

# **The Design and Implementation of a Distributed Photo Sharing Android Application Over Ad-Hoc Wireless**

by

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Submitted to the Department of Electrical Engineering and Computer  
Science

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## **Abstract**

We present a distributed photo-sharing Android application, CameraDP, that uses ad-hoc Wifi connections in addition to the common 3G or 4G cellular network connections. The app utilizes the novel DIstributed Programming Layer Over Mobile Agents (DIPLOMA) programming layer to provide a consistent shared memory over a large distributed system of android phones. The success rate and latency of photo saves and photo gets on CameraDP were compared to the numbers generated from CameraCL, a 3G or 4G-only version of the same user interface as CameraDP. Under near-ideal Wifi conditions and only a 1.4% sacrifice in success rate, a 10-phone CameraDP system yielded a 2.6x improvement over a 10 CameraCL phones running on 4G, and the CameraDP system yielded a 16x improvement over CameraCL running on 3G. The methods and results of this research suggest that this new way of designing phone apps using a distributed Wifi network may be very useful when Wifi becomes more robust and smart phone Wifi ranges increase.

Thesis Supervisor: Li-Shiuan Peh

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# Contents

<b>1</b>	<b>Introduction and Motivation</b>	<b>9</b>
<b>2</b>	<b>Background on DIPLOMA</b>	<b>11</b>
<b>3</b>	<b>User Interface and Functionality Common to Both Camera Apps</b>	<b>15</b>
<b>4</b>	<b>CameraDP Android Application</b>	<b>19</b>
<b>5</b>	<b>CameraCL Android Application</b>	<b>23</b>
<b>6</b>	<b>Experiments and Code Improvements</b>	<b>25</b>
6.1	Experiment 1 . . . . .	27
6.1.1	Improvements . . . . .	28
6.2	Experiment 2 . . . . .	29
6.2.1	Improvements . . . . .	32
6.3	Experiment 3 . . . . .	33
6.4	Experiment 4 . . . . .	35
6.4.1	Improvements . . . . .	37
6.5	Experiment 5 . . . . .	38
6.5.1	Improvements . . . . .	39
6.6	Experiment 6 . . . . .	39
<b>7</b>	<b>Discussion and Conclusion</b>	<b>43</b>





# Chapter 1

## Introduction and Motivation

Smart phones rely heavily on the Cloud to carry out extensive computations or get access to abundant storage. Frequent communication with the Cloud via the 3G (HSPA) or 4G (LTE) cellular networks, especially in an area dense with smartphones, can cause an increased latency time, to the immediate frustration of the users. A solution to this problem is to set the phones in a distributed shared-memory network. Given reliable and strong ad-hoc Wifi conditions, requests to nearby phones should be faster on average than 3G or 4G requests to the cloud, improving the user experience.

This is an area of active research and we utilize a recently built consistent shared-memory system over ad-hoc Wifi, DIPLOMA, to test the feasibility of a popular photo-sharing app, Paranomio, on a distributed memory system relying mostly on the ad-hoc WiFi.

We created a stripped-down version of Paranomio that only have two functions: TAKE new photos and GET other photos. In order to quantify the advantage of ad-hoc WiFi, we built two functionally identical apps: CameraDP and CameraCL. CameraDP uses DIPLOMA in the background while CameraCL is the control case where each request is independently sent to the cloud through a 3G or 4G connection.

The two different apps are: DiplomaCamera and CloudCamera. Even though their UI are identical, DiplomaCamera handles the pictures using DIPLOMA while CloudCamera is the control of the experiment, handling all requests with the cloud.



## Chapter 2

# Background on DIPLOMA

In order for the experimental section to make sense, a few aspects of DIPLOMA need to be explained. You can think of DIPLOMA as the postal service, working for you to get your mail messages delivered or help you receive your packages. Before doing so, keep in mind that a paper detailing DIPLOMA is, as of May 2012, in the process of being submitted to a conference. So we won't be able to reference it here, but feel free to look it up online for more details on DIPLOMA.

In DIPLOMA, the phones are assigned into regions based on their GPS location. Given a map of the entire area of interest, the map should be sectioned off into invisible regions so that the phones inside the same region are close to each other in physical distance. There is no limit to the number of regions you can make. Since phones are mobile, if a phone walks out of a region it is assigned to a neighboring region. There should be no overlapping of regions or unassigned phones. Every phone in the region should be technically able to hear from every other phone in the region through ad-hoc Wifi.

Inside each region a phone is designated to be the LEADER of the region. All the other phones in the regions are NONLEADERS. If a new phone comes into the region from another region or because it's turned on inside the region, it will try to JOIN the region through an exchange with the LEADER. LEADERS inform the NONLEADERS of its continued existence by broadcasting periodic *I'm alive* heartbeat packets. The LEADER in the region saves photo data that the NONLEADERS (and

itself) take. The LEADER is also responsible to communicating with other LEADERS to retrieve and relay a remote region's photo to a NONLEADER in the region. This LEADER-to-LEADER communication is called *multi-hop* because at any step, neighboring LEADERS relay the request, so the request moves from LEADER to LEADER until the destination LEADER is reached.

In addition to these these ad-hoc Wifi requests, LEADERS have the right and privilege to communicate with a cloud server via the cellular 3G or 4G network, just like in CameraCL, but with fewer cloud accesses. In CameraDP, the cloud server acts like a last resort for keeping a region's state consistent. For example, if the LEADER phone leaves the old region to go to a neighboring region, the NONLEADERS of the old region will detect that by the missed heartbeat packets. Within a few seconds, the NONLEADERS will randomly choose a new LEADER among themselves. This potential new leader will try to send a packet to the old leader, from which the old leader will give the new leader its states. However if the old leader never hears back from the new leader or if the old leader knows that there are no other phones in the region, then in this case there is no phone to pass on the state of the region to so the leader upload the state into the cloud server, much like what happens for every request in CameraCL. Whenever a new leader is formed in a region, under any circumstance, a cloud request is made to ask the cloud server to give it permission to become the new leader (preventing double leaders in a region). If the new leader is approved by the cloud, it also receives from the leader any old states of the region, so that data for that region can remain consistent. [omit leader heartbeat to cloud, cloud rejecting leadership (timeouts) for a while after leader crashes, and leader HANDINGOFF, they do not directly affect Camera app]

Another aspect of DIPLOMA that is important to the CloudDP app is its regions. As mentioned before, each region have to small enough so that every phone in the region are in range with each other, but also big so that more phones can be contained in one region. Recall that leaders of neighboring regions must be able to communicate with each other. If there is any one region that is missing a LEADER or have an out-of-range LEADER along a linear path of multi-hop, then the DIPLOMA request

is broken and the request cannot be completed successfully. In other words, if there is a chain of regions, all regions must have a leader and that leader must be in range with its neighboring leaders. This implies that we must make the region size small enough that two phones anywhere inside two adjacent regions, not one, could hear each other. But how wide should a region be? If the region widths are set as the limiting range of the phones (20 meters in our case), the only way a DIPLOMA multi-hop would work is if the leaders are exactly 20 meters from each other. If one leader just moves a little bit, it will fall out of range of the farther neighboring leader and thus breaking DIPLOMA multi-hops.

Even though technically the region width should be half of the phone range, with the GPS inaccuracy of the phones, setting the region width to 10 meters is not ideal. If the regions are too small, and the phone's innate GPS inaccuracies varies a lot, we could end up with insensible region allocations. In the worst case, region monotonicity may be broken, e.g. a phone could be erroneously assigned to region 2, between a region 3 and region 4 phone. Without region monotonicity, DIPLOMA multi-hop would not be concrete. (We found in Experiment 3 that setting the region width down from 20 meters in width to 10 meters in width did not improve the rate of success at all.)



# Chapter 3

## User Interface and Functionality Common to Both Camera Apps

CameraDP and CameraCL, unlike traditional photo sharing apps where each phone functions individually, assigns the phones into different regions based on their GPS locations and a region's leader collectively saves the newest photos for all the phones in the region (it's easy to change the code to save more than one phones). This implies: a) a new photo is saved on its phone's region, not the phone itself and b) a phone can only request the newest photo of a region, not of another individual phone.

From the user's point of view, CameraDP and CameraCL are identical. Both apps allow users to share photos among themselves using their Android phones. The users can take new photos on their phones, by pressing the "Take Photo" button and request to see the latest photos taken by other phones by pressing the "Get X Photo" button where "X" correspond to the desired region number. The "Take Photo" button press triggers a TAKE request in CameraDP and the "Get X Photo" button press triggers a GET request. These are the two main requests crucial to our experiments.

The rest of the UI are add-ons to help debugging in the process. Log messages are displayed in the middle. Success rates of TAKEs and GETs are displayed on the bottom of the screen, along with request latency information. The textfield is for setting a new region width. Remember when changing the region width on one

phone, all the other phones involved must have the region width changed as well to keep the region assignments consistent among all phones.

The last button is a switch for hysteresis, allowing you to pick different percentages of the region width you want to be applied to be the hysteresis buffer region. If hysteresis is set, the region of the phone cannot be changed inside the few meters (based on the hysteresis percentage chosen) around the boundaries of the regions. The reason for this was because we were worried that the GPS would be very imprecise and cause phone standing near region boundaries to flicker between 2 regions.

The downside of hysteresis is that you want to change regions at those boundary areas. Compounded with the fact that phones have internal offsets, adding a hysteresis made everything confusing when the region sizes are now only 20 meters in length. So for a large percentage of a region area, phones next to each other had different regions. This caused me to add a hystereses selector that defaults to 0% of hysteresis, i.e. no hysteresis. Hysteresis was only used in the first 2 experiments and we have noticed no adverse affects so far after having hysteresis set to 0.

In our experiment, six square consecutive regions (0 to 5) about 30 meters wide were created along a stretch of busy road. Users walked around and pressed buttons on the apps to take new photos or request photos from different regions. With two apps on two different phones, the users synchronized the button presses so that sequences of events for the two app types are similar. We record the number of success of requests and the latency of the responses.

===== \* Use CameraSurfaceView bug discussion? The reason for this change was because the \*intent/sd card solution only works on Nexus S phones, not Galaxy Notes\* phones. In Galaxy Notes, the Mux is killed and restarted before and after the camera intent (because StatusActivity is paused), causing a "Cannot open socketAddress already in use" error: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/8de606e548b4854807ea91a4822b7638a250843c/logcats/galaxy\\_note\\_camera\\_crash.txt#L470](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/8de606e548b4854807ea91a4822b7638a250843c/logcats/galaxy_note_camera_crash.txt#L470) CameraSurfaceView fixes this problem because StatusActivity never has to be paused when taking a photo. Since it works on both types of phones, we used this solution for both.



=====

timeouts \* bug of timeouts discussion? - \*N.B.\* Moved code order on leaders to have better completion rates for TAKEs. Before, the buttons are enabled after the leader do all the packet processing, during which time the timeout period could have been reached and counted the completed request as a timedout. Now, enabling the buttons is the first thing the phone does after it receives a packet. "It was at the very last step because I thought the photo processing should be done first. But I guess the photo processing stuff is either fast enough or it doesn't really conflict with pressing buttons, because I have not seen a failure after" this change [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/commit/6164e1ce1699b87bf5a21c724130af9a6d807a19](https://github.com/haoqili/Android_DIPLOMA_CAMERA/commit/6164e1ce1699b87bf5a21c724130af9a6d807a19)



## Chapter 4

# CameraDP Android Application

\* NO discussion on hysteresis (it's discussed in previous section) \* Region width - leader spacing — where is that?

The DIPLOMA design introduces a leader in each of the regions. The leaders take care of all the requests coming from all phones (clients) in the region. When a phone takes a new photo, it broadcasts the photo data to its leader, where the photo is saved. When a phone requests a photo from Region X, this request is broadcasted to its leader, which in turn uses DIPLOMA to relay the request and receive Region Xs photo data from Xs leader.

The code is divided into three big components:

1. StatusActivity.java for UI and client processing 2. UserApp.java for leader and remote leader functions 3. The DIPLOMA java files: Mux.java, VCoreDaemon.java, DSMLayer.java are unchanged.

**\*\* TODO: Add to this!!\*\***

StatusActivity.java contains listeners for the button presses that send requests to its region leader and a handler that processes replies from the region leader. Each phone has a unique id based on its IP address that can help a regions leader distinguish the non-leader phones in its region.

Pressing the button that takes a picture triggers that buttons listener to retrieve the photo information from the Camera SurfaceView. The photo data is then put into a packet along with the phones ID, the phones region number, and type of

request (UploadPhoto). This packet is serialized inside StatusActivity.java into a UDP broadcast that reaches the leader of the region.

Similarly, pressing a button that requests the newest photo from region X triggers the request buttons listener to get information on the target region number that the user is requesting. A UDP packet consisting of the phones ID, the phones region number, the target region number, and the type of request (DownloadPhoto). Again, StatusActivity.java broadcasts this packet to the leader of the region.

Let Original Leader (OL) be the leader of the phone that made the request.

OLs UserApp.java:handleClientRequest processes the UDP packet by the type of request. In both cases, OL sends a DIPLOMA DSM atom request, along with the additional information from the UDP packet, to the Remote Leader (RL). In the UploadPhoto case, RL is the same as the OL, since new photos are processed locally. In the DownloadPhoto case, RL is the leader of the target region. RLs UserApp.java:handleDSMRequest processes the DSM atom request from the OL. For UploadPhoto, the photo info is saved in RLs DIPLOMA memory as the first element of an ArrayList. (For the experiment, we only save one photo at a time. But theoretically, there is no limit to the number of photos that can be saved.) The reverse happens for DownloadPhoto, where RL retrieves the newest photo from its DIPLOMA memory. In both cases, RL sends a reply back to the OL, arriving at OLs UserApp.java:handleDSMReply which sends a UDP packet containing DIPLOMA latency and a success boolean, and also the photo data in the case of DownloadPhoto, back to the original non-leader.

Finally back to the original phone, its StatusActivity.java handler gets the UDP reply from OL and logs the replies. In the case of DownloadPhoto, the remote regions newest photo is displayed.

\* I dont think the UI of leader showing new photos from nonleaders is important to write about

NO Leader transitions

Other things ————— To avoid confusion and inconsistency of the region numbers, phone buttons only work if the phone is in a LEADER or NONLEADER state.

To avoid double-sending a request (and possibly crash the camera surface view), a ProgressDialog is shown until the client has received a leader reply or until a timeout.



## Chapter 5

# CameraCL Android Application

In CloudCamera, every request is sent to the cloud server. The cloud server keeps a dictionary linking each region to its newest photo. Codewise, CloudCamera only has one file: CameraCloud.java that is analogous to DiplomaCameras StatusActivity.java, but instead of sending UDP packets, CloudCamera sends HTTP post requests.





# Chapter 6

## Experiments and Code

## Improvements

We performed a total of 6 data-collection experiments in a span of almost 2 months. Through time, the apps had fewer bugs and more robust code bases. However, it was impossible to fix the most critical issue – the Wifi range and consistency of the phones. The interference of 20 phones carried by 10 people moving simultaneously and randomly made collecting meaningful data infeasible with the current Wifi abilities of the phones. In the final 2 experiments, we resorted to a controlled indoors experiment with minimal Wifi interference and obtained more expected results.

Two pre-experiments were conducted.

Pre-experiment 1: Test DIPLOMA multi-hop and phone WiFi range

Three people, each held a Galaxy Note phone, conducted the experiment outside northeastern entrance of the Stata Center. One person stood at the corner of the entrance while the other two people each stood along a different wall. The phones were held vertically, the outer phones faced the middle phone. There were no obstructions in the path of transmission. We would later find out that the range from this test would be too optimistic for multi-user experiments where users moved around and obstructed each other all the time. By first disabling CameraDP on the middle phone,

we increased the distance between the middle phone to the two outer phones until the outer phones could not consistently complete GET requests, i.e. they were out of each other’s WiFi range. This distance was about 20 meters for each leg. We then turned on CameraDP on the middle phone and observed that GET requests between the two outer phones worked again, demonstrating that DIPLOMA multi-hop at least works for three phones.

While outside, we also conducted a 2-phone range test on an open field, where Phone A was stationary and Phone B moved away. When Phone B took a new picture, a hand gesture was shown and Phone A would try to get this newest picture. The GET requests did not work if the two phones stood more than 20 meters apart. However, when we used *ping*, the range of success increased to at least 25 meters.

#### Pre-experiment 2: Test phone WiFi range at 436 Mass Ave

Two people holding two Galaxy Note phones walked near 436 Mass Ave using CameraDP. Even though all future outdoor experiments were conducted strictly on the eastern sidewalk of Mass Ave, this experiment was also run on both sidewalks. The phones successfully got each other’s pictures at opposite ends of Mass Ave.

#### Outdoor experiment setup:

The volunteers holding the phones were instructed to walk around independently and freely in the valid regions, pressing buttons to take and get pictures at their own will and pace. During runs where volunteers to hold a phone running CameraDP in one hand and a phone running CameraCL in the other hand, the volunteers were instructed to press buttons in the same sequence on both phones.

The volunteers did not know the details of DIPLOMA other than the fact that regions exist. However from the second experiment onwards, the UI improved so that unfavorable circumstances would prevent GET and TAKE buttons from working. Examples of unfavorable circumstances include: walking out of the valid regions, phones in a state other than LEADER or NONLEADER.

If an app hangs for a certain period of time, the Android operating system would

prompt a message saying "xxx is not responding. Would you like to close it? 'Wait' 'Okay'". We instructed the volunteers that they must press "Wait", not "Okay". If 'Okay' is pressed, the CameraDP might crash.

## 6.1 Experiment 1

Location: 77 Massachusetts Avenue

Date: March 15, 2012

Weather: Drizzling and cold

Phones: 20 Nexus S: 10 running CameraDP, 10 running CameraCL

People: 10 People: each held 1 CameraDP and 1 CameraCL of same type of phone

Regions: 6 linear regions each with width 52 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/81e87e790c13ed3c8c4cd45703528e5216f04ec4](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/81e87e790c13ed3c8c4cd45703528e5216f04ec4)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/camera\\_diploma\\_exp1\\_data](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/camera_diploma_exp1_data)

CameraDP notes: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/camera\\_diploma\\_exp1\\_data/diploma\\_notes.md](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/camera_diploma_exp1_data/diploma_notes.md)

CloudDP notes: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/camera\\_diploma\\_exp1\\_data/cloud\\_notes.md](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/camera_diploma_exp1_data/cloud_notes.md)

Before walking to 77 Mass Ave, the servers and the apps were started with Region 0 located at the intersection of Amherst St and Mass Ave and the regions increment northwestwards.

No usable quantitative data was extracted from this experiment due to the frequent crashes on both the CameraDP app and CameraCL. Insufficient and inadequate stress testing beforehand meant that these problems were not discovered until the experiment started. Later analysis revealed that the crashes were mainly due to two reasons: double pressing the TAKE button and an OutOfMemory error caused by

the camera interface using up too much VM heap.

The region width was too large, preventing successful communication even for phones in the same region. Compounded to this was a bug that forced users to walk to region 0 whenever the apps crashed. The region assignment based on GPS was observed to be robust. There were no requests generated from outside of region 3.

### 6.1.1 Improvements

We prevented users from double clicking by using a ProgressDialog to freeze the UI. A boolean flag was introduced to double check that no additional buttons are clicked during the processing time of a previous button.

The OutOfMemory error on Nexus S phones occur when multiple TAKEs were pressed one after the other. The first few TAKEs would behave normally and complete successfully. However around the third to sixth TAKE, the app would crash at the line `'BitmapFactory.decodeByteArray()'`, which converts the byte array of the image into a bitmap object to be displayed to the user. To work around this problem, we added an additional parameter into the `decodeByteArray` function so that the byte array is downsampled once every 12th pixel, greatly reducing the memory requirement. In addition, we manually placed system garbage collection calls before the memory-intensive functions. After these two workarounds were coded, we tested the phone by continuously pressing the TAKEs over 100 times, multiple times, and did not observe any crashes.

#### The Region 0 bug

The bug that causes users to reset from region 0 after every crash was fixed. The bug came about from the logic to prevent inaccuracies in the GPS location. From pre experiment GPS testing, we observed some rare cases where GPS was greatly off for a few seconds. In this case, the the region assignment would unrealistically jump multiple regions. So we put in the logic that unless a new region differs from the old region by 1, the old region remains the same. The code initializes the region to be -1. During Experiment 1, our logic backfired if the app crashes inside regions 1 or above.

Since the app would restart and be set to -1 and GPS would indicate the new region should be 1 or above, the logic prevents the old region to be changed unless the user walks back to region 0, the only region that is 1 away from -1.

After Experiment 1, we removed the GPS and hysteresis check and let the regions to be updated to any new region of any distance away from the old region. Even though we very occasionally notice that phones would jump to an insensible region, the GPS glitch would only last a few seconds, not long enough to cause any concern.

## 6.2 Experiment 2

Location: 436 Massachusetts Avenue

Date: April 6, 2012

Weather: Sunny and cold

Phones: 20 Nexus S and 20 Galaxy Notes: each with 10 running CameraDP, 10 running CameraCL

People: 10 People: each held 1 CameraDP and 1 CameraCL of same type of phone

Regions: 6 linear regions each with width 52 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/b8a64242d4e6974c74d1c86a](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/b8a64242d4e6974c74d1c86a)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/experiment2\\_april\\_6](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/experiment2_april_6)

Results: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment2\\_april\\_6/log\\_process\\_aniru\\_jason/0411c\\_meeting.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment2_april_6/log_process_aniru_jason/0411c_meeting.txt)

Table 6.1: Experiment 2 4G (Galaxy Notes) Results

	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	80	225	74	345
successes	54	202	15	314
percentage	67.5%	89.7%	20%	91%

Table 6.2: Experiment 2 3G (Nexus S) Results

	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	74	70	128	106
successes	73	62	39	95
percentage	99%	88.5%	30.4%	89.6%

Table 6.3: Experiment 2 4G (Galaxy Notes) Latency

	CameraDP	CameraCL
mean	558 ms	837 ms
stdv	991 ms	769 ms
median	205 ms	479 ms

The server was started in Stata on hermes5.csail.mit.edu (which we will later discover that this server periodically drops connections for security reasons). The experiment was conducted on the eastern sidewalk of 436 Mass Ave to 2 blocks northwestwards. This stretch of road is very busy, filled with restaurants and small businesses, which possibly caused a lot of Wifi interference with the large number of Wifi hotspots.

Run 1: We handed 2 Nexus S phones to each of the 10 people, 1 Nexus and 1 Galaxy note. When people started to press buttons, the Cloud phone request made the phone hung for over 2-3 minutes or some phones never stopped hanging. This can be seen in the large CameraCL latency numbers in Table 6.4, which are within a minute, but they are averaged over all the runs in this experiment. Still, these numbers are orders of magnitude larger than the rest of latencies in Table 6.4 and Table 6.3.

We decided to restart the servers by connecting a laptop to the strongest free Wifi

Table 6.4: Experiment 2 3G (Nexus S) Latency

	CameraDP	CameraCL
mean	263 ms	22546 ms
stdv	276 ms	20284 ms
median	205 ms	15557 ms

in the area. Even though we were able to restart the server for run 2, we had to restart the server multiple times in the rest of the runs because the Wifi connection dropped frequently.

Run 2: With the server restarted, we started this run with Galaxy Notes phones instead of Nexus S phones and the exact setup.

The cloud requests did improve and were completed within 20 seconds. However, users complained about phones waiting for a long time to JOIN a region. People moved around a lot, sometimes forming occasional pairs or triples (to chat with each other). We do not know how much phones that were next to each interfered with each other's Wifi. It would not be significant since we rarely observed near-range interference indoors.

Run 3: Noticing that phones were stalling on JOIN, as if each time the server has to time out a region leader to let a new leader in, we decided to have stationary leaders. First we positioned individual people in the different regions and observed that they became leaders of their regions. After all the 6 leaders are set up, we had 2 non-leader phones as well as all the leaders pressing buttons (the other 2 people were monitoring the server, restarting it when necessary). The 2 non-leaders could walk around.

There were fewer JOIN request hangs in this run. Later we would discover bugs in DIPLOMA that fixed these hangs.

The low CameraDP GET success, see Tables 6.1 and 6.2, was a concern and we decided to improve the setup and code for another experiment. Also note from the result tables that CameraDP had higher success rates and lower latencies with 3G than 4G.

### 6.2.1 Improvements

The Wifi was not reliable during this experiment. Even testing pinging between two phones within an arm's distance would fail, most likely due to the Wifi hotspots interference. To fix this, the next experiment was moved back to 77 Mass Ave, a less busier section of the street.

The region width of 52 meters were too big. So phones within a region could not hear each other (nonleaders and leaders) and leaders in adjacent regions could not hear each other either. In the next experiment the app the region width decreased to 20 meters and we made the UI possible to modify the width during the experiment.

The phones were not at their optimal arrangement for ad-hoc Wifi communication. The volunteers held the phones flat on their palms, which in Experiment 4 was discovered that this horizontal configuration reduced the Wifi range of the phones. In addition, people were facing different directions. Wifi range is reduced greatly behind a person's back. Since the regions were linear and not circular, transmitting through the back was inevitable.

Most of the time half of the regions were unpopulated, which would cause multi-hop problems in CameraDP, since Wifi hops in a chain would only work if there are leaders present in all the regions of the chain.

Since hermes5 would drop periodically, we switched to a more reliable server for future experiments.

We added acks for first and final legs of CameraDP, so that there are 4 chances to make the first leg or final leg succeed. However after the later experiments we found that this addition did not improve results drastically, possibly due to the 4 repeated sends occurred within 1 second, during which time the status of the Wifi would not likely to be changed. Note that these acks had a bug that was not fixed until Experiment 5.



## 6.3 Experiment 3

Location: 77 Massachusetts Avenue

Date: April 25, 2012

Weather: Sunny

Phones: 20 Nexus S and 20 Galaxy Notes: each with 10 running CameraDP, 10 running CameraCL

People: 10 People: each held 1 CameraDP and 1 CameraCL of same type of phone

Regions: 6 linear regions each with width 20 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/e22605b1b644aa60aff54a08](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/e22605b1b644aa60aff54a08)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/experiment3\\_april\\_25\\_2011](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/experiment3_april_25_2011)

Results: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment3\\_april\\_25\\_2011/results.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment3_april_25_2011/results.txt)

Table 6.5: Experiment 3 4G (Galaxy Notes) Results

	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	82	111	75	105
successes	22	83	17	58
percentage	26%	74%	22%	55%
latency mean	206 ms	651 ms	1033 ms	268 ms
latency stdv	455 ms	1450 ms	1048 ms	394 ms
latency median	93 ms	495 ms	92 ms	166 ms

Table 6.6: Experiment 3 3G (Nexus S) Results

	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	362	388	470	455
successes	251	388	131	438
percentage	69%	100%	27%	96%
latency mean	900 ms	3749 ms	1858 ms	2704 ms
latency stdv	1328 ms	4134 ms	1355 ms	3175 ms
latency median	259 ms	2567 ms	2169 ms	2264 ms

Table 6.7: Experiment 3 4G (Galaxy Notes) GET Hop Results

	Hop 0	Hop 1	Hop 2	Hop 3+
requests	23	28	21	3
success rate	65%	7%	0%	0%

Table 6.8: Experiment 3 3G (Nexus S) GET Hop Results

	Hop 0	Hop 1	Hop 2	Hop 3+
requests	126	210	92	42
success rate	86%	7%	6%	0%

The first region of this experiment started around the intersection of Amherst St and Mass Ave, the last region ended around 77 Mass Ave. The location is chosen due to its much smaller number of Wifi hotspots compared to busy location last time. MIT Building 5 was the only building on the same side of the street as the experiment. Opposite the street were an MIT undergraduate dorm Maseeh Hall and the MIT Chapel.

In order to have a more stable server, we used a laptop connected to the ethernet in one of the Building 5 classrooms. The connection was stable during the experiment, i.e. no server crashes occurred. One person was watching the server for the entire duration.

There were 4 runs, with the later runs of people concentrated in the first two regions. One trial with Nexus S set the region width to 10 meters instead of 20 meters, but the success rate of GETs did not improve (23%). (see the chapter on DIPLOMA to learn about complications with smaller region sizes.)

The results of the 4 trials are congregated into 6.5 and 6.6. Again, CameraDP had higher success rates on 3G than 4G. CameraDP TAKE failures came from time outs, i.e. requests that do not respond within 6 seconds, which was caused by weak Wifi conditions. For the Nexus S results, 58% of CameraDP GET requests failed in DIPLOMA, due to the leader unable to get a response from the requested remote leader. There are two causes for DIPLOMA level failures, either the leaders were not in range with each other or at least one region in the multi-hop path were absent of a

leader. The rest of the CameraDP GET requests failed due to the 6-second time out just like the case in TAKES. For Galaxy Notes, only 22% of CameraDP GET failures were caused by DIPLOMA.

This is the last experiment where we used multi-hop. The Wifi conditions were not good enough to yield good multi-hop results, see Tables 6.7 and 6.8, which was why we stopped using multi-hop.

Due to bad Wifi connectivity outdoors, the future experiments were run indoors in a much smaller area.

## 6.4 Experiment 4

Location: Inside Stata, in the lounge closest to the Vassar/Main St intersection

Date: April 30, 2012

Weather: Sunny

Phones: 20 Galaxy Notes: with 10 running CameraDP, 10 running CameraCL

People: 10 People: each held 1 CameraDP and 1 CameraCL of same type of phone

Regions: 6 2x3 or 4 2x2 regions each with width of around 5 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/892b9793536613366b5293ee](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/892b9793536613366b5293ee)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/experiment4\\_april30](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/experiment4_april30)

Results: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment4\\_april30/results.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment4_april30/results.txt)

This is an indoors experiment with volunteers walking around different 5mx5m regions marked on the ground, manually pressing a button to change their region whenever a new region is entered (GPS turned off on all phones). In the 5 runs, only Run 2 used 3G (from a 3G/4G switch app).

We used 6 regions only in Run 0, else we used a 2x2 4-region setup. No DIPLOMA multi-hops were used, so that means every phone must be in range of every other

Table 6.9: Experiment 4 Run 0 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	87	87	160	159
successes	56	87	61	158
percentage	64%	100%	38%	99%
latency mean	362 ms	871 ms	853 ms	395 ms
latency stdv	652 ms	334 ms	1163 ms	432 ms
latency median	102 ms	831 ms	344 ms	346 ms

Table 6.10: Experiment 4 Run 1 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	154	150	238	351
successes	124	150	166	349
percentage	80%	100%	47%	99%
latency mean	526 ms	909 ms	830 ms	366 ms
latency stdv	965 ms	566ms	909 ms	288 ms
latency median	183 ms	835 ms	638 ms	339 ms

phone, regardless of the region. Since it Run 0 had the largest area of experiment, we would expect its success rates to be lower, but that’s only the case for CameraDP TAKEs, and its CameraDP GETs result is the second lowest, only 2% better than the lowest (6.9). In the only 3G run CameraDP had both TAKE and GET success rates above 50% (Table 6.11).

Similar to the previous experiment, TAKE failures were mostly due to timeouts and GET failures were mostly due to a DIPLOMA failure of unable to contact remote regions. This should not have been the case since there were always at least 1 person in each region during the experiment, and leader transitions did not take very long. The first explanation is that Wifi still did not work consistently. Indeed, at one point

Table 6.11: Experiment 4 Run 2 Results

3G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	131	136	279	286
successes	103	136	192	280
percentage	78%	100%	68%	97%
latency mean	364 ms	2302 ms	857 ms	1215 ms
latency stdv	718 ms	762 ms	939 ms	755 ms
latency median	214 ms	2171 ms	599 ms	1080 ms

Table 6.12: Experiment 4 Run 3 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	153	152	189	168
successes	124	152	69	168
percentage	81%	100%	36%	100%
latency mean	772 ms	726 ms	774 ms	347 ms
latency stdv	1172 ms	235 ms	757 ms	338 ms
latency median	163 ms	716 ms	483 ms	298 ms

Table 6.13: Experiment 4 Run 4 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	271	272	370	355
successes	202	272	147	354
percentage	74%	100%	39%	99%
latency mean	695 ms	769 ms	816 ms	361 ms
latency stdv	1188 ms	311 ms	924 ms	316 ms
latency median	146 ms	734 ms	444 ms	324 ms

when users were reporting low success rates, we tried *pinging* between two phones but failed. Another possibility could be the ack bug I introduced pre-Experiment 3.

The success rates were still too low, so we thought maybe a table-top experiment would improve the percentage of success.

### 6.4.1 Improvements

We fixed the bug that caused an entire region to not be able to GET and TAKE for a period of time. This was due to an error in the ack counter, where I set the reply counter independently from the request counter when in fact the standard correct practice is for the reply counter to be the same as its request counter or at least based on it. My erroneous ack counter was based on a counter in UserApp. During every UserApp reset, the counter would be reinitialized to 0, potentially resending the same counter to the same client of a previous reply. When this client received the reply, it checks against the queue of received reply counters and finds a match, which causes the client to just ignore the reply, thinking that reply were a duplicate.

I made this mistake because it did not occur to me that UserApp does not continue

from region to region. The fix was simply changing the construction of the leader reply counter to be based on the request counter. Since all request counters are unique, reply counters would also be unique.

## 6.5 Experiment 5

Location: Inside Stata, in the lounge closest to the Vassar/Main St intersection

Date: May 6, 2012

Weather: Sunny

Phones: 19 Galaxy Notes: with 10 running CameraDP, 9 running CameraCL

People: 2, controlled experiment Regions: 6 2x3 regions each with width of around 5 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/aeb358fc5a8f887c4193d761](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/aeb358fc5a8f887c4193d761)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/experiment5\\_may6\\_indoors](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/experiment5_may6_indoors)

Results: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment5\\_may6\\_indoors/results.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment5_may6_indoors/results.txt)

Table 6.14: Experiment 5 Run 0 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	55	48	409	378
successes	55	48	404	378
percentage	100%	100%	98%	100%
latency mean	131 ms	515 ms	180 ms	267 ms
latency stdv	61 ms	85 ms	165 ms	142 ms
latency median	91 ms	525 ms	146 ms	215 ms

In this experiment, we placed the phones on the ground near vertically, supported by plastic phone holders on the back. The GPS were turned off again. The phones were placed in a 2x3 regions arrangement with each region the size of 5mx5m. There were either 2, 3, or 4 phones in each region.

Table 6.15: Experiment 5 Run 1 Results

3G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	41	36	180	171
successes	41	36	180	171
percentage	100%	100%	100%	100%
latency mean	132 ms	1960 ms	208 ms	717 ms
latency stdv	61 ms	793 ms	260 ms	727 ms
latency median	104 ms	2362 ms	161 ms	398 ms

In the two runs we would press the same buttons on all phones before moving onto a new button press on all phones. We also switched regions a few times when no other phones are pressing buttons, so that did not have any affect on the results.

We noticed the average latencies for CameraCL requests were under a second when we watched many requests taking a few seconds. During Experiment 6 we would discover the reason for this peculiarity.

### 6.5.1 Improvements

We added a latency information display on the screen so that in the next experiment we could observe in real time the average latency, median latency, and the newest request's latency. This UI addition helped us find the last bit of information that would finally produce our desired results.

## 6.6 Experiment 6

Location: Inside Stata, in the lounge closest to the Vassar/Main St intersection

Date: May 6, 2012

Weather: Sunny

Phones: 19 Galaxy Notes: with 10 running CameraDP, 9 running CameraCL

People: 2, controlled experiment Regions: 6 2x3 regions each with width of around 5 meters

Files:

Code version: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/7df1600531f730d03cc82498](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/7df1600531f730d03cc82498)

Phone logs and scripts: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/tree/master/experiment6\\_may12\\_indoors](https://github.com/haoqili/Android_DIPLOMA_CAMERA/tree/master/experiment6_may12_indoors)

Results: [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment6\\_may12\\_indoors/results\\_diploma.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment6_may12_indoors/results_diploma.txt)

and [https://github.com/haoqili/Android\\_DIPLOMA\\_CAMERA/blob/master/experiment6\\_may12\\_indoors/results\\_cloud.txt](https://github.com/haoqili/Android_DIPLOMA_CAMERA/blob/master/experiment6_may12_indoors/results_cloud.txt)

Table 6.16: Experiment 6 Run 1 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	40	41	242	241
successes	40	41	242	241
percentage	100%	100%	100%	100%
latency mean	146 ms	551 ms	190 ms	254 ms
latency stdv	61 ms	90 ms	144 ms	95 ms
latency median	148 ms	530 ms	162 ms	226 ms

Table 6.17: Experiment 6 Run 2 Results

3G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	20	20	111	94
successes	20	20	105	94
percentage	100%	100%	94%	100%
latency mean	168 ms	2580 ms	225 ms	813 ms
latency stdv	146 ms	539 ms	268 ms	758 ms
latency median	111 ms	2464 ms	161 ms	415 ms

Table 6.18: Experiment 6 Run 3 Results

3G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	40	40	249	242
successes	39	40	242	242
percentage	97%	100%	97%	100%
latency mean	144 ms	2558 ms	217 ms	2279 ms
latency stdv	69 ms	408 ms	261 ms	285 ms
latency median	109 ms	2465 ms	161 ms	2229 ms

In this experiment, the regions were set up similarly as before, each of area 5mx5m. The two inner regions had two phones each, one running CameraDP and the other running CameraCL. The outer regions had four phones each, two running CameraDP and two running CameraCL. The phones this time were placed flat on the stools.



Table 6.19: Experiment 6 Run 4 Results

4G	TAKEs CameraDP	TAKEs CameraCL	GETs CameraDP	GETs CameraCL
total clicks	44	42	240	240
successes	44	42	240	240
percentage	100%	100%	100%	100%
latency mean	144 ms	546 ms	178 ms	469 ms
latency stdv	84 ms	75 ms	116 ms	51 ms
latency median	107 ms	534 ms	159 ms	469 ms

We forgot to turn off the GPS at the beginning and one of the phones during run 2 got a GPS fix, messing up the results. Then we proceeded to turn off all the phone’s GPS.

The Warm-Up Effect: The sequence of button presses for the first two runs were as follows: TAKE pictures on every phone one by one, then on each phone GET pictures from all the regions (0-5). We were pressing the 6 GET requests on each phone within a second of each other. As we moved from phone to phone, we observed the strange behavior that the first GET request on each phone would be many times slower than the rest of the GET requests, i.e. the GET request latency decreased drastically after the first GET of a batch of GETs. At the end of run 2, we realized that if wait a while between GET requests, the decreased latency effect was not observed. This is a warm-up effect perhaps due to some component(s) in the phone not having to restart on latter GET presses, because the component(s) are already warmed-up.

So for runs 3 and 4 we avoided the warm-up effect by pressing buttons in this sequence: first TAKE pictures on every phone, then GET region 0 on all phones, one by one, then GET region 1 on all phones, etc. So between each addition GET request on a single phone, we’ll have waited about a minute, more than enough to make the warm-up effect disappear. You can see the difference that the warm-up effect makes by comparing the decreased CameraCL GET latencies in Tables 6.16 and 6.17 to the normal latencies in Tables 6.18 and 6.19.

Since in the real world users would not be constantly making requests within

seconds of each other, the more realistic data are from runs 3 and 4, which omit the warm-up effect.

Without the warm-up effect, our data results are even more promising, showing a 12+x improvement in 4G (6.19) and a 10+x improvement in latency over 3G (6.18)!

## Chapter 7

### Discussion and Conclusion