ACCESSING THE INFORMATION AGE: SUMMARY

The problem we face is one of technology and its accessibility. We must find a way to make high-speed internet accessible and equitable for those who are in need of it. One option of making this a reality is mobile broadband, but is that enough to really make the internet a useful resource for the US and the UK?

Unlike many regions of the world, the U.S. and U.K. have a vast and stable internet infrastructure. Due to these circumstances, the U.S' and U.K.'s internet is relatively cheap. With improvements in technology, and greater infrastructure, we have predicted that the U.S.' and U.K's internet prices will only increase by about $0.55 and $0.40 each year, respectively. Hopefully, with cheaper internet prices, more people will have access to reliable internet. Our model predicts that by the year 2031, if the average download speed and inflation rate stays constant, the cost in megabits per second (Mbps) of bandwidth will be $177.57 in the US and $133.50 in the UK per month for one unit of bandwidth.

Different households require different bandwidths. Additionally, people partake in various internet related activities that necessitate minimum bandwidth requirements. Activities such as downloading large files consume large quantities of data while general web surfing only requires a minimal amount of data. Our model dictates that small households need bandwidths as low as 6 Mbps. On the other hand, large households with many members who participate in high data activities need up to one hundred Mbps.

In D8, three regions are given. Among the three regions, each one is unique. Each region and subregion have different characteristics such as population density and network requirements. To determine optimal node placements, we averaged the population density to determine the most equitable and cost effective distribution. We also took into account the percent average of household electronics that use broadband internet. We came to the reasonable conclusion that in region A, there should be two mid-band cell towers that span the area of the less densely populated regions. We would also put high-band towers in the more densely populated regions. For region B, we decided that having two low-band cell towers would cover the majority of the region, but also have 3 mid-band towers in the more specified densely packed regions. Finally, in region C, because of the population density, we would have two high-band towers in the more densely packed subregions in the south and a mid-band tower more towards the north to achieve full coverage.

Although we only created solutions to hypothetical problems, we have come to a better understanding of internet accessibility through cost, usage, and practicality. We're looking forward to a future where more and more people have access to the internet, ushering in a world of new ideas, opinions and information.

Accessing the Information Age

INTRO

Although the internet has reached practically infinite proportions, many people remain unconnected to the internet, removing them from larger society. With information comes power, but the information of the internet is reserved for those who can pay for it. When we approached these questions, we kept equity and efficiency in mind while finding a solution to bring internet access to more people.

Our task is to review and analyze data taken from previous years and circumstances and develop a model to help us, and the world, find an answer to the problem of internet accessibility. Through analyzing internet price changes over the years, individual house usage, and adapting cell towers to a certain community, we will come to a better understanding of equity through internet access and the Age of Information.

MODEL Q1

Restatement

This problem is about finding the cost of bandwidth, which is typically measured in Megabits per second (Mbps). The goal is to build a model for the next 10 years that predicts the cost per unit of bandwidth in dollars or pounds per Mbps in the U.S. and U.K.

Analysis

The bandwidth is expressed in megabits per second. Finding the cost per unit of bandwidth in dollars or pounds per Mbps requires knowing the average number of Mbps being used as well as the cost for each Mbps.

Design of Models

The first thing we did was find the average download speed for the next 10 years after 2021. We used the table given to show the average download speed in Mbps in the U.S. and U.K. from 2009 to 2017.

		Average Download Speed (Mbps)	
Data Source	**Year**	**US**	**UK**
Akamai	2017	18.7	16.9
Akamai	2016	15.3	14.9
Akamai	2015	11.9	11.6
Akamai	2014	10.5	9.9
Akamai	2013	8.6	7.9
Akamai	2012	6.7	5.6
Akamai	2011	5.3	4.6
Akamai	2010	4.7	3.8
Akamai	2009	4.2	3.7

(Akamai 2017)

For the U.S. and U.K. separately, we input in the table values into the Desmos graphing tool and found equations that modelled the tables. Our equation for the U.S. average download speed was $f(x)=3.78845(1.21975)^x$, where x is the year since 2009 and f(x) is the average download speed in the U.S. in that year in Mbps. Our equation for the U.K. average download speed was $f(x)=3.34084(1.22994)^x$, where x is the year since 2009 and f(x) is the average download speed in the U.K. that year in Mbps. Using these equations, we created tables showing the average download speed in Mbps for the 10 years after 2021 in the U.S. and the U.K.

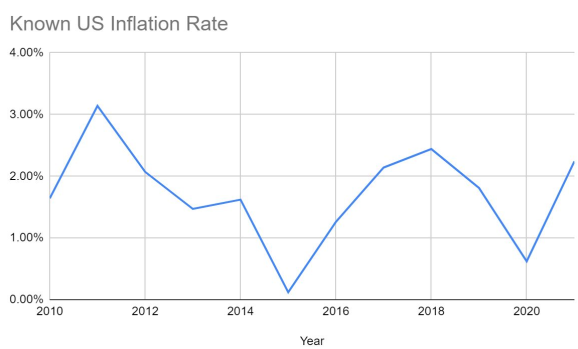
U.S.

Year	Average download speed in Mbps
2022	50.1167
2023	61.1298
2024	74.5631
2025	90.9483
2026	110.9342
2027	135.3120
2028	165.0469
2029	201.3159
2030	245.5551
2031	299.5158

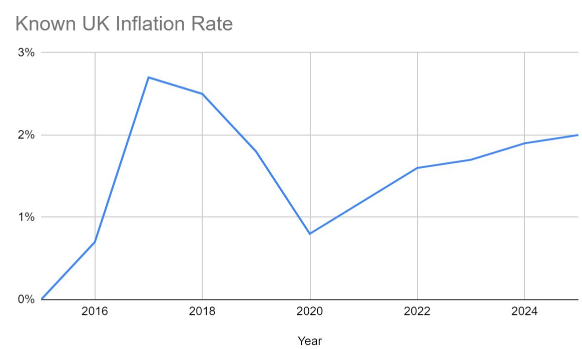
U.K.

Year	Average download speed in Mbps
2022	49.2432505
2023	60.56624352
2024	74.49284556
2025	91.62173046
2026	112.6892312
2027	138.600993
2028	170.4709053
2029	209.6689853
2030	257.8802717
2031	317.1772614

The next step was finding the cost per Mbps, taking into account inflation rates. For the U.S., we found that the average cost for 100 Mbps of speed was $50 in 2021, which is $0.50 per Mbps of speed (Dilley 2021). For the U.K. we found that people paid an average of $0.34 per Mbps of speed in 2017 (Jackson 2017). We then found the inflation rates for both countries in order to estimate the cost per Mbps for 10 years after 2021.



(Stipp 2021)



(Baron 2021)

Using the inflation rates for the U.S. and U.K., we found the average inflation rate in the U.S. to be ~1.714167% and the average inflation rate in the U.K. to be ~1.536363636%.

With the average inflation rates in the U.S. and U.K., we found the cost per Mbps of bandwidth in the U.S. and U.K. for the next 10 years by using the known cost and adding the average inflation rate to it.

U.S.

Year	Cost (US dollars per Mbps)
2022	$0.51
2023	$0.52
2024	$0.53
2025	$0.54
2026	$0.54
2027	$0.55
2028	$0.56
2029	$0.57
2030	$0.58
2031	$0.59

U.K.

Year	Cost (US dollars per Mbps)
2022	$0.37
2023	$0.37
2024	$0.38
2025	$0.38
2026	$0.39
2027	$0.40
2028	$0.40
2029	$0.41
2030	$0.41
2031	$0.42

Now that we know the average bandwidth speed in Mbps and the cost per Mbps, we can calculate the cost per unit of bandwidth in dollars per Mbps. We multiplied the average bandwidth speed in Mbps by the cost per Mbps for each year for the U.S. and U.K. for the 10 years after 2021 to get our models.

U.S.

Year	Cost per Mbps of bandwidth
2022	$25.49
2023	$31.62
2024	$39.23
2025	$48.67
2026	$60.39
2027	$74.92
2028	$92.95
2029	$115.32
2030	$143.07
2031	$177.50

U.K.

Year	Cost per Mbps of bandwidth
2022	$18.07
2023	$22.57
2024	$28.18
2025	$35.19
2026	$43.95
2027	$54.89
2028	$68.54
2029	$85.60
2030	$106.90
2031	$133.50

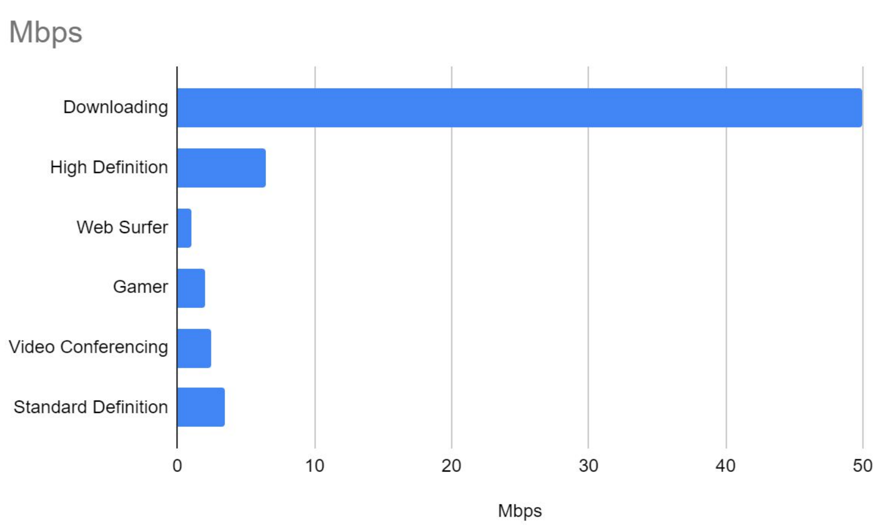
MODEL Q2

The main categories of Mbps consumption usually fall among high definition and low definition streaming, video conferencing, gaming, and general web surfing. Since bandwidth or Mbps are not a unit of speed but of data importation capacity, calculating bandwidth necessities is a matter of addition or subtraction (Nerdwallet 2021). Additionally, devices subtract bandwidth from networks leaving less bandwidth to other devices not necessarily slowing down the network. To predict the bandwidth requirements of various households we created the equation
$f(x) = 1(w) + 2(g) + 2.5(c) + 3.5(s) + 6.5(h) + 50(d)$. By multiplying the amount of people who participate in the various internet activities with its respective Mbps requirement, you can calculate the bandwidth requirements. To calculate the bandwidth requirement for 90% and 99% of the time we multiplied f(x) by 9/10 and 99/100 respectively.

$$f(x) = 9/10(1(w) + 2(g) + 2.5(c) + 3.5(s) + 6.5(h) + 50(d))$$

$$f(x) = 99/100(1(w) + 2(g) + 2.5(c) + 3.5(s) + 6.5(h) + 50(d))$$

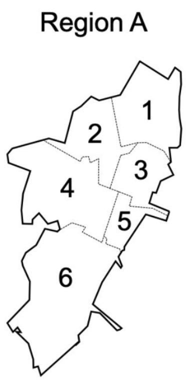
# of people web surfing	*w*
# of people gaming	*g*
# of people downloading files	*d*
# of people streaming high def video	*h*
# of people streaming standard def video	*s*
# of people video conferencing	*c*



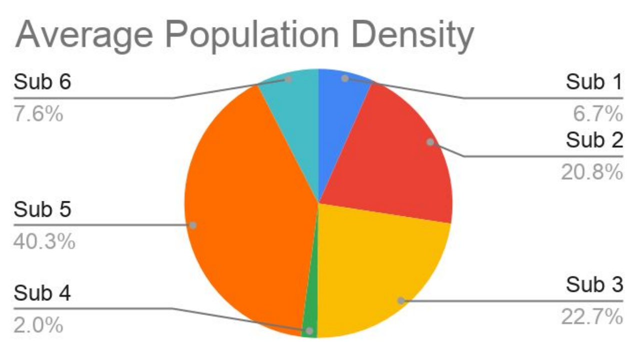
MODEL Q3

Through averaging the population density of each region and their respective sub regions, we decided the network requirements and the best place to put different types of broadband nodes. Along with population, we took into account factors such as types of devices which require various bandwidths or use broadband as opposed to routers. After we created a general model, we later introduced additional variables such as age, professions, and broadband usage.

Region A: Baseline Broadband Usage Estimate



For Region A, we began to evaluate the regions, their population density, and percentage of homes with broadband and percentage of homes that use smartphones (D8 Region A). Taking into account the relatively small population density and the overall medium number of households with broadband internet and cellular phones, Region A takes mild precedent for higher bandwidth. To continue, we've estimated that region A should have two mid-ranged bandwidth towers that reach to both ends of the region (Venture Beat). This would cover the less densely populated sub regions such as regions 4, 6, and 1. Assuming that the towers cover the regions, we would also place high band towers in the more densely populated areas such as sub region 5, and maybe sub region 3 and 2 (Venture Beat). This would cover the most amount of households while not taking too many resources.



Region A: Population Averages

Region A	Average Population Density (people/sq. mile)
Subregion 1	570.24
Subregion 2	1777.5
Subregion 3	1944.7
Subregion 4	168.48
Subregion 5	3452
Subregion 6	650

Total Population: 6327 people (D8 Region A)
Total Area: 6.83 sq. miles (D8 Region A)
Total Average Density: 926.35 people per sq. mile

Region A: Percentages of Household Electronics

% households w/ desktop or laptop…………………………….... 64.3%

% households w/ broadband internet service……………………. 49.5%

% households w/ a smartphone……………………………….. 69.2%

% households w/ smartphone - no other computing device……... 4.3%

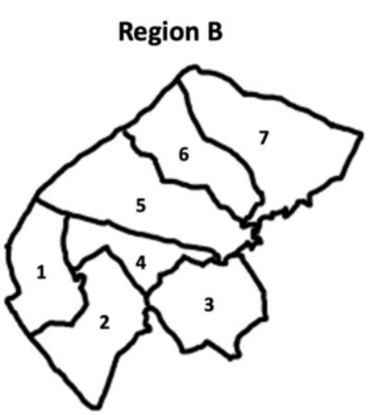
Region A: General Notes

- None of the percentages for electronics possession surpasses 70%
- Generally small population with pockets of higher density (see Sub 5)
- Relatively medium sized area compared to other regions
- Pretty average pop density compared to other regions

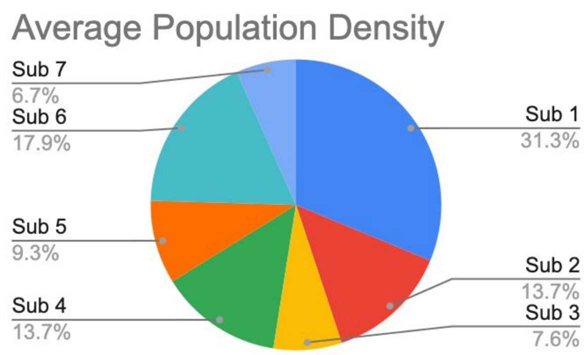
***Region A: Percentage of Usage Estimate** *(see page 13 for explanation)*
½ - ½: 59.35%
⅔ - ⅓: 56.067%
¾ - ¼: 54.425%

Region A: Final Thoughts/Conclusion
Lastly, considering the ¾-¼ broadband that we calculated, we believe our estimates would still be accurate to a certain degree. With our broadband estimates, we found that the percentage of people who need faster internet is somewhere between 54.425% - 59.35%. We felt that our estimate is accurate to the internet speed needed. Something else to note, we did consider unemployment, poverty, and other specific statistics but thought that they wouldn't affect the final results too much because the percentages of households wouldn't change.

Region B: Baseline Broadband Usage Estimate:



Due to a very low percentage of households with a broadband internet service but a very high percentage of households with a smartphone, Region B would take a lower precedent for bandwidth needs (D8 Region B). In order to keep costs and maintenance low and due to the large geographical size and low population, we have estimated that Region B should have 2 low band nodes on the northern and southern portions of the region (Venture Beat). This way, there is a blanket amount of low speed internet for all the regions, to secure that everybody has at least some semblance of broadband. However, while this is equal, it is not equitable. To make this equitable, we would put three mid band nodes, one in Subregion 1, one in Subregion 3, and one in Subregion 6. We would put one in Subregion 1 and 6, respectively, because they have the largest population density, which would mean more demand for broadband bandwidth. We have also included one in Subregion 3, due to the fact that it is separated from the other subregions and so therefore may not be completely covered by the blanket low maintenance nodes. We have decided to not include any high band nodes because there is not enough demand to justify the cost and maintenance of the towers.



Region B: Population Averages

Region B	Average Population Density
Subregion 1	1112.931
Subregion 2	485.997
Subregion 3	270.043
Subregion 4	486.638
Subregion 5	330.637
Subregion 6	636.074
Subregion 7	237.931

Total Population: 15054 people (D8 Region B)
Total Area: 33.64 sq. miles (D8 Region B)
Total Average Density: 447.503 people per sq. mile

Region B: Percentage of Household Electronics

% households w/ desktop or laptop…………………………………….. 92.77

% households w/ broadband internet service…………………………… 4.41

% households w/ a smartphone………………………………………… 86.21

% households w/ smartphone - no other computing device…………….. 1.22

Region B: General Notes

- Possession of electronics percentage pretty high (92.77% desktop/laptop)

- Comparatively very large population (mostly even sub, except Sub 1 is large)
- Large area (sq miles)
- Low average pop density

Region B: Percentage of Usage Estimate *(see page x for explanation)*

½ - ½: 45.31%

⅔ - ⅓: 31.677%

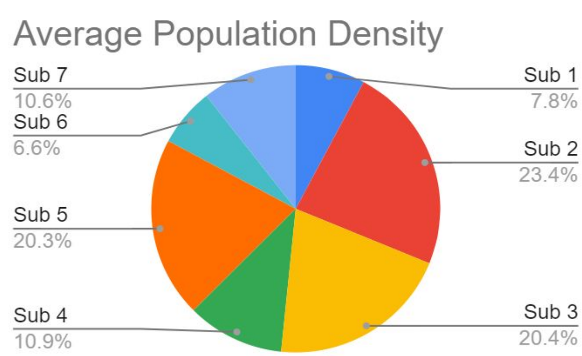
¾ - ¼: 24.86%

Region B: Final Thoughts/Conclusion

This seems to be the most reasonable solution with the information given. The percentage of broadband usage estimates an average between 45.31% - 24.86%, which is quite a large gap in estim
ate. However, all estimates are still less than half, meaning less than 1 of every 2 people use broadband internet. Plus, the subregions are, on average, roughly the same size in both geography and population. This region does not have any outliers that harshly affect any averages. This concludes that Region B really doesn't need much broadband connection, justifying the blanket low band nodes, occasional mid band nodes, and lack of high power nodes (Venture Beat). If there isn't demand, there is no reason to use many resources on it. Lastly, we discussed questions of age demographics and low income wages, but due to the parameters of this region, we came to the conclusion that those do not affect the overall result enough to affect our node placement.

Region C: Baseline Broadband Usage Estimate

Region C is the most prominent. With the smallest total area and the largest population (shown in the data provided below), region C would likely need the strongest internet all around (D8 Region C). Region C has the highest percentage of households that use broadband internet and households with smartphones. Because of the high percentages and the large population, region C would naturally need an internet that is open to everyone. We came to the baseline conclusion that region C would have 2 high



bandwidth towers that are spaced evenly apart (Venture Beat). This would give high end internet access to the entire region. However, the more densely packed regions (according to our pie chart) are more on the southern end of Region C, while the less packed areas are to the north. Because of this, we thought to arrange the higher speed towers a bit more to the south and perhaps include a mid-band tower more towards the north that could reach to the end of sub region 7. This model would pretty accurately estimate the internet needs of Region C.

Region C: Population Averages

Region C	Average Population Density
Subregion 1	3863
Subregion 2	11600
Subregion 3	10120
Subregion 4	5396
Subregion 5	10069
Subregion 6	3252
Subregion 7	5262

Total Population: 9505 people (D8 Region C)

Total Area: 1.64 sq. miles (D8 Region C)

Total Average Density: 5796 people per sq. mile

Region C: Percentage of Household Electronics

% households w/ desktop or laptop…………………………………….. 89.49

% households w/ broadband internet service…………………………... 90.42

% households w/ a smartphone……………………………………….... 87.52

% households w/ smartphone - no other computing device……………. 2.7

Region C: General Notes

- Electronic possession is all around 90%
- Very dense population
- Small area region
- Sub regions of higher density; but still overall a very small area.

Region C: Percentage of Usage Estimate *(see page 13 for explanation)*

½ - ½: 88.97%

⅔ - ⅓: 89.453%

¾ - ¼: 89.695%

Region C: Final Thoughts/Conclusion

To conclude, being that this region is the most compact, there isn't much fluctuation in the model. All the regions are nicely compacted together and very densely populated making the high-band towers the obvious choice (Venture Beat). Considering the percentage of usage estimate that we calculated, the percentage of people needing high-band internet would be anywhere from 88.97% - 89.695%. This percentage would easily justify having a high-band internet in this region. To continue, we still didn't think the specific statistics would affect the internet priority because the internet priority is based on the percentage of households and people (provided) that use the internet.

Regarding the Percentage of Usage Estimate:

We have given 3 options of estimates here. One is the flat out average, half is the percentage of households with a broadband internet service, and the other half is the percentage of households that own a smartphone. We did this to get a rough estimate of how much broadband is used on average in each region. However, we decided to give other values to more correctly model the way people use broadband on their phone. This is where the ⅔ - ⅓ and ¾ - ¼ percentages come into play. By ⅔ - ⅓ we mean that the average is two parts households with broadband, one part smartphone (divided by three). Likewise, by ¾ - ¼ we mean three parts households with broadband, one part smartphone (divided by four). We give these three options, but recommend trusting the ¾ - ¼ percentage the most, because it seems to be the most accurate to reality. The problematic assumption that the average of ½ - ½ makes is that when people use their phones to browse the interwebs, they are never at home. This is not very realistic. About half the time, folks are outside, and likewise, people are at home about half the time. When they are at home, it can be reasonably concluded that they have connected to their home's broadband rather than still using the cellular towers, both for a better connection and cost efficiency. So if they are at home using their home's broadband half the time and using the cellular broadband the other half of the time (on average), that would mean the cellphone percentage should be halved, one half containing the use of broadbands directly to smartphones and the other half being the households with a pre-existing connection to broadband. This is why we have put the ¾ - ¼ average, seeing as it is a more realistic depiction of how much one would use their phone on their household broadband and a direct broadband to their smartphone. One last reminder that this is a very rough estimate, and this does not fully represent the percentage of broadband usage for each region.

DISCUSSION

Q1

These models demonstrated that as the average download speed in Mbps increases and inflation increases the cost per Mbps, the average cost of bandwidth increases steadily up to $177.50 in the U.S. and $133.50 in the U.K. per month by 2031. These models use current average download speeds in Mbps along with past and present inflation rates to estimate the increase in cost.

These models have some weaknesses. Among them are different factors that could affect either the average download speeds or the cost per Mbps. One factor could be a maximum cap in download speeds that are reached, however download speeds are predicted to reach 10 gigabytes per second (NCTA 2017). Other factors could be new advances in technology that decrease the cost per Mbps of download speeds.

A different and more developed model could take into account a lot more factors that affect download speeds and cost per Mbps. Specific areas could have different download speeds and costs depending on the income of the population. The formulas used in these models are pretty simple, involving simple addition and multiplication with two exponential equations used. As more factors are added in, different kinds of formulas could be tested that might better model the situation.

Q2

Since this function only models a household at a particular time, it cannot be completely accurate. Throughout the year, a household's data consumption can vary. For example, during the summer, kids could be playing video games that require new network requirements. Families could be streaming movies and videos at home. Some could be video calling relatives who live far away. Other people who work at home could be downloading files and video conferencing with others. Or maybe people could be traveling and becoming reliant on their mobile broadband, using less of their WiFi network.

Q3

People are constantly changing their way of life. Whether they move to a new city, get a new job or acquire new electronics, they are influencing their communities bandwidth. Communities are never stagnant, they constantly change.

For Q3, we used the data provided to come to a reasonable conclusion for the population density in each region. We then came up with our own calculation to create an estimate for priority of internet speed. Our estimate could be off because of this, but we felt that it retained a number close to the household percentages. On top of this, we also didn't do too much calculation when it came to the individual ages, jobs, poverty, and etc. We didn't feel that those specific statistics would affect the overall household electronics that were given to us. The overall percentage of households that have electronics or need broadband would still need broadband regardless of their age and job. To conclude, we agreed that the deviation that may be caused by the age and jobs of the residents in these regions wouldn't affect the population's density and therefore wouldn't affect their need for their internet bandwidth and consumption. Given more time, we *would* explore the age difference per region to acquire a more accurate model, but time is limited.

CONCLUSION

In our data collecting and modeling, we have come up with well structured and thought out answers for each question. For the first question, we discovered that internet pricing increases each year in both the US and the UK. In the second question, we developed the equation $f(x) = 0.99(1(w) + 2(g) + 2.5(c) + 3.5(s) + 6.5(h) + 50(d))$ and $f(x) = 0.9(1(w) + 2(g) + 2.5(c) + 3.5(s) + 6.5(h) + 50(d))$ to accurately represent Mbps usage per different households. And finally, to answer the last question, we averaged the population density of each subregion and calculated the average amount of broadband that would be used in order to efficiently and effectively place broadband nodes where they are needed in a cost efficient way.

With the introduction of the internet, we have been able to communicate and share information like never before. Though accessibility to the internet is so useful to everyday life, not everyone can afford the prices. Some people have inadequate and unequal access to information, further perpetuating the gaps between the privileged and the less fortunate. While universal internet coverage may appear to be a lofty goal, the benefits of a completely connected world can outweigh the costs of infrastructure.

With universal internet coverage, everybody could have access to education and opportunities. Also, the internet can offer insightful advice like medical information that could save people's lives. Additionally, the internet enables communication between people that is much needed in underdeveloped areas.

Those without internet access are at a significant disadvantage. Without the internet, many children cannot attend school, especially during the time of the pandemic, thus missing out on their education. Although online school will soon come to an end, the Information Age will always be biased to those with consistent internet access.

Hopefully the future can bring us into a new age of communication and shared knowledge that can benefit all.

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