AUTHSCOPE: Towards Automatic Discovery of Vulnerable Authorizations in Online Services

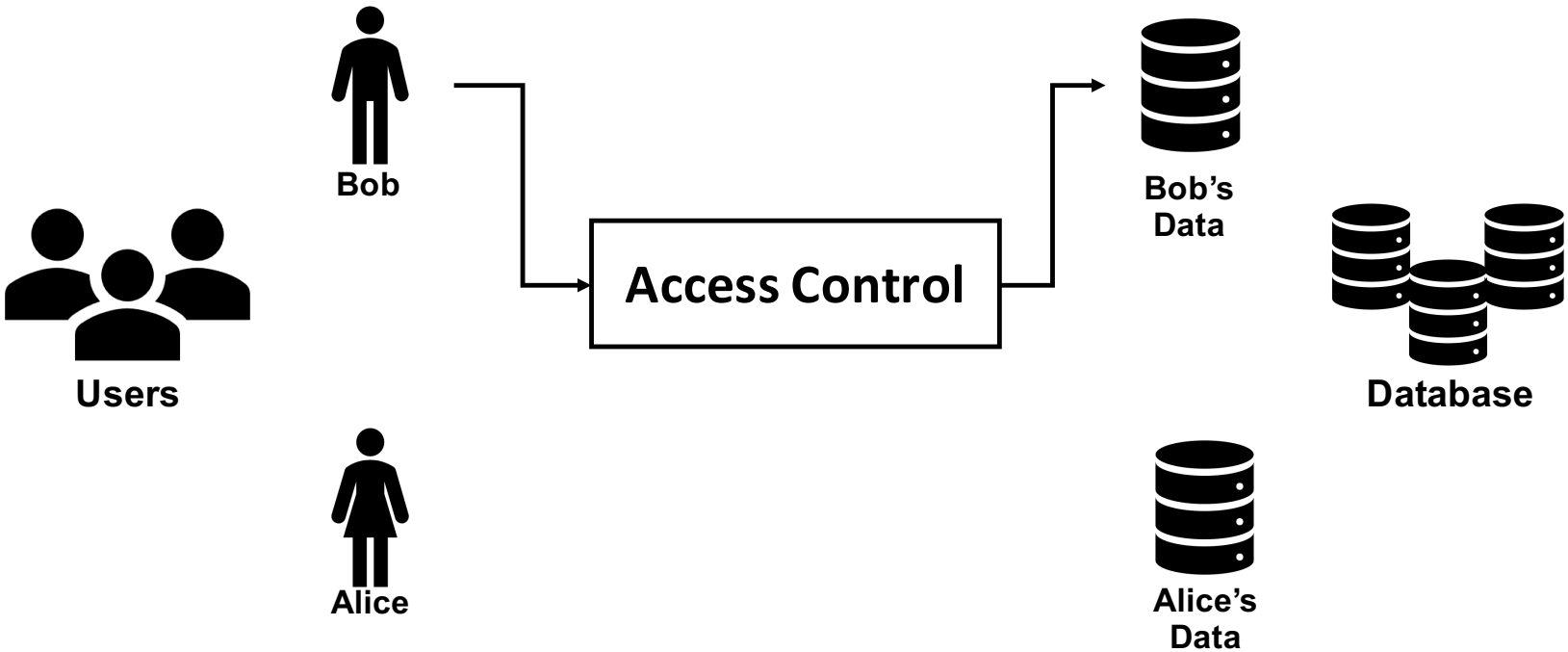
Chaoshun Zuo, **Qingchuan Zhao**, Zhiqiang Lin

University of Texas at Dallas

Nov 1^{st}, 2017

Access Control In a Multi-User System

Access Control In a Multi-User System



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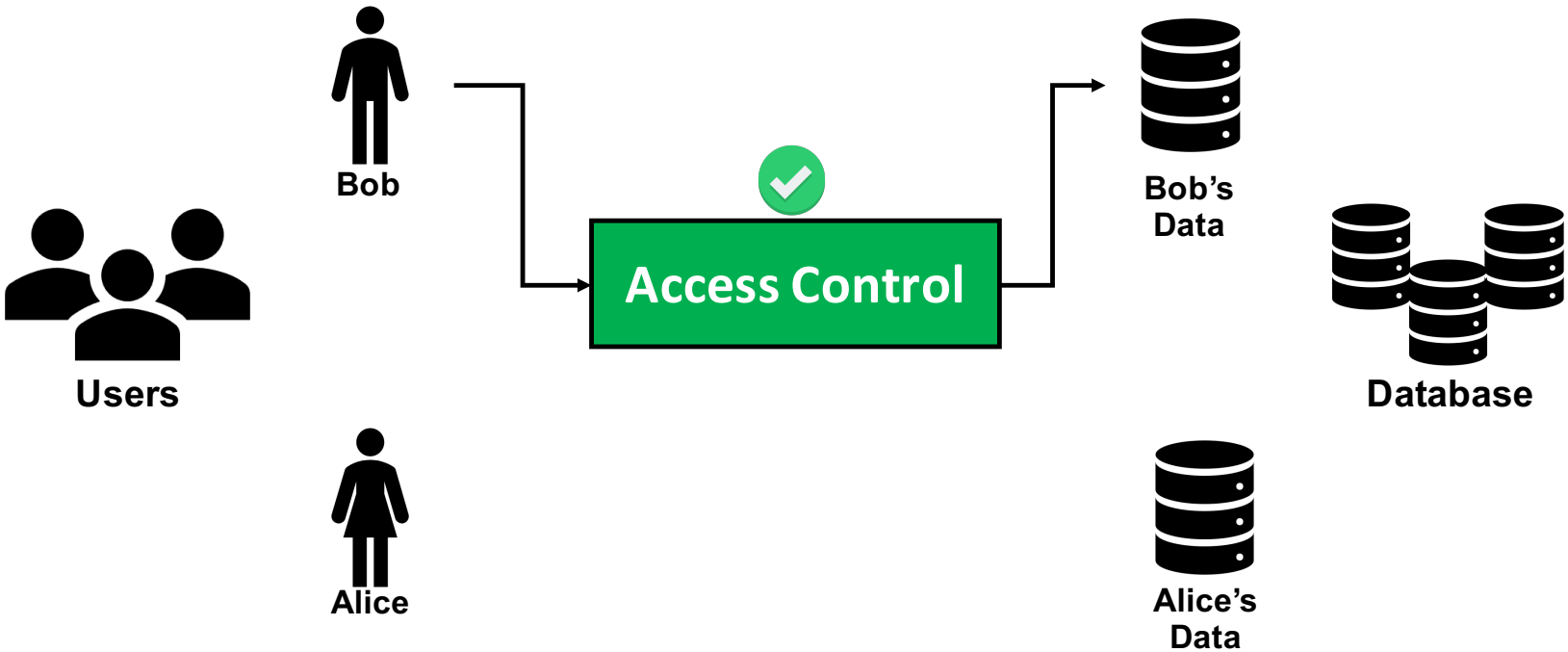

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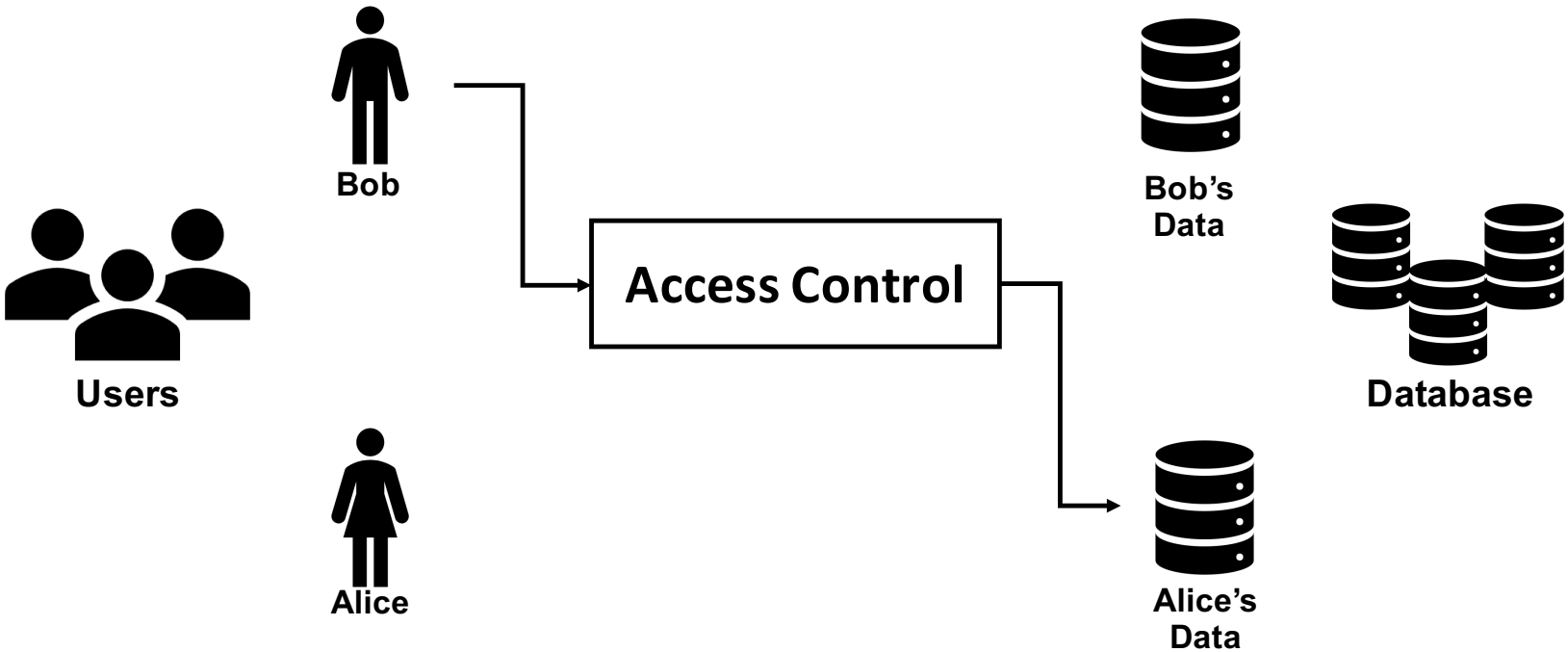

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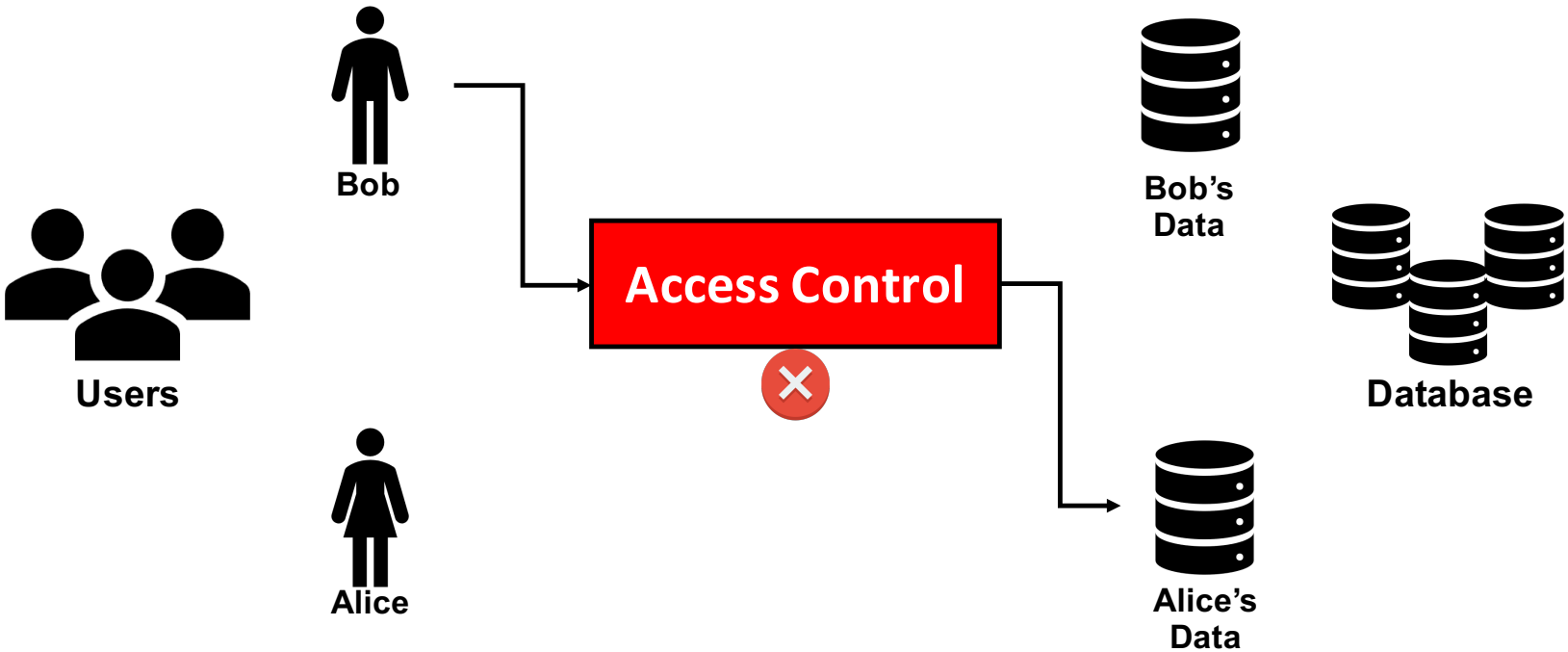

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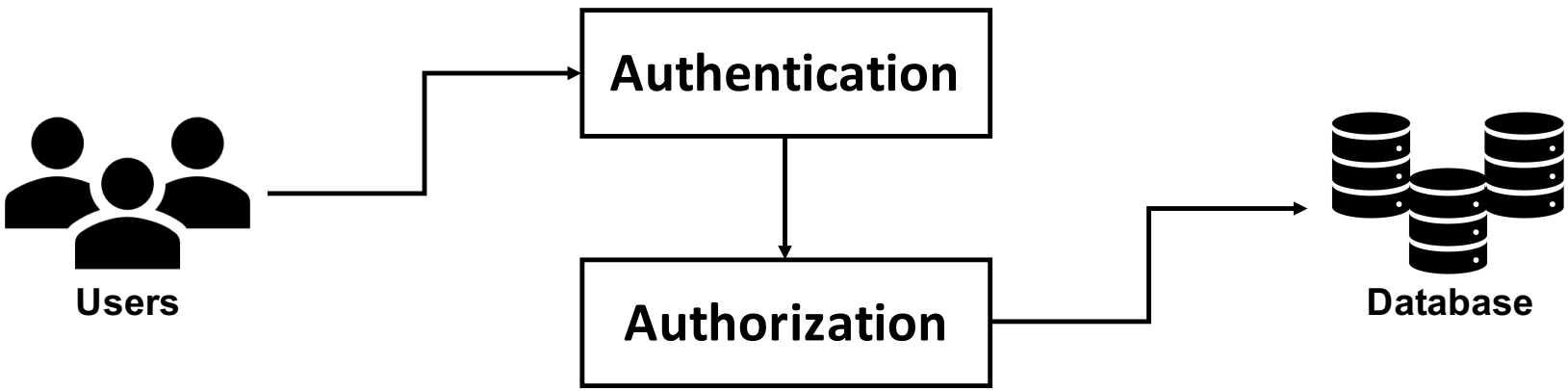

Challenges in Online Service

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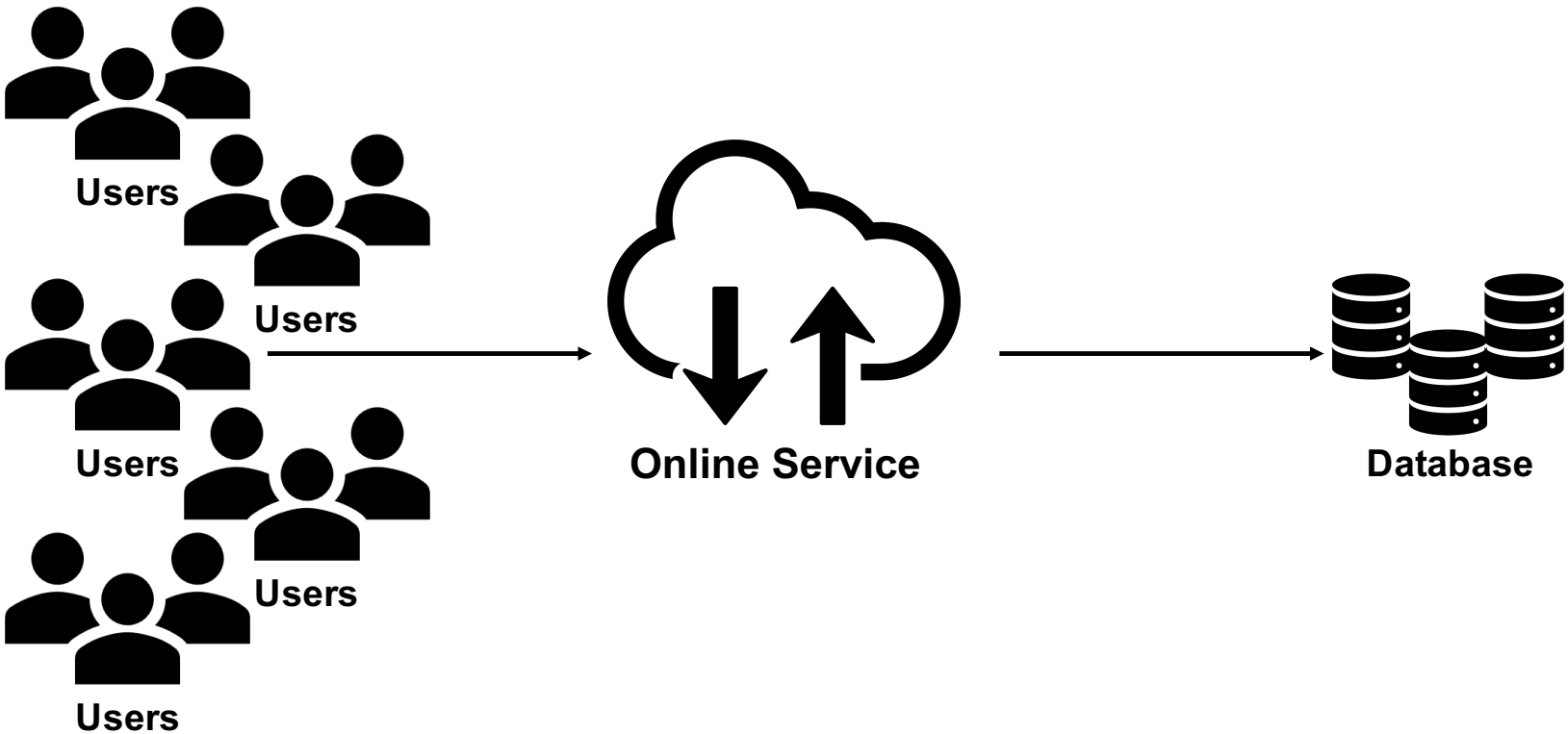

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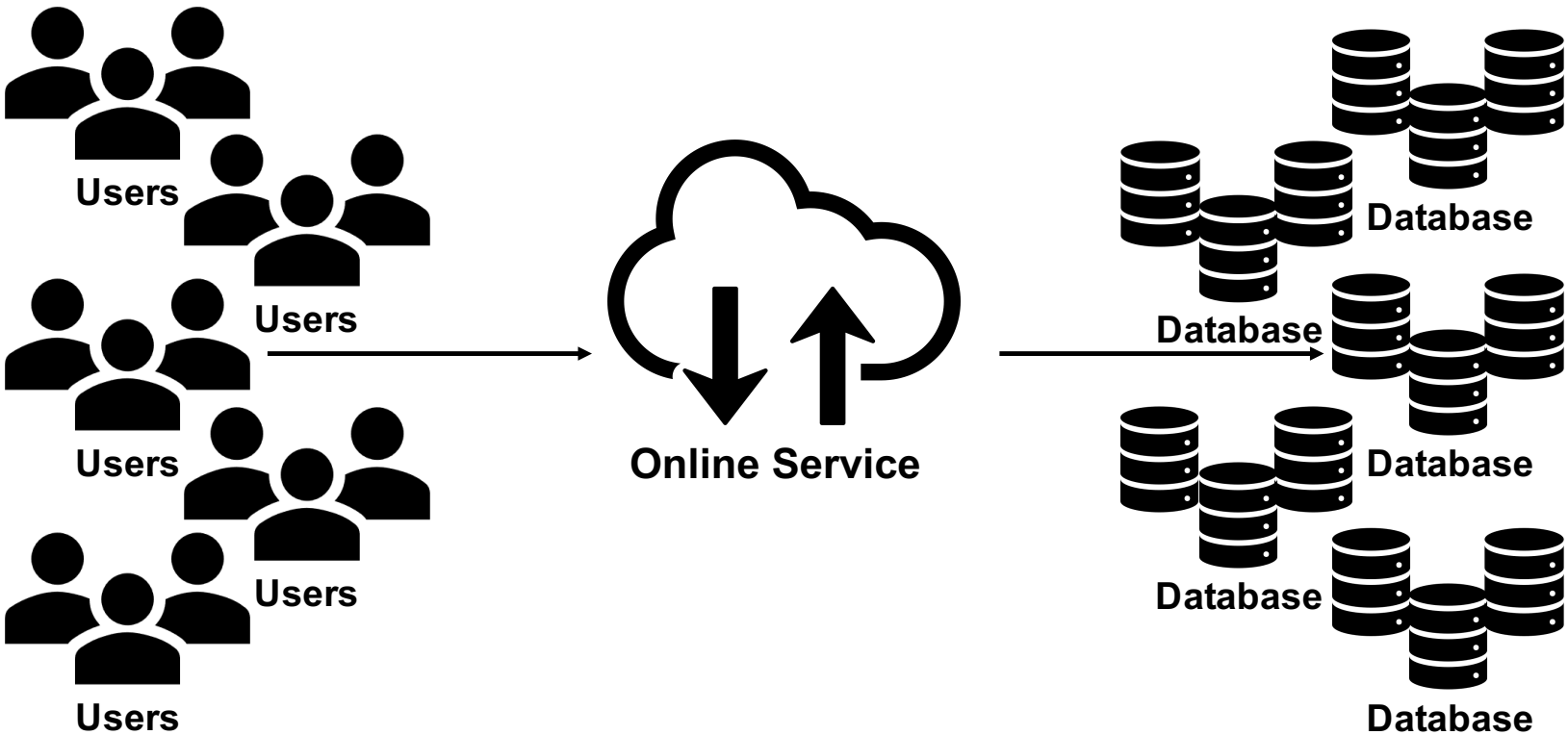

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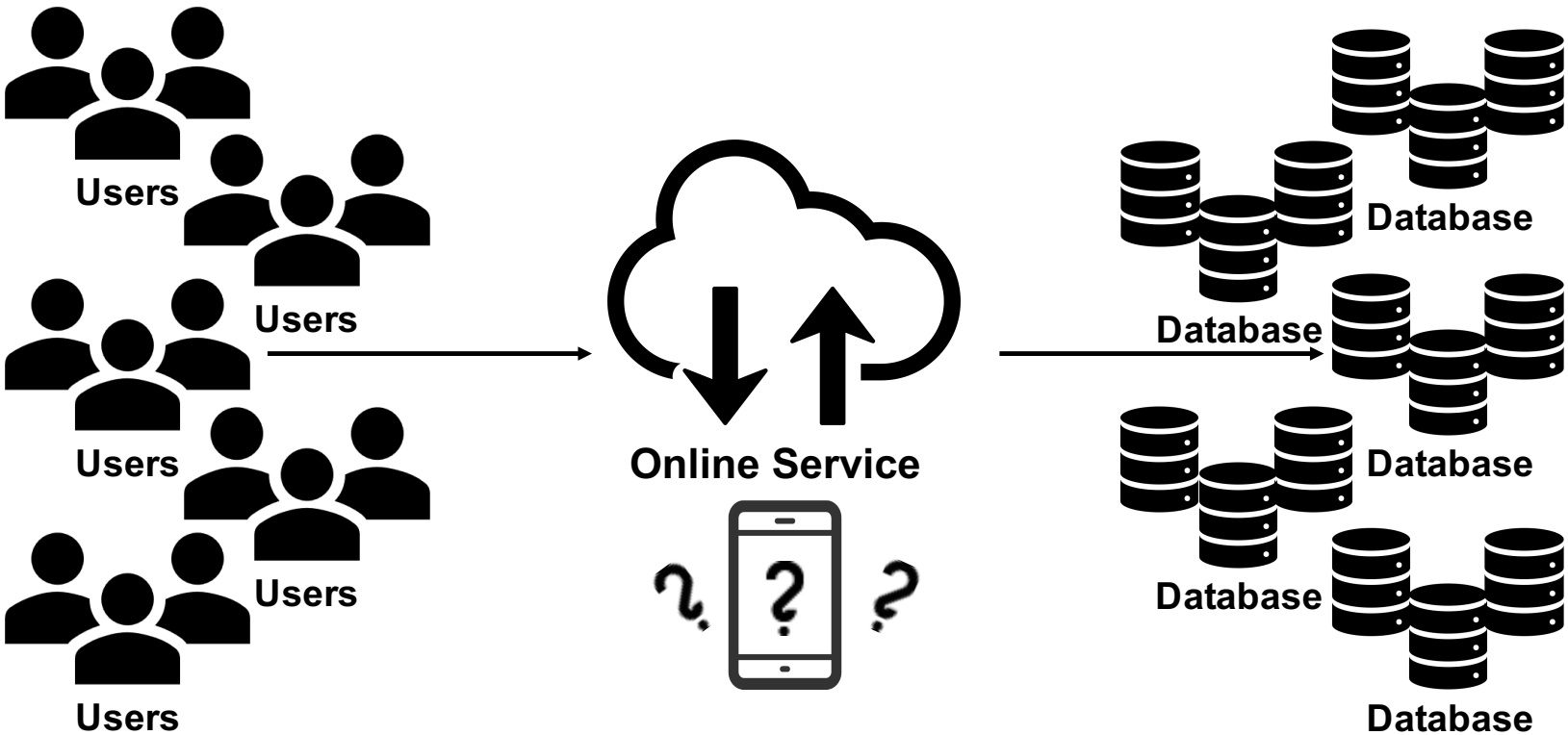

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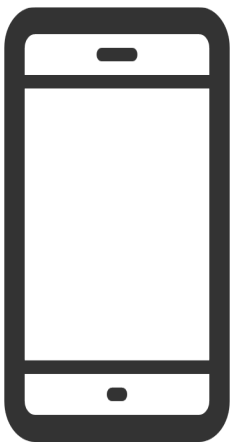
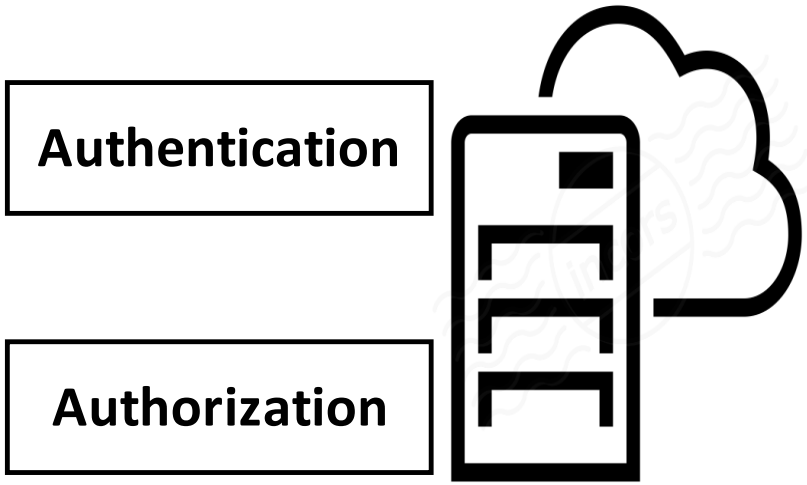
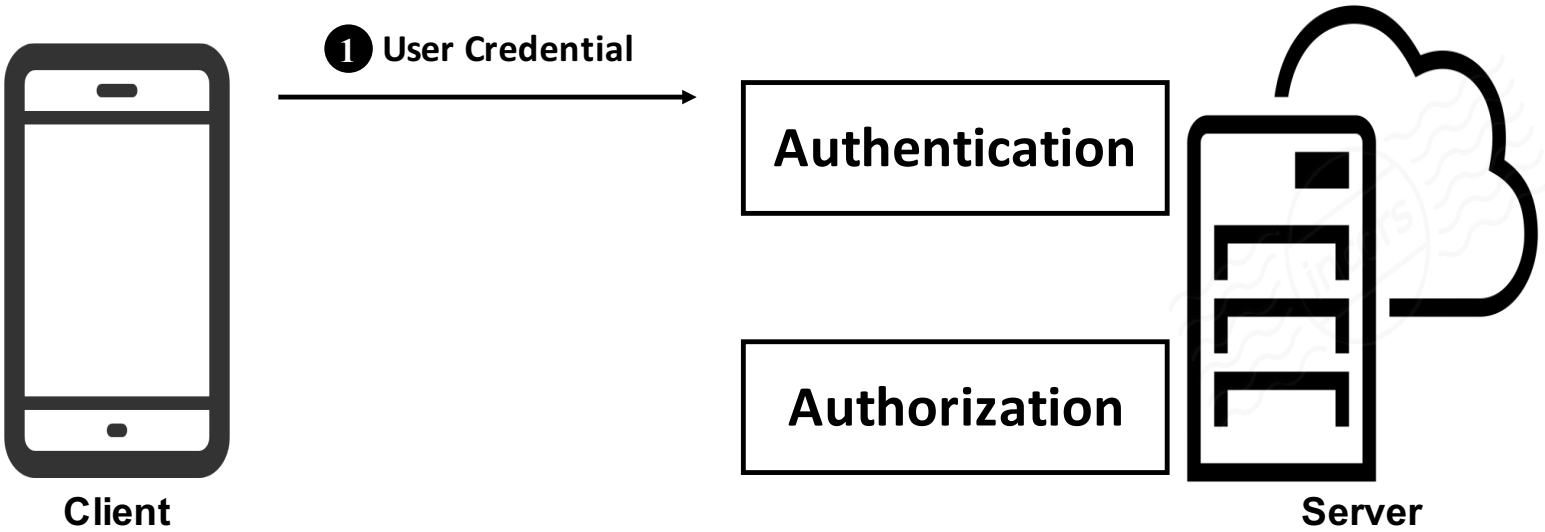


Client



Server

Access Control in Online Service



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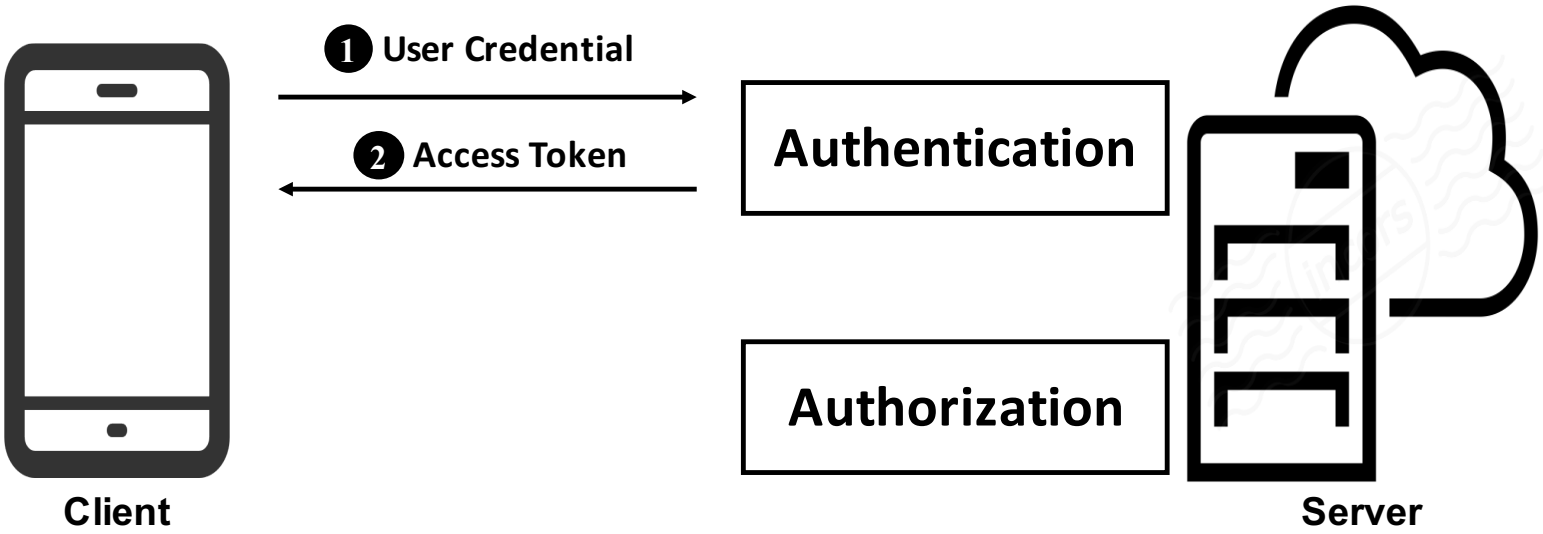

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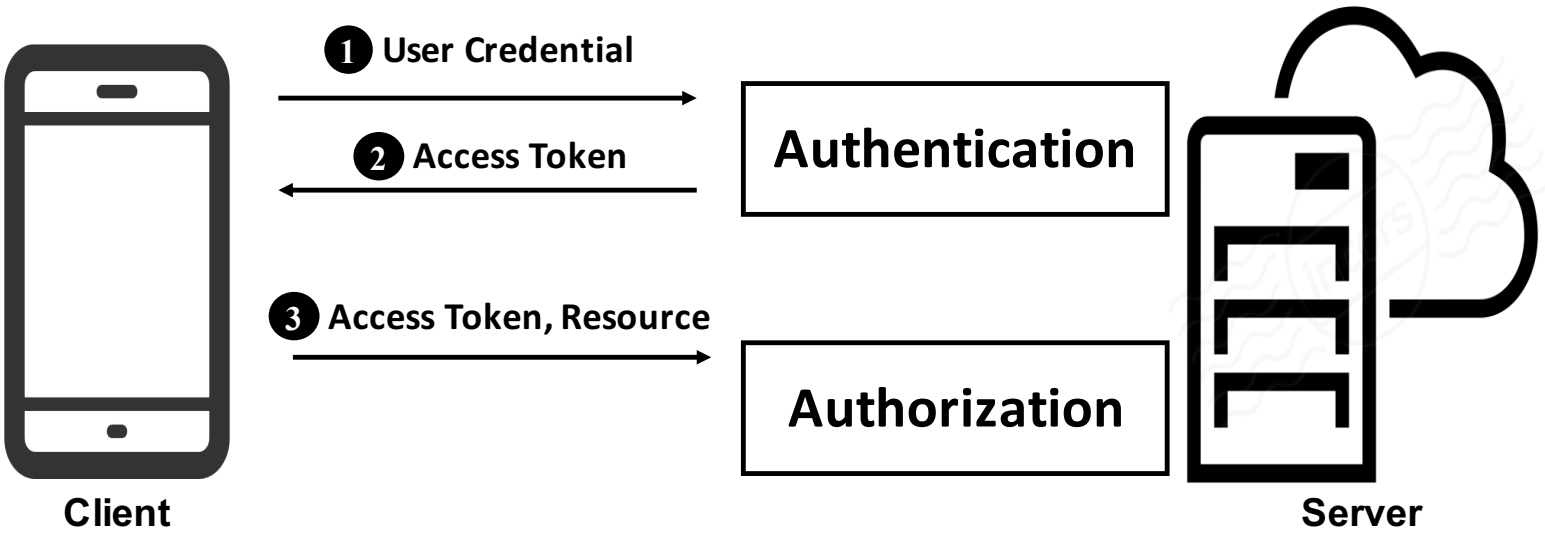
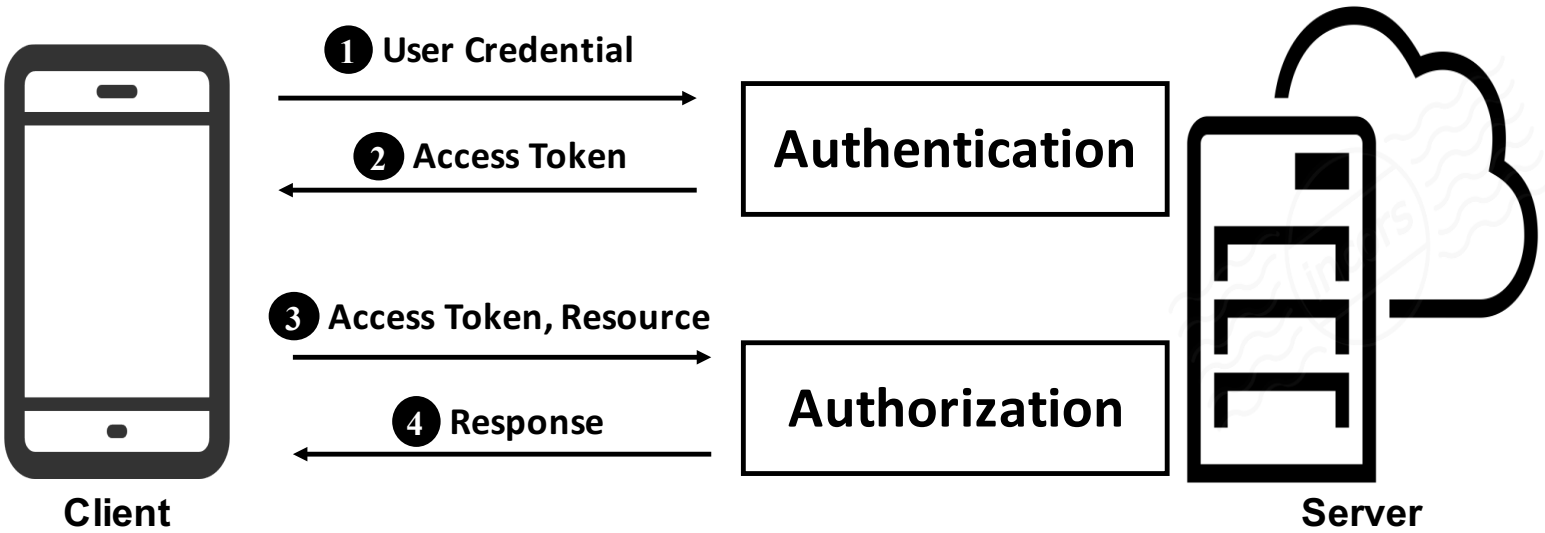


Access Control in Online Service



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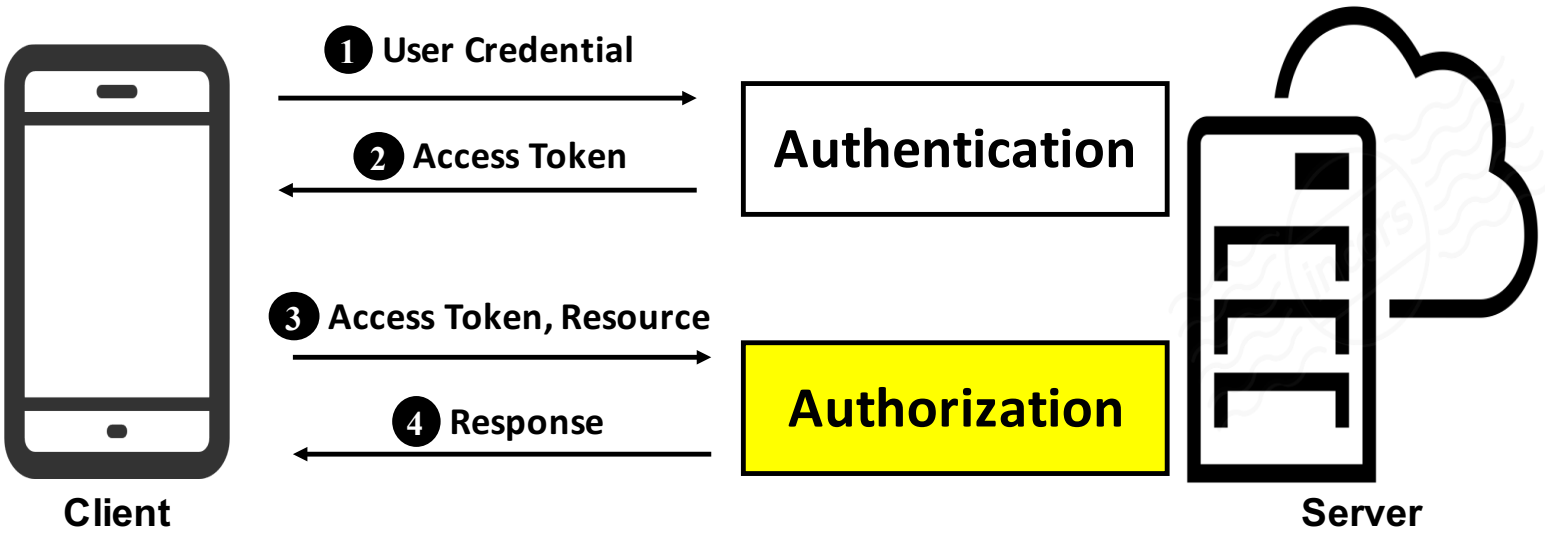

Possible Vulnerabilities

Vulnerabilities in Authorization

- No security token

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- No security token
- No randomness of resource ID

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  $https://www.overleaf.com/9357323vdzpzwzmwdmx$

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Vulnerabilities in Authorization

- No security token
- No randomness of resource ID

Possible Vulnerabilities

Vulnerabilities in Authorization

- No security token
- No randomness of resource ID
- No access control enforcement

A Running Example

```
GET /api/v1//users/21690/notifications?in_app_token=e67315b35aa3
8d4ac8cac3cd9c7f88ae7f576d373f HTTP/1.1
Host: api.w****.com
Connection: close
```

```
HTTP/1.1 200 OK
Cache-Control: max-age=0, private, must-revalidate
Content-Type: application/json
ETag: W/"5319d96924bb6d0a761b5f13b248919c"
Server: nginx/1.6.2
X-Request-Id: 5775d45e-cc3b-4665-8bc6-c2c7a2c9180d
X-Runtime: 0.027840
Content-Length: 191
Connection: Close

[{"id":433222,"sender":null,"dog":null,"notification_type":15,"n
otification_text":"Welcome to w****.","object_id":21690,"is_seen
":true,"is_read":true,"created_at":"2017-01-28T23:54:59.831Z"}]
```

Alice's first request and response message after login

A Running Example

```
GET /api/v1//users/21691/notifications?in_app_token=fb153b7d8c0a
0c6ac841d7bfbd9446de627c642858 HTTP/1.1
Host: api.w****.com
Connection: close
```

```
HTTP/1.1 200 OK
Cache-Control: max-age=0, private, must-revalidate
Content-Type: application/json
ETag: W/"6ee365b32e7f3e145d5c74778ea243cd"
Server: nginx/1.6.2
X-Request-Id: 4970cafb-9438-4a70-96e0-ca2f789f0d5d
X-Runtime: 0.022889
Content-Length: 192
Connection: Close

[{"id":433227,"sender":null,"dog":null,"notification_type":15,"n
otification_text":"Welcome to w****.","object_id":21691,"is_seen
":true,"is_read":false,"created_at":"2017-01-28T23:56:40.533Z"}]
```

Bob's first request and response message after login

A Running Example

```
GET /api/v1//users/21690/notifications?in_app_token=e67315b35aa3
8d4ac8cac3cd9c7f88ae7f576d373f HTTP/1.1
Host: api.w****.com
Connection: close
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Alice's first request message after login

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Bob's first request message after login

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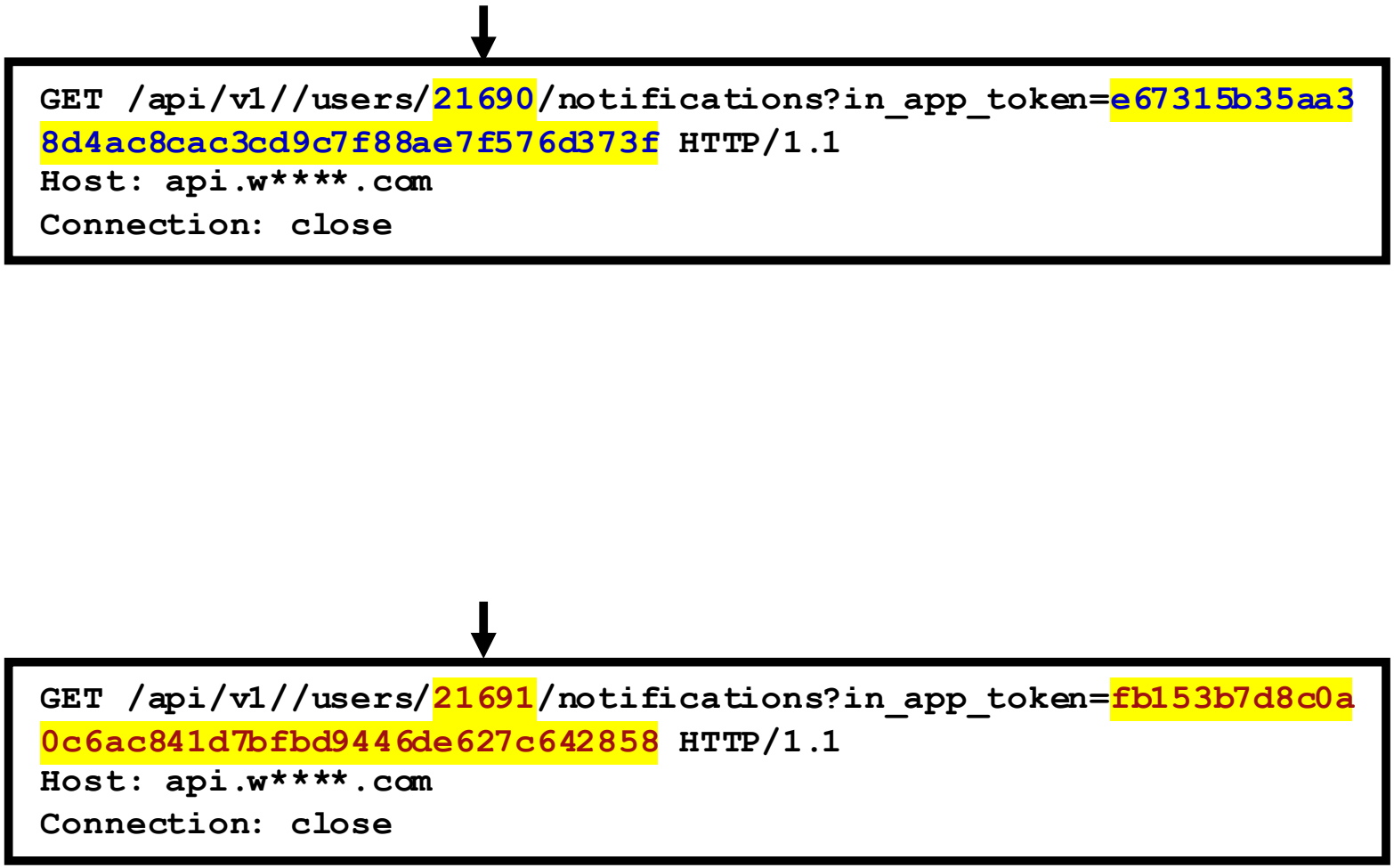

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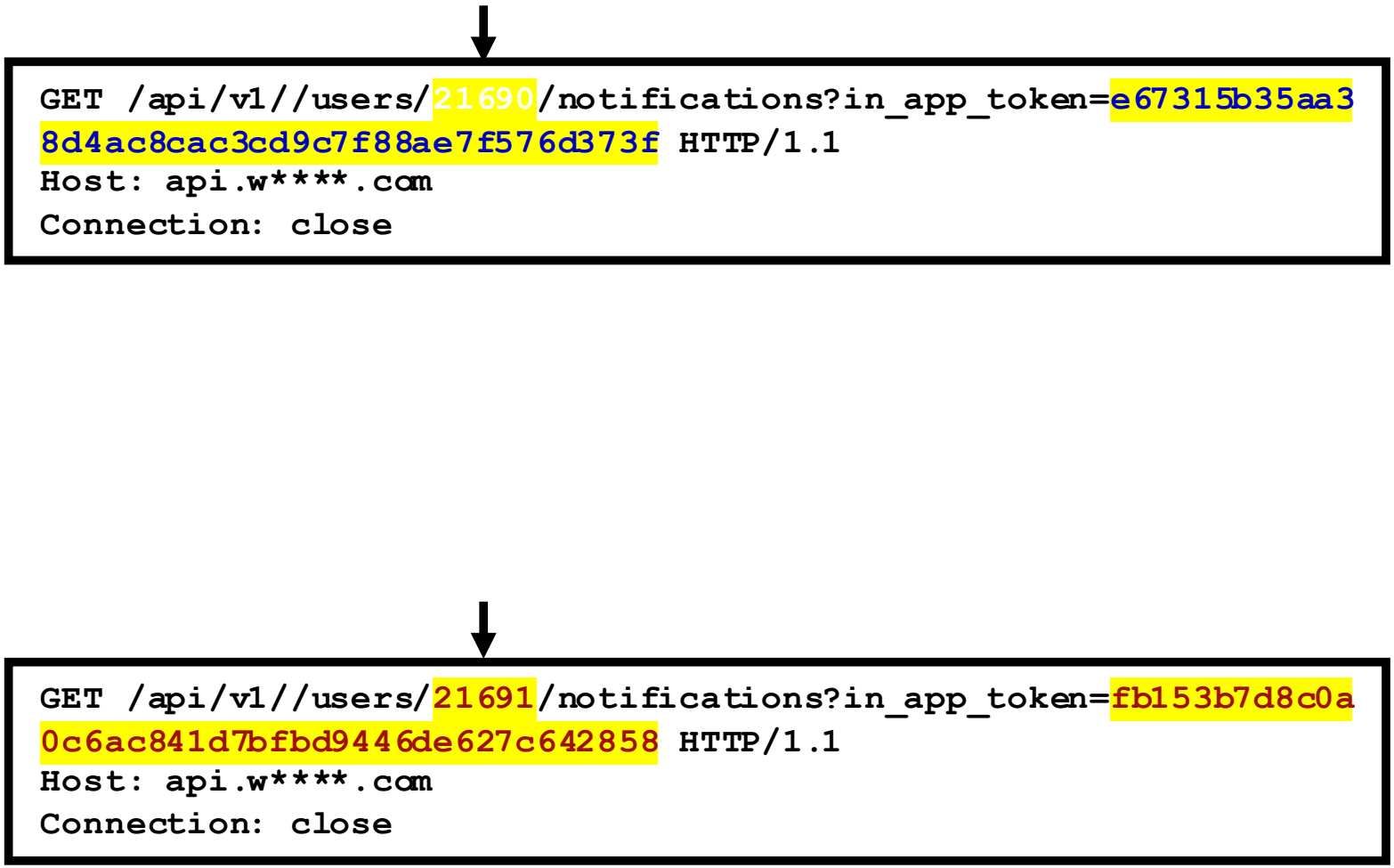

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Alice reads Bob's notifications

Challenge: Obtain the post-authentication messages

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Alice's first request message after login

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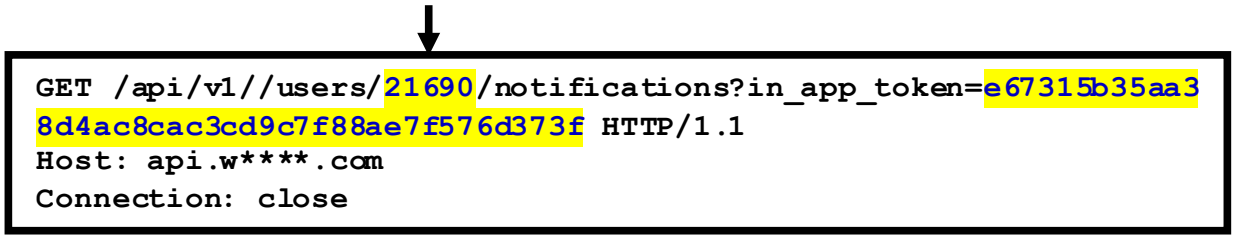
Bob's first request message after login

Insights

Executing the app with single-sign-on.

Challenge: Recognize&Substitute fields of interest



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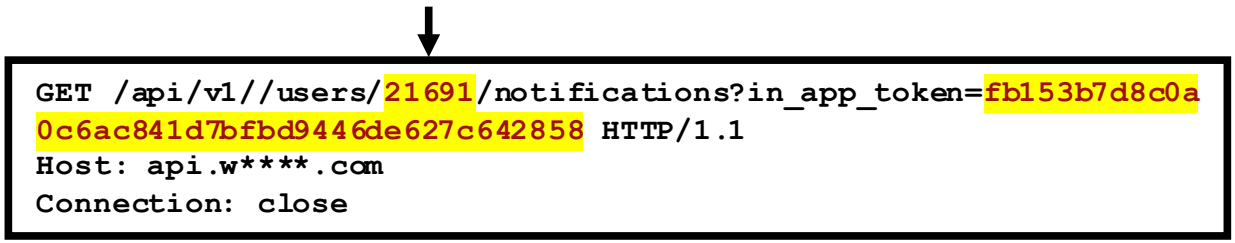

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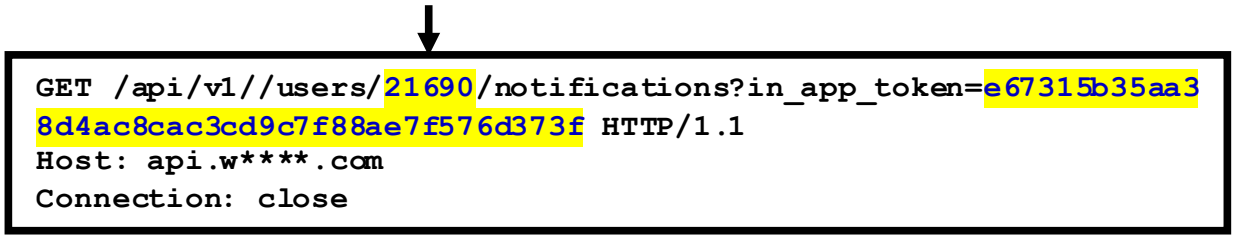

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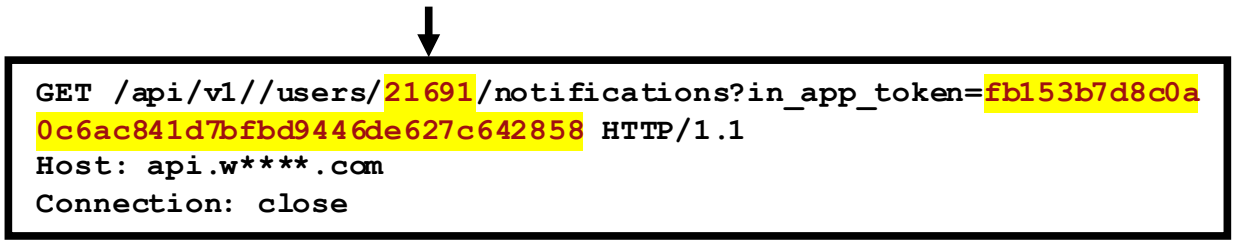

Bob's first request message after login

Insights

Differential traffic analysis and small Euclidean distance.

Challenge: Identify the vulnerability

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Insights

Labeling server response with differential traffic analysis.

Problem Statement & Assumption

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- Given a mobile app
- Automatically identify whether its server is vulnerable to access control violation

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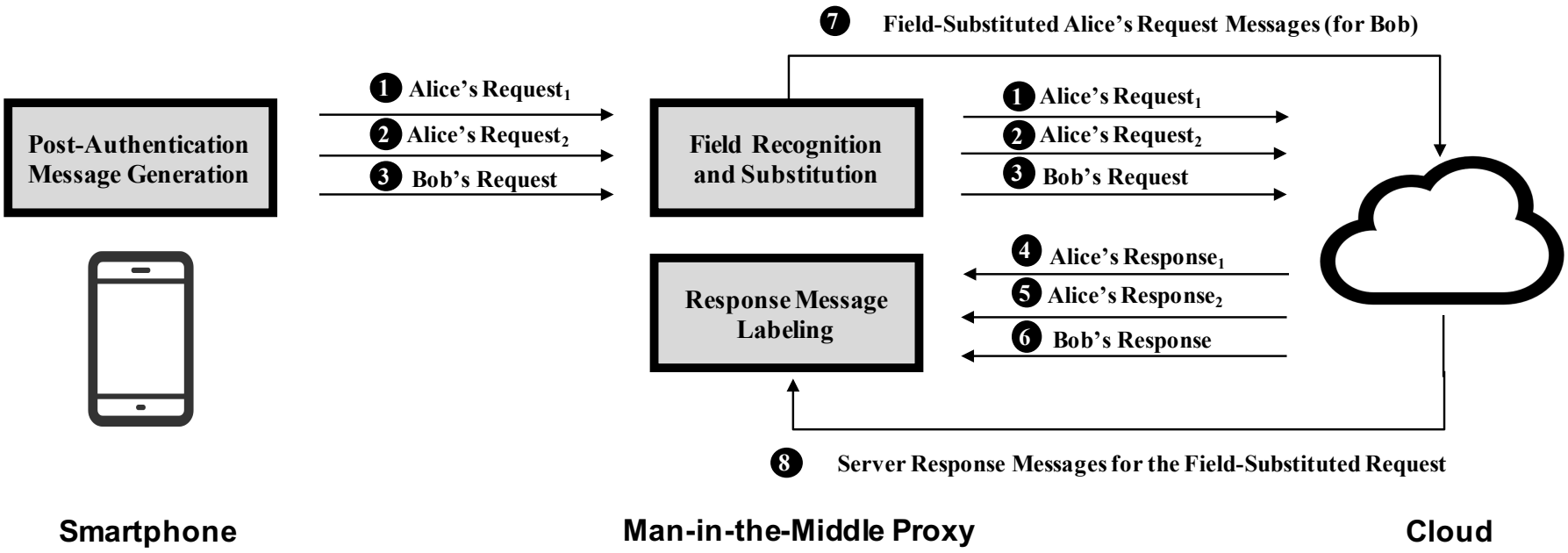
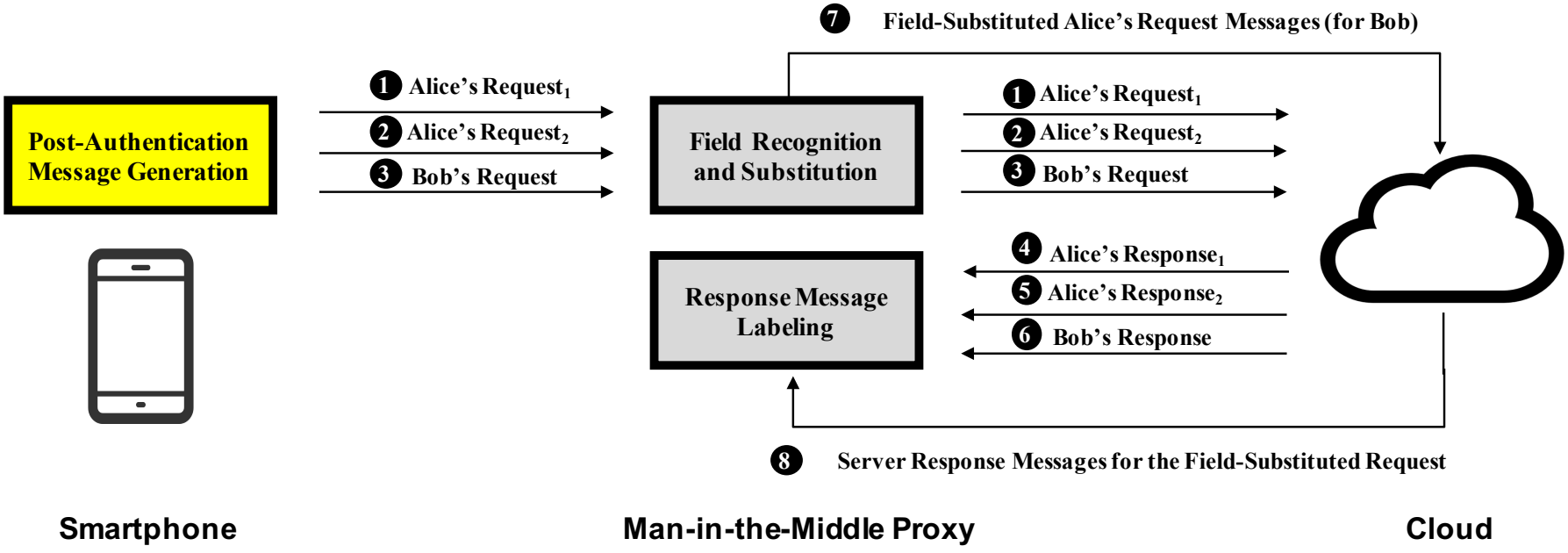
Assumptions

- HTTP/HTTPS protocol
- Facebook login

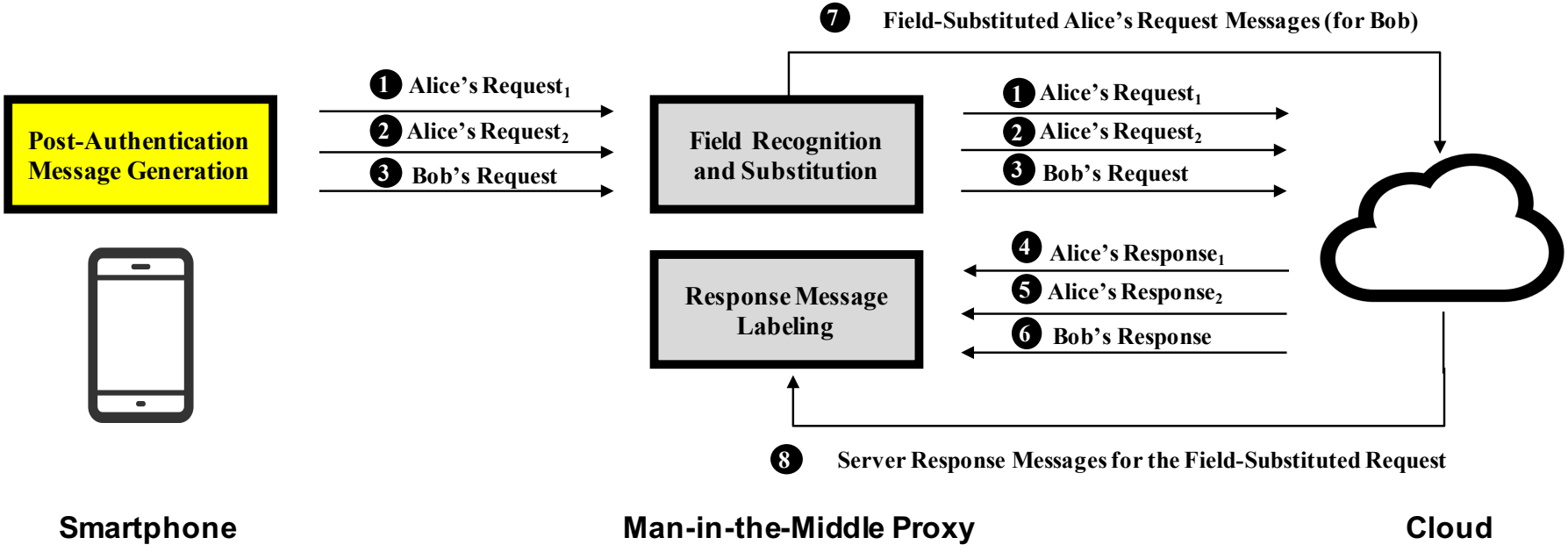
Overview of AUTHSCOPE



Post-Authentication Message Generation

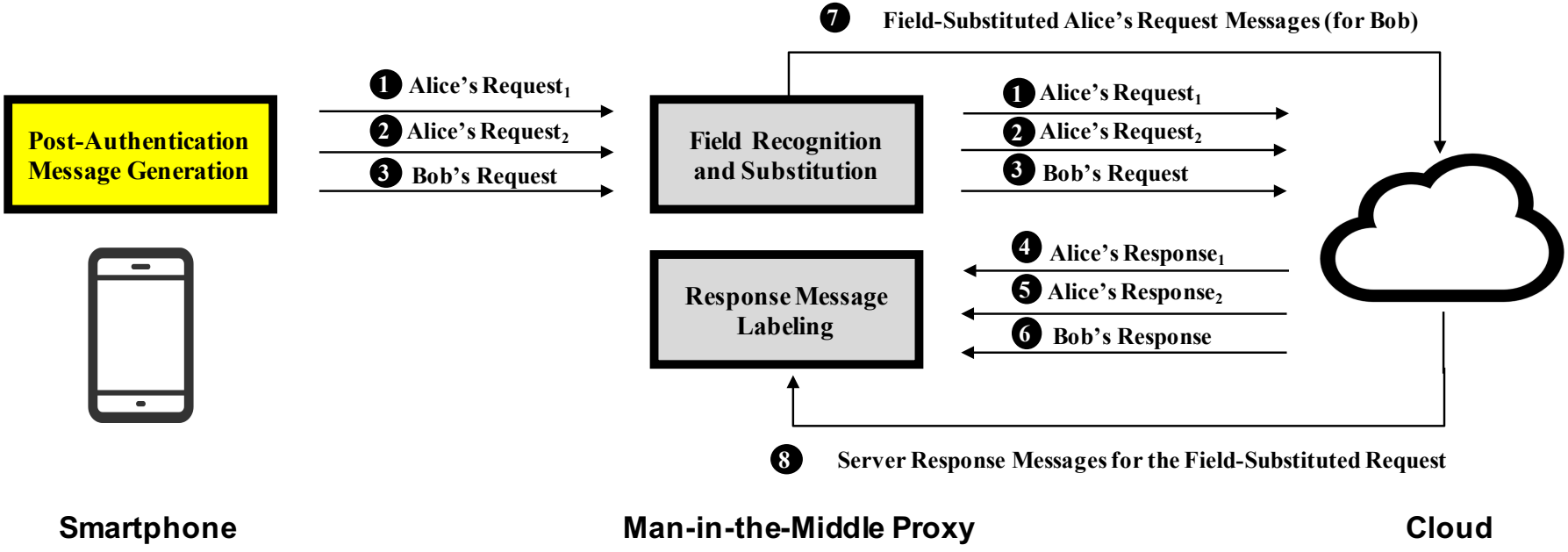


Post-Authentication Message Generation



- View Identification and Exploration

Post-Authentication Message Generation



- View Identification and Exploration
- Automatic Social-based Service Login

Post-Authentication Message Generation Cont

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Button 1

Post-Authentication Message Generation Cont

Button 1

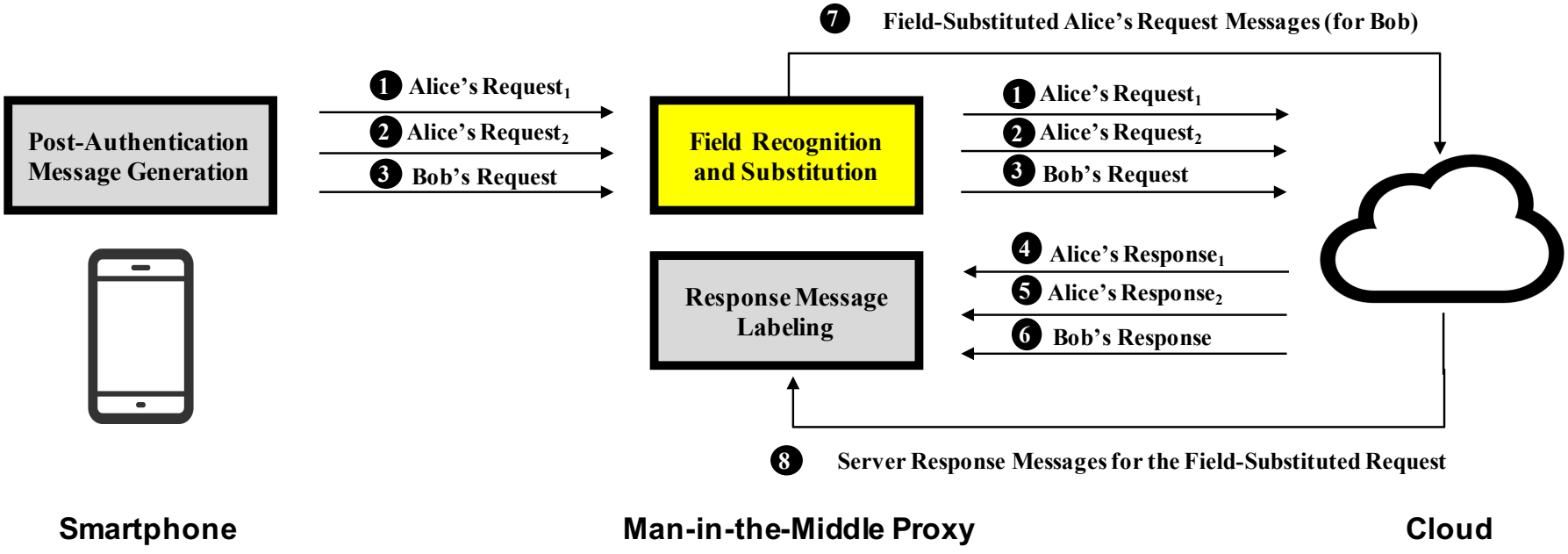
Button 2

Post-Authentication Message Generation Cont

Button 1 → FaceBook Login

Button 2

Field Recognition and Substitution



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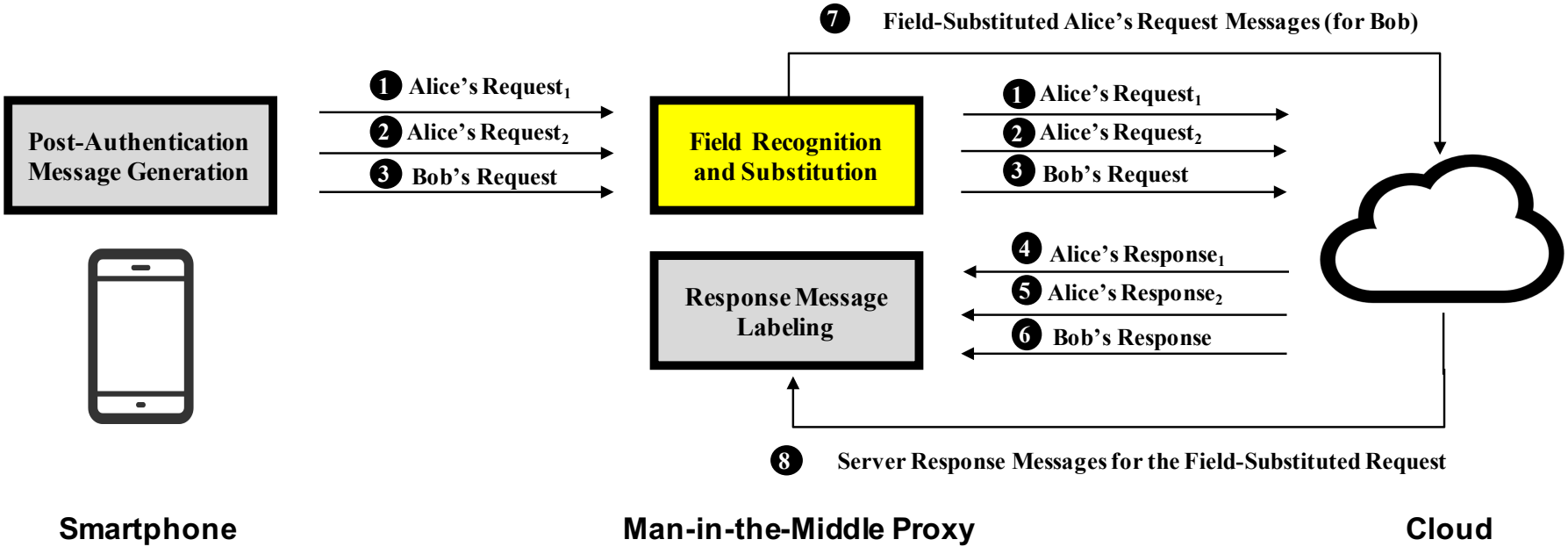
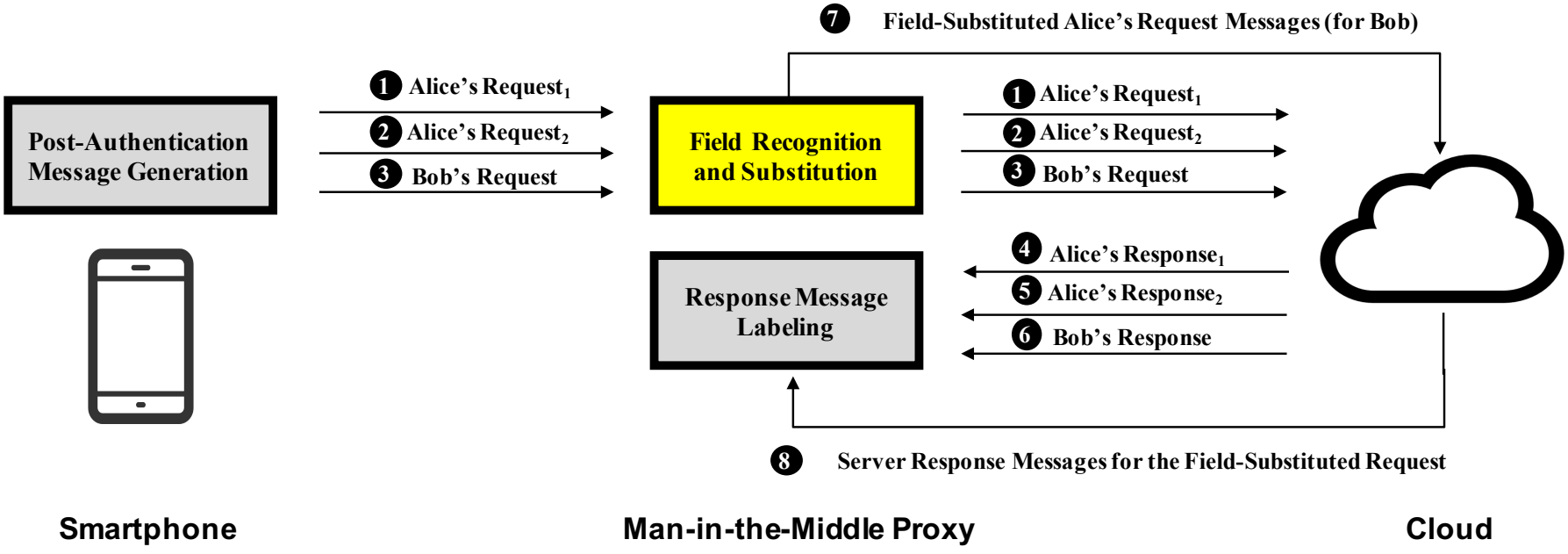


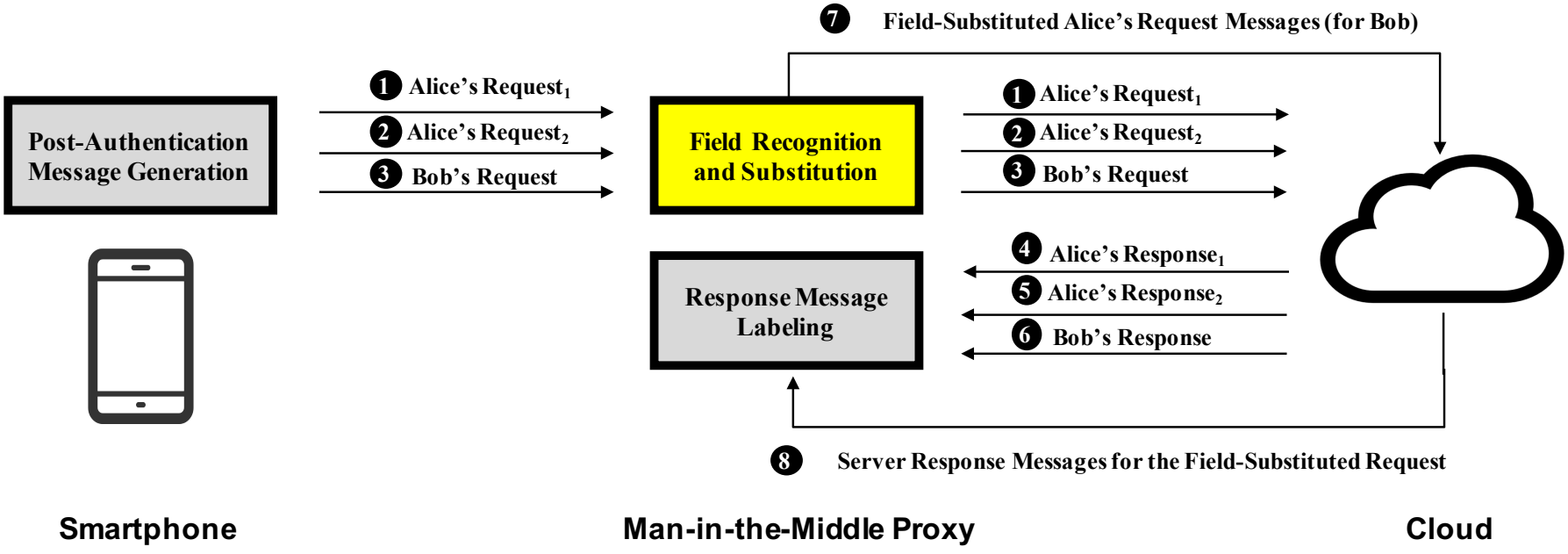
- Parsing Message Fields

Field Recognition and Substitution



- Parsing Message Fields
- Identifying Fields of Interest

Field Recognition and Substitution

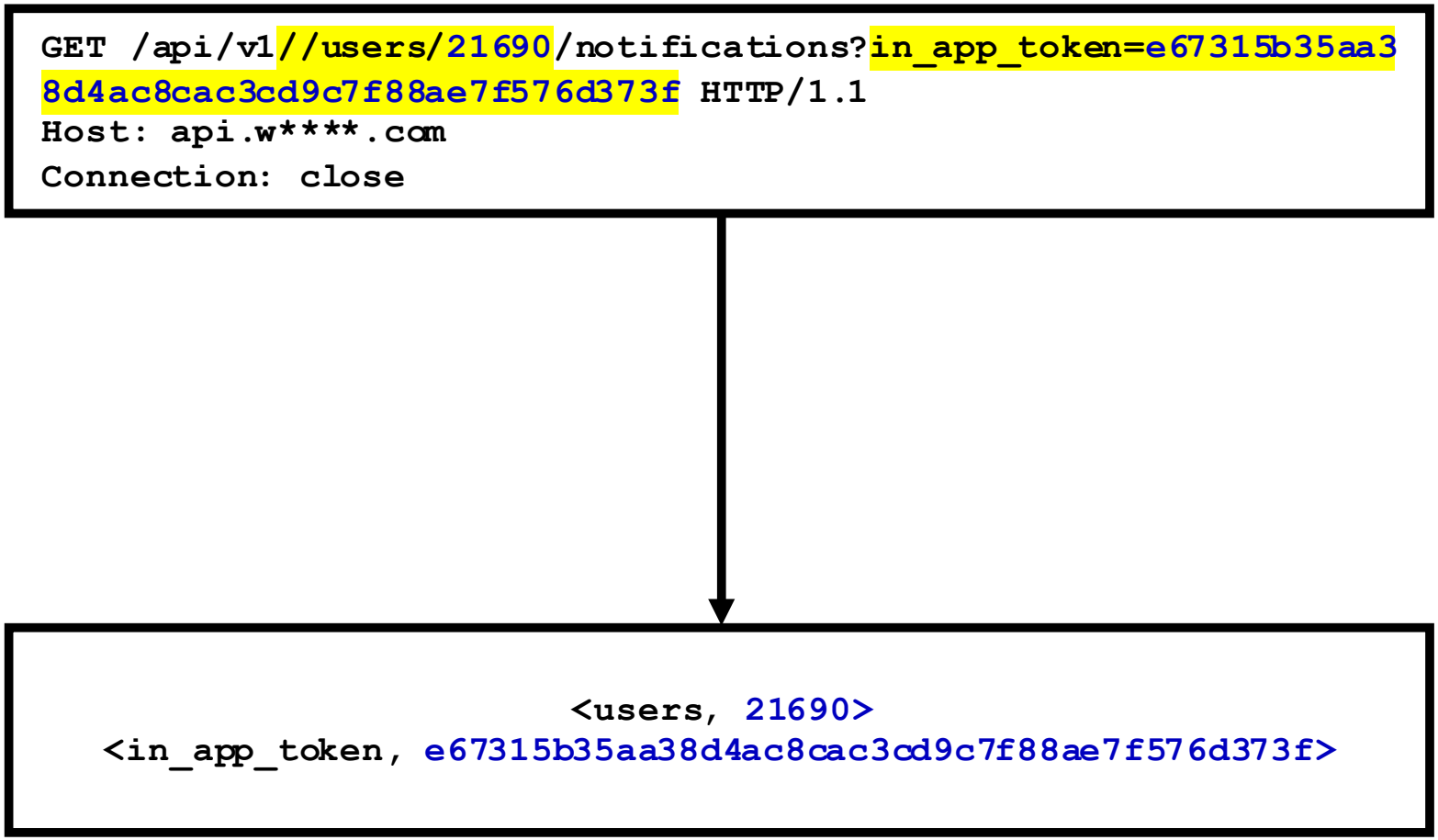


- Parsing Message Fields
- Identifying Fields of Interest
- Substituting Enumerable Fields

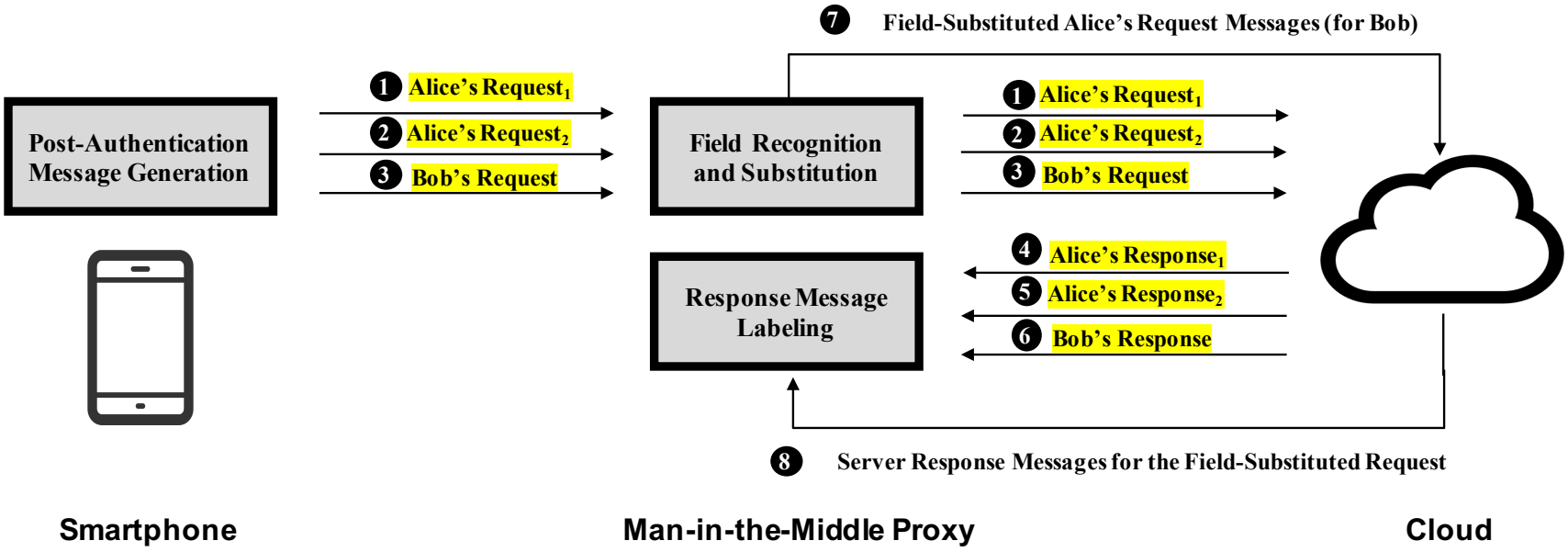
Field Recognition and Substitution Cont

```
GET /api/v1//users/21690/notifications?in_app_token=e67315b35aa3
8d4ac8cac3cd9c7f88ae7f576d373f HTTP/1.1
Host: api.w****.com
Connection: close
```

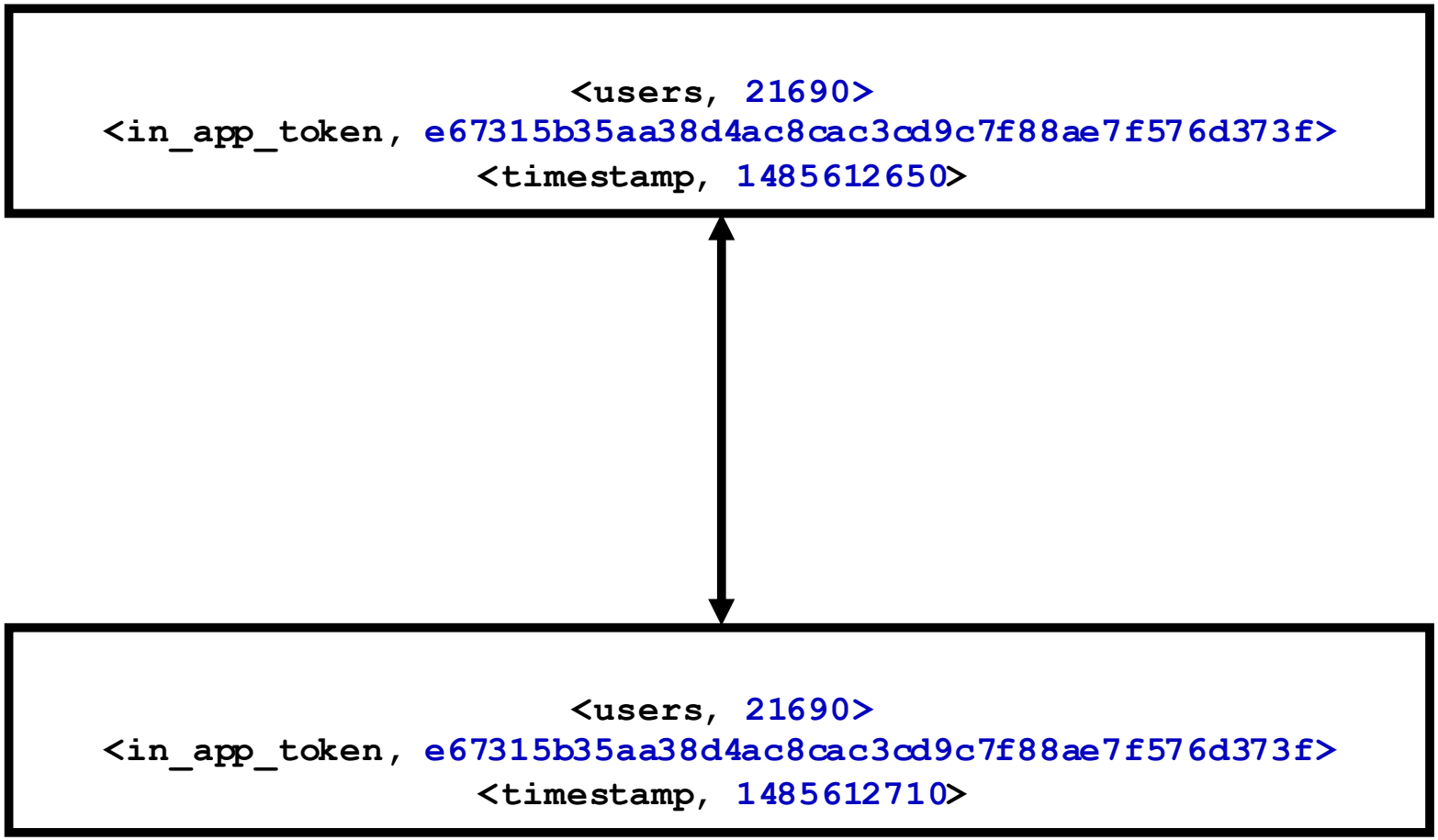
Field Recognition and Substitution Cont



Field Recognition and Substitution Cont



Field Recognition and Substitution Cont



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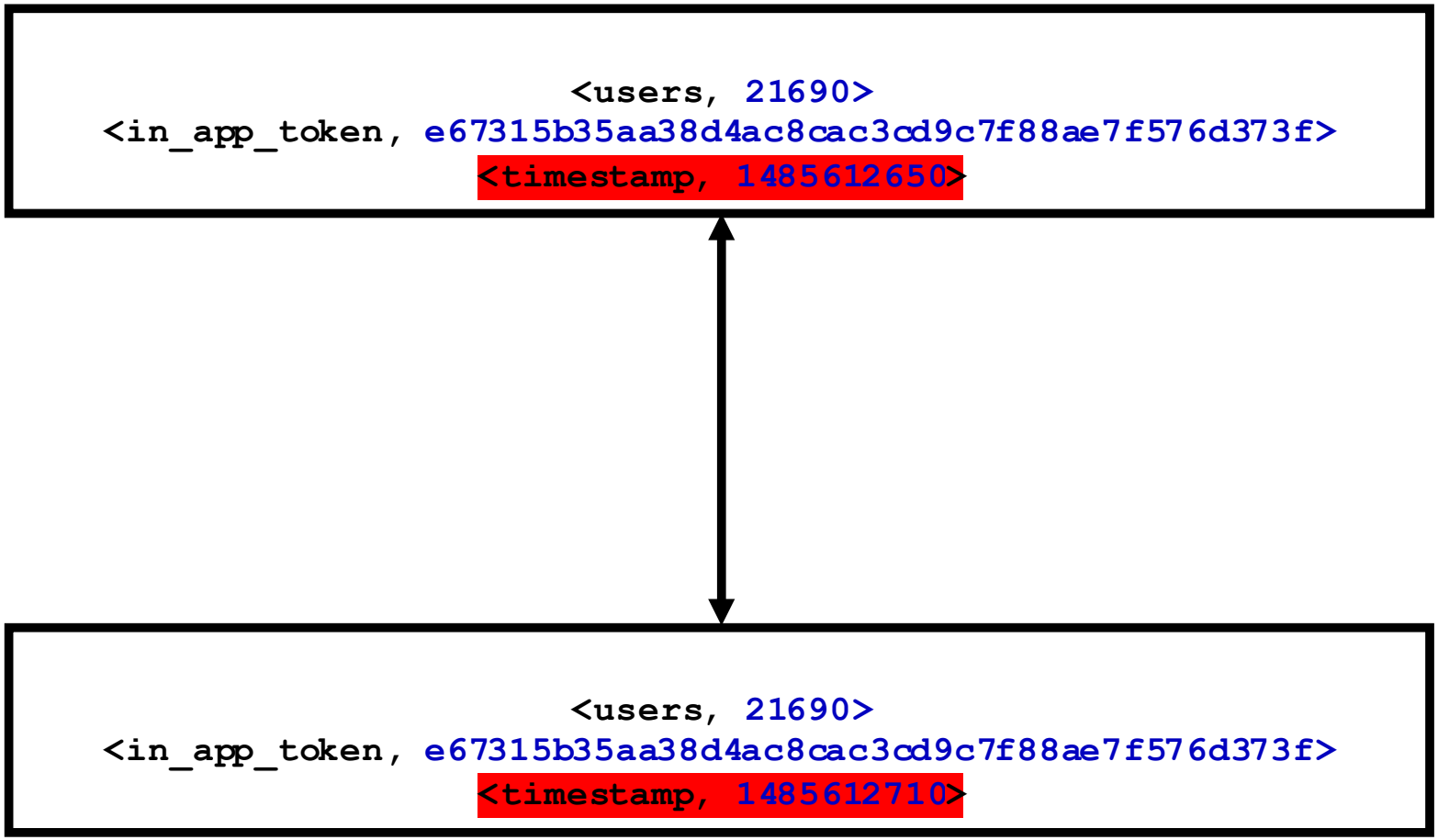
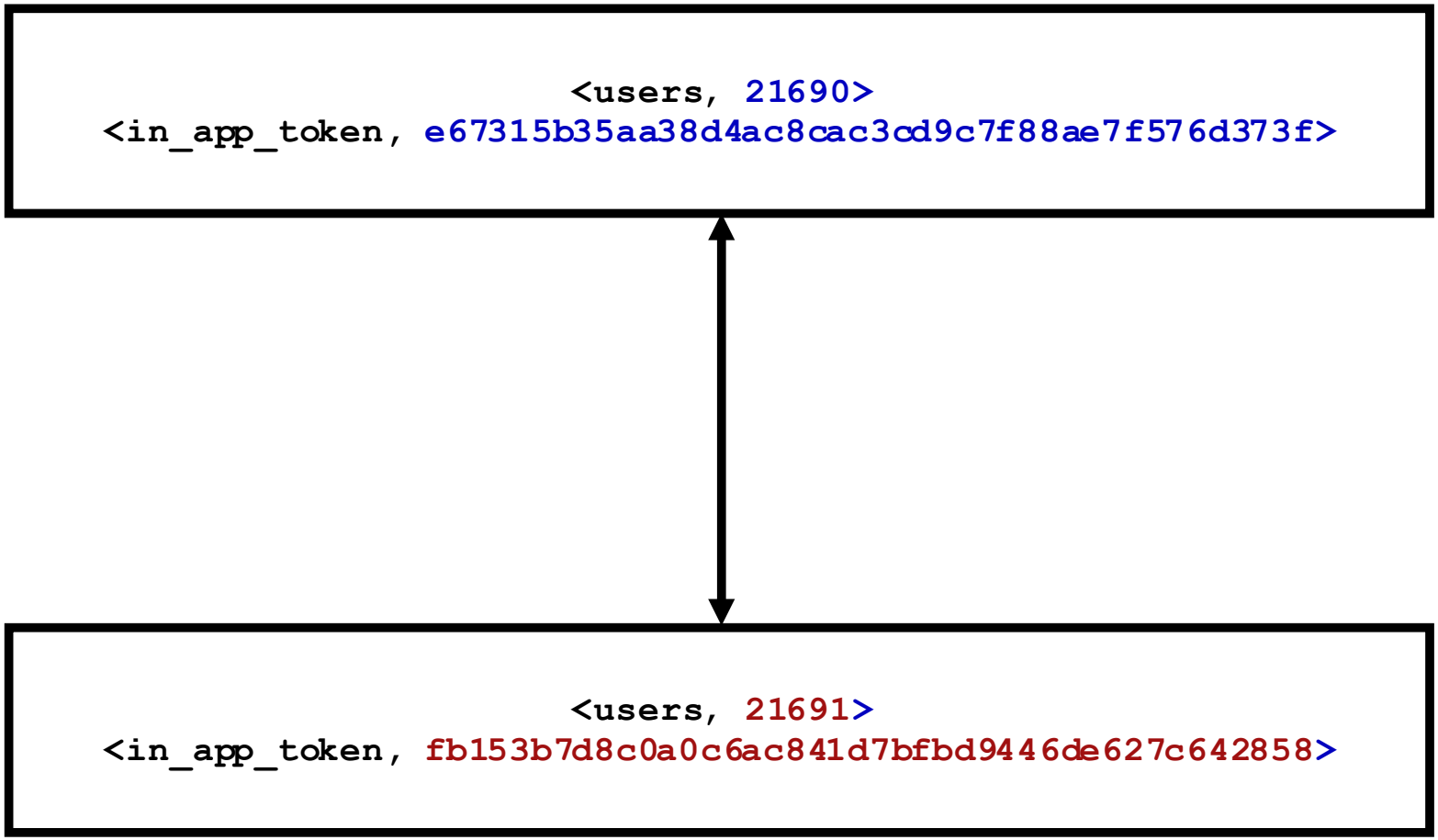


Field Recognition and Substitution Cont

```
<users, 21690>
<in_app_token, e67315b35aa38d4ac8cac3cd9c7f88ae7f576d373f>
```

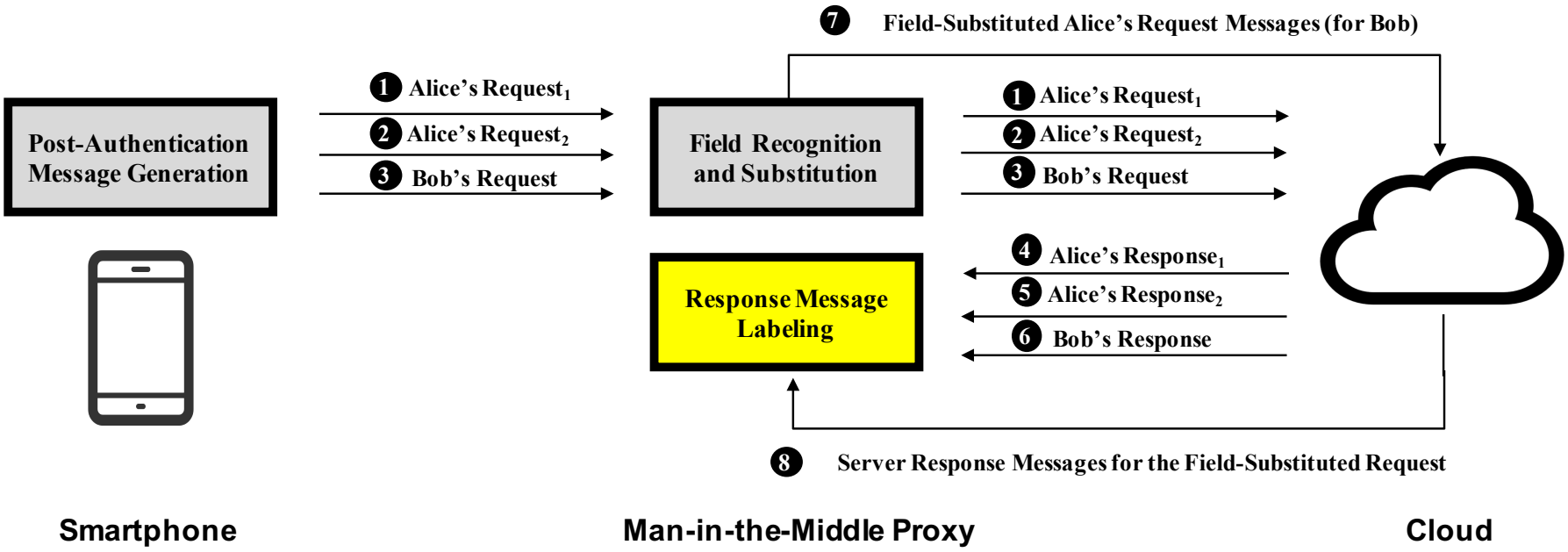
Field Recognition and Substitution Cont



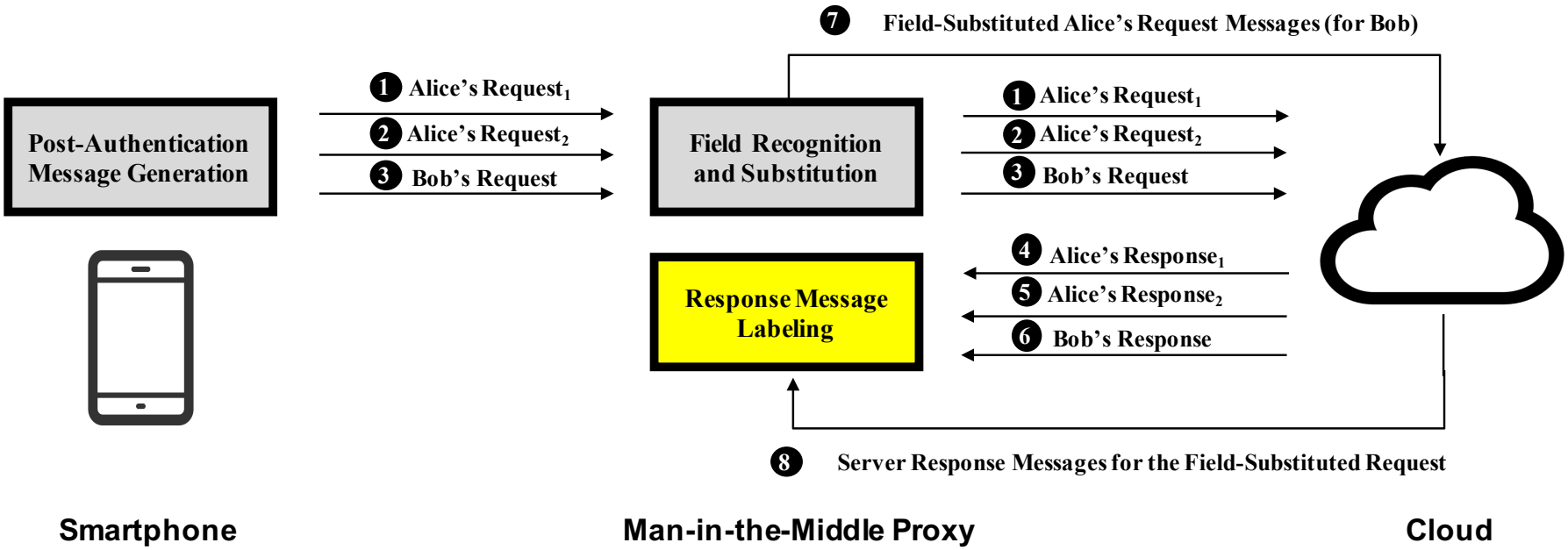
Field Recognition and Substitution Cont

Field-Value of Alice vs. Field-Value of Bob	ED
e67315b35aa38d4ac8cac3cd9c7f88ae7f576d373f	$+\infty$
fb153b7d8c0a0c6ac841d7bfbd9446de627c642858	
21690	1.0
21691	

Response Message Labeling

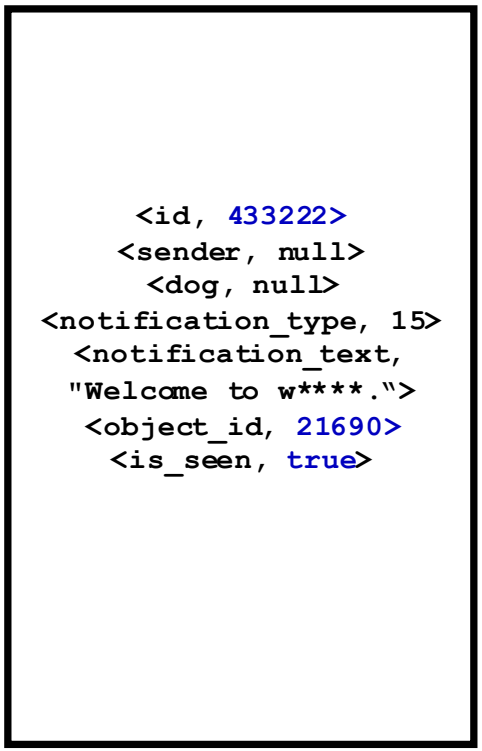


Response Message Labeling

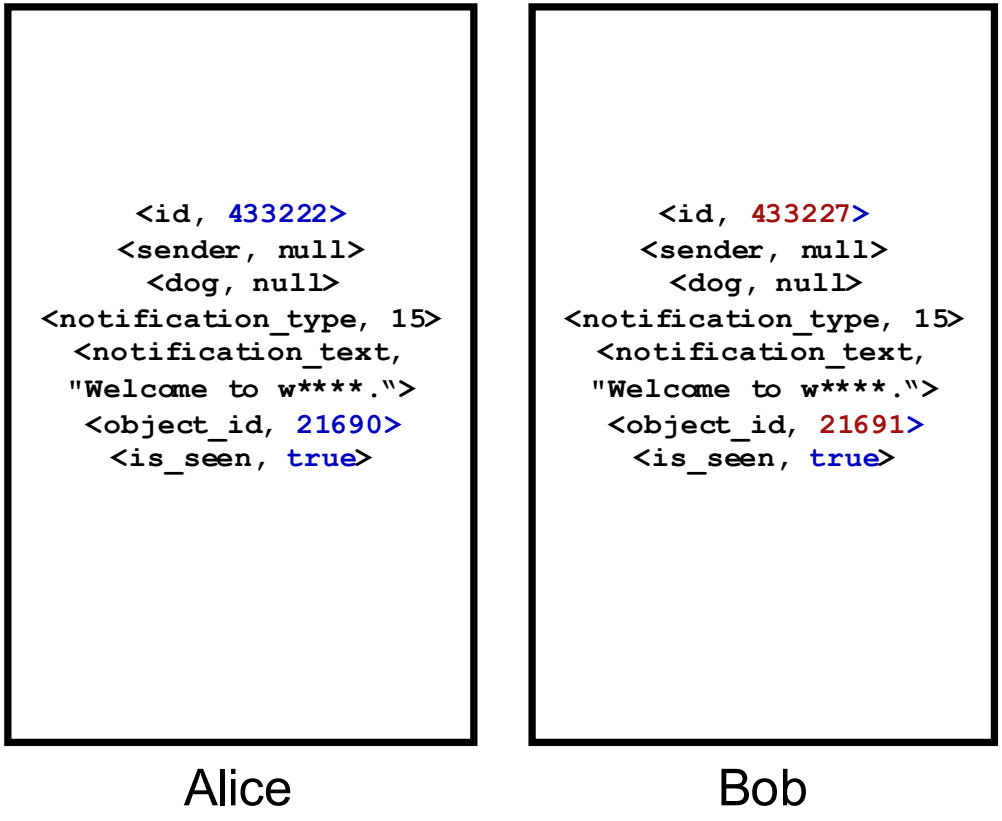


- Labeling response messages indicate vulnerability

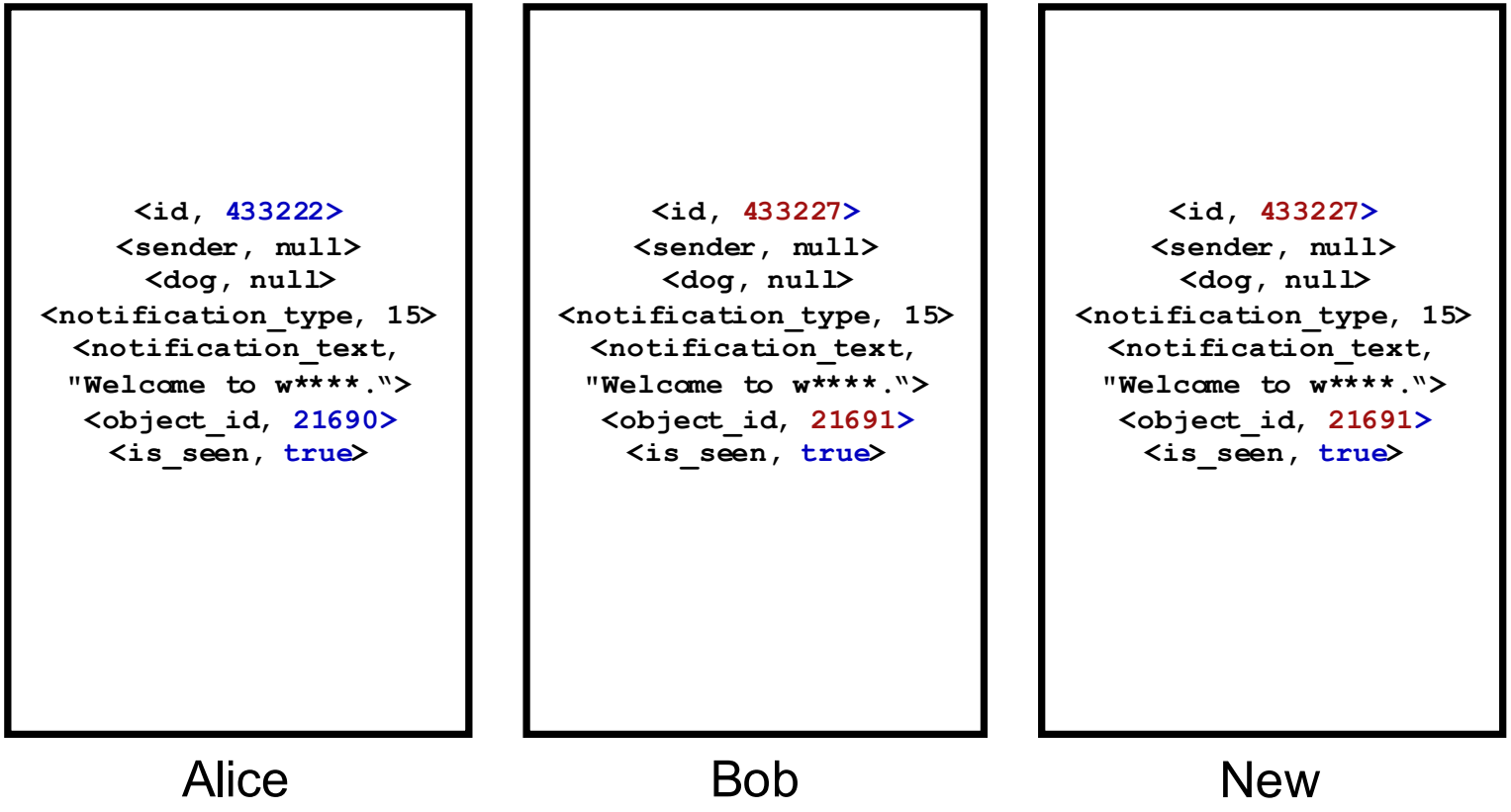
Response Message Labeling Cont



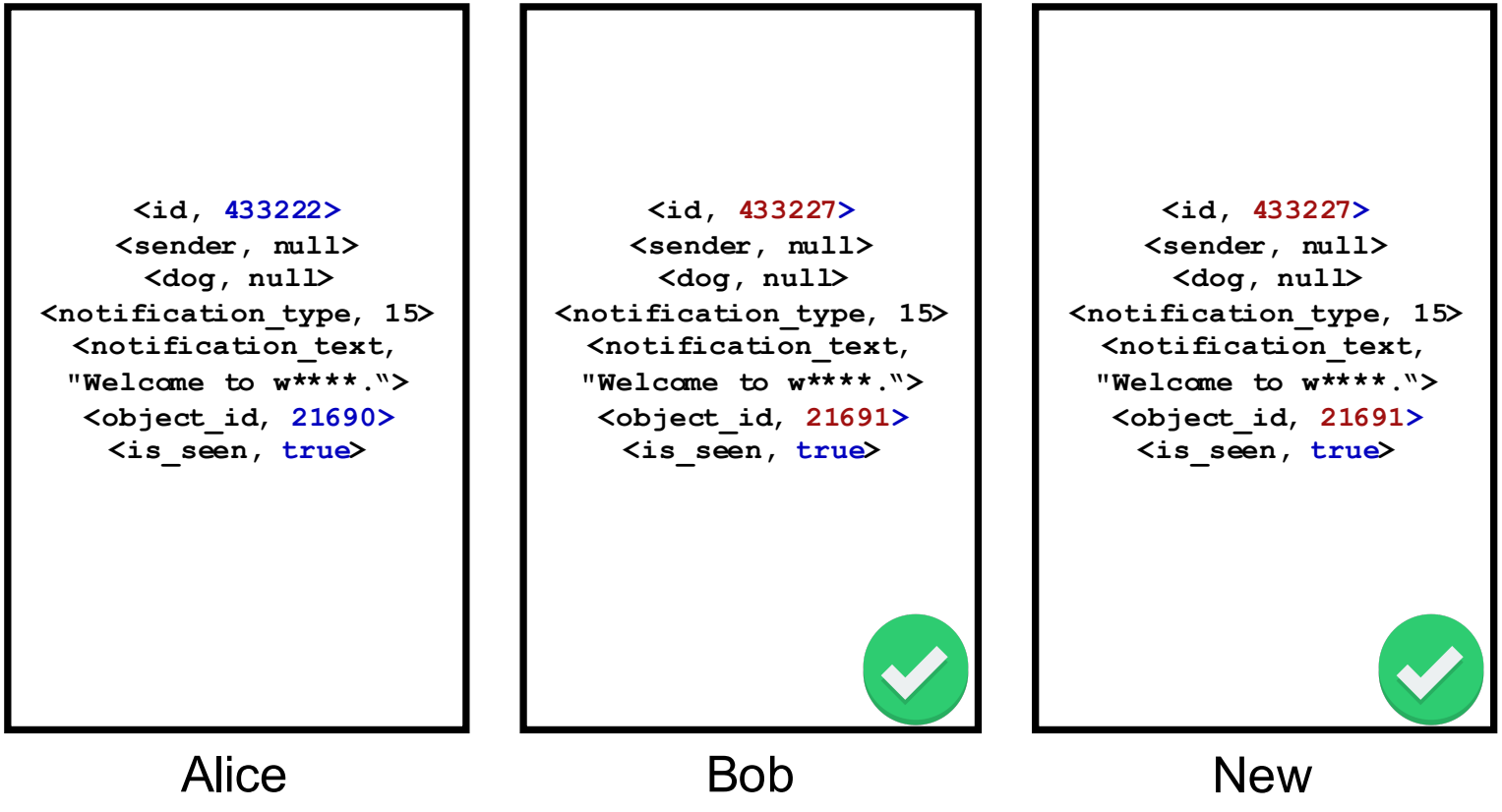
Response Message Labeling Cont



Response Message Labeling Cont



Response Message Labeling Cont



Response Message Labeling Cont

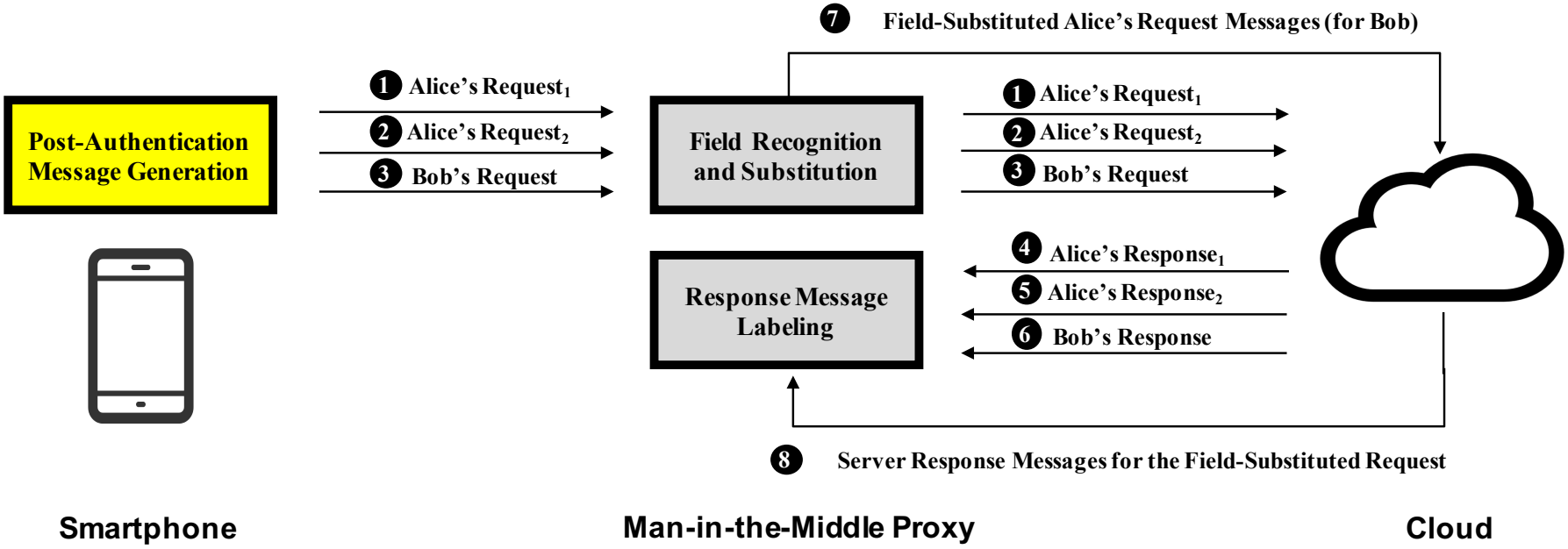
Prune Public Interfaces

Response Message Labeling Cont

Prune Public Interfaces

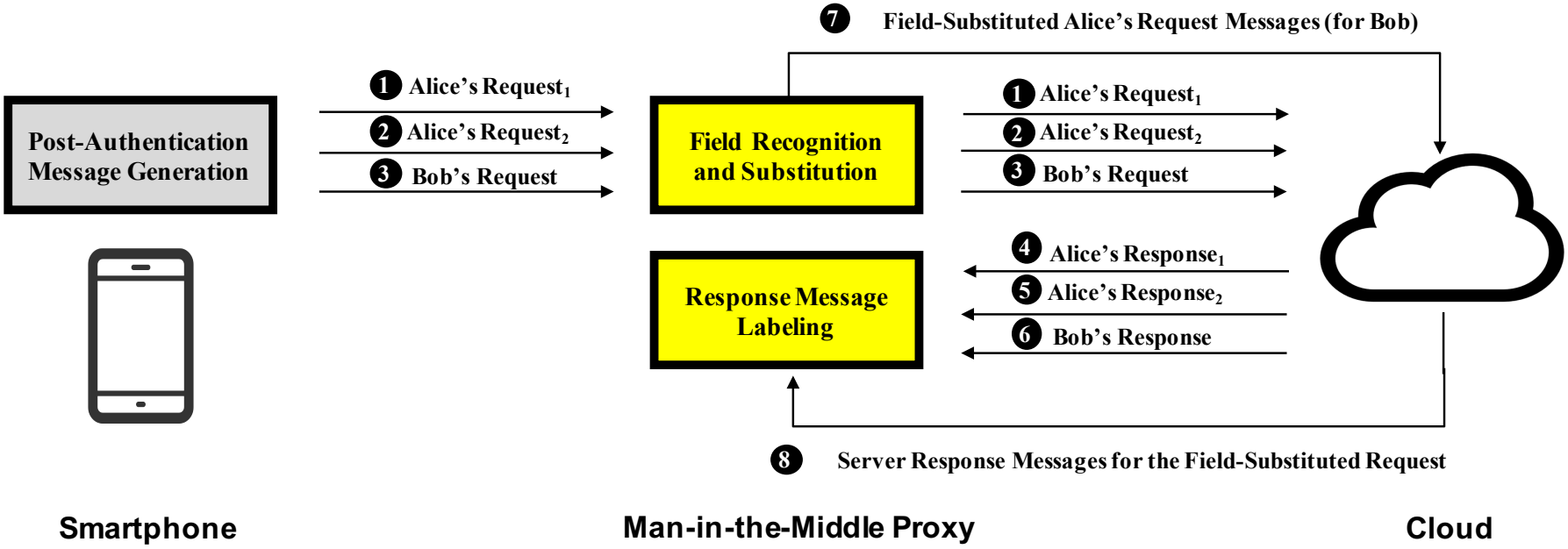
- News App

Implementation



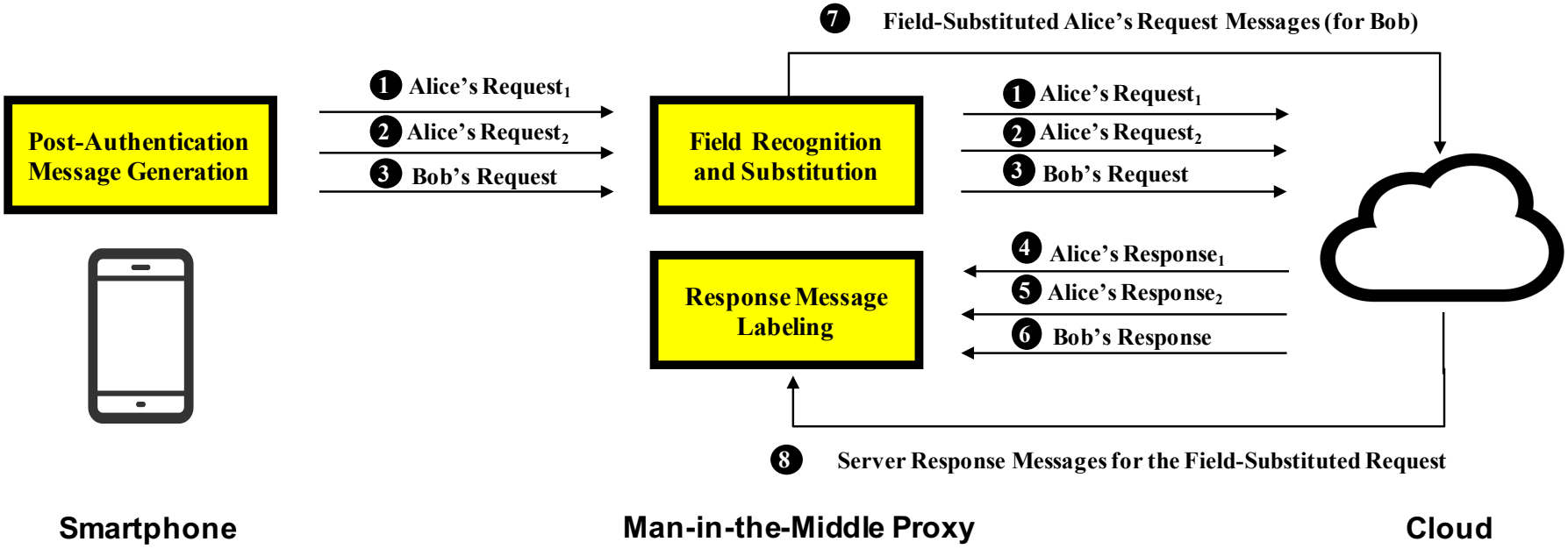
- Atop Android 4.4 with Xposed framework

Implementation



- Burp Suite for man-in-the-middle proxy

Implementation



- 5,000 lines of Java and 300 lines of Python

Experiment Setup

Dataset Collection

- Top 10% free mobile apps from Google Play, totally 200,000 apps
- Filtered out the app that does not have Facebook libraries, remaining 33,950 apps
- Filtered out the app that has no Facebook login button or invoking code, finally we have 4,838 apps

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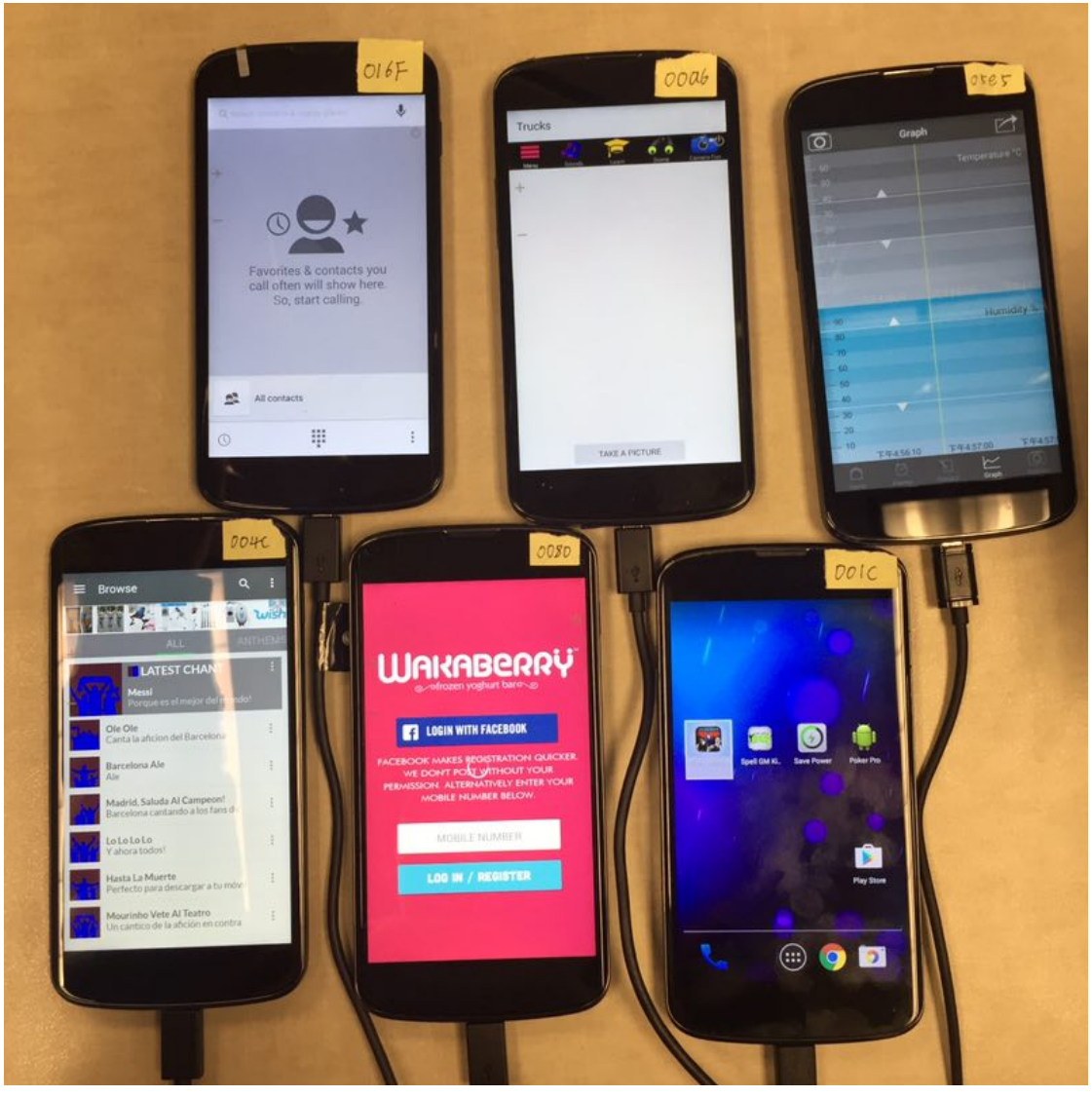
- Top 10% free mobile apps from Google Play, totally 200,000 apps
- Filtered out the app that does not have Facebook libraries, remaining 33,950 apps
- Filtered out the app that has no Facebook login button or invoking code, finally we have 4,838 apps

Testing Environment

- LG Nexus 4 with Android 4.4
- Ubuntu 14.04 on Intel i7-6700k CPU with 8G memory
- Two Facebook accounts:Alice: alice4testapp@gmail.com & Bob: bob4testapp@gmail.com

Experiment Setup



Overall Experiment Result

Item	Value
Total # Apps	4,838

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Total # Apps	4,838
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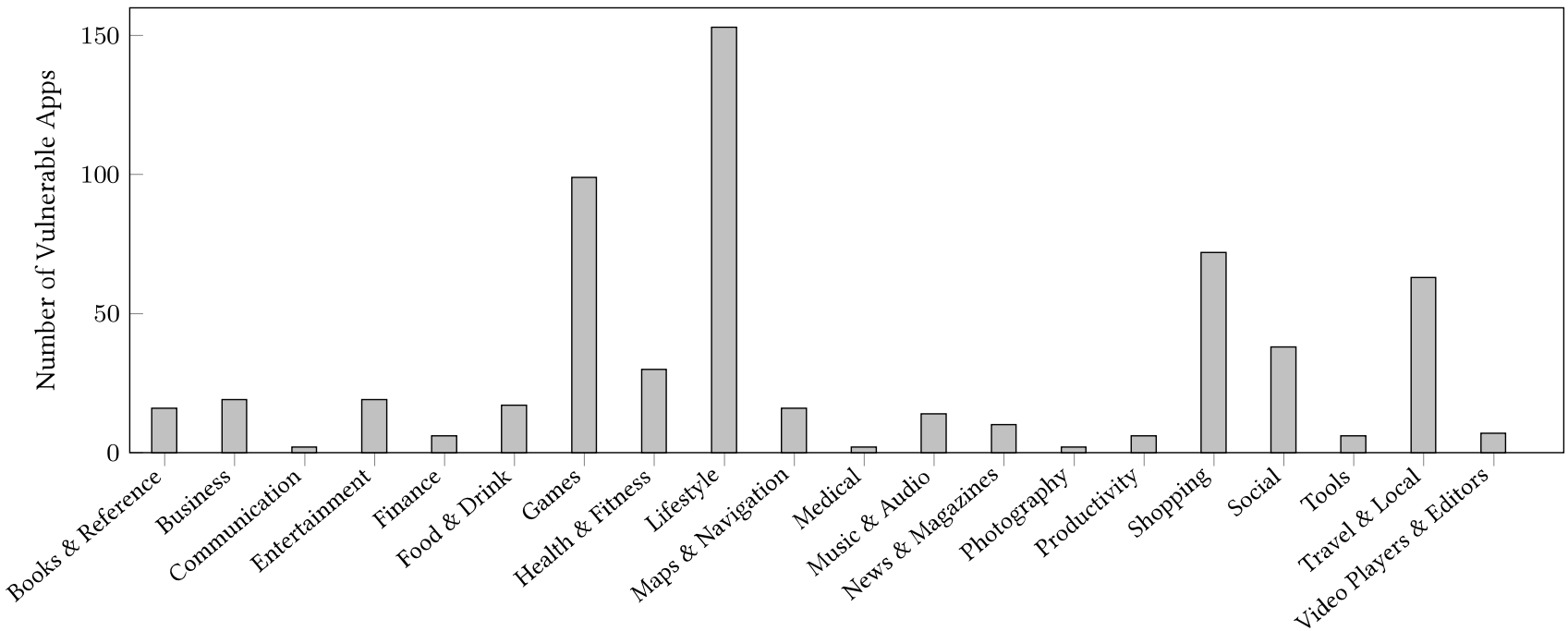
Overall Experiment Result

Item	Value
Total # Apps	4,838
Total Time of testing (hours)	562.4
Total # Request Messages	3,220,886
Total # Suspicious Interfaces	2,976
Total # Public Interfaces	2,379
Total # Vulnerable Interfaces	597

Distribution of the Vulnerable Interfaces



Detailed Results for Top Tested App in Each Category

Category	Package Name	# Activities	# Views	Time to Login (s)	#Request Messages	#Mutated Fields	#Public Interfaces	#Vulnerable Interfaces
Books & Reference	com.***.e***	3	288	45	975	16	5	3
Business	com.***.k***	8	1,224	30	927	12	2	3
Communication	com.***.w***	18	970	41	727	1	0	1
Entertainment	com.***.c***	3	184	32	739	2	0	1
Finance	com.***.m***	8	549	16	790	7	0	2
Food & Drink	com.***.h***	10	924	21	1,032	8	4	1
Games	com.***.c***	7	609	20	1,050	7	3	1
Health & Fitness	com.***.u***	12	788	15	966	10	2	2
Lifestyle	com.m***	17	1,938	25	1,229	29	5	5
Maps & Navigation	com.******.c***	11	667	26	490	12	7	1
Medical	com.***.a***	18	1,616	23	927	9	2	1
Music & Audio	com.b***	2	456	25	933	15	3	1
News & Magazines	com.***.a***	5	462	37	880	9	0	2
Photography	com.***.j***	15	909	26	965	7	0	1
Productivity	com.***.d***	15	1,347	32	882	10	5	1
Shopping	cl.******.i***	8	795	44	961	10	0	5
Social	in.v***	10	645	20	1,068	20	4	5
Tools	com.mediaingea.uptodown.lite	7	1,347	112	1,276	25	6	1
Travel & Local	com.t***	5	321	35	1,024	10	0	2
Video Players & Editors	cz.***.n***	4	218	25	821	5	1	1

User Privacy & Vulnerability Details

Category	Detailed Privacy Type
User E-Profile	⑴ Email, ⑵ User ID, ⑶ Registration Date, ⑷ IP Address, ⑸ Last Login Date, ⑹ Last Update Date
User Physical-Profile	⑺ Real Name, ⑻ Birthday, ⑼ Geo-location, ⑽ Home Address, ⑾ Phone Number, ⑿ Body Information
User Secrets	⒀ Token, ⒁ Password, ⒂ Pass Code
App Specific Private Data	⒃ In App Messages, ⒄ Shopping History, ⒅ Book Shelf, ⒆ Favorites or Subscription, ⒇ Account Balance
	(21) Contacts Information, (22) Payment Information, (23) Private Activity Information

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App Specific Private Data	⒃ In App Messages, ⒄ Shopping History, ⒅ Book Shelf, ⒆ Favorites or Subscription, ⒇ Account Balance ㉑ Contacts Information, ㉒ Payment Information, ㉓ Private Activity Information

APP	Version	Credential Type	User E-Profile	User Physical-Profile	User Secrets	App Specific Private Data
com.***.e***	2.2	N	⑴⑵	⑺⑻ ⑽⑾		⑱
com.***.k***	2.0.11	E	⑴⑵⑶⑷ ⑹	⑺ ⑼⑽⑾	⒀⒁	⑰ ⑲
com.***.w***	1.0.5	F	⑴⑵	⑺	⒀	⑯ ⑲ ㉑
com.g***.c***	2.4.1	E	⑴⑵	⑾	⒀	⑰ ⑳
com.***.m***	1.6.8	N	⑴⑵	⑺ ⑼⑽⑾	⒂	⑯ ⑳ ㉒
com.***.h***	2.5.6.0	E	⑴⑵		⒀	⑯ ⑲
com.***.c***	2.6.1	F	⑴	⑺ ⑽	⒀	⑲
com.***.u***	2.03	N	⑴⑵⑶	⑺⑻ ⑿		⑯ ⑲
com.m***	7.3.0	N	⑵	⑺⑻ ⑽		⑯ ⑲⑳
com.******.c***	7.5.5v	F	⑴⑵	⑺ ⑼⑽⑾	⒀	⑲ ㉒
com.***.a***	3.09	F	⑴⑵	⑺	⒀	⑯ ⑲
com.b***	2.0.4	N				⑲
com.***.a***	2.3.2	N	⑴ ⑶⑷⑸	⑺⑻⑼	⒀	⑯ ⑲
com.***.j***	2.7.4	F	⑴⑵⑶	⑺	⒀	⑯ ⑲
com.***.d***	2.4.2	E	⑵⑶	⑺ ⑼	⒀	㉓
cl.******.i***	2.1.0	N	⑴⑵	⑺⑻⑼		⑳
in.v***	4.4.5.2	N		⑺⑻		⑯ ⑲ ㉑
com.mediaingea.uptodown.lite	3.18	F	⑵		⒀	⑯ ⑲
com.t***	1.4.0	F	⑴⑵	⑽⑾	⒀	⑯ ㉓
cz.***.n***	4.8	F	⑵	⑺	⒀	㉓
Statistics		8 4 8	14 16 05 02 01 01	15 06 06 07 06 01	13 01 01	11 02 01 13 04 02 02 03

Impact

Up to **61 MILLION** mobile users

Case Study-App K


```
00 {
01  "pk_i_id": "163126",
02  "dt_reg_date": "2017-04-30 23:21:59",
03  "dt_mod_date": "2017-04-30 23:36:58",
04  "s_name": "Bob Ccs",
05  "s_username": "163126",
06  "s_password": "7c4a8d09ca3762af61e59520943dc26494f8941b",
07  "s_secret": "6stgMaAb",
08  "s_email": "bob4testapp@gmail.com",
09  "s_website": "bob.ccs\/index.html",
10  "s_phone_mobile": "4695855213",
11  "s_pass_ip": null,
12  "fk_c_country_code": null,
13  "s_country": "Tanzania",
14  "s_address": "15246 Sni Rd. APT 252 Tanzania",
15  "fk_i_region_id": "17",
16  "s_region": "Mara",
17  "d_coord_lat": null,
18  "d_coord_long": null,
19  "b_company": "0",
20  "i_items": "1",
21  "i_comments": "0",
22  "dt_access_date": "2017-04-30 23:46:05",
23  "s_access_ip": "",
24  "b_prefer_phone": "1",
25  "s_dialing_code": "+255",
26  "fk_i_category_id": "22",
27  "s_facebook_page": "http:\/\/",
28  ...
29 }
```

Case Study-App K

User Privacy

Password

```
00 {
01  "pk_i_id": "163126",
02  "dt_reg_date": "2017-04-30 23:21:59",
03  "dt_mod_date": "2017-04-30 23:36:58",
04  "s_name": "Bob Ccs",
05  "s_username": "163126",
06  "s_password": "7c4a8d09ca3762af61e59520943dc26494f8941b",
07  "s_secret": "6stgMaAb",
08  "s_email": "bob4testapp@gmail.com",
09  "s_website": "bob.ccs\/index.html",
10  "s_phone_mobile": "4695855213",
11  "s_pass_ip": null,
12  "fk_c_country_code": null,
13  "s_country": "Tanzania",
14  "s_address": "15246 Sni Rd. APT 252 Tanzania",
15  "fk_i_region_id": "17",
16  "s_region": "Mara",
17  "d_coord_lat": null,
18  "d_coord_long": null,
19  "b_company": "0",
20  "i_items": "1",
21  "i_comments": "0",
22  "dt_access_date": "2017-04-30 23:46:05",
23  "s_access_ip": "",
24  "b_prefer_phone": "1",
25  "s_dialing_code": "+255",
26  "fk_i_category_id": "22",
27  "s_facebook_page": "http:\/\/",
28  ...
29 }
```

Case Study-App K

User Privacy
Registration Date
Last Update Date
User ID
Email


```
00 {
01  "pk_i_id": "163126",
02  "dt_reg_date": "2017-04-30 23:21:59",
03  "dt_mod_date": "2017-04-30 23:36:58",
04  "s_name": "Bob Ccs",
05  "s_username": "163126",
06  "s_password": "7c4a8d09ca3762af61e59520943dc26494f8941b",
07  "s_secret": "6stgMaAb",
08  "s_email": "bob4testapp@gmail.com",
09  "s_website": "bob.ccs\/index.html",
10  "s_phone_mobile": "4695855213",
11  "s_pass_ip": null,
12  "fk_c_country_code": null,
13  "s_country": "Tanzania",
14  "s_address": "15246 Sni Rd. APT 252 Tanzania",
15  "fk_i_region_id": "17",
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17  "d_coord_lat": null,
18  "d_coord_long": null,
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28  ...
29 }
```

Case Study-App K

User Privacy
Real Name
Phone Number
Home Address
Geo Location


```
00 {
01  "pk_i_id": "163126",
02  "dt_reg_date": "2017-04-30 23:21:59",
03  "dt_mod_date": "2017-04-30 23:36:58",
04  "s_name": "Bob Ccs",
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08  "s_email": "bob4testapp@gmail.com",
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13  "s_country": "Tanzania",
14  "s_address": "15246 Sni Rd. APT 252 Tanzania",
15  "fk_i_region_id": "17",
16  "s_region": "Mara",
17  "d_coord_lat": null,
18  "d_coord_long": null,
19  "b_company": "0",
20  "i_items": "1",
21  "i_comments": "0",
22  "dt_access_date": "2017-04-30 23:46:05",
23  "s_access_ip": "",
24  "b_prefer_phone": "1",
25  "s_dialing_code": "+255",
26  "fk_i_category_id": "22",
27  "s_facebook_page": "http:\/\/",
28  ...
29 }
```

Case Study-App I

```
00 {
01  ...
02  "response":{
03   "user":{
04    "idnum":false,
05    "name":"Bob",
06    "lastname":"Ccs",
07    "birthday":"1990-04-26",
08    "gender":"M",
09    "email":"bob4testapp@gmail.com",
10    "type":"EMAIL",
11    "firstlogin":"1",
12    "country":{
13     "id":"10",
14     "name":"United States",
15     ...
16    },
17    "post_on_activities":"disabled",
18    "bananas_count":0,
19    "id":"673491",
20    "fbid_number":"106611716575863",
21    "current_latitude":”30.9863214",
22    "current_longitude":”-86.7501116",
23    "bananas_history":"https:\/\/profile.i******.com\/bananas\
/store\/673491\/?accesstoken=debda35ccd92f4b8e2e06f0bff3b6e49279
a557d&latitude=30.9863214&longitude=-86.7501116&lang=",
24    ...
25   }
26  }
27 }
```

Case Study-App I

User Privacy

Email

User ID

```
00 {
01  ...
02  "response":{
03   "user":{
04    "idnum":false,
05    "name":"Bob",
06    "lastname":"Ccs",
07    "birthday":"1990-04-26",
08    "gender":"M",
09    "email":"bob4testapp@gmail.com",
10    "type":"EMAIL",
11    "firstlogin":"1",
12    "country":{
13     "id":"10",
14     "name":"United States",
15     ...
16    },
17    "post_on_activities":"disabled",
18    "bananas_count":0,
19    "id":"673491",
20    "fbid_number":"106611716575863",
21    "current_latitude":”30.9863214",
22    "current_longitude":”-86.7501116",
23    "bananas_history":"https:\/\/profile.i******.com\/bananas\
/store\/673491\/?accesstoken=debda35ccd92f4b8e2e06f0bff3b6e49279
a557d&latitude=30.9863214&longitude=-86.7501116&lang=",
24    ...
25   }
26  }
27 }
```

Case Study-App I

User Privacy

Real Name

Birthday

Geo Location

```
00 {
01  ...
02  "response":{
03   "user":{
04    "idnum":false,
05    "name":"Bob",
06    "lastname":"Ccs",
07    "birthday":"1990-04-26",
08    "gender":"M",
09    "email":"bob4testapp@gmail.com",
10    "type":"EMAIL",
11    "firstlogin":"1",
12    "country":{
13     "id":"10",
14     "name":"United States",
15     ...
16    },
17    "post_on_activities":"disabled",
18    "bananas_count":0,
19    "id":"673491",
20    "fbid_number":"106611716575863",
21    "current_latitude":”30.9863214",
22    "current_longitude":”-86.7501116",
23    "bananas_history":"https:\/\/profile.i******.com\/bananas\
/store\/673491\/?accesstoken=debda35ccd92f4b8e2e06f0bff3b6e49279
a557d&latitude=30.9863214&longitude=-86.7501116&lang=",
24    ...
25   }
26  }
27 }
```

Case Study-App I

User Privacy

Account Balance

```
00 {
01  ...
02  "response":{
03   "user":{
04    "idnum":false,
05    "name":"Bob",
06    "lastname":"Ccs",
07    "birthday":"1990-04-26",
08    "gender":"M",
09    "email":"bob4testapp@gmail.com",
10    "type":"EMAIL",
11    "firstlogin":"1",
12    "country":{
13     "id":"10",
14     "name":"United States",
15     ...
16    },
17    "post_on_activities":"disabled",
18    "bananas_count":0,
19    "id":"673491",
20    "fbid_number":"106611716575863",
21    "current_latitude":"30.9863214",
22    "current_longitude":"-86.7501116",
23    "bananas_history":"https:\/\/profile.i******.com\/bananas\
/store\/673491\/?accesstoken=debda35ccd92f4b8e2e06f0bff3b6e49279
a557d&latitude=30.9863214&longitude=-86.7501116&lang=",
24    ...
25   }
26  }
27 }
```

Limitation and Future work

Limitations

- Only Facebook Login
- Only authrization vulnerabilities that leads to information leakage and account hijacking
- Only Android Platform and HTTP/HTTPS protocol

Limitation and Future work

Limitations

- Only Facebook Login
- Only authrization vulnerabilities that leads to information leakage and account hijacking
- Only Android Platform and HTTP/HTTPS protocol

Future Work

- Addressing the first two limitations
- Extend to other platforms and protocols

Related Work

- **Vulnerability Discovery in Online Service.** SQL injection [HVO06], cross-site-scripting [VNJ+07], cross-site-forgery [BJM08], broken authentication [DKZ09], application logic vulnerabilities [WCWQ11, PB14, WZC+13, XCWC13]
- **Access Control in Online Service.** security with single-sign on [WCW12, ZE14], oauth [SB12, CPC+14], authentication vulnerability scanning [BLM+13], password brute-force attacks with online services [ZWWL16]

Related Work

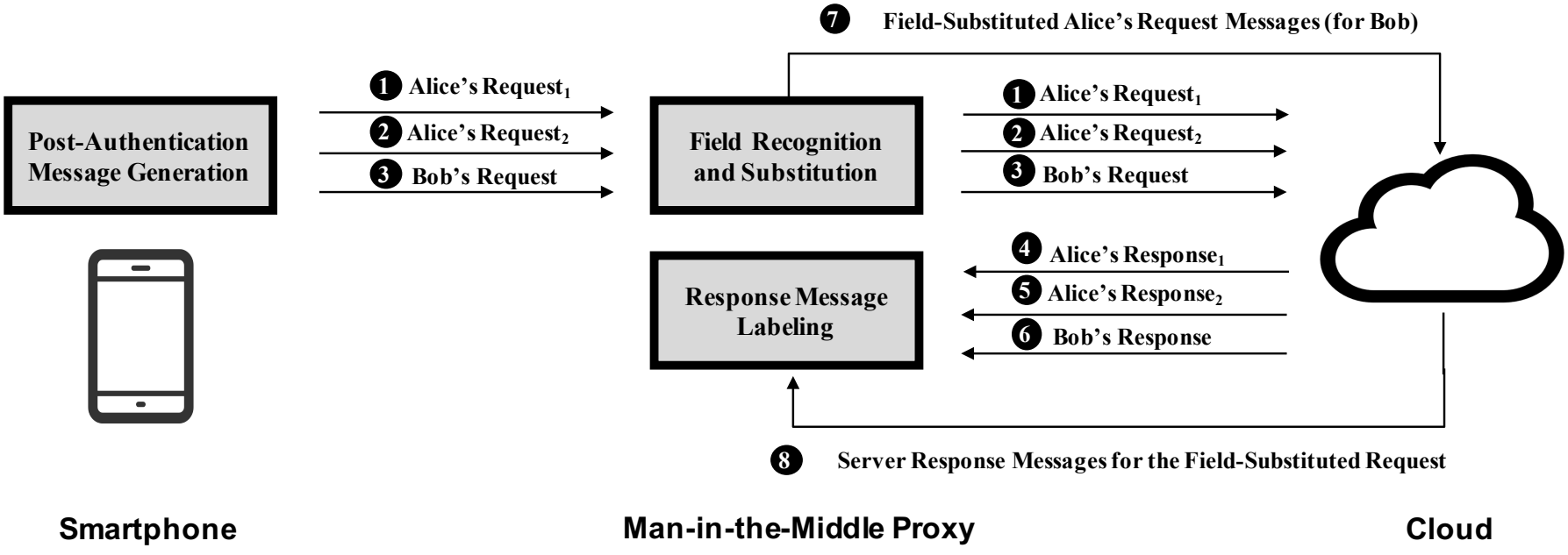
- **Dynamic Analysis of Mobile Apps.** Monkey [mon17], Robotium [Rob], AppsPlayground [RCE13], DynoDroid [MTN13], symbolic execution [ANHY12, MMP+12, WL16, ZL17]
- **Protocol Reverse Engineering.** Analyzing network messages [Bed17, MLK+06, CKW07, CFL+17], and instructions traces [CS07, WMKK08, LJXZ08, LZ08, CPC+08, MWKK09] to discover protocol formats. Inspired by the protocol informatics project [Bed17], and uses a customized Needleman-Wunsch algorithm [NW70] to align and diff the protocol messages and infer only the fields of our interest.

Conclusion

AUTHSCOPE

- Automatically identify whether an app's server is vulnerable to access control violation
- 597 vulnerable implementations in 306 mobile apps over 4,838 apps

Thank you



To contact us

{chaoshun.zuo, qingchuan.zhao, zhiqiang.lin}@utdallas.edu

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