– Independent Work Report, 2017 –

Drone Based Measurement of Signal Propagation in Urban Environments and Analysis

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Abstract

ABSTRACT PLACEHOLDER

1. Introduction (In Progress)

1.1. The Problem: ISP Monopolies in the United States

Home Internet users in the United States are at the mercy of their Internet Service Provider(ISP). Users seeking relatively modern download (> 25 Mbps) and upload (> 3 Mbps) speeds for home Internet are extremely restricted in their choices. The FCC states that 30% of Americans (measured in developed census blocks) have no ISPs delivering home Internet at these speeds, while another 48% of Americans have only one ISP providing service at these speeds[1].

As a result of this lack of choice (and competition), American home Internet are forced to pay disproportionately high prices for relatively slow connections. For example, Americans pay higher prices for home Internet than Europeans across all categories of broadband speed[cite connectivity]:

INSERT FIGURE

The plight of the American home Internet user is exposed even more when considering the highest available home Internet speeds for affordable Internet plans. While residents of Seoul and Hong Kong can choose among plans offering 300 Mbps connections in the price range of $35-$50, no American city has any plans offering > 50 Mbps speeds for the same price range. [cite connectivity] The much cheaper and faster connections available in Asia demonstrate that it is technologically feasible to provide fast home Internet connections for a low price.

Not coincidentally, ISPs in Asia operate in a much more competitive landscape, forcing them to provide quality service at a lower price. In South Korea, for example, upstart ISPs can lease, and

sell, unused bandwidth from a public utility that reaches the vast majority of the clustered, urban population. Further, the South Korean government forced Korea Telecom to open its network in the '90s, leading to increased competition and lower prices for users[cite wired].

The competitive landscape of Home internet service in the United States is dramatically different for a few reasons. First, the FCC has not taken as drastic action to spur competition as government entities in Asia have. In 2014, Tom Wheeler, Chairman of the FCC, acknowledged the lack of competition among ISPs and recognized a need for the FCC to do more to protect and create competition in the United States [cite Wheeler]. The policy aspects of ISP competition are an entirely separate issue that will not be tackled here.

Secondly, the population of the United States is large and spread out over a vast expanse of land. Reaching more homes in the United States requires laying lots of costly wire, which is often prohibitively expensive. Consider the efforts of Google Fiber. Google Fiber aims to offer connection speeds of 1000 Mbps at a comparable price to existing plans, reaching consumers in select neighborhoods of select American cities[cite google fiber]. According to Google, the process of bringing Fiber to a city involves initial exploration, network design, construction (laying fiber), and finally, customer sign up and installation. A Goldman Sachs report on Fiber, estimated that it would cost around $140 billion for Google to cover the whole country[cite Goldman]. Further, the involved process required to dig and install fiber is extremely time consuming. The cost and time required to lay fiber across a wide geographic area makes it extremely difficult for even established companies like Google to enter the ISP realm, much less a host of smaller companies or startups.

1.2. A (Potential) Solution: Wireless Mesh Networks

With the cost of establishing novel, last-mile wired networks being so high, there has been a lot of work on establishing wireless networks. One such notable project is Roofnet, a wireless mesh featuring over 40 nodes spread out over the urban area of Cambridge, Massachusetts. Roofnet nodes consist of a small PC, an 802.11b card, and an 8 dBi omni-directional antenna. These nodes are primarily installed on three to four story tall buildings, with packets hopping wireless nodes until

they reach a wireless node which is also connected to a gateway to the rest of the wired Internet[cite roofnet]. Individual users install these nodes on their roofs or windows and join the network.

Similar to Roofnet, another community powered mesh exists in Red Hook, Brooklyn[cite NYT Red Hook]. The goal of these networks is to provide a cheaper, more accessible form of Internet architecture in comparison to the extremely expensive deployment of fiber cables. However, these wireless networks face challenges operating in the urban environment.

1.3. Challenges with Wireless: Propagation and Measurement

The propagation of wireless signals in a noisy, obstacle-ridden urban environment often results in wireless networks operating below peak efficiency. Buildings and other environmental obstacles, such as trees, can greatly increase the path loss of a wireless link between two nodes. Then, establishing a line-of-sight (LOS) connection between two wireless links is important for low-loss links and robust wireless networks. However, the Fresnel Zone (an ellipsoid-shaped volume) around the LOS must also be clear of obstacles for optimally low path loss between a transmitter and receiver. Much work has been conducted on measurement campaigns of wireless signal propagation. Theodore S. Rapaport has conducted many such campaigns in a variety of settings in order to explore real-world propagation in different environments. For example, Rapaport, Durgin, and Xu's "Measurements and Models for Radio Path Loss and Penetration Loss In and Around Homes and Trees at 5.8GHz" conducted such a campaign in a suburban area. Signal strength measurement were taken by moving a receiver around a 1m square area and averaged to represent the path loss for a given room or outdoor location[cite Rappaport]. Such campaigns, while useful for sampling signal strength at key locations, don't give a complete understanding of signal strength over a space. Other campaigns have attempted to get a more complete measurement in an urban environment. A group of Brazilian researchers conducted a measurement campaign in Rio De Janeiro with a fixed transmitter on the window of an 8 story building. They built a receiver block with GPS and collected measurements by driving around streets surrounding the building housing the transmitter. GPS and signal strength measurements collected by the receiver block are joined to construct a map

of measured signal strength at street level. While this may be useful for mobile Internet users at the street level, participants in a wireless mesh for home Internet may have receiver nodes at various heights, necessitating a more 3-D measurement of signal propagation in urban areas.

1.4. [THIS PROJECT]: Robust Measurement

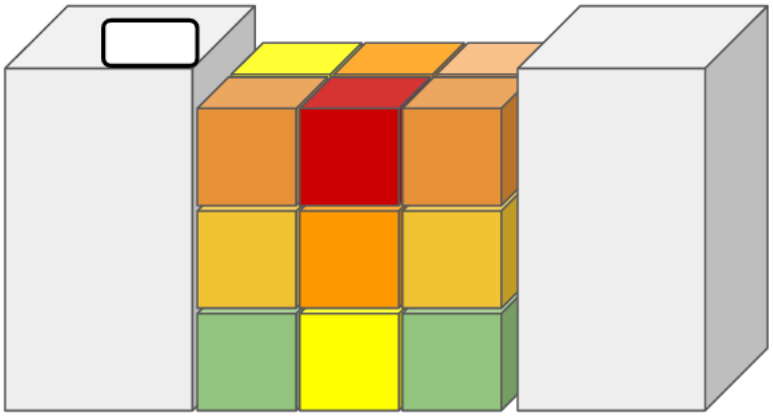
This project aims to develop a novel, robust measurement technique to measure signal propagation in urban environments. Specifically, we aim to develop a technique that will provide a complete picture of signal propagation in 3-dimensional space around urban features. This is motivated by the desire to identify favorable locations for wireless mesh network nodes in cities and suburbs.
To do this, we will conduct a drone based wireless signal propagation measurement campaign in a handful of locations on the Princeton campus. A measurement apparatus collecting measurements across the 2.4GHz wireless spectrum and a GPS antenna will be mounted on a drone, which will collect measurements at varying heights. The collected data can then be aggregated to get a comprehensive, robust 3-dimensional map of signal strengths around a certain urban feature, such as a courtyard or a street with buildings on both sides.

The main research goal of this project is to be able to construct a plot of 3-D "buckets" where the value associated with each bucket is the average signal strength measurement at a given frequency collected in the space occupied by that bucket. Fig 1 illustrates what such a plot may look like. A secondary research goal is to analyze these buckets of averaged values and determine which urban features led to higher overall signal strength.

This approach is novel because it yields a comprehensive, 3-Dimensional understanding of signal strength; existing measurement techniques are restricted to 2-Dimensional maps or point measurements. Since this project is motivated by wireless mesh networks,conducting measurements at various heights is important as users can be situated at various floors. Another benefit of this novel approach is the ability to potentially automate this measurement procedure for larger urban

environments in the future.

Figure 1: A mockup of the primary research goal: constructing a plot of 3-D "buckets" representing signal strength around urban features (gray buildings) given a fixed position transmitter (white).



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2. Outline

2.1. Introduction

- Motivation - What is the problem? Why is it important?
- Goal - What are we trying to accomplish?
- Overview of challenge and previous work
- Approach
- Summary of implementation
- Summary of results
- (optional) Roadmap: The remainder of this paper is organized as follows....

2.2. Problem Background and Related Work

- Survey of prior work with similar goals
- For each previous approach, explain what has been done and why it does not meet your goal

2.3. Approach

- Key novel idea
- Why it is a good idea

2.4. Implementation

- System overview (flow chart of key steps?)
- Subsection for each step or issue you addressed
  - Problem statement
  - Possible approaches
  - Chosen approach and why
  - Implementaton details

2.5. Evaluation

- Experiment design...
- Data...
- Metrics...
- Comparisons...
- Qualitative results...
- Quantitative results...

2.6. Summary

- Conclusions...
- Limitations...
- Future work...

References

[1] Industry Analysis and Technology Division, "Internet access services: Status as of december 31, 2015," Federal Communications Commission (FCC), Tech. Rep., 2016.

[2] L. Lamport, *LaTeX: A Document Preparation System*, 2nd ed. Reading, Massachusetts: Addison-Wesley, 1994.

[3] F. Lastname1 and F. Lastname2, "A very nice paper to cite," in *International Symposium on Computer Architecture*, 2000.
[4] F. Lastname1 and F. Lastname2, "Another very nice paper to cite," in *International Symposium on Computer Architecture*, 2001.
[5] B. Salzberg and T. Murphy, "Latex: When Word fails you," in *Proceedings of the 33rd Annual ACM SIGUCCS Conference on User Services*, ser. SIGUCCS '05. New York, NY, USA: ACM, 2005, pp. 241–243.

3. TEMPLATE REFERENCE: KAJ IGNORE

4. Preparation Instructions

4.1. Paper Formatting

There are no minimum or maximum length limits on IW reports. We are including this template because we think it will be helpful for citing things properly and for including figures into formatted text. If you are using LaTeX [2] to typeset your paper, then we strongly suggest that you start from the template available at http://iw.cs.princeton.edu – this document was prepared with that template. If you are using a different software package to typeset your paper, then you can still use this document as a reasonable sample of how your report might look. Table 1 is a suggestion of some formatting guidelines, as well as being an example of how to include a table in a Latex document.

Field	Value
Paper size	US Letter 8.5in $\times$ 11in
Top margin	1in
Bottom margin	1in
Left margin	1in
Right margin	1in
Body font	12pt
Abstract font	12pt, italicized
Section heading font	14pt, bold
Subsection heading font	12pt, bold

Table 1: Formatting guidelines.

Please ensure that you include page numbers with your submission. This makes it easier for readers to refer to different parts of your paper when they provide comments.

We highly recommend you use bibtex for managing your references and citations. You can add bib entries to a references.bib file throughout the semester (e.g., as you read papers) and then they

will be ready for you to cite when you start writing the report. If you use bibtex, please note that the references.bib file provided in the template example includes some format-specific incantations at the top of the file. If you substitute your own bib file, you will probably want to include these incantations at the top of it.

4.2. Citations and Footnotes

There are various reasons to cite prior work and include it as references in your bibliography. For example, If you are improving upon prior work, you should include a full citation for the work in the bibliography [3, 4]. You can also cite information that is used as background or explanation[5]. In addition to citing scholarly papers or books, you can also create bibtex entries for webpages or other sources. Many online databases allow you to download a premade bibtex entry for each paper you access. You can simply copy-paste these into your references.bib file.

Sometimes you want to footnote something, such as a web site.[1] Note that the footnote number comes after the punctuation.

4.3. Figures and Tables.

Figure 2 shows an example of how to include a figure in your report. Ensure that the figures and tables are legible. Please also ensure that you refer to your figures in the main text. Make sure that your figures will be legible in the expected forms that the report will be read. If you expect someone to print it out in gray-scale, then make sure the figures are legible when printed that way.

In Section 4.1, an example of a table was given. (Note that the "S" in Section is capitalized. Here's one more example - see Table 2.

Here's an example that shows how you can have side-by-side figures - see Figure 3 and Figure 4. (Note that the the "F" in Figure is capitalized.

[1] http://www.cs.princeton.edu

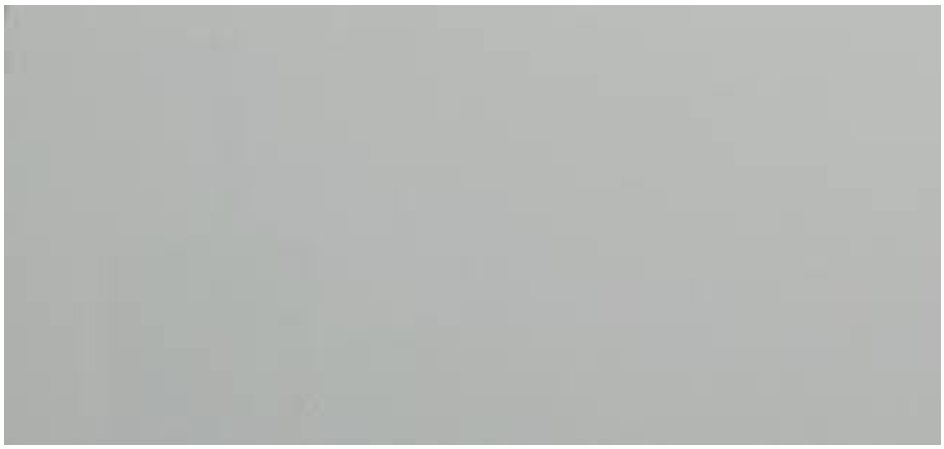

Figure 2: This is a gray image.

Some field	Another field
200	10000
400	20000
800	40000
1600	80000
3200	160000
6400	320000

Table 2: Some data in a table.

4.4. Double Quotes.

Latex double quotes are not the same as the double quote key on your keyboard. The standard way of writing quotes and double quotes in LaTeX is with “ and ” not with " and ".

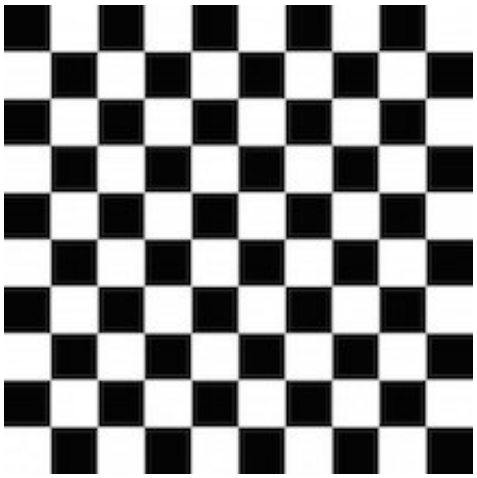

Figure 3: Plain checkerboard.

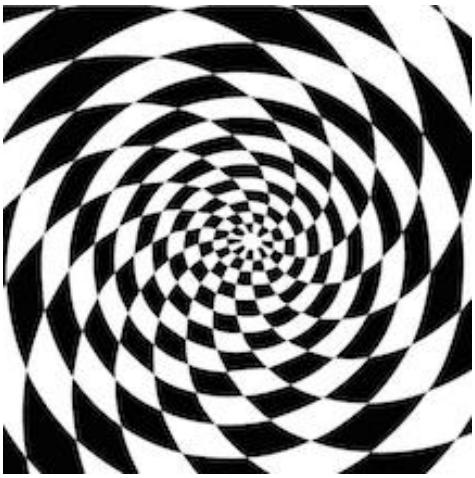

Figure 4: Cool checkerboard.

Now that may be confusing, so you may want to use the \{quotes} command. For example “The quick brown fox.”

4.5. Main Body.

Avoid bad page or column breaks in your main text, i.e., last line of a paragraph at the top of a column or first line of a paragraph at the end of a column. If you begin a new section or sub-section near the end of a column, ensure that you have at least two (2) lines of body text on the same column.