A STUDY ON THE CELLULAR TELECOMMUNICATIONS FACILITY COVERAGE TO PUBLIC ELEMENTARY SCHOOLS IN THE PHILIPPINES

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As the world is overwhelmed by the COVID-19 pandemic, many schools and universities are trying to understand how they will navigate the crisis through online education. For mobile network operators, it's an opportunity to serve the communities, especially in the underserved areas, and to ensure consistent and reliable telecommunication services across government and private sectors amidst the public health emergency. To ensure continuity of learning amid the COVID-19 situation in the country, the Philippines' Department of Education has partnered with the local telecommunication companies to provide free access to its new online learning platform. In this study, the performance of Philippine-based private telecommunications facilities and the available connectivity of various schools were investigated. Using a geographical information system software tool, the number and distance of cellular towers to schools were surveyed and comparisons in terms of bandwidth availability between urban and rural areas were analyzed. Free public WiFi access node and distribution methodology were also included in the investigation. Results show that a classification among the regions is very evident which further emphasized the impact of the telecommunication facilities in providing connectivity for online education to schools. Moreover, a huge discrepancy between rural and urbanized regions in terms of bandwidth availability near school areas is apparent. It can be deduced that the delivery and access to online education in the Philippines has been very challenging due to limited connectivity, particularly to public schools in the underserved communities, in this time of the pandemic.

Keywords: *cell towers; connectivity; facilities; public schools; telecommunications*

I. INTRODUCTION

The global provision of schooling is facing unprecedented challenges as a result of the COVID-19 crisis. Within the span of a few months, 191 countries had closed their schools to deploy social distancing measures in accordance with the World Health Organization (WHO) recommendations. More than 1.5 billion students from pre-primary to university-level have been affected by these closures, with classroom-based learning interrupted for indefinite periods of time. While some education systems, teachers, students and parents were somewhat prepared to adapt to existing distance learning programs and platforms, millions were not.

Without adequate information and communication technology (ICT) devices, internet/mobile network access, educational resources and teachers' training, students simply cannot partake in distance education to continue on their learning trajectories. At most risk of being left behind are students from resource-poor areas, remote rural areas and low-income households. In addition, learners with disabilities or those who use a different language in the home than in school will require more individualized support.

Reports of parents, teachers, communities and networks that have developed innovative and makeshift interventions, such as mobile-based Wi-Fi networks as well as on-demand content and textbooks available in clouds -- to broaden digital capacities have certainly sparked optimism. However, these grassroots efforts largely serve as a short-term band-aid solution. Although they are inspiring, more fundamental developments to bolster access to and use of ICT are required – both at home and in schools, and especially for younger learners at the primary and secondary levels where gaps are largest. Hastily put-together remote teaching approaches have not proven to be optimal learning experiences and could be off-putting to some students.

There were 73.00 million internet users in the Philippines in January 2020. Internet penetration in the Philippines stood at 67% in January 2020. On the other hand, there were 73.00 million social media users in the Philippines in January 2020. The number of social media users in the Philippines increased by 5.8 million (+8.6%) between April 2019 and January 2020. Social media penetration in the Philippines stood at 67% in January 2020. Moreover, there were 173.2 million mobile connections in the Philippines in January 2020. The number of mobile connections in the Philippines increased by 38 million (+28%) between January 2019 and January 2020. The number of mobile connections in the Philippines in January 2020 was equivalent to 159% of the total population [1].

The Akamai State of the Internet Report for the 2nd Quarter 2016 ranks the Philippines at 6th out of 15 Asia-Pacific countries with an average mobile internet speed of 8.5 Mbps. Peak connection speeds also reached a high 105.1 Mbps for the Philippines. Countries in the Asia Pacific Region with higher mobile internet speeds than the Philippines are: South Korea, New Zealand, Japan, Taiwan and Australia. According to the 2nd Quarter report, it was also observed that there was a 1.0% quarterly decrease in global internet connectivity. The global average connection speed decreased 2.3% to 6.1 Mbps from 6.3 Mbps, while the average peak connection speed increased 3.7% to 36.0 Mbps from 34.7. Mobile data traffic grew by 11% over the previous quarter. The Philippines hopes to enjoy faster speeds soon, as the two major network service providers in the country (Smart-PLDT and Globe Telecom) announced in the second quarter, the purchase of the

700 MHz frequency from SMC that is expected to enable faster Internet service speeds at lower costs, albeit for the wireless (mobile) connectivity [2].

In 2020, the necessity of access to the internet became even more evident as the COVID-19 outbreak led several countries including the Philippines to implement community quarantine to minimize the spread of infection through social contact [3]. To adjust to this new situation, education institutions shifted to remote teaching modalities. However, this new learning method relied heavily on the availability of electronic devices and a reliable internet connection, which are not accessible by everyone. Some schools have had to suspend online classes in consideration of the inequality [4].

The main contribution of this study is to classify the various public elementary schools based on their connectivity performance to a mobile telecommunication tower. Using an open-source geographics information system and bandwidth statistics dataset, the cellular towers near public schools in key cities and municipalities in the Philippines were collected and mapped. The mobile data coverage and strength dataset used was obtained using a crowdsourcing mobile application called BASS (Bandwidth and Signal Statistics). The school distances and cell tower coverage in terms of bandwidth and signal strength were collected and presented with corresponding analysis.

This paper is organized as follows: Section 2 discusses the state-of-the-art related studies on performance of cellular telecommunications facilities. Section 3 details the data gathering procedure and mapping of cellular towers locations with respect to public school coverage. Section 4 presents the results obtained and the corresponding analysis. Section 5 concludes the paper.

II. RELATED WORKS

Several previous works have initiated studies on the performance of cellular telecommunication facilities in terms of connectivity.

In [5], a dataset was used to investigate a comprehensive model of user satisfaction and electronic word of mouth (e-WOM). Building on the perceived telecommunication service quality and perceived value dimensions in enhancing and improving users' satisfaction and e-WOM, we empirically investigated how the dimensions of service quality as a second-order construct and perceived value dimensions affect users' satisfaction and e-WOM in the context of mobile operators in North Cyprus. The data were collected through a self-administered questionnaire at Girne American University. The dataset was empirically evaluated using a survey of 500 respondents regarding their perceptions of the service provided by the mobile telecom operator. Data analysis involved structural equation modelling (SEM) using Statistical Package for the Social Sciences (SPSS) 23 and Analysis of Moment Structures (AMOS) 24. First, we conducted exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural modelling, followed by hypothesis testing. The outcomes obtained from this dataset indicated that perceived telecommunication service quality was positively related to perceived value dimensions (performance value and emotional value) and user satisfaction. At the same time, performance value, value for money, and social value were found to have a direct impact on user satisfaction. Specifically, there was a significant relationship between user satisfaction and e-WOM. The results may provide further insights into mobile value-added services.

Another study investigated the inequalities of opportunity in the access and use of telecommunication services in Togo using a parametric approach [6]. The results of estimations indicate that, inequalities of opportunities are larger for men and the elderly than respectively women and youths and are more pronounced in urban areas and regions such as the Plateaux and Savanna regions. Moreover, the circumstance variables such as the ‘place of residence’ and the ‘region’ are the key variables in explaining the inequalities of opportunities in the access and use of telecommunication services in Togo. So, policies toward reducing inequalities of opportunity in the access and use of telecommunication services in Togo should be designed with regards to men, the elderly, and people living in urban areas and regions such as the Plateaux and Savanna regions.

Moreover, another work embraces both an estimation component and a policy scenario component [7]. Attention was called to the importance of estimating the number of unique mobile subscribers to gauge the intensity of the digital divide within a country. A demonstration of how the system dynamics approach offers advantages over purely statistical estimation models in that it enables dynamic exploratory policy assessments by the telecommunication companies and relevant government agencies was also presented. Further a system dynamics model can be embedded within an interface which allows easier model use by those not familiar with the methodology or the software employed. This allows dissemination of an effective policymaking aid despite low institutional capacity. Employing the system dynamics methodology, the rate of diffusion was estimated, identify its major determinants and the true market size in the case of Pakistan. This research can be useful for policymaking and business strategy development in, but not limited to, the mobile telecommunication sector in developing countries [7].

In [8], authors demonstrated the effect of spectrum caps' determination using frequency allocation in Thailand as a case study. This paper employs data from Q3 2012 - Q1 2020 for the three major mobile operators in Thailand (AIS, TRUE, and DTAC) and analyzes the mean difference of six operating parameters by 1 MHz spectrum and the industry average. Results revealed that AIS was the largest carrier with the most spectrum amount, the greatest number of users, with revenue exceeding the industry average. AIS also had a statistically significant operational efficiency in all six of the evaluated dimensions. However, TRUE which is second in the total number of users in Thailand was determined to have no statistically significant operating efficiencies. Furthermore, the study determined that operators need additional spectrum so that they can increase market share through improved service quality. Finally, the empirical evidence suggests that spectrum caps when set in conjunction with each auction did not create any significant operator's efficiency problem.

Finally, a work analyzed the value co-creation through sustainable strategic alliance amongst commercial and not-for-profit organizations in Bangladesh [9]. The research adopts qualitative method in the form of in-depth interviews from thirty-four senior management of commercial and not-for-profit organizations and industry experts in Bangladesh. Findings highlight the underlying drivers of strategic alliance that lead to value co-creation for concerned parties. The findings also suggest that strategic alliance constitutes service-ecosystem that facilitates emergence, engagement and evolution of social innovation that eventually drives value co-creation through sustained and successful social innovation. As such, the paper contributes to relevant literature and offers useful insights for practitioners and policy makers.

III. EVALUATION OF MOBILE TELECOMMUNICATION FACILITIES

This work presents an integrated approach based on geospatial arrangement and analysis of data of the existing cellular tower coverage performance to public elementary schools by taking into consideration all the constraints like resources available. First step of this integrated approach is mapping of cellular tower location. Then the algorithm designed for signal strength and bandwidth strategy is implemented by developing a plug-in that provides an interactive graphical user interface for visualization.

QGIS Application

QGIS (also known as Quantum GIS) is one of the leading open-source GIS programs which supports viewing, editing, and analysis of geospatial data. It was developed by Gary Sherman in 2002 and it can be run on Windows, Linux and Mac operating systems [10, 11].

QGIS was written in C++ program language, and it contains seven different libraries:

- Core – has all basic GIS functionality
- GUI – adds reusable GUI widgets
- Analysis – tools for spatial analysis of vector and raster data
- Server – adds map server components to QGIS
- 3D – for3Ddata
- Plugin – classes related to the implementation of QGIS plugins
- QgsQuick – QT Quick based GUI library primarily for mobile/tablet devices

Moreover, QGIS has implemented a Python API (Application Program Interface), which gives to Python developers a whole new range of functionality and potential for process automatization [12].

Figure 1 shows the sample mapping of cellular towers in the Philippines as of December 2019 using available data from Department of Information and Communications Technology (DICT) of the Republic of the Philippines while QGIS was used to generate the mapping. On the other hand, Figure 2 shows a magnified section of the map specifically in the Province of Sorsogon province with three cellular towers and their respective distance from different public schools in the area. The Province of Sorsogon is a province in the Philippines located in the Bicol Region. It is the southernmost province in Luzon and is subdivided into fourteen municipalities and one city. Its capital is Sorsogon City and borders the province of Albay to the north. Sorsogon province is situated at the southernmost section of Luzon. It is bounded to the north by Albay, the Pacific Ocean to the east, the San Bernardino Strait to the south, and the Ticao and Burias Pass to the west. It has a land area of 2,119.01 square kilometers and a population of 792,949 in 2015. It has 14 municipalities and a capital City, Sorsogon.

The province has 517 public elementary schools whose governance is divided into the Division of the Province of Sorsogon and city schools' division.

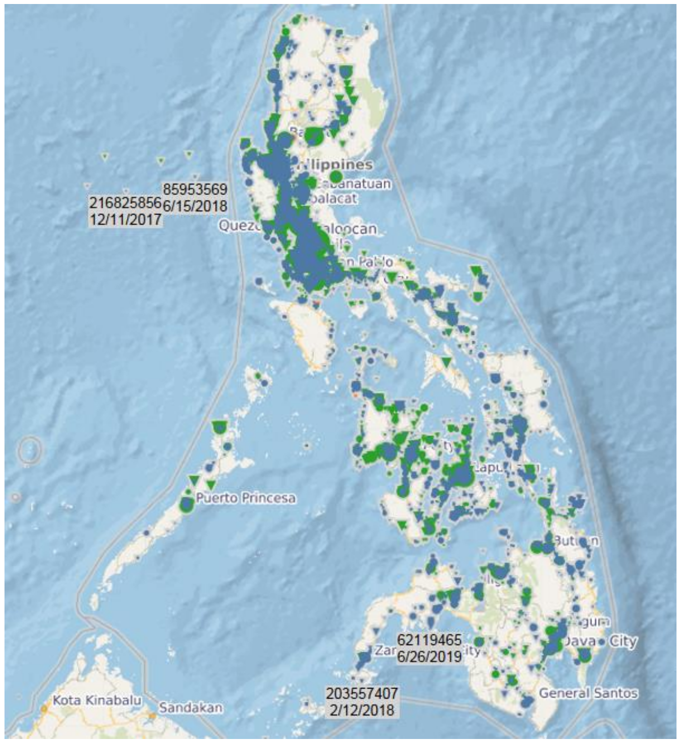

Figure 1. Satellite locations in the Philippines as of 2019

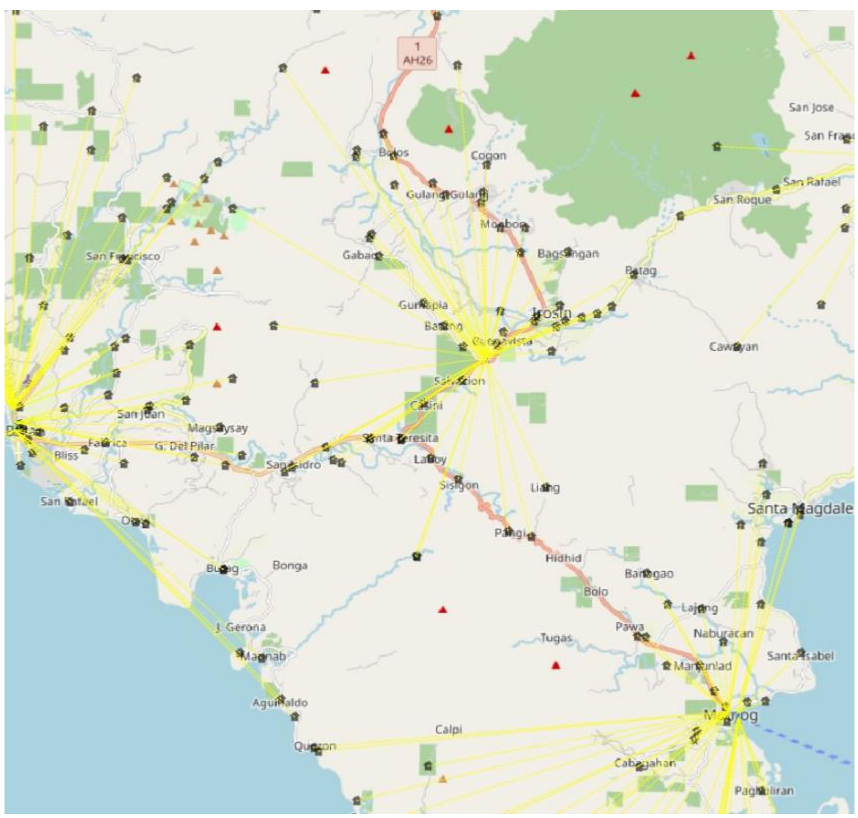

Figure 2. Cell tower coverage in rural area in Sorsogon, Philippines

QGIS is a free and open-source software that allows viewing, editing, and analyzing georeferenced data. It is a Geographic Information System (GIS) software composed by tools that allow to manipulate geographic information and consequently to create maps which help to get a better understanding and organization of geospatial data. Figure 3 shows the sample processing of QGIS while importing data from the dataset while Figure 4 shows the generated map of public elementary schools in the area.

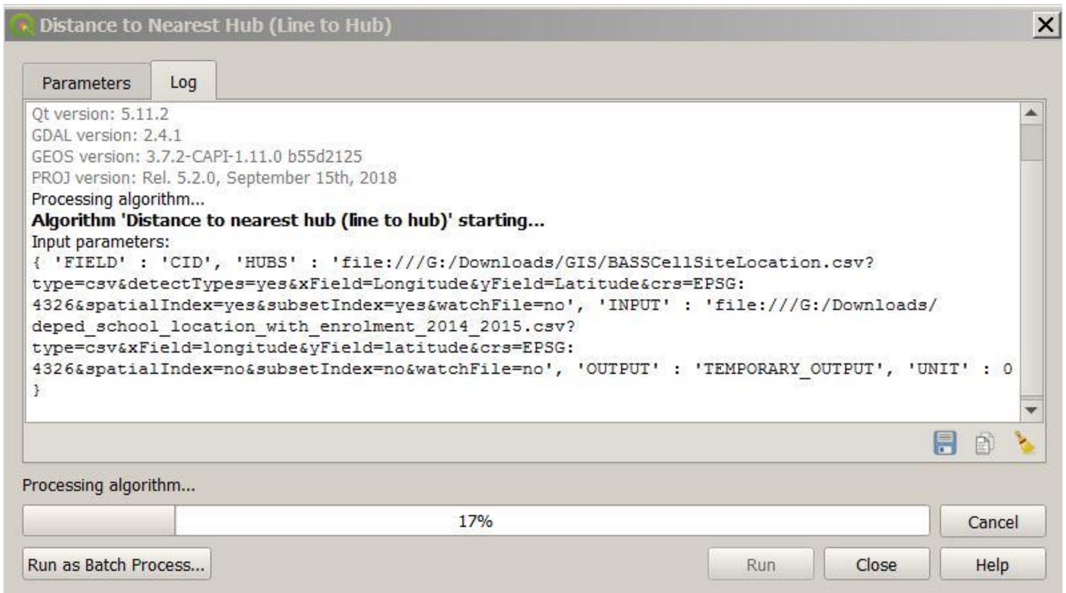

Figure 3. Sample processing of QGIS

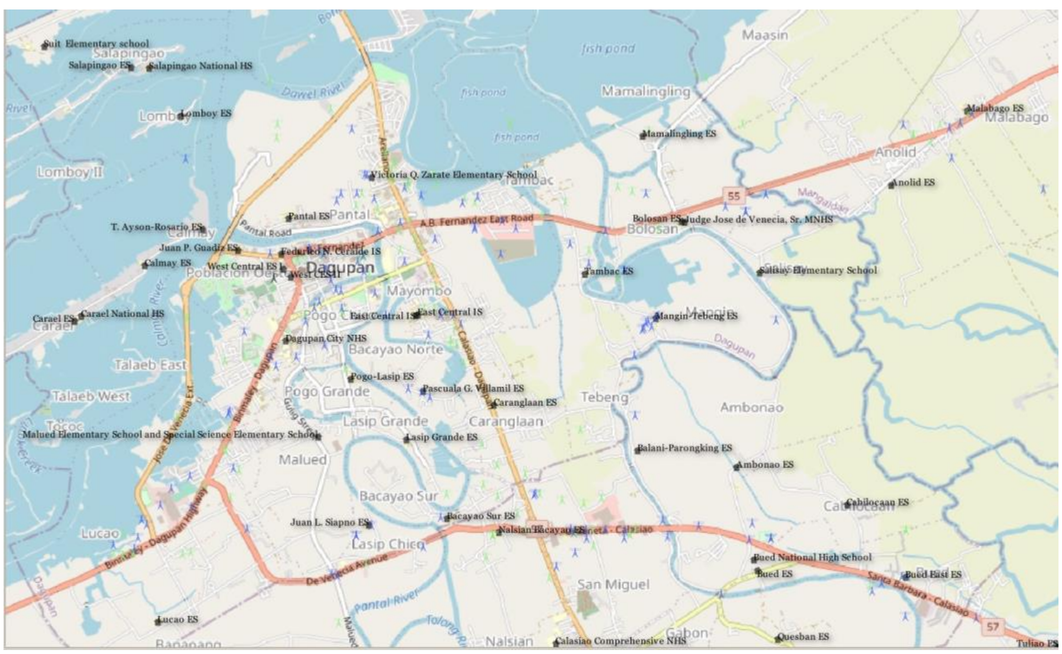

Figure 4. Sample mapping of QGIS

BASS Dataset

Data obtained from BASS PH (Bandwidth and Signal Strength). BASS PH is a mobile application designed by volunteers for volunteers to crowdsource location-based bandwidth and signal strength measurements of their carrier of choice to compile actionable data that will used to improve the state of local internet quality in the Philippines. In the past, it could not measure bandwidth. So, no one thought of monitoring it for the entire country. Yet, things have changed. Mobile phones have more abilities now. It can be used to measure speeds and signal strengths. It can be used to collect the data. It can analyze and extract insights. It can "crowd source" for volunteers. Collectively you and I can now measure bandwidth and signal strength of each carrier at any location at any time. It just needs a measurement tool and a server to collect the data.

Collection of network information from the access points was done using a mobile application that focuses on sensing RSSI values and conducting speed tests for bandwidth. The data collected was sent to a cloud server where it was stored and processed for visualization that users can view through a web application.

Activity Dataset

Activity dataset reflect the user activity through the number of SMS, call or Internet. Before releasing, the data are aggregated spatially to the level of regular grid and in 10 minutes time slots [13, 14].

Additional aggregation was performed over activity data to obtain distribution on a daily level. As expected, the values of activity differ significantly from day to day, and from one cell to the another. Automatization steps for activity data analytics are presented in Figure 5. Here, standard QGIS functions was applied such as `Joins`, `GraduatedSymbolRenderer` and `PrintLayout`. Map-canvas was also used, which is implemented based on the Qt Graphics View framework.

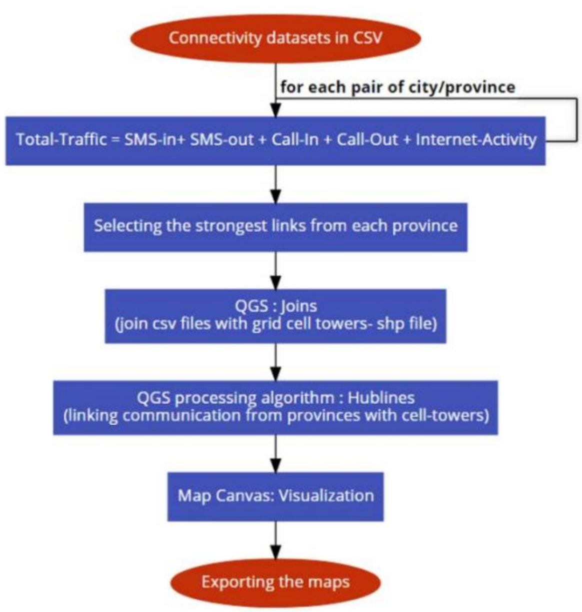

Figure 5. Flowchart for analytics of connectivity

Connectivity Dataset

Connectivity dataset reflect the level of interaction between a single square cell in Philippine provinces. The level of interaction is represented as a decimal number which is proportional to the number of exchanged calls. Visual analytics of such data provide opportunity to observe interaction patterns between a city and the whole country.

To provide examples for visual analytics, we first aggregated communication exchanged between same pairs, to get daily basis snapshot of connectivity patterns. To avoid visual clutter, we selected only the strongest links, links with the highest level of interaction between provinces and presented those links on the map. Connectivity data are analyzed in a few steps, presented in flowchart in Figure 5. Developed automatic pipeline enabled a fast creation of maps without manual importing data into QGIS and adjustment of parameters for visualization. In this pipeline the functions `Joins` and `PrintLayout` were applied, as well as the processing algorithm hub lines and the map-canvas.

IV. RESULTS AND DISCUSSIONS

This section presents the data collected and visualization of different public schools in the Philippines using school distance and cellular tower coverage in terms of bandwidth and signal strength.

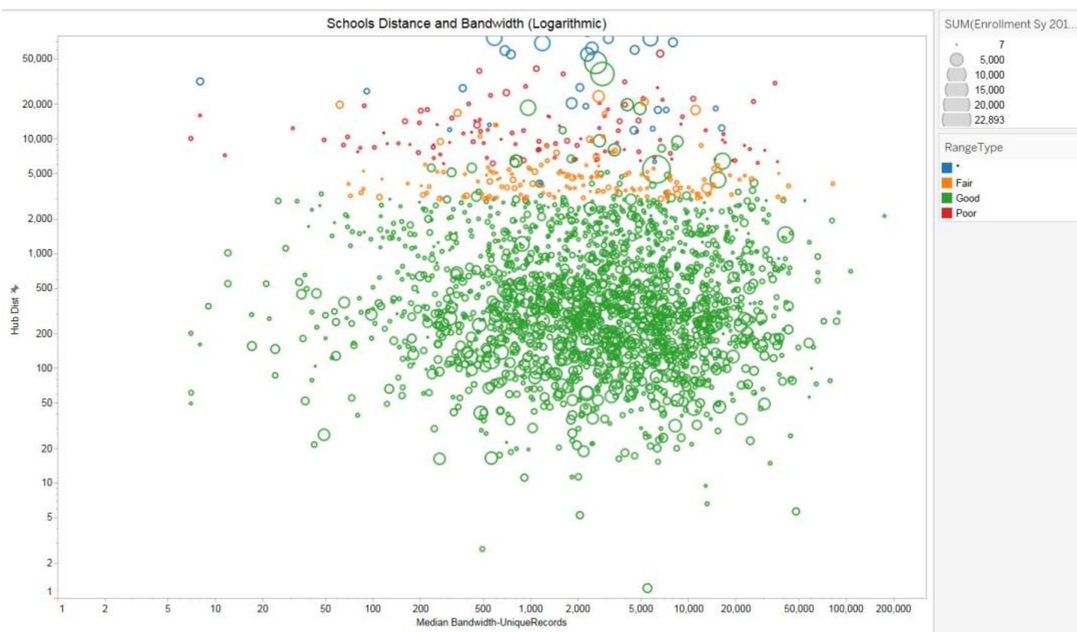

Figure 6. School distance vs bandwidth

Figure 6 shows the school distance to the hub line (in km) against the available bandwidth (in kHz) in the area in logarithmic representation. It can be seen that most schools located near the cellular tower have at least a “good” coverage. Those who have significant distance with the cell tower have either “poor” or “fair” coverage. It can also be observed that the median bandwidth range between 1000 to 10,000 kHz.

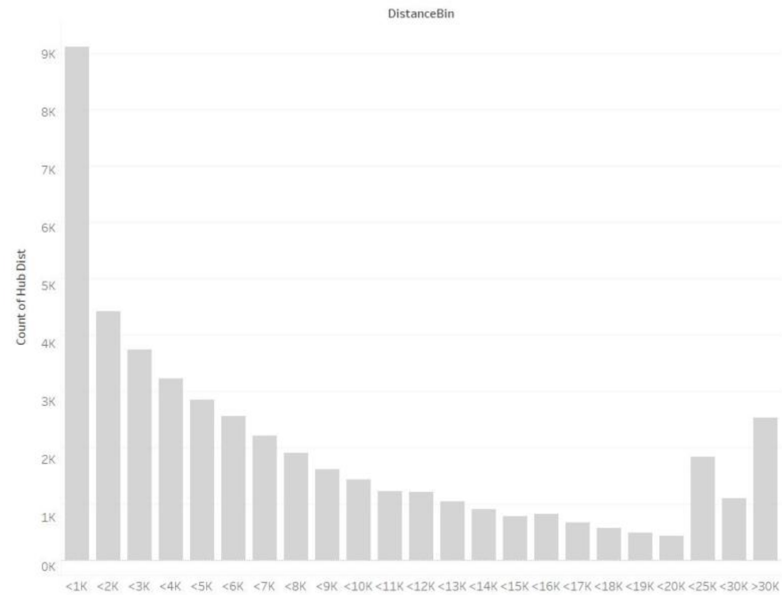

Figure 7. Distance versus median bandwidth

Figure 7 shows another representation of hub distance (in km) against median bandwidth availability (in kHz). On the other hand, Figure 8 shows the category of schools in the Philippines in terms of cell tower coverage and bandwidth availability. It can be noticed that 44% of the schools were classified as “poor” while around 37% were classified as “good”. This only shows that majority of public schools in the Philippines do not have enough coverage in their area affecting their connectivity and access to mobile communication and internet. In addition, the schools that belong to “poor” classification are the ones located in rural areas while the ones classified as “good” are located in urban areas. Thus, there is a clear divide between the public-school location as well as the available cellular towers provided by the telecommunication companies.

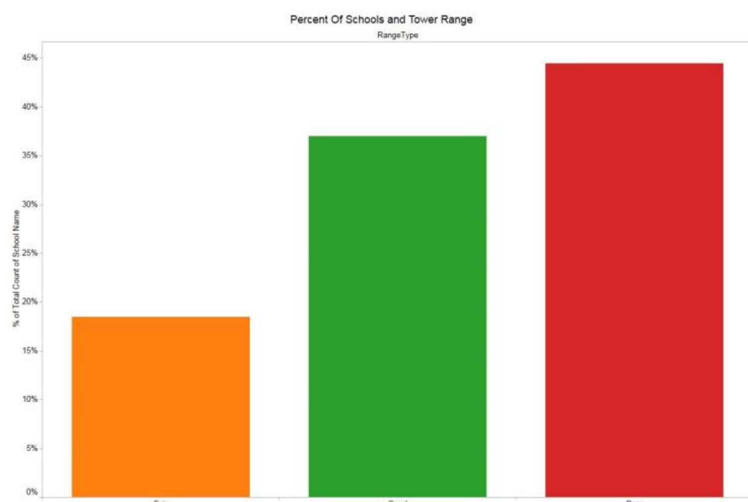

Figure 8. Percentage of schools with fair, good, and poor tower coverage

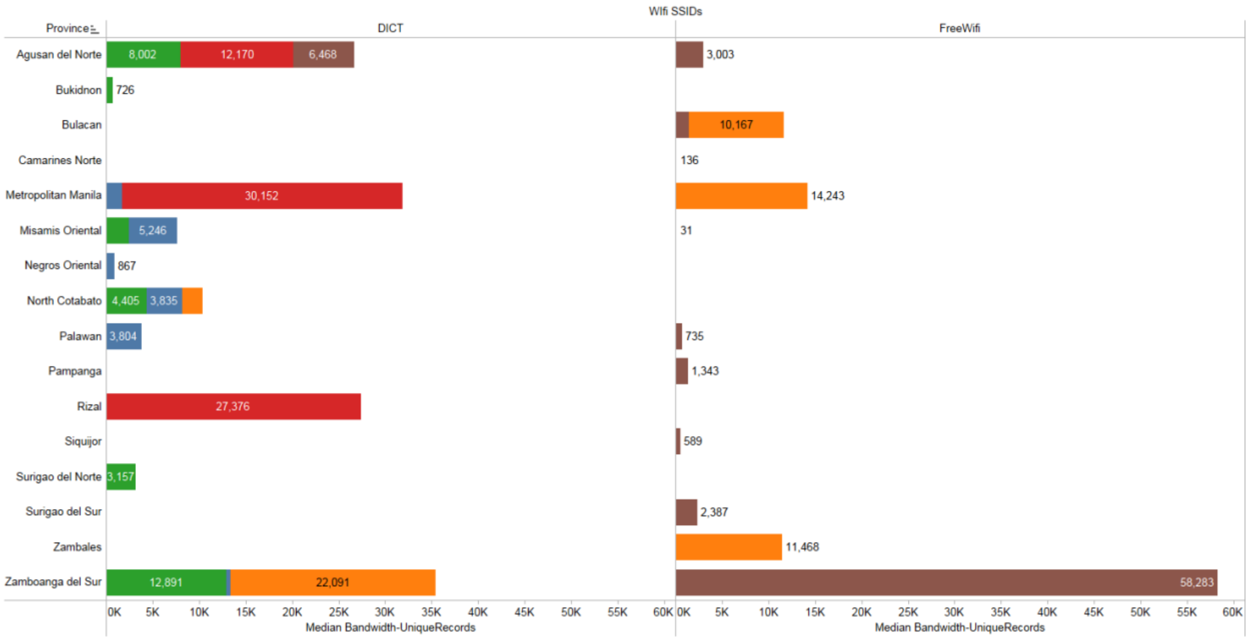

Figure 9. Median bandwidth performance of some provinces

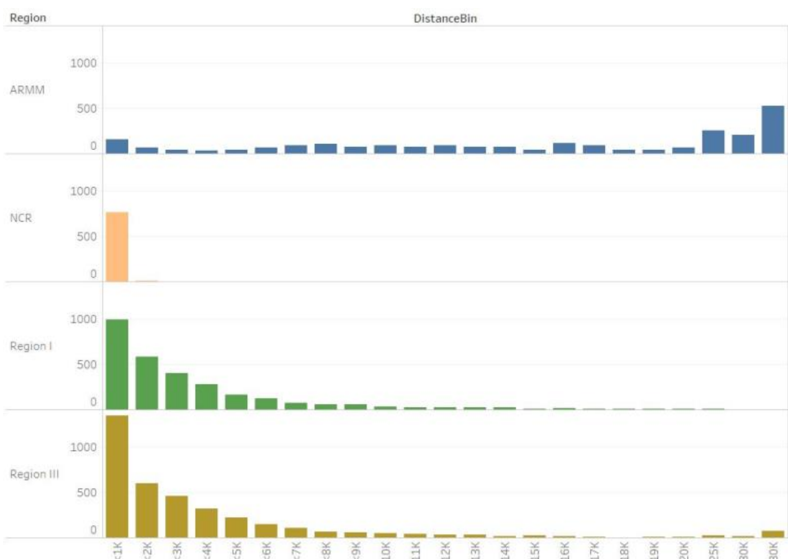

Figure 10. Regional performance vs distance

In addition to cellular coverage, this work included measurement on accessing WiFi points in the public schools. Figures 9 and 10 show the provincial and regional coverage against the median bandwidth availability, respectively, by accessing WiFi points specifically the “FreeWiFi” offered by the DICT to the public. This brings to light a very important issue about the broadband performance metrics that the government is using to assess the real state of Internet access, quality, and affordability that will inform policymaking and regulation. Data, after all, is only relevant and valuable when it reflects the reality on the ground and provides insights that can lead to solutions.

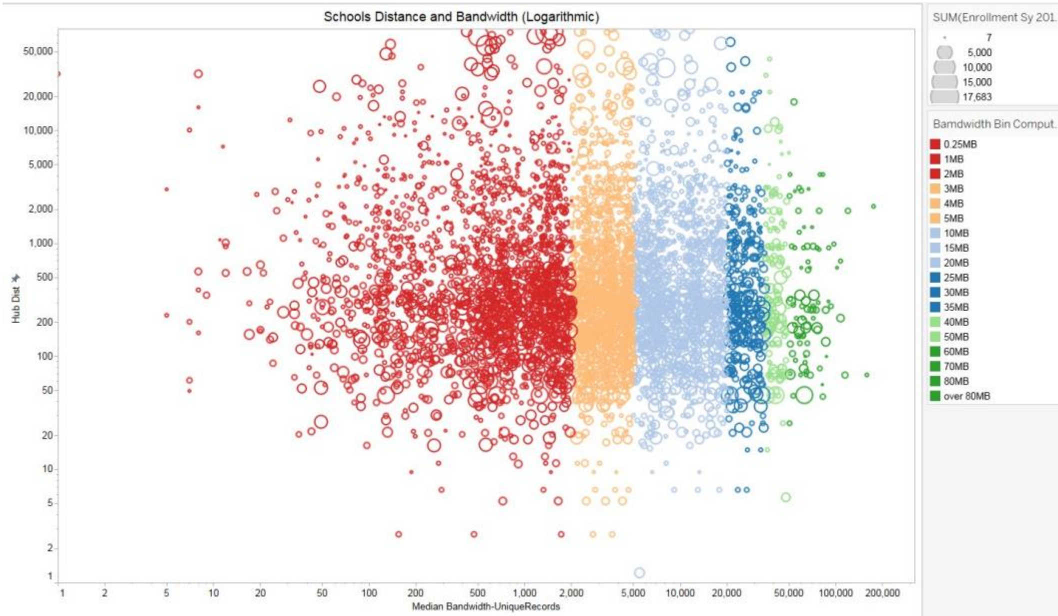

Figure 11. School distance vs bandwidth

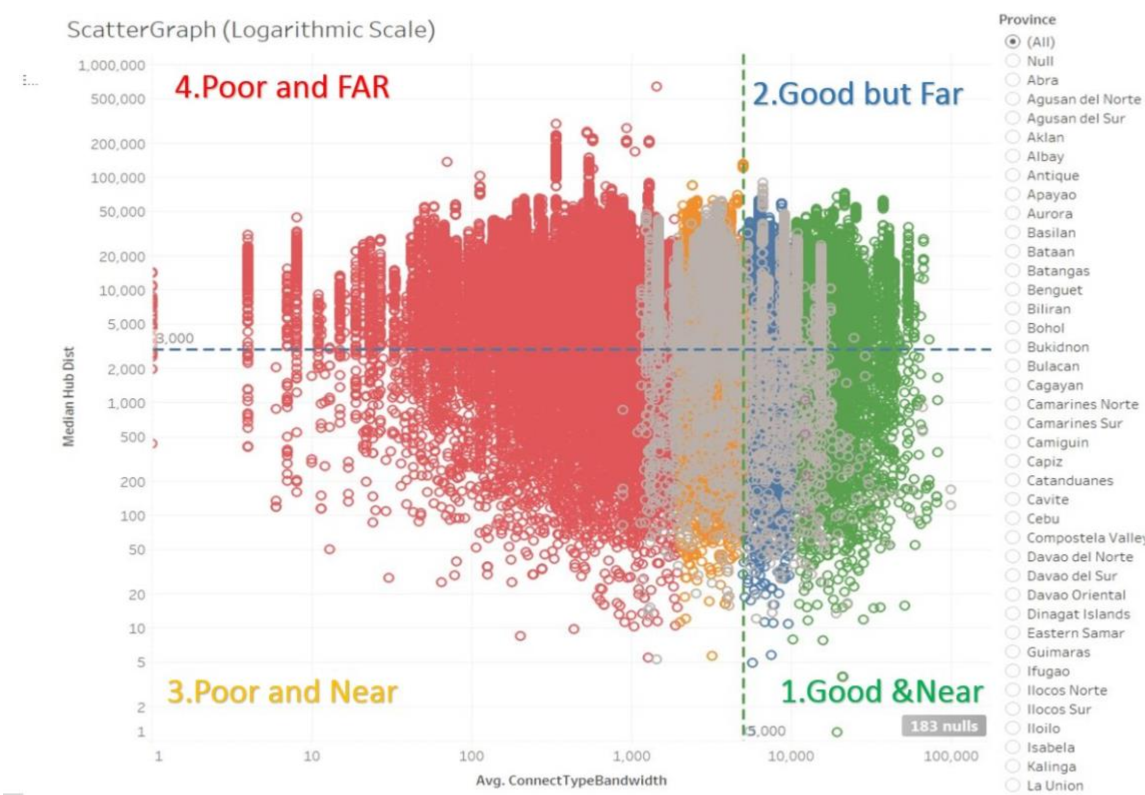

Figure 12. Public school classification based on 4 quadrant categories

The school's connectivity to the nearest cell tower were divided into four quadrants as shown in Figure 11. These four quadrants are divided on the Y axis by 3 km line and on the X axis by the 5 Mbps line as shown in Figure 12.

The lower quadrant represents the ideal. Schools are near a cell tower with higher median bandwidth. The upper right quadrant represents schools that are far from a cell tower with higher median bandwidth. This means that the schools are unlikely to be able to get higher bandwidths due to their distance. The potential solution can be is to get external antennas, or demand telecommunication companies to add more cellular towers in the area.

The lower left quadrant is for schools that are near to towers, but these towers have low bandwidth. Solution here is to ask telecommunication companies to increase bandwidth of these towers. The worst is the upper left quadrant. Schools in this quadrant are far from the towers and even if the schools could connect to these towers, the bandwidth they get will likely below broadband standards of 256 kbps. The possible solutions can be the utilization of TV whitespace or satellite Internet. This solution is now on the process of formalizing the satellite-based technologies dedicated to education and other civic causes through the House Bill 7081.

V. CONCLUSION AND RECOMMENDATIONS

As the Philippines ventures into a new mode of learning, several factors need to be considered. This includes teacher capacity, situation and context of the learner, and efficiency of the learning environment. These are, of course, on top of the more obvious issues of internet speed, cost of materials, and mode of delivery. The best way to move forward is to take a step back and design a strategy that engages teachers, students, parents, school administrators, and technology-based companies. This collaborative response based on a collective vision is the kind of creative solution this novel problem warrants.

Reliable data from school-based surveys can provide the quality ICT use data required to better inform education policy and practices, especially in developing countries. Capturing the complex set of factors involved will paint a more accurate picture of what is available and used by both students and teachers. This includes information, such as availability of digital infrastructure; internet connection speed; school activities in which teachers use ICT; training received by teachers to empower them to integrate ICT into their practices; strategies implemented by schools to develop digital skills; and perceptions by principals and teachers on ICT use in education and its barriers. Furthermore, the presence of qualified technical staff (e.g. technicians, librarians) is required to support the use of ICT in schools, including ensuring digital access and ICT learning among teachers.

In this work, a limitation of the WiFi testing conducted at the sites is that the sites chosen most likely have their access points located indoors while the experiment only took measurements from outdoors. This was done because GPS measurements do not perform well indoors and the data obtained from the experiment relies heavily on them. Excluding the data that are nearest to the source and that are not blocked by barriers such as walls would mean that the WiFi signal and bandwidth that were measured will not be including the strongest signals and speeds that are available indoors, and the results will not be able to completely reflect the capability of the WiFi at these sites.

This study believes that the permits issue represents just one aspect of the challenges faced by Philippine Internet. There are inherent problems in the country’s legal framework governing information and communications technology (ICT) infrastructure, which became more apparent during the pandemic. The policy and regulation we use for Internet connectivity are anchored on analog-era fixed telephone and radio broadcast services. We need to have laws that reflect how people connect and communicate in the Digital Age.

While this work is recognizing the DICT's efforts and look forward to the fruits of the National Broadband infrastructure and the Free Public Wi-Fi – if and when these projects are eventually completed – this study implores the government to also act in parallel on structural policy measures that will provide incentives for market players to connect the unserved and underserved areas, as the country works toward healing and bouncing back from the pandemic.

In the future, it is recommended to focus on discovering optimal solutions for visual representation of complex phenomena with the aim of developing a high level of automatization of the process. Moreover, future work may involve gathering crowdsourced data from more sites across the country. A bandwidth measuring tool may also be developed to continuously measure bandwidth over time to determine fluctuations throughout the day and more accurately report the bandwidth measurements.

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