping and only provide opaque scopes like generic, null, or ifttt. We show examples of fine-grained scopes in Table IV. Examples of generic scopes are “spark” or “app.”

| Channel               | Allows User Control | Scope                                      |
|-----------------------|---------------------|--------------------------------------------|
| AT&T M2X              | ✓                   | manage notifications, manage pages, public_profile, publish actions, user_about_me, user_activities, user_events, user_friends, user_location, user_photos, user_posts, user_status, user_website |
| Facebook              | ✓                   | read_camera, write_camera                  |
| Netatmo Welcome       | ✗                   | read_public, write_public, read_secret, write_secret, read_relationships, write_relationships |
| Pinterest             | ✗                   | https://www.googleapis.com/auth/youtube     |

Table IV: Examples of fine-grained scopes requested by channels. 21 channels in total use fine-grained scopes when requesting tokens. Only 4 online services that correspond to these channels allow the user to exert control over them.

C. Measuring Channel-Online-Service Overprivilege

The scope of the OAuth tokens IFTTT gains to operate a channel defines the privilege that channel has over the corresponding online service. As we discuss in §III, a channel implements various triggers and actions. Each of the triggers and actions will correspond to a set of one or more online service APIs. For example, the Particle channel from the DIY electronics category provides triggers to monitor device status and function results. It also provides actions to call functions and to publish events. Ideally, the channel would have privilege to only perform these triggers and actions. However, due to the opaque nature of the scopes, it is difficult to understand whether this is indeed the case.

Therefore, we measure the Channel-Online-Service overprivilege on IFTTT. A channel exhibits such overprivilege if it can access APIs that are not needed to implement its triggers and actions. Given the opaque nature of the scopes, it is not feasible to determine what APIs the channel can access on the online service by simply reading the documentation. Furthermore, many services do not document the scope-to-API mapping. IFTTT is also closed source, and most online services are closed source too, ruling out any source-code inspection to determine the access control policy for a given scope.

Our measurement strategy is to capture scoped tokens identical to what IFTTT uses for a channel and then use those tokens to exhaustively test the online service APIs to compute the set of APIs the tokens give access to. We encountered the following challenges while performing this measurement:

- IFTTT obtains the OAuth token for a channel using server-to-server communication. This precludes the possibility of intercepting the tokens that IFTTT itself uses. We verified that neither the IFTTT client side code nor the IFTTT mobile app is directly involved in the OAuth authorization workflow—all authorization occurs on IFTTT’s back-end cloud service.
- Online services do not document their APIs in consistent ways, making automated large scale testing difficult.
- The types of online service APIs are very diverse, making it challenging to manually create input arguments. Furthermore, online services generally do not provide any unit tests with appropriate testing data, making it difficult to distinguish input argument errors from permission errors.
- Many online services have proprietary APIs that are only exposed to IFTTT. There is no public information on these APIs precluding any kind of measurement.

We built a semi-automated measurement pipeline that addresses all challenges to an extent, except the last one because the online service did not provide any documentation.

Figure 5 shows our measurement tool’s architecture. It takes as input an API specification database. We create this database using two techniques: (1) Manual encoding of a REST API into our database format and (2) Automated screen-scraping of the online service’s API documentation if it is sufficiently regular HTML. The automated step helps us partly overcome the challenge of online services not documenting their APIs in consistent ways.

The token generation step reads in the API specification database and then creates a testing specification that includes two types of tokens: (1) A valid token for the online service and (2) An invalid token for the online service, mutated from the valid token. Then the tool uses PyRestTest [30], an automated REST API testing tool to execute the test specification. We use these two types of tokens to address the challenge of distinguishing input argument errors from permission errors. Since there is a large number of APIs and a large number of online services, it is not possible to scalably create valid input arguments for a given API. The only scalable and automated option is to create randomized inputs. However, this leads to API errors because these randomized arguments are often not what the API expects to function correctly. Therefore, we needed a reliable way to distinguish input validation errors from permission errors. Furthermore, since the OAuth standard does not mandate specific error codes for specific conditions, it is often an implementation-dependent choice on what HTTP error code to use. Therefore, our pipeline performs testing with a known invalid token and with a known valid token. Then we manually analyze the change in error code and error message payload to decide whether the given valid token has permission to access the API function in question or not.
Token generation also overcomes the challenge of server-to-server IFTTT authorization using four techniques:

- **Scope Mirroring**: A lot of channels use opaque scopes like “ifttt” (Table III). Our strategy to analyze opaque scopes is to create a mirror IFTTT-like application for a particular online service and then request the same opaque scope. This involves following the OAuth authorization workflow manually which yields an identically scoped token that IFTTT itself uses for that online service. In the case where the online services do not have opaque scopes, we observe that the scopes that IFTTT uses can be expressed using the publicly available scopes. Therefore, our strategy is to make our IFTTT mirror application request the same public scopes that IFTTT requests and to verify that the resulting OAuth permission screen looks identical to the one we captured as part of the authorization session in the data collection step (§III-A).

- **Downgrade with Open Redirect**: The OAuth 2.0 protocol supports two major authorization workflows: authorization code grant and implicit grant. The authorization code grant is the more secure option since it requires a client secret that is never revealed to client-side code in IFTTT’s case. However, we observe that many OAuth implementations also support the implicit grant flow—no client secret is required, and a third party can obtain a token simply with a redirect from the authorization server. Furthermore, the implicit grant is vulnerable to the open redirector attack [24], where an attacker can replace the redirect_uri component of the authorization URL with an attacker controlled domain. Therefore, our strategy is to attack our own test IFTTT accounts on the online service by pretending to be an IFTTT-like application and performing a downgrade attack with open redirectors. The result is that we obtain an identically scoped token to what IFTTT uses for that online service. In particular online service and then request the same opaque scopes, we observe that the scopes that IFTTT uses can be expressed using the publicly available scopes. Therefore, our strategy is to make our IFTTT mirror application request the same public scopes that IFTTT requests and to verify that the resulting OAuth permission screen looks identical to the one we captured as part of the authorization session in the data collection step (§III-A).

Notice the change in the redirect_uri parameter and the response_type parameter.

- **Downgrade only**: This strategy is similar to the above, except that the online service is vulnerable to a downgrade attack but not vulnerable to an open redirector attack. This prevents us from receiving the access token on an attacker-controlled domain. Instead, we used a man-in-the-browser attack to read the OAuth token.

Once our pipeline produces two API testing results—one with a valid token and one with an invalid token, we manually compare the outputs to produce a privilege mapping. This mapping encodes whether the valid token has access to a given API. The two API testing results make it trivial to observe the change in error code and error message to determine whether the API failed due to a permission error or due to a scoping error.

Once we have a privilege mapping, we manually map channel operations to online service APIs. This step involves examining the documentation of the online service APIs and the trigger/action documentation, followed by conservatively determining whether a particular API can be used to implement a trigger or action. Our goal here is to obtain a conservative lower-bound on channel-online-service overprivilege. At the end of this step, any API for which the token provides access, but is not needed to implement any trigger/action for the channel, is marked as an overprivileged API.

**D. Channel-Online-Service Overprivilege Results**

To compute overprivilege in depth, we applied our measurement pipeline on 24 channels out of a total of 69 channels that can be measured. Figure 6 shows a breakdown of our channel-online-service overprivilege results. Our measurement tool outputs a privilege mapping for 941 APIs across 24 channels. We then performed a manual overprivilege analysis and observed that 18 channels exhibit overprivilege. These overprivileged channels have access to an average of 26 API functions that they do not need to implement the associated trigger and action functionality. We also observed that 6 channels do not exhibit any overprivilege—they use all accessible APIs to implement triggers and actions.
The channels we study in-depth cover 80.4% (46,354/57,632) of all recipes involved in the set of 69 measurable channels. Our overprivilege results potentially impact 86.5% (2,389,181/2,760,341) of all users of the recipes associated with the channels that can be measured. Figure 7 shows the coverage we achieve in terms of the recipes associated with the channels we measure and in terms of the number of users of those recipes. We use number of recipes associated with a channel and number of users of those recipes as a metric that estimates channel adoption and popularity. We note that the coverage CDF only shows coverage for the top 8 channels sorted in terms of recipe counts and user shares. Our actual coverage is slightly higher than what the CDF shows since we also analyze cyber-physical channels. Out of the total of 24 channels, we studied all 16 cyber-physical channels that can be analyzed in-depth—cyber-physical channels have the potential to create a significant security risk since they are associated with physical devices.

Based on our in-depth analysis of channel-online-service overprivilege, we revisit our examples of potentially overprivileged channels here (initially discussed in §II-B) and confirm that the Particle and Google Drive channels have access to online service APIs that they do not need to implement in their sets of triggers and actions. Appendix A contains a complete breakdown of overprivilege by channel.

IV. LESSONS & IMPLICATIONS OF THE EMPIRICAL ANALYSIS

We highlight the lessons we extracted based on the results of our empirical analysis of IFTTT’s authorization model.

• The channel abstraction strikes a good balance in the usability-security trade-off, but results in highly-privileged tokens residing inside IFTTT’s infrastructure. Users sign in to online services only once per channel, and IFTTT obtains an OAuth token that is sufficiently privileged to execute all kinds of recipes it supports. If tokens were recipe-specific, then the user would have to sign in to the online services per recipe, thereby drastically increasing the number of prompts, leading to prompt fatigue.

• Highly-privileged tokens inside IFTTT’s infrastructure are a single point of failure, making it an attractive target for attackers. If IFTTT is compromised and becomes malicious, it can arbitrarily execute a wide variety of functions on the user’s online services, as our empirical analysis shows.

• Coarse-grained bearer tokens themselves are an attractive target for attackers and are susceptible to known OAuth attacks [14], [16]. We analyzed how many channels out of 297 are vulnerable to two types of OAuth attacks directed at the user. We found that 4 channels are vulnerable to the open redirector OAuth attack where a victim user can be tricked into logging into the authentic online service page but with an attacker-controlled redirect URI that would let the attacker obtain an OAuth bearer token. This attack is similar to that of Fernandes et al. [16]. We also found that 22 channels are vulnerable to downgrade-only attacks. Although this attack requires a stronger assumption of a man-in-the-browser, or HTTP-only communications (no HTTPS), it still does highlight the risk that users might face due to overprivileged channels on IFTTT.

Based on the above lessons, our goal is to provide trigger-action functionality to end-users without increasing the number of OAuth permission prompts, while preventing arbitrary misuse of OAuth tokens if IFTTT is compromised. We discuss our design that achieves this goal in the next section.

Threat Model. We assume that the trigger-action platform can be compromised. It can leak the OAuth bearer tokens and it can attempt to invoke actions arbitrarily. It can also try to manipulate the trigger data passing through its infrastructure. For example, if we have a recipe that saves an Instagram image to Dropbox, the untrusted trigger-action platform might instead...
save malware into the user's Dropbox account. A compromised trigger-action platform can leak trigger data that might be privacy sensitive. We do not prevent such leaks. Currently, the user has to trust the platform with access to data it needs to run recipes. We discuss potential ways to overcome this problem in \textsection VII. We assume that online services use HTTPS for their OAuth APIs and that they are not compromised (if an online service is compromised, then an attack is possible independently of IFTTT). We consider denial of service attacks to be outside the scope.

V. DECOUPLED-IFTTT DESIGN

Decoupled-IFTTT splits the logically monolithic IFTTT architecture into a cloud service (dIFTTT-Cloud) that users do not trust, and several clients (dIFTTT-Clients). The dIFTTT-Cloud provides computational infrastructure to execute recipes at large scale, like IFTTT's cloud. We assume that it can be compromised by attackers. We introduce extensions to the OAuth protocol to ensure that the cloud service only has the necessary amount of privilege to execute the set of recipes of a given user. Each user must install a dIFTTT-Client on a device such as a smartphone. Users connect channels to their accounts and setup trigger-action recipes with the help of the these clients. A user trusts a client to manage highly-privileged access to their online services.

We designed the OAuth protocol extensions for dIFTTT to be open allowing anyone to implement the client portion of the protocol. Furthermore, the clients are not implemented by the same entity implementing the untrusted cloud service. Instead, we envision a community of developers building client applications and hosting them at various market places, e.g., Android or Apple store. These app market models naturally result in a few well-built apps emerging, thus making it easy for users to install relatively good and secure implementations of the dIFTTT-Client. Furthermore, the open source community can independently vet open source clients.

As is the case with IFTTT, there are two phases a user must follow to create a recipe: Channel Connection, and Recipe Setup. We will discuss how these two phases work, with the help of an example recipe taken from IFTTT:

\texttt{IF new\_item added to ShoppingList THEN email new\_item to x@y.com}

**Channel Connection.** A user will connect channels using a client. To create the above recipe, the user will have to first connect the ShoppingList and Email channels (assuming they haven’t been connected before). This involves the usual step of the user logging in to the services corresponding to the channels with a username and password, and eventually accepting the OAuth scopes being requested. During this standard OAuth negotiation (we only use authorization code grant flow), the dIFTTT-Client requests an XToken (Transfer Token, see Figure 8). An XToken is coarse-grained and can only be used to obtain recipe-specific tokens without creating a permission prompt. As these tokens are highly-privileged (because they allow the bearer to obtain a recipe-specific token for any of the functions a particular online service provides),

we encrypt their storage when they are not in main memory. The dIFTTT-Client can also use a trusted-hardware-backed keystore when available on a client (VI). We introduce the notion of an XToken to maintain the usability experience of one-time authorizations of channels, and to gain the security of recipe-specific tokens.

**Recipe Setup.** Once the user has connected the trigger and action channels, the next step is to setup the trigger part of the recipe. This involves navigating a UI and eventually clicking on one of the trigger functions that the channel offers. In this case, OnNewItem is a function that fires whenever a new item is added to the user's shopping list. dIFTTT-Client will treat the physical act of the user clicking a specific trigger function in the UI as an implicit authorization for it to obtain a recipe-specific token that can only execute OnNewItem. It transmits the XToken it obtained earlier to the trigger online service including information about the specific function for which it wants a recipe-specific token. As a return value, the trigger service will also transmit its X509 certificate to the client, in addition to the recipe-specific token (Figure 8).

A recipe-specific token only allows the bearer to execute a single function with specific parameters on an online service. For example, assume that the ShoppingList service offers two functions that external parties may call: \texttt{test()}, and \texttt{OnNewItem(String URL)}. The XToken allows the bearer to obtain a recipe-specific token for any of these supported functions. In our example recipe, an external party only needs to call \texttt{OnNewItem} with a String value of “https://difttt-cloud.com/new\_item.” Therefore, the client can obtain a recipe-specific token scoped to only execute \texttt{OnNewItem} (‘https://difttt-cloud.com/new\_item’). That is, a scope in dIFTTT is equivalent to the name of a function in an online service.

Our design relies on two principles to overcome the challenge of an increased number of prompts while using such fine-grained tokens:

- The user authorizes the client to obtain an XToken when a channel is connected. This does not change the number of permission prompts for a user—it is the same as IFTTT. The XToken has the property of allowing the client to obtain a recipe-specific token without creating a permission prompt, as the user has already given the client that amount of privilege by authorizing it to obtain an XToken.
- The client only uses the XToken upon an explicit user interaction. This notion is directly inspired by User-Driven Access Control [29].

Setting up the action part of the recipe is similar to setting up the trigger part. The user will navigate a UI and implicitly authorize the client to obtain a recipe-specific token to invoke a particular action function. However, the token exchange process is slightly different. As Figure 8 shows, the dIFTTT-Client will transmit the action XToken, the trigger service’s X509 certificate, the name of the trigger function (OnNewItem), the action function name (send\_email), and any action function parameters to the action service. The action service will return a recipe-specific token and associate all of this information with that token internally, effectively tying the

\footnote{Out of 297 channels, only 2 used HTTP; all others used HTTPS.}
trusted client

trigger service

request trigger token

[trigger XToken]

[Trigger Token, Trigger Cert]

setup IFTTT Client

Scope-to-Function Map

channel

signup phase

connection phase

trigger setup

action setup

trigger token

[Action Xtoken, Action Scope, Action Parameters, Trigger Scope, Trigger Cert]

action token

[Action Xtoken]

OAuth Transaction

Scope=XToken

OAuth Transaction

Scope=XToken

trigger

XToken

action

XToken

channel

cloud

Fig. 8: dIFTTT authorization model has four phases: Channel signup phase, where the clients obtain scope-to-function maps for every online service; channel connection phase, where the clients gain XTokens to online services the user wishes to use; and trigger and action setup phases where these tokens are used to request recipe-specific tokens.

issued token to a particular triggering function and a particular action function.

At this point, the dIFTTT-Client has obtained two recipe-specific tokens needed to execute the recipe. It transmits these tokens along with a description of the recipe to dIFTTT-Cloud that uses the trigger token to set up a callback to itself whenever the trigger condition (i.e., new item added to shopping list) occurs.

Channel Signup. Currently, IFTTT knows which scopes to request for various trigger and action functions because channels store that scope-to-function mapping in IFTTT's infrastructure. However, in our case, this infrastructure is untrusted. dIFTTT-Cloud could manipulate scope-to-function mappings to trick the clients into requesting the wrong scopes. Our design solves this problem by requiring the online services to create a signed scope-to-function mapping and host those mappings at a well-known location. An online service signs its mapping using the private key corresponding to its X509 certificate. The clients retrieve these signed mappings during the channel signup phase (Figure 8).

Recipe Execution. At runtime, whenever a new item is added to the shopping list, the trigger service will generate an HTTP call to the IFTTT cloud and pass the trigger data (in our example recipe, this will be the item that was added to the shopping list). dIFTTT changes this process slightly, and instead requires the trigger service to generate a trigger blob (see Figure 9).

\[Time, TTL, Trigger Scope, Trigger Data, SIG\]

where \(SIG\) is a digital signature of a concatenation of the other data items. The public key of this signing private key was transmitted to the action service as part of the setup process. \(Time\) is the timestamp when the blob was created, and \(TTL\) specifies the period for which the blob is valid. Once the trigger service creates this blob, it will transmit it to the dIFTTT-Cloud. At that point, the dIFTTT-Cloud will lookup the appropriate recipe, and then invoke the action function using the recipe-specific token it obtained earlier.

Upon receiving the HTTP call from the dIFTTT-Cloud, the action service will first execute a lightweight verification process before invoking the target function. The verification steps are:

- Verify that the passed recipe-specific token exists.
- Verify the signature on the trigger blob using the X509 certificate of the triggering service.
  - Ensure that the time stamp value has increased.
  - Verify that the Time-To-Live (TTL) value inside the trigger blob is current.
  - Check that the trigger scope (function name) inside the blob matches what the action service was given during the setup phase.
- Verify that the HTTP function being called at runtime is the same as the function name given by the trusted client to the action service during the setup phase.
- Finally, verify that the function parameters match those that the trusted client gave the action service during the setup phase.

If all verification checks succeed, then the action service proceeds normally and executes the send_email function. We note that the recipe execution process does not depend on the dIFTTT-Client, as recipe-specific tokens are already
trigger blob. dIFTTT-Cloud transmits this blob and the recipe-tivation, the trigger service contacts dIFTTT-Cloud with a
trigger blob. The trigger blob contains information the action service needs to verify that the corresponding trigger occurred.

A. Security Properties of our Decoupled Design

The above design ensures that the dIFTTT-Cloud can only execute user recipes whenever a trigger occurs, even if it is
compromised. Here, we explain in more detail how the various components of our OAuth protocol additions and decoupled
design provide this guarantee.

Action Misuse Resistance. An untrusted or compromised
IFTTT cloud can invoke action functions at will, even in the
absence of any triggers. Furthermore, based on our empirical
study results, it could invoke a wide variety of functions
given the rampant overprivilege. dIFTTT prevents all of these
problems. First, although XTokens are coarse-grained, they are
never transmitted to the untrusted cloud service. Only recipe-
specific tokens that can execute a single function with specific
parameters are transmitted to the dIFTTT-Cloud. Furthermore,
the dIFTTT-Cloud can successfully execute an action function
only if it can prove that a trigger occurred within some
reasonable amount of time in the past. The signed trigger blob
provides this property.

Trigger Misuse Resistance. dIFTTT-Cloud could try to
misuse the trigger blob and attempt replay attacks. However,
the time stamp and time-to-live value ensures trigger blob
freshness. It could also try to use a trigger blob from another
trigger service or the trigger blob of a different trigger function
on the same service. However, while setting up the recipe, the
trusted dIFTTT-Client instructs the action service to associate
the name of the trigger scope (function name) with the action
token. Furthermore, the signed trigger blob contains this trigger
scope. Therefore, dIFTTT-Cloud can only use a given trigger
blob for a specific action function. In other words, the dIFTTT-
Cloud can only execute the user’s recipe.

Trigger Data Integrity. The untrusted dIFTTT-Cloud may
attempt to modify the data it receives from the triggering
service before delivering it to the action service. An example
of this would be a recipe that saves new images from an
Instagram channel to a Dropbox account. An attacker may
replace the image with malware before uploading the file to
Dropbox. dIFTTT protects against such an attack by requiring
the trigger service to sign the fields of the trigger blob with its
private key. When receiving the trigger blob, the action service
verifies the signature using the public key that was associated
with the action token during recipe setup.

Recipe Deletion. A user can delete recipes with the help of
dIFTTT-Client, that will issue a recipe deletion HTTP API
call to the online services involved in a specific recipe. The
online services will then invalidate the recipe-specific tokens.
A malicious dIFTTT-Cloud can retain the recipe description,
but it won’t be able to execute any trigger or action functions
because the online services will automatically refuse the HTTP
calls as the tokens no longer exist.

No Single Point of Failure. Although the XToken is coarse-
grounded, it is never transmitted to the untrusted cloud service.
Thus, the attacker has to target and compromise individual
devices to obtain the XToken. Therefore, these tokens are not
a single point of failure any more.

B. Usability Properties of our Decoupled Design

From an end-user perspective, dIFTTT retains the concept
of the one-time operation of users connecting channels to their
accounts. However, as users have to use a client app, it does
limit their mobility (see §VII for options to increase mobility).
dIFTTT does not add any additional OAuth prompts—it
leverages User-Driven Access Control to automatically obtain
the recipe-specific tokens.

As we discussed in §III-B, online services in general
do not provide with users fine-grained control over OAuth
permissions and do not provide good descriptions of permissions
being requested. However, dIFTTT enables fine-grained control and good descriptiveness. When a dIFTTT-
Client requests the user’s permission to obtain an XToken, it
can directly list the set of online service functions for which
the XToken can be used to gain access. Furthermore, the
online service can provide an option for users to select the
set of functions they wish to include in the XToken—dIFTTT-
Client will not be able to obtain recipe-specific tokens for
any functions not in that set.

From a developer perspective, dIFTTT requires changes.
Specifically, it requires adding code to implement XTokens,
the recipe-specific tokens, trigger blob generation, and the
verification procedure. This can be a barrier to immediate
adoption. However, as we discuss in §VI §VII we have
implemented dIFTTT in a way to ease the transition for online
service developers by only requiring them to add a single
annotation above HTTP methods in the server.

C. Expressivity of Decoupled-IFTTT

For services that do not natively support a callback inter-
fere for a specific triggering condition, the trigger-action
platform must poll the service and check the triggering condi-
tion itself. For example, a weather channel might only offer an
API that returns the current temperature. To support a trigger
that fires if the temperature goes above 80 degrees, IFTTT
would poll the weather service and compute the predicate
currTemp > 80. However, the dIFTTT-Cloud might simply
ignore the result of the comparison, and invoke the action
service repeatedly. The verification on the action end will
succeed since dIFTTT-Cloud will obtain a valid signed trigger
blob when it polls the trigger service.
dIFTTT handles such situations by allowing the client to associate a predicate with the action token. This predicate is expressed over fields of the trigger data part of the signed trigger blob. The dIFTTT-Client simply maps the condition the user sets up while creating the recipe to a predicate and then instructs the action service to associate the predicate with the resulting recipe-specific token. At runtime, the action service performs the additional step of verifying that the predicate is true.

Encoding such stateless predicates handles a significant fraction of the kinds of conditions that IFTTT supports. We studied the triggers, actions, and online service APIs for 24 channels that covered 80.4\% of recipes in our dataset and did not find any predicates that required storing state. We also studied the Zapier channel creation process but did not find any resources for channels to keep state [12]. Moreover, all Zapier predicates only involve simple boolean operators. Our prototype fully supports expressing such recipes.

VI. IMPLEMENTATION & EVALUATION

We implemented dIFTTT-Client on the Android platform. For additional client-side security, the dIFTTT-Client will use a hardware-backed keystore, when available, to generate a key that we use to encrypt XTokens before storing them on the filesystem. Such keystores have been present in iOS devices since 2013 [13] and have been supported in Android devices since version 6.0 [26].

We built a Python library that online service developers can use to add dIFTTT functionality. The library provides a simple annotation (i.e., Python decorator) that developers can place above sensitive HTTP API methods that require recipe-specific scoping. The annotation automatically invokes the verification procedure (see [7]). Using the Python library, we implemented the dIFTTT-Cloud, and two online services modeled after existing IFTTT channels: (1) an Amazon Alexa inspired ToDo list, (2) an email service.

A. Microbenchmarks

We first quantified micro-performance factors of dIFTTT. We created the following recipe: “IF new item == ‘buy soap’ is added to MyToDo List THEN send_email(new_item).” That is, if a new ToDo item with contents “buy soap” is added to the list, then send an email. This recipe is representative of the kinds of recipes that users can create on IFTTT. It contains all the elements of typical recipes: a condition on data coming from the trigger service, and transfer of trigger service data to an action service function. We deployed dIFTTT locally, created the example recipe, and then measured storage overhead, transmission overhead, and developer effort [8]. We found that using dIFTTT imposes negligible overhead: Each recipe requires an additional 3.5KB in terms of storage, and an additional 7.5KB of transmission per execution. Online service developers using our prototype library only need to add a single line of code per HTTP API function—this is the same as that required by the popular oauthlib library for Python. We elaborate on the results below.

For microbenchmarks, deployment location does not affect the quantities under study.

Fig. 10: Average total transmission size of IFTTT and dIFTTT for 1 – 10 parameters for 5 experiments. Although there is a linear increasing trend in both systems, the difference among the two remains negligible.

Storage Overhead. Using dIFTTT requires online services to store additional state: An online service needs to store an XToken for each trusted client that allows the client to create fine-grained tokens for individual recipes. The online service also needs to store dIFTTT fine-grained tokens for each recipe. These tokens include additional fields (e.g., time, TTL), so they impose storage overhead on the online service. We computed the required storage for the baseline IFTTT system, and for dIFTTT. Our results show that each dIFTTT recipe creates a 3.5KB overhead in addition to the 0.8KB required to store the XToken, compared to the 0.8KB storage cost for the baseline IFTTT system. This extra token storage cost is negligible given the low price of storage and quantity of other user data that these systems collect.

Transmission Overhead. Executing a recipe on dIFTTT requires transmitting more data over the network. This overhead is the result of additional data in the trigger blob (Figure 9) including time, TTL, and sign. To evaluate the transmission overhead, we computed the transmission size of recipe execution in the baseline case and compared it to the same quantity in the dIFTTT case. We varied the number of function parameters passed (1 – 10) and present the average result of five experiments. The number of function parameters matters because the recipe-specific token information encodes data about the specific function being executed. We used Wireshark [11] to measure the flow sizes associated with ports assigned to online services and the dIFTTT-Cloud. Figure [10] presents this overhead for different number of function parameters for the two systems. In our experiments, dIFTTT created 6 – 11% overhead. Even when using 10 parameters the transmission overhead does not exceed 7.5KB.

Developer Effort. We developed dIFTTT as a library for trigger and action services to make it easy for online service developers to transition to the dIFTTT model. Developers must only add a single additional line of code per function to protect it with dIFTTT verifications. When compared to existing OAuth libraries, such as the popular oauthlib [8], this
is the same amount of effort—developers using oauthlib must also place a single annotation above HTTP API methods to create scopes.

B. Macrobenchmarks

We measured end-to-end latency and throughput of recipe execution. We hosted the dIFTTT-Cloud and two online services on separate Amazon t2.micro EC2 instances. Each instance was configured with one 64-bit Intel Xeon Family vCPU@2.5 GHz, 1 GB memory, 8 GB SSD storage, Ubuntu 14.04 with Apache2, and MySQL Server 5.5. Our results show a modest 15 ms latency increase, and 2.5% throughput drop in the online service when compared to the baseline (online service with no dIFTTT protections). This does not represent an inhibiting overhead for an online service especially when considering the effect of network latency and the lack of real-time requirements in these systems. We used the same ToDo list recipe for our tests.

End-to-End Latency. We measured the time between the trigger service being activated due to an item being added to our ToDo list example recipe, and the time the action service issues a send_email call. This time includes network latency, the time to generate a signed trigger blob, and the time to verify the trigger blob and the action token, in the case of dIFTTT. Our baseline case is the IFTTT system, and it only includes network latency, and time to execute the trigger and action functions without any dIFTTT verification. We varied the number of function parameters on the action service between 1 and 10. Figure 11 presents the results of these experiments. Our results show that excluding the network latency, the maximum verification overhead is less than 15 ms. For typical recipes, that send emails, SMSs, or invoke actions on physical devices over a network, we consider this additional latency to be acceptable.

Throughput. We measure throughput as the number of recipes executed per second, under a load of 2000 concurrent HTTP requests. We computed this concurrency level by examining the number of times the most popular IFTTT channel was used in recipes (IF Notification channel was used in 1,514, 188 recipes in our dataset). As per IFTTT’s documentation, this channel will contact an online service once every 15 minutes [6].

TABLE V: dIFTTT reduces throughput by 2.5% when compared to IFTTT. We used ApacheBench to send 10, 000 trigger activations with upto 2000 concurrent activations at a time. meaning that an online service would receive approximately 1, 682 requests/second. Therefore, we chose 2000 as an upper-bound for the number of concurrent requests a service would have to process. We used ApacheBench [2] to conduct throughput testing of dIFTTT and IFTTT by sending 10, 000 trigger activations with upto 2000 concurrent activations at a time. Table V presents our results, averaged over three separate runs. We find that dIFTTT decreases throughput by only 2.5%.

VII. DISCUSSION

Transitions to dIFTTT. Our design has the limitation of requiring changes in online services to support the recipe-specific tokens and the cryptographic extensions to the OAuth 2.0 protocol. This can be a barrier to immediate adoption. We ease this transition by modeling our implementation after the popular oauthlib [3] where developers only have to add a single-line annotation above HTTP methods in the server that need to be protected by recipe-specific tokens. A short-term option is to also construct a trusted proxy or shim around online services that adds dIFTTT support. In this case, users would login to the proxy instead of the online service, and only the proxy is dIFTTT-aware. Once online services have added dIFTTT support, the trusted proxy can be removed.

dIFTTT-Client use. In IFTTT, users can login to the IFTTT website and create recipes from any client device. However, dIFTTT requires users to create recipes via a client device they trust (e.g., their smartphone), which stores XTokens in a private file system. Although our current client prototype does not support transferring client state from one device to another, building such functionality is fairly straightforward. One possible solution is to provide an export function to save the current client state to a disk image, and then provide an import function to load that client state into another device. If a client device is lost, then user recipes continue to execute normally. However, the user will have to download the client again on another device, and go through the channel connection phase to re-establish the XTokens to create future recipes.

Other potential solutions to reduce the negative impact of overprivilege. One option is for online services to issue OAuth tokens that must be refreshed frequently. If the trigger-action platform is compromised, the online services can simply stop processing refresh requests from IFTTT. This technique reduces the useful attack window to the refresh interval plus the time it takes for the knowledge that the platform was compromised to propagate to the online services. This solution requires detecting a compromise in a timely fashion. Furthermore, such a design does not reduce the privilege of the trigger-action platform—it still remains an attractive target.

Another solution is to use OAuth 1.0 tokens because these are not immediately useful to attackers if they are stolen in isolation. It requires stealing the shared signing secret as well.
However, if the trigger-action platform is compromised, then the attacker gains access to the signing key as well.

**Client-Device Loss.** If a client device is lost, existing procedures to erase device data take care of removing OAuth tokens. Also, an “erasure-app” can be built to automatically contact online services and invalidate tokens with cooperation from our modified OAuth helper library. We leave implementing this to future work.

**Data confidentiality.** Our design currently reduces the privilege of the dIFTTT-Cloud—it only gains access to APIs and hence data it needs to run the user’s recipes. This is an improvement over the current state-of-the-art where we have shown through our empirical analysis that an attacker can gain wide access to data and devices. However, even with our improvements, an attacker can still gain access to sensitive information simply by passively recording recipe execution. A potential way to provide data confidentiality in this case is to encrypt data passing through the dIFTTT-Cloud. However, this can result in a loss of expressivity. Currently, IFTTT can evaluate predicates on trigger data (see our weather data example in Figure 1). Although the action service can solely evaluate these predicates, it does increase computational burden, thus defeating the purpose of a system like IFTTT. As our analysis shows, the predicates are stateless and involve simple comparison operators. Therefore, a potential solution is to leverage advancements in use-case-specific homomorphic encryption for secure integer comparison, rule matching, etc., to allow the least-privilege dIFTTT-Cloud to evaluate predicates on encrypted data [27], [34]. We leave this to future work.

**VIII. RELATED WORK**

**Trigger-Action Platform Studies.** A few studies have investigated IFTTT in recent years, although in different contexts. Ur et al. [36] crawled the site in 2015, collecting 224,590 IFTTT programs shared by over 100,000 different users. Their study shows many interesting statistics including the number of different trigger and action channels used by IFTTT users. In contrast, we conduct an empirical overprivilege analysis of how channels interact with the corresponding online services.

Poirot is a security analysis tool that finds vulnerabilities in systems that occur due to discrepancies between a designer’s view of a system and that of an attacker [25]. The authors apply Poirot to IFTTT as a case study and find a previously unknown login CSRF based attack where data from one user account can be written to another unrelated attacker account. In contrast, we assume that the IFTTT platform can be compromised, and introduce a decoupled design where the cloud component executes recipes at scale and is untrusted. dIFTTT ensures that if the cloud component is compromised, the attacker cannot arbitrarily invoke actions. Instead, it can only invoke actions if it can prove trigger occurrence.

TrigGen is a tool that aims to avoid errors caused by users incorrectly creating rules that have insufficient triggering conditions [28]. Our work is not focused on recipe correctness. We study the security of the way that IFTTT interacts with online services.

**OAuth Security Analyses.** Since the Open standard for Authorization (OAuth) debuted in 2007 [23], a number of studies discovered flaws in the protocol and the way the protocol was implemented in web sites [7], [17], [19], [20], [31], [32], [35], [39], [41]. Nonetheless, the OAuth protocol is still popular and it is now commonly used in mobile applications as well. Since the protocol was initially designed for web sites, some of the important details of the protocol was up to developers’ interpretation when adapting OAuth to a mobile application.

Recent work scrutinized implementations of OAuth in many Android mobile applications [14], [33], [38], showing that the majority of implementations were vulnerable [14], [38]. In the context of analyzing the security of the Smart-Things smart home app platform, Fernandes et al. [16] showed that a third-party Android application embedded a client ID and the secret needed to authenticate the relying party in the application binary, allowing an impersonation attack and injecting a backdoor pin code to a doorlock as a result.

Our work is an addition to this growing list of work discovering vulnerabilities associated with implementing the OAuth protocol. However, our focus is to understand over-privilege granted to IFTTT independently of an online service implementing the protocol securely, and then design defenses. The OAuth related vulnerability that we discovered for several online services simply makes the attack easier and more widely applicable. Beside vulnerabilities in implementation, other attacks on trigger-action platforms may also expose user data to attackers. Massive data leaks are happening with increasing commonality. Target [9], Ashley Madison [10], and US voters database [1] are some of the most recent examples of such high profile leaks. Our work introduces the first decoupled trigger-action platform design with the security property of only allowing the attacker who compromises the platform to execute specific user recipes.

Fett et al. conducted a formal security analysis of the OAuth 2.0 standard, and in the process discovered new vulnerabilities [18]. They also propose fixes and then prove the security of the protocol in an expressive web model. These contributions are orthogonal to ours and our work will benefit from their fixes to the OAuth protocol.

**Cloud Platform Compromise.** Beside vulnerabilities in OAuth implementation, other attacks on trigger-action platforms may also expose user data to attackers. Massive data leaks are commonplace. Target [9], Ashley Madison [10], and US voters database [1] are some of the most recent examples of such high profile leaks. Our work introduces the first decentralized trigger-action platform design with the security property of only allowing the attacker who compromises the platform to execute specific user rules.

**IX. CONCLUSIONS**

Trigger-Action platforms enable users to stitch together various online services that represent data and physical devices to achieve useful automation. These platforms work by gaining privilege to access user data and devices in the form of OAuth tokens. These systems pose a long-term security risk—if they are ever compromised, attackers can use these tokens to arbitrarily manipulate data and devices. In this work, we performed the first measurement study aimed at quantifying the risk users face in the event of a compromise. We studied the authorization model of If-This-Then-That (IFTTT), a platform with wide
support for user data and devices with an active and large user community. Using semi-automated measurement tools that we built, we analyzed 24 channels, including 16 cyber-physical channels, and achieved a coverage of 80.4% of all recipes associated with the set of 69 measurable channels. We found that 18/24 channels have access to online service APIs that they do not need to implement their triggers and actions. To demonstrate the abilities of an attacker, we used overprivileged tokens to reprogram a Particle chip’s firmware and delete a user’s Google Drive files. More generally, we conclude that attackers can misuse tokens to arbitrarily manipulate devices and data in current trigger-action platforms.

Motivated by these findings, we designed, built and evaluated dIFTTT, the first decoupled trigger-action platform that provides trigger-action functionality without the corresponding long-term security risks. dIFTTT splits the logically monolithic IFTTT architecture into an untrusted cloud service and a set of clients for users. We introduced the concept of recipe-specific tokens that, upon verification, guarantee that the recipe was executed correctly on valid trigger inputs. Recipe-specific tokens guarantee that even in the event of a total compromise of the cloud service, it cannot cause unauthorized actions to be executed on an action channel. We also introduced the notion of the Transfer Token (XToken), and apply it to achieve the security of recipe-specific tokens without increasing the number of authorization prompts for users, when compared to IFTTT. We built a Python library that online service developers can use to add dIFTTT support with a single-line annotation. We conducted a range of micro- and macro-benchmarks to establish that dIFTTT poses modest overhead: an additional 15ms latency in executing a recipe end-to-end, and a 2.5% throughput drop while servicing 2000 concurrent trigger activations.

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This can cause data loss if the corresponding token is stolen. We observe that the Google Drive channel requests multiple scopes. However, the OAuth prompt only provides the user with a binary choice of either approving or denying the request.

We also study the following channels’ overprivilege results in detail, in addition to the above:

**Facebook.** This channel can post status messages and upload photos. However, our API testing reveals that the channel has overprivileged access to the Facebook API that allows it to delete likes on various types of objects and also initiate refunds. This can lead to potential financial issues. This channel requests relatively fine-grained scopes, and the corresponding OAuth permissions prompt allows users to modify the requested permissions.

**Twitter.** This channel can post tweets on behalf of the user, can send direct messages, and update the biography page. However, our API testing reveals that the channel has overprivileged access to the Twitter API that allows it to delete tweets, retweet other tweets, delete direct messages, follow friends, delete friends, and even update the profile banner. This can cause data loss and even profile defacement if the corresponding token is stolen. We also observe that Twitter’s REST API is based on OAuth 1.0 and therefore there is no scope argument to the authorization URL. The permissions are set up in the developer app console. Furthermore, the Twitter OAuth prompt only provides a binary choice to the user while requesting authorization—either approve all requested permissions, or deny the request.

**Dropbox.** This channel provides actions to add new files to a user’s account or to append to existing files. However, our API testing reveals that the channel has overprivileged access to the Dropbox API that allows it to delete files, change file sharing settings, and even create file sharing links. This can cause data loss and even profile defacement if the corresponding token is stolen. We also observe that the Dropbox channel does not use a scope argument in the OAuth authorization URL. The permissions are set in the developer app console. Furthermore, the Dropbox OAuth prompt only provides the user with a binary choice—either approve all requested permissions, or deny the request with no way to customize the granted permissions.

**MyFox Home Control.** This channel can arm or disarm the MyFox security system. However, our API testing reveals that the channel has overprivileged access to the MyFox Home Control API that allows it to stop live video recording, turn on/off electric devices, and change the state of the heaters. This can result in security breaches, overheating and large utility bills if the corresponding token is stolen. We also observe that MyFox Home Control does not provide any kind of scoped access. This forces the channel to request complete access to the API. Furthermore, the MyFox Home Control OAuth prompt only provides a binary choice during authorization—either approve all requested permissions, or deny the request.

**Ubi.** This smart home channel can trigger whenever there is a spoken command and it can speak announcements. However, our API testing reveals that the channel has overprivileged access to the Ubi API that allows it to also send speech commands, get the geo-location of the device, and get a list of all authenticated Ubis for a user. These overprivileged APIs can enable an attacker to send commands to the Ubi device.
| Channel               | Example Overprivileged APIs                                                                 | Description                                                                 |
|----------------------|---------------------------------------------------------------------------------------------|------------------------------------------------------------------------------|
| Facebook             | ![Example](https://graph.facebook.com/v2.7/from.id_status-id)                               | Updates status that was posted by the app itself                              |
|                      | ![Example](https://graph.facebook.com/v2.7/object-id/likes)                                 | Deletes likes                                                                |
|                      | ![Example](https://graph.facebook.com/v2.7/payment-id/refunds WITH BODY currency=USD&amount=value) | Initiates a refund                                                           |
| Twitter              | ![Example](https://api.twitter.com/1.1/statuses/destroy/240854986359455234.json)          | Deletes a status message                                                     |
|                      | ![Example](https://api.twitter.com/1.1/statuses/retweet/241259202004267009.json)          | Re-tweets a message                                                         |
|                      | ![Example](https://api.twitter.com/1.1/account/update_profilebanner.json?width=1500&height=500&offset_top=0&offset_left=0&banner=FILE_DATA) | Updates profile banner                                                       |
| Dropbox              | ![Example](https://api.dropboxapi.com/2/files/delete)                                       | Deletes a file                                                               |
|                      | ![Example](https://api.dropboxapi.com/2/sharing/add_file_member)                           | Shares a file with a member                                                  |
|                      | ![Example](https://api.dropboxapi.com/2/sharing/create_shared_link)                        | Creates a file sharing link                                                  |
| Google Drive         | ![Example](https://www.googleapis.com/drive/v3/files/file-id)                               | Deletes a file                                                               |
|                      | ![Example](https://www.googleapis.com/drive/v3/files/file-id/permissions)                  | Creates a permission for a file                                              |
|                      | ![Example](https://www.googleapis.com/drive/v3/files/file-id/revisions/rev-id)             | Permanently deletes a revision of a file                                     |
| Particle             | ![Example](https://api.particle.io/v1/devices/device-id)                                   | Flushes a device with a pre-compiled binary                                  |
|                      | ![Example](https://api.particle.io/v1/devices/device-id) WITH BODY name=new_name          | Unclaims a device                                                           |
|                      | ![Example](https://api.particle.io/v1/devices/device-id) WITH BODY name=new_name          | Renames a device                                                            |
| MyFox Home Control   | ![Example](https://api.myfox.me:443/v3/site/site-id/device/cam-id/camera/recording/stop)  | Stops camera recording                                                       |
|                      | ![Example](https://api.myfox.me:443/v3/site/site-id/device/dev-id/heater/on)              | Sets heater to ‘on’ mode                                                    |
|                      | ![Example](https://api.myfox.me:443/v3/site/site-id/device/dev-id/socket/on or off)      | Turns a device on or off                                                     |
| Ubi                  | ![Example](https://portal.theubi.com/v2/ubi/list)                                          | Lists all connected Ubi devices                                             |
|                      | ![Example](https://portal.theubi.com/v2/ubi/ubi-id/speech?phrase=hello)                   | Sends a speech command                                                       |
|                      | ![Example](https://portal.theubi.com/v2/ubi/ubi-id/location)                              | Returns geo-location of the Ubi                                             |
| Google Glass         | ![Example](https://www.googleapis.com/mirror/v1/locations)                                | Gets a location that is associated with a timeline item                      |
|                      | ![Example](https://www.googleapis.com/mirror/v1/timeline/id)                               | Deletes a timeline item                                                      |
|                      | ![Example](https://www.googleapis.com/mirror/v1/contacts)                                 | Gets all contacts                                                            |

TABLE VI: Examples of overprivileged APIs channels can access that are not used in any of their triggers or actions.

causing security and safety issues. We find that this online service provides the opaque scope=ifttt and provides an all-or-nothing choice to the user when a channel requests privilege. Furthermore, the Ubi online service is vulnerable to the downgrade-with-open-redirect attack.

**Google Glass.** This popular wearable-category channel can send a notification to the Glass device. However, our API testing reveals that the channel has overprivileged access to the Glass API that allows it to get all user contacts, delete timeline items, and get locations associated with timeline items. This can result in data loss or data leakage. We find that this online service provides fine-grained scopes, but surfaces an all-or-nothing OAuth prompt to the user.

**APPENDIX B: DISTRIBUTION OF TRIGGERS AND ACTIONS IN IFTTT CHANNELS**

Figure 12 shows a distribution of the number of triggers and actions per channel in IFTTT.
| Channel                  | Triggers | Actions | Total APIs | Overpriv. APIs | Not overpriv. APIs | Unknown Access | Measurement Strategy |
|--------------------------|----------|---------|------------|----------------|-------------------|----------------|---------------------|
| **Non-Cyber-Physical Channels**                                    |
| Facebook                | 10       | 3       | 217        | 172            | 18                | 27             | scope-mirroring     |
| Twitter                 | 10       | 6       | 92         | 72             | 16                | 4              | scope-mirroring     |
| Dropbox                 | 2        | 3       | 81         | 61             | 16                | 4              | scope-mirroring     |
| Gmail                   | 6        | 1       | 56         | 37             | 7                 | 12             | scope-mirroring     |
| Google Calendar         | 3        | 1       | 37         | 33             | 4                 | 0              | scope-mirroring     |
| YouTube                 | 3        | 0       | 50         | 31             | 5                 | 14             | scope-mirroring     |
| Google Drive            | 0        | 4       | 34         | 31             | 3                 | 0              | scope-mirroring     |
| Pocket                  | 4        | 1       | 13         | 9              | 4                 | 0              | scope-mirroring     |
| MyFoxHomeControl       | 5        | 4       | 72         | 61             | 9                 | 2              | scope-mirroring     |
| ATT M2X                 | 3        | 3       | 93         | 34             | 12                | 47             | scope-mirroring     |
| Google Glass            | 0        | 1       | 22         | 19             | 2                 | 1              | downgrade           |
| Camio                   | 3        | 4       | 27         | 17             | 3                 | 7              | actual-ifttt-token  |
| Particle                | 4        | 2       | 34         | 15             | 6                 | 13             | actual-ifttt-token  |
| Recon                   | 0        | 1       | 21         | 15             | 0                 | 6              | scope-mirroring     |
| UPByJawbone             | 13       | 4       | 46         | 11             | 12                | 23             | scope-mirroring     |
| Ubi                     | 1        | 1       | 6          | 3              | 3                 | 0              | downgrade-open-redirect |
| Pavlok                  | 0        | 4       | 20         | 2              | 9                 | 9              | downgrade           |
| Netatmo Welcome         | 9        | 0       | 8          | 2              | 3                 | 3              | downgrade-open-redirect |
| Netatmo Thermostat      | 6        | 8       | 6          | 0              | 5                 | 1              | scope-mirroring     |
| Netatmo Weather Station | 17       | 0       | 2          | 0              | 1                 | 1              | scope-mirroring     |
| Nest Thermostat         | 4        | 3       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| Nest Protect            | 5        | 0       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| Nest Cam                | 3        | 0       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| LaMetric                | 1        | 1       | 1          | 0              | 1                 | 0              | downgrade-open-redirect |

**Cyber-Physical Channels**

| Channel                  | Triggers | Actions | Total APIs | Overpriv. APIs | Not overpriv. APIs | Unknown Access | Measurement Strategy |
|--------------------------|----------|---------|------------|----------------|-------------------|----------------|---------------------|
| MyFoxHomeControl        | 5        | 4       | 72         | 61             | 9                 | 2              | scope-mirroring     |
| ATT M2X                 | 3        | 3       | 93         | 34             | 12                | 47             | scope-mirroring     |
| Google Glass            | 0        | 1       | 22         | 19             | 2                 | 1              | downgrade           |
| Camio                   | 3        | 4       | 27         | 17             | 3                 | 7              | actual-ifttt-token  |
| Particle                | 4        | 2       | 34         | 15             | 6                 | 13             | actual-ifttt-token  |
| Recon                   | 0        | 1       | 21         | 15             | 0                 | 6              | scope-mirroring     |
| UPByJawbone             | 13       | 4       | 46         | 11             | 12                | 23             | scope-mirroring     |
| Ubi                     | 1        | 1       | 6          | 3              | 3                 | 0              | downgrade-open-redirect |
| Pavlok                  | 0        | 4       | 20         | 2              | 9                 | 9              | downgrade           |
| Netatmo Welcome         | 9        | 0       | 8          | 2              | 3                 | 3              | downgrade-open-redirect |
| Netatmo Thermostat      | 6        | 8       | 6          | 0              | 5                 | 1              | scope-mirroring     |
| Netatmo Weather Station | 17       | 0       | 2          | 0              | 1                 | 1              | scope-mirroring     |
| Nest Thermostat         | 4        | 3       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| Nest Protect            | 5        | 0       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| Nest Cam                | 3        | 0       | 1          | 0              | 1                 | 0              | scope-mirroring     |
| LaMetric                | 1        | 1       | 1          | 0              | 1                 | 0              | downgrade-open-redirect |

**TABLE VII:** Channel-Online-Service overprivilege results detail. Only 6 of the 24 did not have overprivileged access to online service APIs. *actual-ifttt-token* means that we were able to obtain the token that IFTTT itself was using through an administrative API.