qoe-final

February 21, 2017

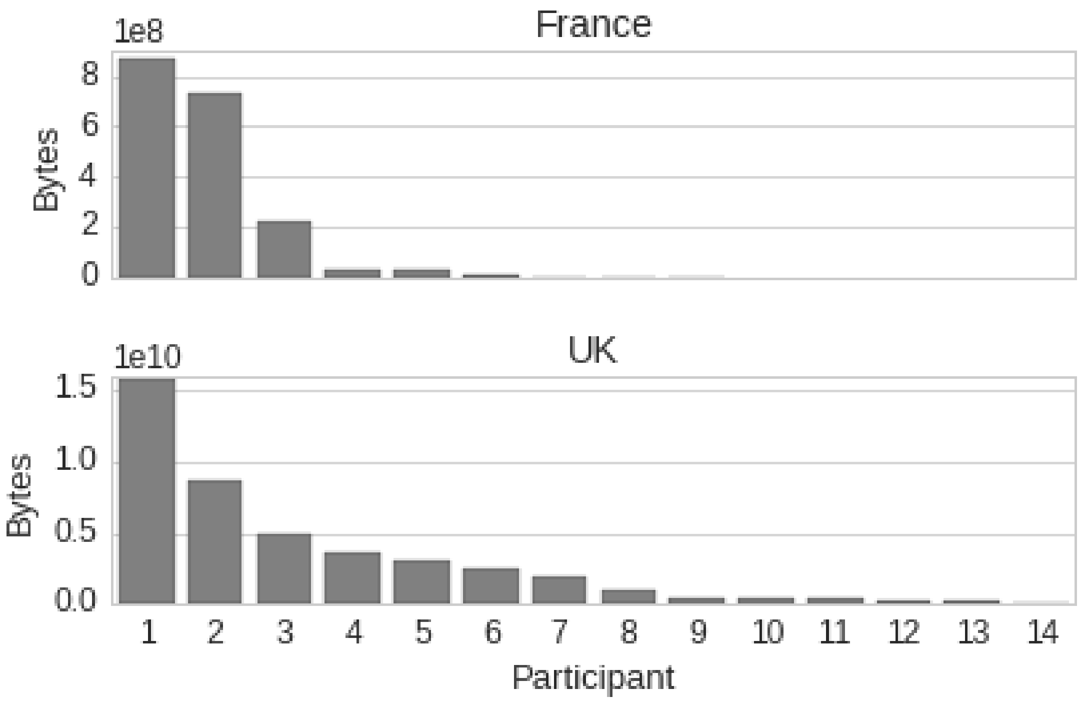
```
In [68]: import numpy as np
         import scipy as sci
         import pandas as pd
         import ipaddress
         import re

         from collections import defaultdict, Counter
         from datetime import datetime, timedelta

         import seaborn as sns
         import matplotlib.pyplot as plt
         %matplotlib inline

         from bokeh.plotting import figure, show, output_notebook
         from bokeh.charts import *
         output_notebook()

         from sqlalchemy import create_engine, text, func, or_, and_, not_, distinct
         from sqlalchemy.orm import sessionmaker
         from sqlalchemy.pool import NullPool

         from model.Base import Base
         from model.User import User
         from model.Device import Device
         from model.DeviceTraffic import DeviceTraffic
         from model.DeviceAppTraffic import DeviceAppTraffic
         from model.HttpReq import HttpReq
         from model.DnsReq import DnsReq
         from model.Location import Location
         from model.user_devices import user_devices;

         import datautils

         DB='postgresql+psycopg2:///ucnstudy'

         engine = create_engine(DB, echo=False, poolclass=NullPool)
         Base.metadata.bind = engine
```

```
Session = sessionmaker(bind=engine)

sns.set(style="whitegrid", context="paper", font_scale=1.5)
palette = sns.light_palette("grey", n_colors=8, reverse=True)
revpalette = sns.light_palette("grey", n_colors=8, reverse=False)
sns.set_palette(palette)
sns.set_color_codes()

cmap = sns.light_palette("grey", as_cmap=True)
```

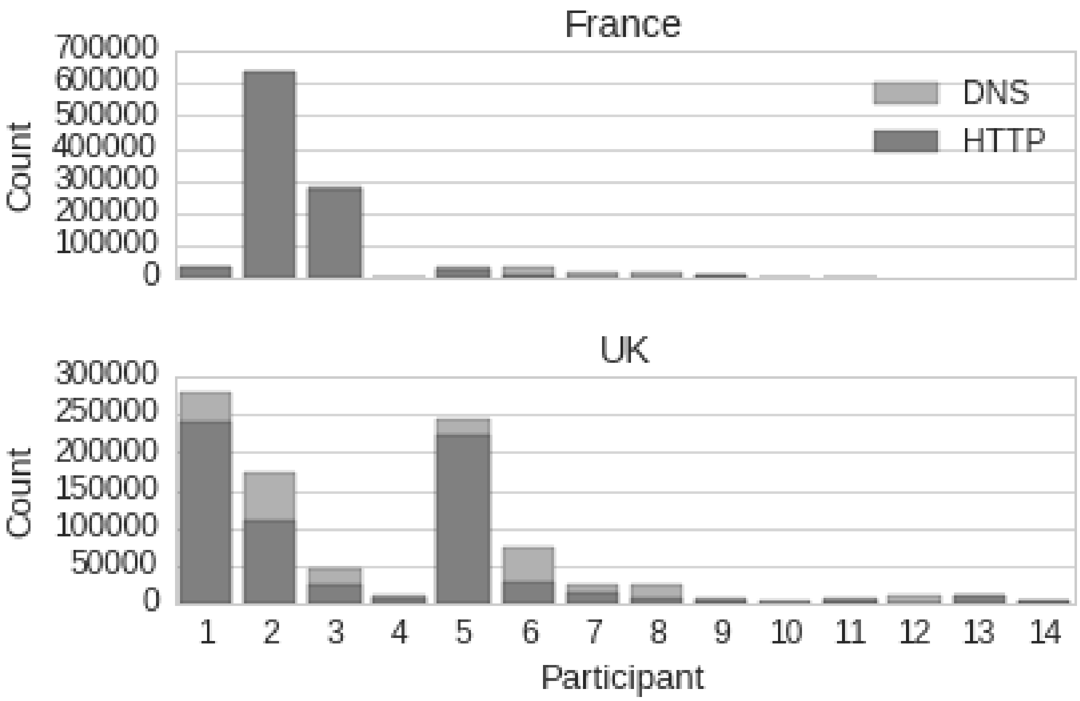
In [38]:
```
# For section2: basic data set
ses = Session()

data = defaultdict(list)
for u in ses.query(User).all():
    devs = [d.id for d in u.devices if not d.shared]

    data['uid'].append(u.id)
    data['devsmobile'].append(len([d.id for d in u.devices if not d.shared and (d.devty
    data['devstablet'].append(len([d.id for d in u.devices if not d.shared and (d.devty
    data['devspc'].append(len([d.id for d in u.devices if not d.shared and (d.devtype =
    data['devslaptop'].append(len([d.id for d in u.devices if not d.shared and (d.devty
    data['devs'].append(len(devs))
    data['cc'].append(u.country)

    bytes = ses.query(func.sum(DeviceAppTraffic.bytes_in)+func.sum(DeviceAppTraffic.byt
                DeviceAppTraffic.devid.in_(devs)).scalar()
    data['bytes'].append(bytes)

    dns = ses.query(func.count(DnsReq.ts)).filter(DnsReq.devid.in_(devs)).scalar()
    data['dns'].append(dns)

    http = ses.query(func.count(HttpReq.ts)).filter(HttpReq.devid.in_(devs)).scalar()
    data['http'].append(http)

    data['app'].append(http+dns)

ses.close()

df = pd.DataFrame(data, index=range(0,len(data['uid']),1))
df = df.sort_values('bytes', ascending=False)
df['rank'] = list(range(1, len(df['uid'])+1, 1))
```

In [28]:
```
# FRANCE
df1 = df[df['cc']=='fr'].sort_values('bytes', ascending=False)
df1['x'] = list(range(1, len(df1['uid'])+1, 1))

# UK
```

```
         df2 = df[df['cc']=='uk'].sort_values('bytes', ascending=False)
         df2['x'] = list(range(1, len(df2['uid'])+1, 1))

In [72]: f, ((ax1),(ax2)) = plt.subplots(2, 1, figsize=(6, 4), sharex=True)

         sns.barplot(data=df1, x='x', y='bytes', ax=ax1, color=palette[0])
         ax1.set_ylabel("Bytes")
         #ax1.set_yscale('log')
         ax1.set_yticks([y*1e8 for y in np.arange(0.0,10.0,2.0)])
         #ax1.set_yticklabels([y*1e9 for y in np.arange(0.0,2.0,0.25)])
         ax1.set_xlabel("")
         ax1.set_title("France")

         sns.barplot(data=df2, x='x', y='bytes', ax=ax2, color=palette[0])
         ax2.set_ylabel("Bytes")
         #ax2.set_yscale('log')
         ax2.set_yticks([y*1e9 for y in np.arange(0.0,20.0,5.0)])
         #ax2.set_yticklabels([y*1e1 for y in np.arange(0.0,2.0,0.25)])
         ax2.set_xlabel("Participant")
         ax2.set_title("UK")

         plt.tight_layout()
         f.savefig("../figs/dataset_traffic.eps")
```



```
In [73]: f, ((ax1),(ax2)) = plt.subplots(2, 1, figsize=(6, 4), sharex=True)

         sns.barplot(data=df1, x='x', y='app', ax=ax1, color=palette[3], label='DNS')
         sns.barplot(data=df1, x='x', y='http', ax=ax1, color=palette[0], label='HTTP')
         ax1.set_ylabel("Count")
         #ax1.set_yscale('log')
         ax1.set_xlabel("")
         ax1.set_title("France")
         ax1.legend(loc='best')

         sns.barplot(data=df2, x='x', y='app', ax=ax2, color=palette[3], label='DNS')
         sns.barplot(data=df2, x='x', y='http', ax=ax2, color=palette[0], label='HTTP')
         ax2.set_ylabel("Count")
         #ax2.set_yscale('log')
         ax2.set_xlabel("Participant")
         ax2.set_title("UK")

         plt.tight_layout()
         f.savefig("../figs/dataset_appact.eps")
```



```
In [76]: frselected = df1['uid'].head(6)
         ukselected = df2['uid'].head(8)

         devsperuser = {}
```

```
selecteddevs = []
for u in ses.query(User).filter(or_(User.id.in_(frselected),User.id.in_(ukselected))).a
    udevs = [d.id for d in u.devices if not d.shared]
    devsperuser[u.id] = udevs
    selecteddevs += udevs

print 'users', len(devsperuser), 'devices',len(selecteddevs)

# sorted order from above
sortedusers = [uid for uid in df['uid'] if uid in devsperuser]

totalbytes = ses.query(
        func.sum(DeviceAppTraffic.bytes_in)).filter(DeviceAppTraffic.devid.in_(selected
        func.sum(DeviceAppTraffic.bytes_out)).filter(DeviceAppTraffic.devid.in_(selecte

totalhttpbytes = ses.query(
        func.sum(DeviceAppTraffic.bytes_in)).filter(
            DeviceAppTraffic.devid.in_(selecteddevs),
            or_(DeviceAppTraffic.dstport==80,DeviceAppTraffic.srcport==80)).scalar() +
        func.sum(DeviceAppTraffic.bytes_out)).filter(
            DeviceAppTraffic.devid.in_(selecteddevs),
            or_(DeviceAppTraffic.dstport==80,DeviceAppTraffic.srcport==80)).scalar()


totalhttpsbytes = ses.query(
        func.sum(DeviceAppTraffic.bytes_in)).filter(
            DeviceAppTraffic.devid.in_(selecteddevs),
            or_(DeviceAppTraffic.dstport==443,DeviceAppTraffic.srcport==443)).scalar()
        func.sum(DeviceAppTraffic.bytes_out)).filter(
            DeviceAppTraffic.devid.in_(selecteddevs),
            or_(DeviceAppTraffic.dstport==443,DeviceAppTraffic.srcport==443)).scalar()

#print totalbytes,totalhttpbytes,totalhttpsbytes
print 'http traffic (%)',100.0*totalhttpbytes/totalbytes
print 'https traffic (%)',100.0*totalhttpsbytes/totalbytes
print 'http+https traffic (%)',100.0*(totalhttpsbytes+totalhttpbytes)/totalbytes
```

```
users 14 devices 27
http traffic (%) 28.3749635991
https traffic (%) 68.3376883216
http+https traffic (%) 96.7126519207
```

```
In [43]: # construct top-x locations per traffic,app,user for each user

         # uid => location => bytes
         trafficperloc = {}
```

```
# uid => location => dns+http reqs
appperloc = {}

# uid => location => user reqs
userperloc = {}

ses = Session()
for uid in sortedusers:
    for devid in devsperuser[uid]:
        trafficperloc[devid] = defaultdict(long)
        appperloc[devid] = defaultdict(long)
        userperloc[devid] = defaultdict(long)

    q = ses.query(func.sum(DeviceAppTraffic.bytes_in+DeviceAppTraffic.bytes_out),
                     Location.name, Location.devid).join(Location,
                        and_(DeviceAppTraffic.devid==Location.devid,
                             DeviceAppTraffic.ts>=Location.entertime,
                             DeviceAppTraffic.ts<=Location.exittime)).filter(
                                Location.devid.in_(devsperuser[uid]),Location.overlap==
    for row in q.all():
        loc = row[1]
        if (loc==None):
            loc = "default"
        trafficperloc[row[2]][loc] = row[0]

    q = ses.query(func.count(DnsReq.ts),
                  Location.name, Location.devid).join(Location,
                        and_(DnsReq.devid==Location.devid,
                             DnsReq.ts>=Location.entertime,
                             DnsReq.ts<=Location.exittime)).filter(
                                Location.devid.in_(devsperuser[uid]),Location.overlap==

    for row in q.all():
        loc = row[1]
        if (loc==None):
            loc = "default"
        appperloc[row[2]][loc] += row[0]

    q = ses.query(func.count(HttpReq.ts),
                  Location.name, Location.devid).join(Location,
                        and_(HttpReq.devid==Location.devid,
                             HttpReq.ts>=Location.entertime,
                             HttpReq.ts<=Location.exittime)).filter(
                                Location.devid.in_(devsperuser[uid]),Location.overlap==
    for row in q.all():
        loc = row[1]
        if (loc==None):
            loc = "default"
        appperloc[row[2]][loc] += row[0]


    q = ses.query(func.count(DnsReq.ts),
                  Location.name, Location.devid).join(Location,
                        and_(DnsReq.devid==Location.devid,
                             DnsReq.ts>=Location.entertime,
                             DnsReq.ts<=Location.exittime)).filter(
                                DnsReq.devid.in_(devsperuser[uid]),
                                DnsReq.user_req==True,
                                DnsReq.duplicate==False,
                                Location.overlap==False).group_by(Location.name, Locati
    for row in q.all():
        loc = row[1]
        if (loc==None):
            loc = "default"
        userperloc[row[2]][loc] += row[0]

    q = ses.query(func.count(HttpReq.ts),
                  Location.name, Location.devid).join(Location,
                        and_(HttpReq.devid==Location.devid,
                             HttpReq.ts>=Location.entertime,
                             HttpReq.ts<=Location.exittime)).filter(
                                HttpReq.devid.in_(devsperuser[uid]),
                                HttpReq.user_url==True,
                                Location.overlap==False).group_by(Location.name, Locati
    for row in q.all():
        loc = row[1]
        if (loc==None):
            loc = "default"
        userperloc[row[2]][loc] += row[0]
ses.close()
```

In [44]:

```
ses = Session()

# get total traffic per device
devtotals = defaultdict(lambda : defaultdict(float))

q = ses.query(DeviceAppTraffic.devid,
              func.sum(DeviceAppTraffic.bytes_in)+func.sum(DeviceAppTraffic.bytes_out))
                 DeviceAppTraffic.devid.in_(selecteddevs)).group_by(DeviceAppTraffic.de
for row in q.all():
    devid = str(row[0])
    devtotals[devid]['bytes'] = row[1]*1.0

# DNS reqs (all) per device
q = ses.query(DnsReq.devid,
              func.count(DnsReq.devid)).filter(DnsReq.devid.in_(selecteddevs)).group_by
```

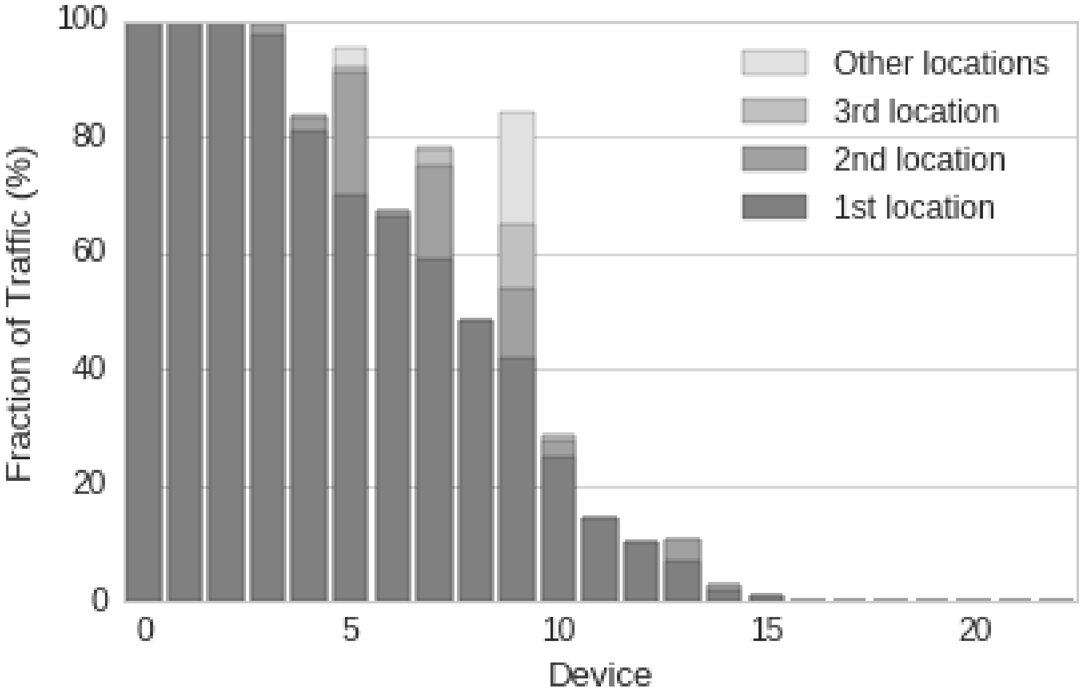
```
                                 DnsReq.devid)
         for row in q.all():
             devid = str(row[0])
             devtotals[devid]['dns_all'] = row[1]*1.0

         # filtered DNS reqs
         q = ses.query(DnsReq.devid,
                       func.count(DnsReq.devid)).filter(DnsReq.devid.in_(selecteddevs)).filter(
                             DnsReq.user_req==True).group_by(
                                 DnsReq.devid)
         for row in q.all():
             devid = str(row[0])
             devtotals[devid]['dns_filt1'] = row[1]*1.0


         # filtered DNS reqs
         q = ses.query(DnsReq.devid,
                       func.count(DnsReq.devid)).filter(DnsReq.devid.in_(selecteddevs)).filter(
                             DnsReq.user_req==True).filter(DnsReq.duplicate==False).group_by(
                                 DnsReq.devid)
         for row in q.all():
             devid = str(row[0])
             devtotals[devid]['dns_filt2'] = row[1]*1.0



         # HTTP reqs (all) per device
         q = ses.query(HttpReq.devid,
                       func.count(HttpReq.devid)).filter(HttpReq.devid.in_(selecteddevs)).group_
                                 HttpReq.devid)
         for row in q.all():
             devid = str(row[0])
             devtotals[devid]['http_all'] = row[1]*1.0

         # filtered HTTP reqs
         q = ses.query(HttpReq.devid,
                       func.count(HttpReq.devid)).filter(HttpReq.devid.in_(selecteddevs)).filter
                             HttpReq.user_url==True).group_by(HttpReq.devid)
         for row in q.all():
             devid = str(row[0])
             devtotals[devid]['http_filt'] = row[1]*1.0

In [75]: # Build activity data for top-x locations
         TOPX=3

         data = defaultdict(list)
         for devid in selecteddevs:
             allbytes = devtotals[str(devid)]['bytes']
```

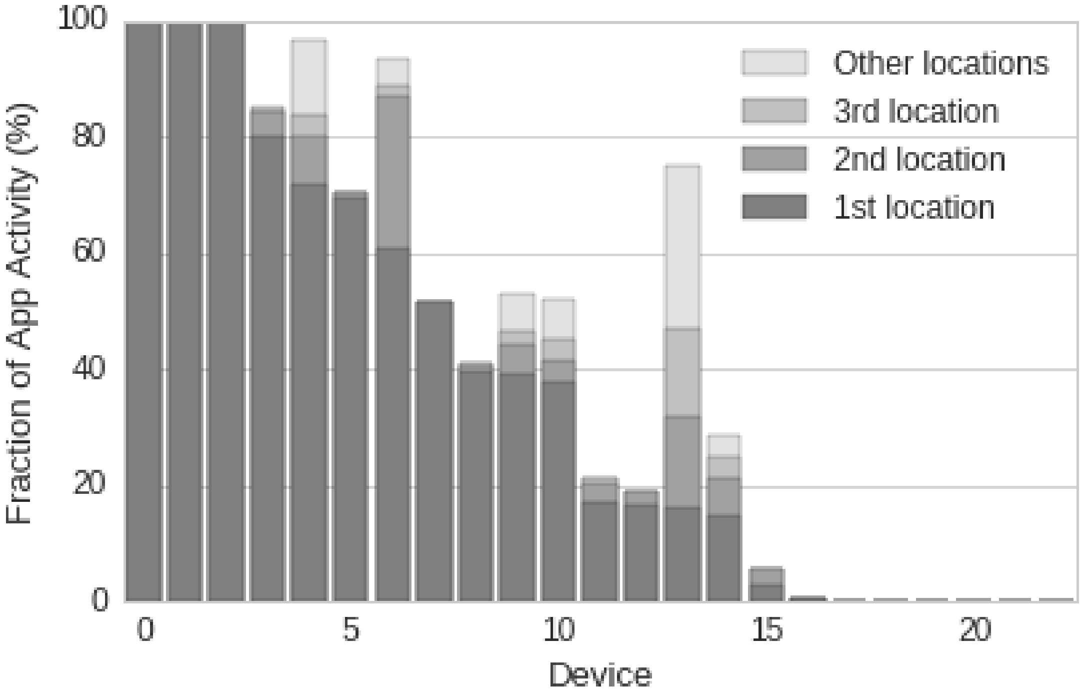
```
        allappbytes = devtotals[str(devid)]['dns_all']+devtotals[str(devid)]['http_all']
        alluserbytes = devtotals[str(devid)]['dns_filt2']+devtotals[str(devid)]['http_filt'
        if (allbytes == 0):
            continue

        data['devid'].append(devid)
        data['bytes'].append(allbytes)

        # if we've only ever seen a single location
        # from this device => assume stationary and flag all from that loc
        locs = ses.query(Location.name, func.count(Location.id)).filter(
                Location.devid==devid).group_by(Location.name).all()

        # top three traffic
        if (len(locs)>1):
            # been in more than one loc

            for i,loc in enumerate(sorted(trafficperloc[devid].keys(), key=lambda x : traff
                data['tloc%d'%(i+1)].append(100.0 * (trafficperloc[devid][loc]*1.0/allbytes
            i = min(len(trafficperloc[devid]),3)
            while (i<3):
                data['tloc%d'%(i+1)].append(0.0)
                i += 1

            bc = 0.0
            for i,loc in enumerate(sorted(trafficperloc[devid].keys(), key=lambda x : traff
                bc += trafficperloc[devid][loc]*1.0
            data['tloco'].append(100.0*(bc/allbytes))

            # top three app
            for i,loc in enumerate(sorted(appperloc[devid].keys(), key=lambda x : appperloc
                data['aloc%d'%(i+1)].append(100.0 * (appperloc[devid][loc]*1.0/allappbytes)
            i = min(len(appperloc[devid]),3)
            while (i<3):
                data['aloc%d'%(i+1)].append(0.0)
                i += 1

            bc = 0.0
            for i,loc in enumerate(sorted(appperloc[devid].keys(), key=lambda x : appperloc
                bc += appperloc[devid][loc]*1.0
            data['aloco'].append(100.0*(bc/allappbytes))


            # top three user
            for i,loc in enumerate(sorted(userperloc[devid].keys(), key=lambda x : userperl
                data['uloc%d'%(i+1)].append(100.0 * (userperloc[devid][loc]*1.0/alluserbyte
            i = min(len(userperloc[devid]),3)
            while (i<3):
```

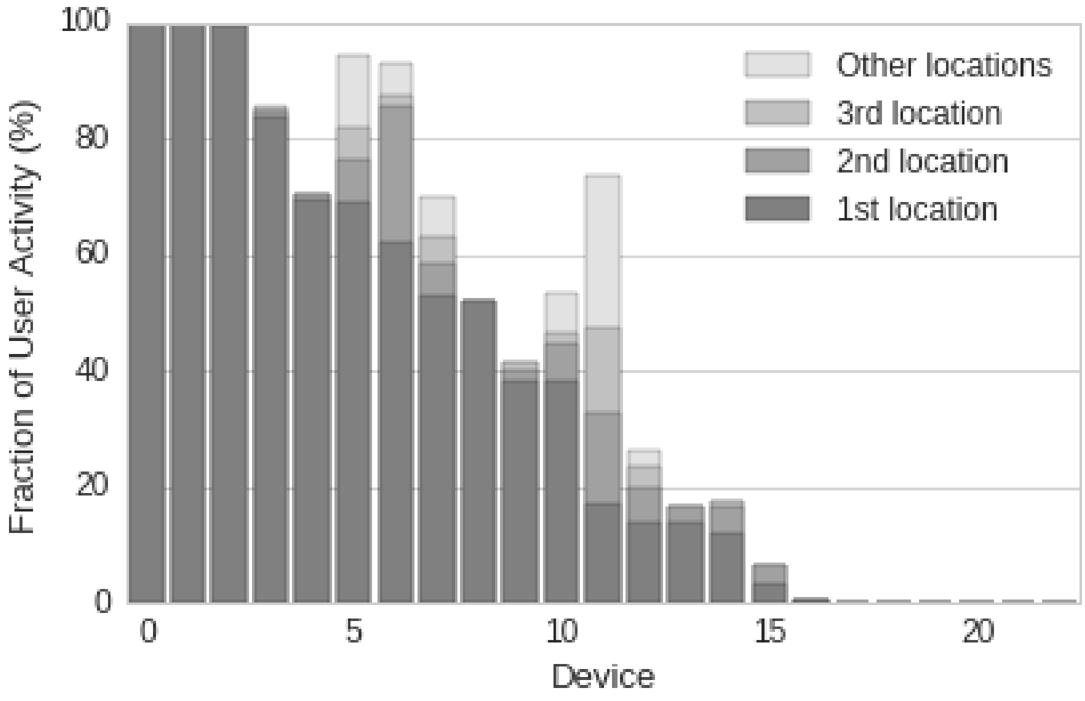
```
            data['uloc%d'%(i+1)].append(0.0)
            i += 1

        bc = 0.0
        for i,loc in enumerate(sorted(userperloc[devid].keys(), key=lambda x : userperl
            bc += userperloc[devid][loc]*1.0
        data['uloco'].append(100.0*(bc/alluserbytes))

    elif (len(locs)==1):
        # single location device

        data['tloc1'].append(100.0)
        data['tloc2'].append(0.0)
        data['tloc3'].append(0.0)
        data['tloco'].append(0.0)

        data['aloc1'].append(100.0)
        data['aloc2'].append(0.0)
        data['aloc3'].append(0.0)
        data['aloco'].append(0.0)

        data['uloc1'].append(100.0)
        data['uloc2'].append(0.0)
        data['uloc3'].append(0.0)
        data['uloco'].append(0.0)

    else:
        # no loc

        data['tloco'].append(0.0)
        data['tloc1'].append(0.0)
        data['tloc2'].append(0.0)
        data['tloc3'].append(0.0)

        data['aloco'].append(0.0)
        data['aloc1'].append(0.0)
        data['aloc2'].append(0.0)
        data['aloc3'].append(0.0)

        data['uloco'].append(0.0)
        data['uloc1'].append(0.0)
        data['uloc2'].append(0.0)
        data['uloc3'].append(0.0)

#for k in data:
#    print k,len(data[k])

ldf = pd.DataFrame(data)
```

```
# stacked fractions
ldf['tloc2st'] = ldf['tloc1']+ldf['tloc2']
ldf['tloc3st'] = ldf['tloc1']+ldf['tloc2']+ldf['tloc3']
ldf['tlocost'] = ldf['tloc1']+ldf['tloc2']+ldf['tloc3']+ldf['tloco']
ldf['tlocna'] = 100.0

ldf['aloc2st'] = ldf['aloc1']+ldf['aloc2']
ldf['aloc3st'] = ldf['aloc1']+ldf['aloc2']+ldf['aloc3']
ldf['alocost'] = ldf['aloc1']+ldf['aloc2']+ldf['aloc3']+ldf['aloco']
ldf['alocna'] = 100.0

ldf['uloc2st'] = ldf['uloc1']+ldf['uloc2']
ldf['uloc3st'] = ldf['uloc1']+ldf['uloc2']+ldf['uloc3']
ldf['ulocost'] = ldf['uloc1']+ldf['uloc2']+ldf['uloc3']+ldf['uloco']
ldf['ulocna'] = 100.0

ses.close()
```

```
In [77]: # For section4: Device use vs locations
         f, ax1 = plt.subplots(1, 1, figsize=(6, 4))

         ldf = ldf.sort_values('tloc1', ascending=False)
         ldf['rank'] = list(range(len(data['devid'])))

         sns.barplot(data=ldf, x='rank', y='tlocost', ax=ax1, orient='v', color=palette[6], labe
         sns.barplot(data=ldf, x='rank', y='tloc3st', ax=ax1, orient='v', color=palette[4], labe
         sns.barplot(data=ldf, x='rank', y='tloc2st', ax=ax1, orient='v', color=palette[2], labe
         sns.barplot(data=ldf, x='rank', y='tloc1', ax=ax1, orient='v', color=palette[0], label=

         ax1.set_ylabel("Fraction of Traffic (%)")
         ax1.set_xticks(range(0,len(data['devid']),5))
         ax1.set_xticklabels(range(0,len(data['devid']),5))
         ax1.set_xlabel("Device")
         ax1.legend(loc='best')

         plt.tight_layout()
         f.savefig("../figs/corr_device_location_bytes.eps")

         f, ax1 = plt.subplots(1, 1, figsize=(6, 4))

         ldf = ldf.sort_values('aloc1', ascending=False)
         ldf['rank'] = list(range(len(data['devid'])))

         sns.barplot(data=ldf, x='rank', y='alocost', ax=ax1, orient='v', color=palette[6], labe
         sns.barplot(data=ldf, x='rank', y='aloc3st', ax=ax1, orient='v', color=palette[4], labe
         sns.barplot(data=ldf, x='rank', y='aloc2st', ax=ax1, orient='v', color=palette[2], labe
         sns.barplot(data=ldf, x='rank', y='aloc1', ax=ax1, orient='v', color=palette[0], label=
ax1.set_ylabel("Fraction of App Activity (%)")
ax1.set_xticks(range(0,len(data['devid']),5))
ax1.set_xticklabels(range(0,len(data['devid']),5))
ax1.set_xlabel("Device")
ax1.legend(loc='best')

plt.tight_layout()
f.savefig("../figs/corr_device_location_app.eps")


f, ax1 = plt.subplots(1, 1, figsize=(6, 4))

ldf = ldf.sort_values('uloc1', ascending=False)
ldf['rank'] = list(range(len(data['devid'])))

sns.barplot(data=ldf, x='rank', y='ulocost', ax=ax1, orient='v', color=palette[6], labe
sns.barplot(data=ldf, x='rank', y='uloc3st', ax=ax1, orient='v', color=palette[4], labe
sns.barplot(data=ldf, x='rank', y='uloc2st', ax=ax1, orient='v', color=palette[2], labe
sns.barplot(data=ldf, x='rank', y='uloc1', ax=ax1, orient='v', color=palette[0], label=

ax1.set_ylabel("Fraction of User Activity (%)")
ax1.set_xticks(range(0,len(data['devid']),5))
ax1.set_xticklabels(range(0,len(data['devid']),5))
ax1.set_xlabel("Device")
ax1.legend(loc='best')

plt.tight_layout()
f.savefig("../figs/corr_device_location_user.eps")
```


Other locations
3rd location
2nd location
1st location
Fraction of Traffic (%)
0
20
40
60
80
100
0
5
10
15
20
Device


Other locations
3rd location
2nd location
1st location
Fraction of App Activity (%)
0
20
40
60
80
100
0
5
10
15
20
Device



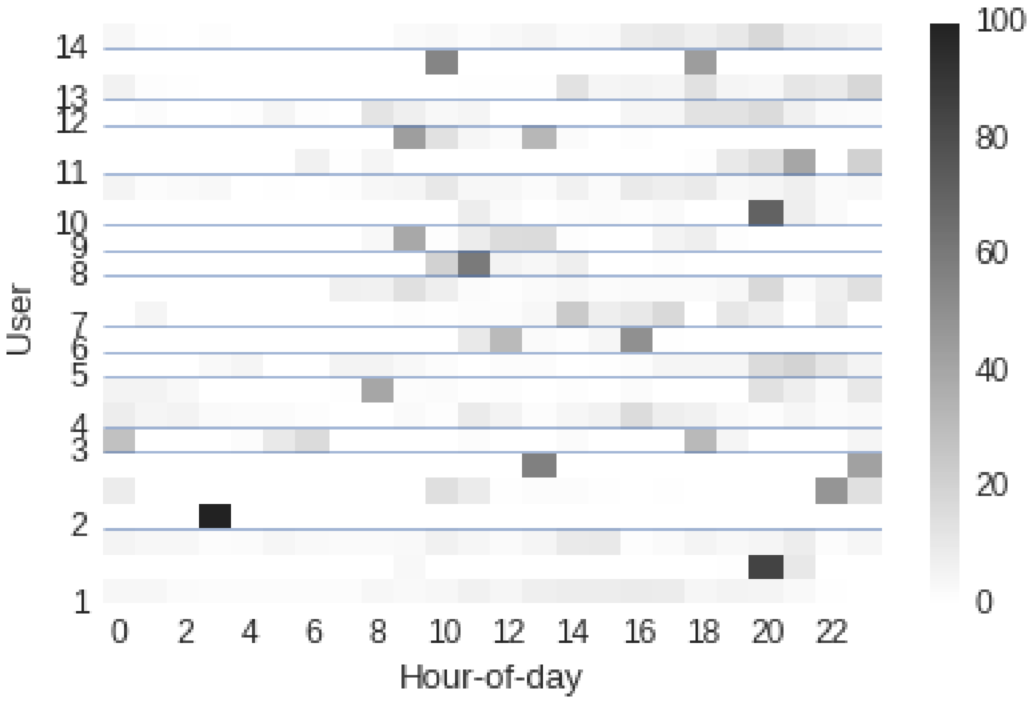
```
In [47]: # collect heatmap data for device use to time-of-day
         ses = Session()

         # minutes
         BINSIZE=60

         trafficdata = []
         appdata = []
         userdata = []

         yticks = []
         yidx = 0

         ignoreddevs = {}

         for uid in sortedusers:
             yticks.append(yidx)

             for devid in devsperuser[uid]:
                 alltotal = 0.0
                 alldays = {}
                 for k in range(0,24*60,BINSIZE):
                     k = k/BINSIZE
                     alldays[k] = 0.0
```

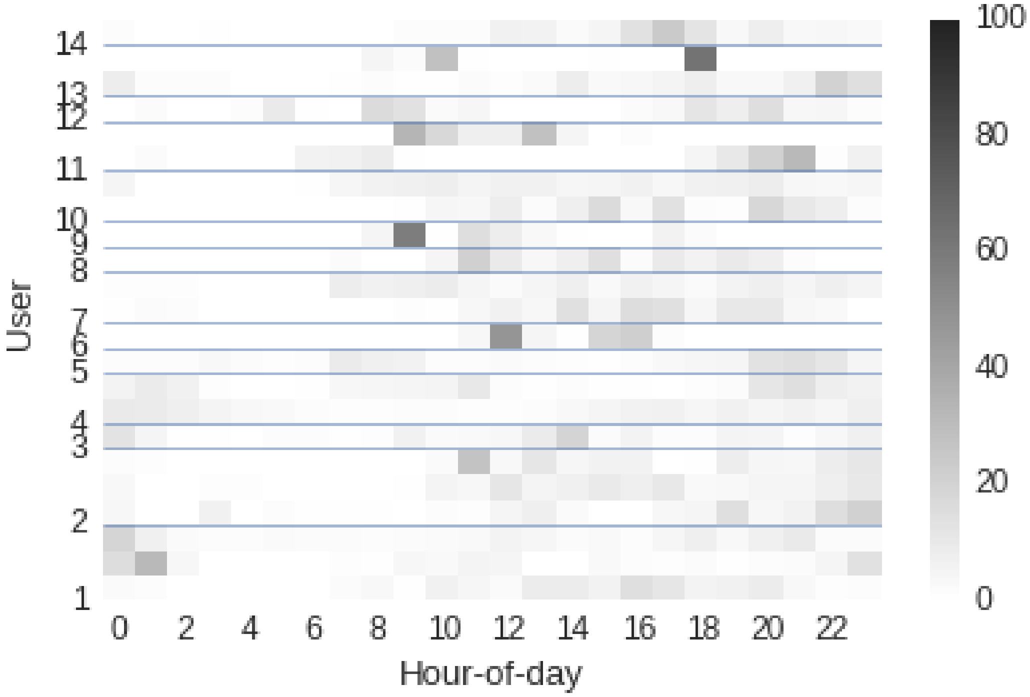
```
q = ses.query(DeviceAppTraffic.ts,
              DeviceAppTraffic.bytes_in+DeviceAppTraffic.bytes_out).filter(
                DeviceAppTraffic.devid==devid)

for (ts,bytes) in q.all():
    timeofday = ts.hour*60 + ts.minute
    binidx = timeofday/BINSIZE
    alldays[binidx] += bytes
    alltotal += bytes

if (alltotal==0):
    ignoreddevs[devid] = True
    continue
yidx += 1

# to % of bytes
for k in range(0,24*60,BINSIZE):
    k = k/BINSIZE
    if (alltotal>0):
        alldays[k] = 100.0*(alldays[k]*1.0/alltotal)

trafficdata.append(alldays.values())

if (devid in ignoreddevs):
    continue

alltotal = 0.0
alldays = {}
for k in range(0,24*60,BINSIZE):
    k = k/BINSIZE
    alldays[k] = 0.0

q = ses.query(HttpReq.ts).filter(HttpReq.devid==devid)
for row in q.all():
    ts = row[0]
    timeofday = ts.hour*60 + ts.minute
    binidx = timeofday/BINSIZE
    alldays[binidx] += 1
    alltotal += 1

q = ses.query(DnsReq.ts).filter(DnsReq.devid==devid)
for row in q.all():
    ts = row[0]
    timeofday = ts.hour*60 + ts.minute
    binidx = timeofday/BINSIZE
    alldays[binidx] += 1
    alltotal += 1
```

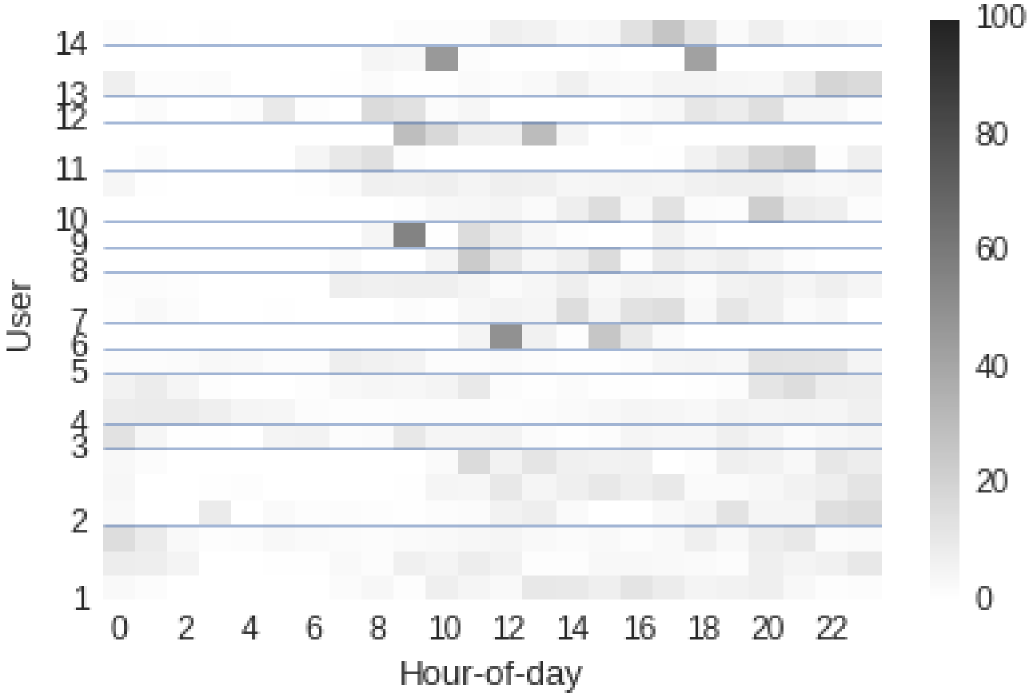
```
            # to % of bytes
            for k in range(0,24*60,BINSIZE):
                k = k/BINSIZE
                if (alltotal>0):
                    alldays[k] = 100.0*(alldays[k]*1.0/alltotal)

            appdata.append(alldays.values())

            alltotal = 0.0
            alldays = {}
            for k in range(0,24*60,BINSIZE):
                k = k/BINSIZE
                alldays[k] = 0.0

            q = ses.query(HttpReq.ts).filter(
                            HttpReq.devid==devid).filter(
                            HttpReq.user_url==True)
            for row in q.all():
                ts = row[0]
                timeofday = ts.hour*60 + ts.minute
                binidx = timeofday/BINSIZE
                alldays[binidx] += 1
                alltotal += 1

            q = ses.query(DnsReq.ts).filter(
                            DnsReq.devid==devid).filter(
                            DnsReq.user_req==True, DnsReq.duplicate==False)
            for row in q.all():
                ts = row[0]
                timeofday = ts.hour*60 + ts.minute
                binidx = timeofday/BINSIZE
                alldays[binidx] += 1
                alltotal += 1

            # to % of bytes
            for k in range(0,24*60,BINSIZE):
                k = k/BINSIZE
                if (alltotal>0):
                    alldays[k] = 100.0*(alldays[k]*1.0/alltotal)

            userdata.append(alldays.values())

        ses.close()
```

```
In [79]: cmap = sns.dark_palette("#ffffff", as_cmap=True, reverse=True)

         def doplot(data,fname=None):
```

```
    f, ax = plt.subplots(1, 1, figsize=(6, 4))
    ax = sns.heatmap(data,
                     cmap=cmap,
                     vmin=0,
                     vmax=100.0,
                     yticklabels=False,
                     xticklabels=2)

    ax.set_xlabel("Hour-of-day")

    ax.set_ylabel("User")
    ax.yaxis.set_ticks(yticks)
    ax.set_yticklabels([i+1 for i in range(len(yticks))])
    for ymaj in ax.yaxis.get_majorticklocs():
        ax.axhline(y=ymaj,ls='-',lw=0.5, color='b')

    plt.tight_layout()
    plt.show()
    if (fname!=None):
        f.savefig(fname)

doplot(trafficdata, "../figs/corr_traffic_timeofday.eps")
doplot(appdata, "../figs/corr_app_timeofday.eps")
doplot(userdata, "../figs/corr_user_timeofday.eps")
```




14
13
12
11
10
9
8
User
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16
18
20
22
Hour-of-day
100
80
60
40
20
0


14
13
12
11
10
9
8
User
7
6
5
4
3
2
1
0
2
4
6
8
10
12
14
16
18
20
22
Hour-of-day
100
80
60
40
20
0

```
In [49]: # get unique ips, dns+http domains, user dns+http domains / user / device
         data = defaultdict(list)

         ses = Session()

         for rank,uid in enumerate(sortedusers):
             uniqueips = defaultdict(set)
             uniqueapps = defaultdict(set)
             uniqueuser = defaultdict(set)
             for devid in devsperuser[uid]:
                 q = ses.query(distinct(DeviceAppTraffic.dstip)).filter(DeviceAppTraffic.devid==
                 uniqueips[devid] = set([r[0] for r in q.all()])

                 q = ses.query(distinct(DnsReq.query)).filter(DnsReq.devid==devid)
                 uniqueapps[devid] = set([r[0] for r in q.all()])

                 q = ses.query(distinct(HttpReq.req_url_host)).filter(HttpReq.devid==devid)
                 uniqueapps[devid] = uniqueapps[devid] | set([r[0] for r in q.all()])

                 q = ses.query(distinct(DnsReq.query)).filter(
                         DnsReq.devid==devid, DnsReq.user_req==True, DnsReq.duplicate==False)
                 uniqueuser[devid] = set([r[0] for r in q.all()])

                 q = ses.query(distinct(HttpReq.req_url_host)).filter(
                         HttpReq.devid==devid, HttpReq.user_url==True)
                 uniqueuser[devid] = uniqueuser[devid] | set([r[0] for r in q.all()])

             data['rank'].append(rank)
             data['devs'].append(len(devsperuser[uid]))

             c = 0
             fulls = set([])
             for devid in devsperuser[uid]:
                 # count ips unique to this dev
                 s = uniqueips[devid]
                 fulls = fulls | s
                 for devid2 in devsperuser[uid]:
                     if (devid==devid2):
                         continue
                     s = s - (s&uniqueips[devid2])
                 c += len(s)
             data['ip'].append(100.0*(c*1.0/len(fulls)))
             data['ipcount'].append(len(fulls))

             c = 0
             fulls = set([])
             for devid in devsperuser[uid]:
                 # count ips unique to this dev
```

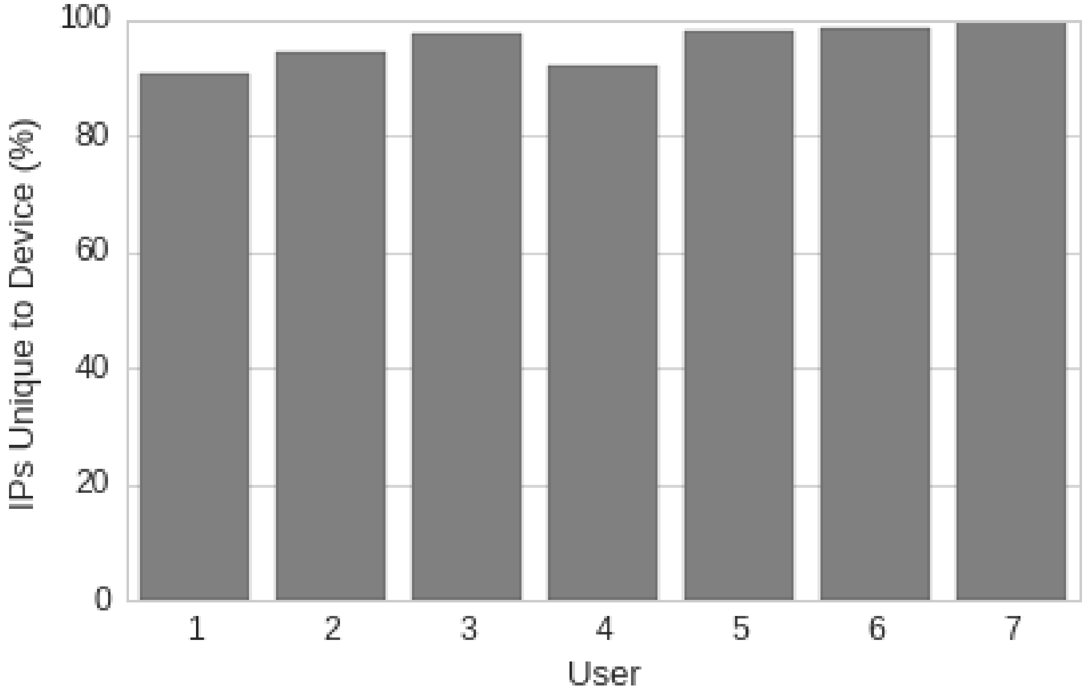
```python
        s = uniqueapps[devid]
        fulls = fulls | s
        for devid2 in devsperuser[uid]:
            if (devid==devid2):
                continue
            s = s - (s&uniqueapps[devid2])
        c += len(s)
    data['app'].append(100.0*(c*1.0/len(fulls)))
    data['appcount'].append(len(fulls))

    c = 0
    fulls = set([])
    for devid in devsperuser[uid]:
        # count ips unique to this dev
        s = uniqueuser[devid]
        fulls = fulls | s
        for devid2 in devsperuser[uid]:
            if (devid==devid2):
                continue
            s = s - (s&uniqueuser[devid2])
        c += len(s)
    data['user'].append(100.0*(c*1.0/len(fulls)))
    data['usercount'].append(len(fulls))

cdf = pd.DataFrame(data)

ses.close()
```

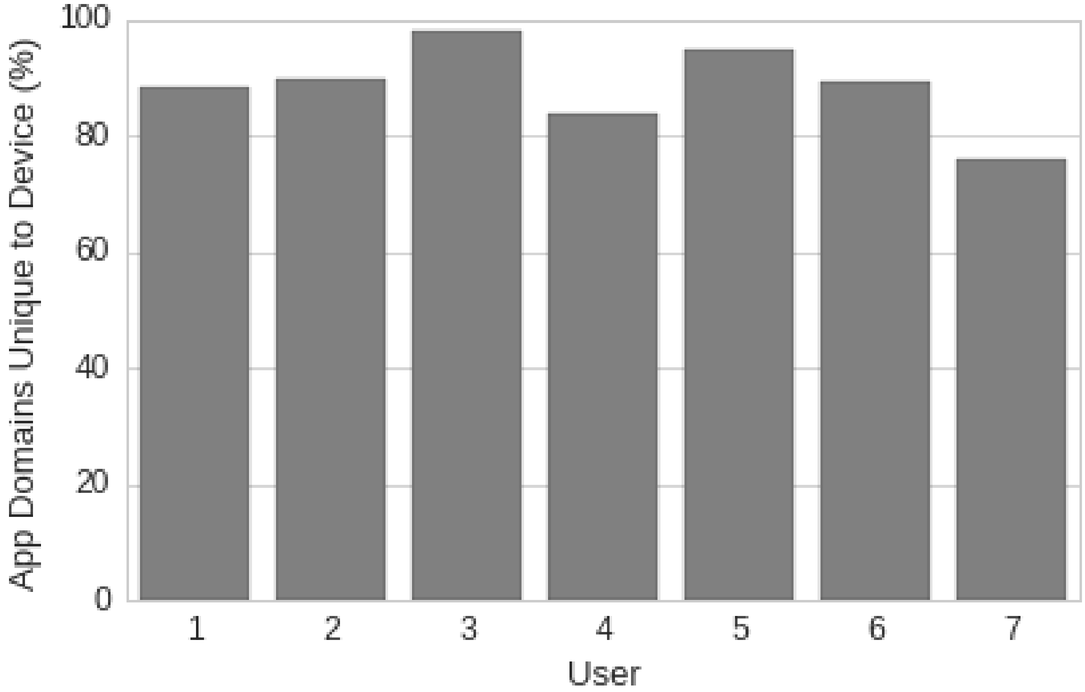
In [88]:

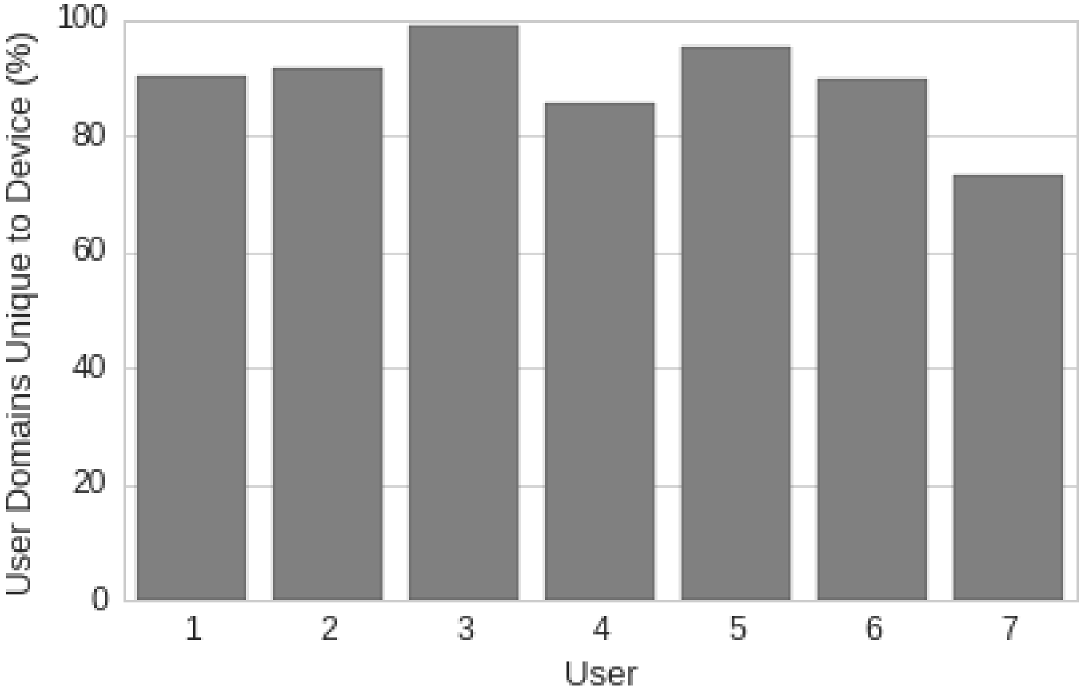
```python
# get unique ips, dns+http domains, user dns+http domains / user / device
data = defaultdict(list)

ses = Session()

def toplevelset(domains):
    """Filter domains to include only top-level info."""
    res = []
    for d in domains:
        tmp = d.split('.')
        if (d.endswith('co.uk') and len(tmp)>3):
            res.append("%s.%s.%s"%(tmp[-3],tmp[-2],tmp[-2]))
        elif (len(tmp)>2):
            res.append("%s.%s"%(tmp[-2],tmp[-2]))
        else:
            res.append(d)
    return set(res)

for rank,uid in enumerate(sortedusers):
    if (len(devsperuser[uid])==1 or len([devid for devid in devsperuser[uid] if devid i
    continue

uniqueips = defaultdict(set)
uniqueapps = defaultdict(set)
uniqueuser = defaultdict(set)
for devid in devsperuser[uid]:
    q = ses.query(distinct(DeviceAppTraffic.dstip)).filter(DeviceAppTraffic.devid==
    uniqueips[devid] = set([r[0] for r in q.all()])

    q = ses.query(DnsReq.query, func.count(DnsReq.ts)).filter(DnsReq.devid==devid).
    uniqueapps[devid] = toplevelset([r[0] for r in q.all() if r[1]>1])

    q = ses.query(HttpReq.req_url_host, func.count(HttpReq.ts)).filter(
        HttpReq.devid==devid).group_by(HttpReq.req_url_host)
    uniqueapps[devid] = uniqueapps[devid] | toplevelset([r[0] for r in q.all() if r

    q = ses.query(DnsReq.query, func.count(DnsReq.ts)).filter(
            DnsReq.devid==devid, DnsReq.user_req==True, DnsReq.duplicate==False).gr
    uniqueuser[devid] = toplevelset([r[0] for r in q.all() if r[1]>1])

    q = ses.query(HttpReq.req_url_host, func.count(HttpReq.ts)).filter(
            HttpReq.devid==devid, HttpReq.user_url==True).group_by(HttpReq.req_url_
    uniqueuser[devid] = uniqueuser[devid] | toplevelset([r[0] for r in q.all() if r

data['rank'].append(rank)
data['devs'].append(len(devsperuser[uid]))

c = 0
fulls = set([])
for devid in devsperuser[uid]:
    # count ips unique to this dev
    s = uniqueips[devid]
    fulls = fulls | s
    for devid2 in devsperuser[uid]:
        if (devid==devid2):
            continue
        s = s - (s&uniqueips[devid2])
    c += len(s)
data['ip'].append(100.0*(c*1.0/len(fulls)))
data['ipcount'].append(len(fulls))

c = 0
fulls = set([])
for devid in devsperuser[uid]:
    # count ips unique to this dev
    s = uniqueapps[devid]
    fulls = fulls | s
    for devid2 in devsperuser[uid]:
            if (devid==devid2):
                continue
            s = s - (s&uniqueapps[devid2])
        c += len(s)
    data['app'].append(100.0*(c*1.0/len(fulls)))
    data['appcount'].append(len(fulls))

    c = 0
    fulls = set([])
    for devid in devsperuser[uid]:
        # count ips unique to this dev
        s = uniqueuser[devid]
        fulls = fulls | s
        for devid2 in devsperuser[uid]:
            if (devid==devid2):
                continue
            s = s - (s&uniqueuser[devid2])
        c += len(s)
    data['user'].append(100.0*(c*1.0/len(fulls)))
    data['usercount'].append(len(fulls))

cdf = pd.DataFrame(data)

ses.close()
```

```
In [89]: #    correlation of visits to sites on multiple devices
         # => % of ips, app, user visited on single device / per user (100 for 1 dev users, for

         #f, ((ax1),(ax2)) = plt.subplots(2, 1, figsize=(6, 4), sharex=True)
         f, ax1 = plt.subplots(1, 1, figsize=(6, 4), sharex=True)

         cdf = cdf.sort_values('ipcount', ascending=False)
         cdf['rank'] = list(range(len(data['rank'])))

         #sns.barplot(data=cdf, x='rank', y='ipcount', ax=ax1, orient='v', color=palette[0])
         #ax1.set_ylabel("Unique")
         #ax1.set_xlabel("")

         sns.barplot(data=cdf, x='rank', y='ip', ax=ax1, orient='v', color=palette[0])
         ax1.set_ylabel("IPs Unique to Device (%)")
         ax1.set_xlabel("User")
         ax1.set_xticklabels([i+1 for i in range(len(data['rank']))])

         plt.tight_layout()
         f.savefig("../figs/corr_device_traffic.eps")


         #f, ((ax1),(ax2)) = plt.subplots(2, 1, figsize=(6, 4), sharex=True)
```

```
f, ax1 = plt.subplots(1, 1, figsize=(6, 4), sharex=True)

cdf = cdf.sort_values('appcount', ascending=False)
cdf['rank'] = list(range(len(data['rank'])))


#sns.barplot(data=cdf, x='rank', y='appcount', ax=ax1, orient='v', color=palette[0])
#ax1.set_ylabel("Unique")
#ax1.set_xlabel("")

sns.barplot(data=cdf, x='rank', y='app', ax=ax1, orient='v', color=palette[0])
ax1.set_ylabel("App Domains Unique to Device (%)")
ax1.set_xlabel("User")
ax1.set_xticklabels([i+1 for i in range(len(data['rank']))])

plt.tight_layout()
f.savefig("../figs/corr_device_app.eps")

#f, ((ax1),(ax2)) = plt.subplots(2, 1, figsize=(6, 4), sharex=True)
f, ax1 = plt.subplots(1, 1, figsize=(6, 4), sharex=True)

cdf = cdf.sort_values('usercount', ascending=False)
cdf['rank'] = list(range(len(data['rank'])))

#sns.barplot(data=cdf, x='rank', y='usercount', ax=ax1, orient='v', color=palette[0])
#ax1.set_ylabel("Unique")
#ax1.set_xlabel("")

sns.barplot(data=cdf, x='rank', y='user', ax=ax1, orient='v', color=palette[0])
ax1.set_ylabel("User Domains Unique to Device (%)")
ax1.set_xlabel("User")
ax1.set_xticklabels([i+1 for i in range(len(data['rank']))])

plt.tight_layout()
f.savefig("../figs/corr_device_user.eps")
```


IPs Unique to Device (%)
0
20
40
60
80
100
1
2
3
4
5
6
7
User


App Domains Unique to Device (%)
0
20
40
60
80
100
1
2
3
4
5
6
7
User


User Domains Unique to Device (%)
0
20
40
60
80
100
1
2
3
4
5
6
7
User