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# SPATIAL ANALYSIS OF THE INFRASTRUCTURAL DEMANDS OF INTEGRATING 5G TECHNOLOGY: A CASE STUDY IN THE CITY OF DETROIT

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# SPATIAL ANALYSIS OF THE INFRASTRUCTURAL DEMANDS OF INTEGRATING 5G TECHNOLOGY: A CASE STUDY IN THE CITY OF DETROIT

By

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| | |
|---|---|
| 2G | $2^{nd}$ generation cellular network |
| 4G | $4^{th}$ generation wireless technology for cellular communications |
| 5G | $5^{th}$ generation wireless technology for cellular communications |
| FTTA | Fiber to the Antenna |
| LTE | Long-Term Evolution |
| RRH | Remote Radio Head |

## Abstract

The invention of 5G technology is expected to revolutionize wireless communication, technology, and capabilities. One major challenge in realizing this vision is the actual deployment of 5G nodes and the development of 5G network infrastructure. Higher frequency and shorter wavelengths that are characteristic of 5G technology is expected to decrease signal range radii of 5G nodes, which could have serious implications for the implementation of a 5G network. This study assessed cell signal density and cell signal coverage that could be achieved using existing 4G infrastructure in the city of Detroit. Results indicate that existing infrastructure is not capable of supporting a new 5G network and that significant investment in infrastructure development will be necessary to generate comprehensive 5G coverage within the city of Detroit. Ultimately the implementation of 5G will require a telecommunications overhaul and significantly more planning and design than may have been originally anticipated.

# 1 Introduction

The invention and integration of technologies such as the telephone, internet, and wireless communications into modern life and infrastructure have had lasting effects on society. The ability to communicate and interact with others without being in the same space, or even on the same continent has completely changed business practices, the economy, and interpersonal relationships in recent decades. The creation of the 3rd generation cellular network (3G) in the early 2000's, which allowed for internet access anywhere in the range of a connecting antenna/tower, has spurred the development of smart phones, social media, live interfacing, smart phone applications, and the transfer of large quantities of data. The initial success of 3G technology drove the development of 4th generation wireless technology for cellular communications (4G), which would perform faster than 3G technologies and allow for the integration of other wireless technologies (Hui & Yeung, 2003). As we become increasingly reliant on wireless communications and technology, and continue to develop smart devices that rely on secure and fast wireless networks, the need to further increase wireless network speeds and capabilities has begun to be addressed with the design and early implementation of 5th generation wireless technology for cellular communications (5G) (Andrews et al., 2014; Gupta & Jha, 2015). The purpose of this study is to assess how well current 4G infrastructure can support the up-and-coming 5G network. Results will allow for an assessment of the work required to develop a comprehensive 5G network in a given location.

## 1.1 Overview of Current 4G Infrastructure and Technology

The 4G wireless network was released just over a decade ago. While 4G technology is generally considered commonplace these days, it required a massive infrastructure and technology effort in order to be successfully implemented (Gozde et al., 2015; Hui & Yeung, 2003; Sigle et al., 2009). Establishing a 4G antenna network with good signal coverage and connectivity between antenna using remote radio head (RRH) modules and fiber to the antenna (FTTA) networks required a massive investment of time and money (Kardaras et al., 2010). Despite initial challenges in setting up these networks, they have been successfully designed and implemented in numerous places, allowing for 4G connectivity throughout most of the country. Continued implementation of 4G in locations that do not yet have it should be relatively easy now that telecommunications engineers and companies have a better understanding of what is required to set these systems up.

Existing 4G technologies offer data rates over 100 megabits per second, efficient and low-cost use, and a variety of impressive capabilities including the implementation of graphical user interfaces, advanced gaming, and high-definition images and video (Krenik, 2008). 4G technology advancements paired with network improvements that allow for increased speed and decreased network congestion as compared to 3G (Huang et al., 2012; Sule & Joshi, 2014). This has allowed us to access mobile videos, email, video-chat, game, interface with home technologies, and many other things which we all commonly do on a day to day basis.

## 1.2 5G Technology and Infrastructure Needs

The implementation of 5G technology will be another challenge in terms of updating infrastructure and network capabilities. 5G technology will provide significantly faster data rates in the gigabits per second range, which will allow for enhanced speed, decreased network congestion and the use of more advanced technologies supported on the network as compared to 4G (Andrews et al., 2014; Chang et al., 2014). The major change in 5G technology that will allow for this is the increased frequency and decreased wave lengths that it uses as compared to 4G technology (Chang et al., 2014; Delmade et al., 2018). While this will greatly enhance the speed and decrease latency of the network, 5G technology is not compatible with current 4G infrastructure. The differences in wavelength and frequency result in a much smaller signal range for 5G technologies as compared to 4G. As a result this will require the establishment of a denser antenna and fiber optic network which will have to be emplaced within the current 4G network as those locations are updated with new 5G antenna and large fiber optic cable lines (Andrews et al., 2014; Chang et al., 2014; Ge et al., 2016; Oshima, 2016; Sule & Joshi, 2014).

This presents a significant engineering challenge, as the exact working range of 5G antenna needs to be tested in order to determine how to update the network to support a comprehensive 5G network. Simulation studies have indicated that space may become a limiting factor in the ability to successfully deploy 5G (Ge et al., 2016; Liu et al., 2017). This could create significant engineering and cost challenges as telecommunications teams work to find unique solutions to install antenna and fiber-optic cables where they need to go to generate a 5G network. In addition to this, existing antenna and fiber optic cable networks need to be updated as they do not support the right wave lengths or frequencies and do not have enough fiber optic cables, respectively, to support the amount of data transfer that will occur under a 5G network (Chang et al., 2014). In order to plan for this infrastructural shift a predictive coverage analysis for 5G demand needs to be performed. This study assesses predicted 5G signal coverage in the city of Detroit, MI if 5G updates were made using only the existing 4G infrastructure. Results will indicate how much work is required to update the network and provide comprehensive 5G coverage in the city of Detroit.

## 2 Methods

The following analysis was conducted in the city of Detroit, MI, which hosts some of the highest population concentrations in the state of Michigan (U.S. Census Bureau, 2012). This case study aims to analyze if existing 4G wireless service infrastructure can support new 5G wireless service across the United States. Given the fact that the 4G wireless infrastructure dataset for the entire country is rather large, a case study using the city of Detroit was used for this project in order to decrease computational cost. When setting up this project and analyzing data, two primary assumptions were made for existing and future antenna sites:

**Assumption 1: Existing fiber networks will provide fiber only to existing antennas.**

- This assumption is necessary as this is a signal-based study and does not take into consideration what is necessary to build new antenna or fiber networks. While the construction and network development needed for new 5G towers and corresponding network connection is an important part of this process it will not be considered in this study.

**Assumption 2: Core signal strength for the 5G signal antenna type will be constant.**

- There are many factors that determine the strength and distance a signal can travel from a given cell type (i.e. 4G or 5G antennas/nodes). This is represented in the 4G analysis, as signal range data has been collected in a variety of settings. Factors that contribute to 4G signal range include height of antenna, obstacles such as mountains, buildings and trees, signal wattage, user data sue, and weather conditions. For this study, the universal core strength range is used for 5G analysis. 5G utilizes short waves for antenna connections which can reach a maximum usable distance of approximately 300 meters. Based on this standard value, 5G nodes will be assigned a 300-meter radius for a serviceable area.

## 2.1 Data Acquisition and Pre-Processing

Cell site data a was acquired from a private vendor of cellular service, namely Verizon Telecommunications. These data contain not only Verizon tower data, but data from all cell towers in the United States. Due to the inherent large nature of this dataset, a small subset in the city of Detroit, MI was used as previously mentioned.

Each data point represents a cell site. These sites can be macro sites (large tower, high wattage, maximum signal distance), small cells (small towers, i.e. light poles, tops of buildings, lower wattage), and antennal nodes (antennas positions inconspicuously in multiple places, including indoor locations). Each cell has many attributes, but for our purposes, we utilized the location, signal range, and activity (if activity = 0 the cell site data was discarded) data from each cell.

The study area contains approximately 8,713 4G LTE antennas. This number changes slightly on a daily basis, but this was the number of antennas as of July 1, 2019, when data for this project was collected. Antenna locations were geo-processed and projected using the ArcPy package within ArcMap v10.7 (ESRI, 2011) to show spatial distribution (Figure 1). Using these locations, the signal coverage of each antenna can be produced by buffering each point with a radius equal to the industry standard signal range estimate of 300 meters

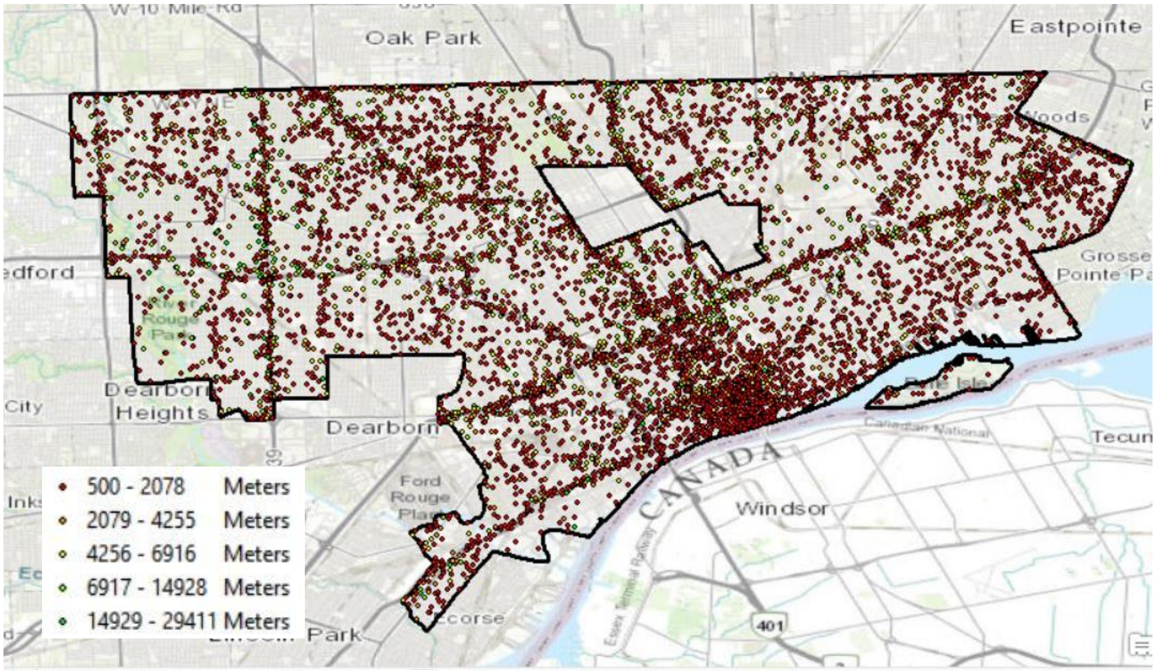


**Figure 1. Spatial distribution of 4G LTE sites in the City of Detroit**: The sites are segmented by their classification of signal range. For this project, the ranges were broken in to five range categories. Distances are measured radially in meters.

(Verizon Wireless, New York, NY, USA). Doing this at each location generates overlapping polygons in certain locations, which are representative of areas where there is signal redundancy in wireless coverage. Understanding signal redundancy is important, as the more signal redundancy a single location has, the better the signal connectivity and data transfer speeds are in that area. These two kinds of data (signal coverage and redundancy) provide critical information for understanding overall signal coverage and signal strength in an area. The overwhelming redundancy in the City of Detroit makes it impossible to visualize where, and how many signals are crossing, however, this data provides a basis for performing density and intensity coverage analyses for 5G wireless technologies.

Infrastructure design currently analyzes two critical aspects for telecommunications construction planning. The first is overall coverage of an area, which in most metropolitan areas is not an issue. The second aspect is redundancy of signal strength, which is essential for efficient wireless network use in high population density areas. The following signal density analysis takes the number of redundant radial signal polygons and is mapped as a signal strength map. This predictive analysis is performed in three phases:

1. A signal density analysis that shows overall 4G/5G coverage (including redundant density)

2. 4G/5G signal strength redundancy analysis that illustrates where the strongest signal repeaters are located

3. Combining both signal coverage and signal strength to generate an overall “Cell Signal Coverage” map for both 4G and 5G (antenna replacement) areas.

## 2.2 Signal Density Analysis

Density analysis was calculated by using a modified kernel density technique that is outlined below (Botev et al., 2010; Silverman, 1981). The modified kernel density equation considers the redundant signal areas instead of single weights, and the signal distance instead of using a standard distance and fixed radii determined by the traditional equation

$$SD_w = \sqrt{\frac{\sum_{i=1}^{n} w_i(x_i - \bar{X}_w)^2}{\sum_{i=1}^{n} w_i} + \frac{\sum_{i=1}^{n} w_i(y_i - \bar{Y}_w)^2}{\sum_{i=1}^{n} w_i} + \frac{\sum_{i=1}^{n} w_i(z_i - \bar{Z}_w)^2}{\sum_{i=1}^{n} w_i}}$$

**Equation 1:** Weighted distance formula where Wi is the weight for feature i, and (Wwi, Ywi, Zw) represent the Weighted mean Center for a given coordinate set

(ESRI, 2011). Two components need to be calculated prior to signal evaluation. The first is the weighted distance ($SD_w$), in which location points are weighted by the feature (in this case redundancy) and multiplied by the representative weighted mean center (Equation 1). The weighted mean center is calculated by multiplying the coordinates available for a given point (x,y,z) by the redundancy (feature) weight and summing for all the coordinates individually. This value is then divided by the sum of all the weights.

The next component is the search radius or for our purpose the bandwidth (Equation 2). The previous equation (Equation 1) which provides weighted mean centers for each location enables us to solve for this. The search radius, or bandwidth, is calculated by obtaining the mean center of the input points and weighing them by the redundancy value calculated earlier in the project. The distance from the mean center then needs to be obtained for all the points in the case area, and the medians (*Dm*) of these distances are determined.

$$Bandwidth\ (\beta) = 0.9 \times \sqrt{\left(\frac{1}{\ln(2)}\right) \times (Dm)} \times n^{-0.02}$$

**Equation 2:** Search radius or "bandwidth" equation where Dm is the weighted median distance from the weighted mean center, SD is the standard distance, and n is the sum of the population (redundancy in this case).

Bandwidth can then be calculated by multiplying $SD_w$ or the *Dm* by constants and the n value for the case area. This calculation is completed using both $SD_w$ and *Dm*. The calculation with the smallest final bandwidth estimate is used later on for kernel estimation.

In this case study, *Dm* resulted in the smaller bandwidth value, and was used in the equation (Equation 2).

With both values formulated, we can calculate the Signal Density Equation:

$$Density = \frac{1}{(radius)^2} \sum_{i=1}^{n} \left[ \frac{3}{\pi} \cdot pop_i \left( 1 - \left( \frac{dist_i}{radius} \right)^2 \right)^2 \right]$$

$$\text{For } dist_i < radius$$

The density value is then multiplied by the sum of the redundancy value, so that the final value is equal to the number of total observations rather than equal to 1.

This whole process is performed for each point of redundancy, and the resulting values are exported spatially. Values are then mapped to the center of a raster "cell" (size determined by the point data density of the project) and can be mapped and scaled accordingly. This results in a map displaying redundancy-scaled signal density values in an area.

This process was performed using active 4G cell sites and their respective signal ranges, and for the same 4G cell site locations using 5G predictive ranges.

## 2.3 4G/5G Signal Strength Redundancy Analysis

Signal repetition is critically important for areas that have high population density. In order to quantify this, focal statistics from one cell site to its radial bounds needs to be compared to its neighbor(s) (Bryn et al., 2013). This is achieved using a four-step process. The first step is to relate a given cell site with the number of radii that it intercepts. This is accomplished by a one-to-many relationship in which a single cell site is referenced to the number of cell circumferences that it intercepts. This counted number is then assigned to the cell site as a new field. A simple calculation of subtracting the join count by one will allow the actual count to omit the base cell. The cell coverage polygons are then rasterized in order to assign a given value to each cell within the sample area. Focal statistics are then performed in a annul method aligned with the cell coverage perimeter for each cell. This is performed in a sequence as follows:

1. The annulus shape is comprised of two circles defined by the cell size. The data scientist defines a smaller circle inside an outer perimeter circle; thus, the processing shape resembles that of a donut. Cell centers that intersect the inner radius perimeter of the cell inside the radius of the larger perimeter cell are processed for the given neighborhood. The area in which this process occurs becomes a single annulus neighborhood. This process is performed on each cell in the processing area.

2. The radius of a cell is identified in meters based on the radial output of the signal range. The size is then measured perpendicular to the x- or y-axis. The resulting radii produce an area that closely resembles the area calculated for the signal range. Any cell center encompassed by the annulus is included in the annulus processing neighborhood.

3. For the 4G interaction, the annulus neighborhood changes for each cell as the signal range varies. For the 5G analysis, the neighborhood area is set to 300 meters, as this is our defined signal range (Verizon Wireless, New York, NY, USA).

The results of these analyses are exported as a raster with a weight assigned to each cell. The weight is representative of overlap redundancy for a given pixel. This can then be used to determine the overall signal strength at any point. The determination of signal strength assumes that the radial neighborhood is a perfect circle. In reality, the signal radius of an antenna can vary in shape based on many of the conditions previously discussed.

## 2.4 Generating a Cell Signal Coverage Map

A simple raster calculation of spatial averages allows us to obtain overall cell signal coverage. By multiplying the cell values of both the signal density and signal strength redundancy analyses across individual cells, then dividing each cell by two (average), we can obtain the overall coverage for both 4G and 5G signals. To properly display the results on a map all the raster cells need to be normalized. To do this, a simple normalization was performed, and the outputs were scaled so that each of the four data sets reflect the same ranges. The output of this calculation gives an index scale from 0-250, where 250 represents the strongest signal and zero represents no signal at all.

# 3 Results

Results from the analyses described above show that cell signal density is highly comprehensive and cellular coverage is average to excellent throughout the city of Detroit for 4G technologies. Cell signal density is high along main roadways, but poor throughout the rest of the city of Detroit for 5G technologies. Cellular coverage is extremely poor throughout the city of Detroit for 5G technologies, with coverage along major roadways bordering on average. Results are described in more detail in the following two sections.

## 3.1 Predicted 5G Signal Density in Detroit, MI

Signal density as calculated in Chapter 2.2 was plotted within the city of Detroit boundaries for both 4G (Figure 2) and 5G (Figure 3) technologies. Within Figures 1 and 2 areas represented by warm colors represent low signal density (or low levels of overlapping signal) and cool colors represent high signal density (or high levels of overlapping signal). Cell tower sites are not plotted separately on this figures, rather signal density within 9 $m^2$ geographical map cells is plotted.

Signal density for 4G technologies is very high within the city of Detroit, represented by the abundance of cool colors plotted on the map (Figure 2). This indicates that within city boundaries 4G signal is abundant and should be capable of supporting large numbers of devices and fast data transfer. Since 4G technology infrastructure has been established in the city for several years, we expected signal density to be strong in the area. This initial analysis confirmed this and indicates that the methods used can provide an accurate estimate of cell signal density and should provide useful information on the signal density that could be achieved by 5G utilizing existing infrastructure.

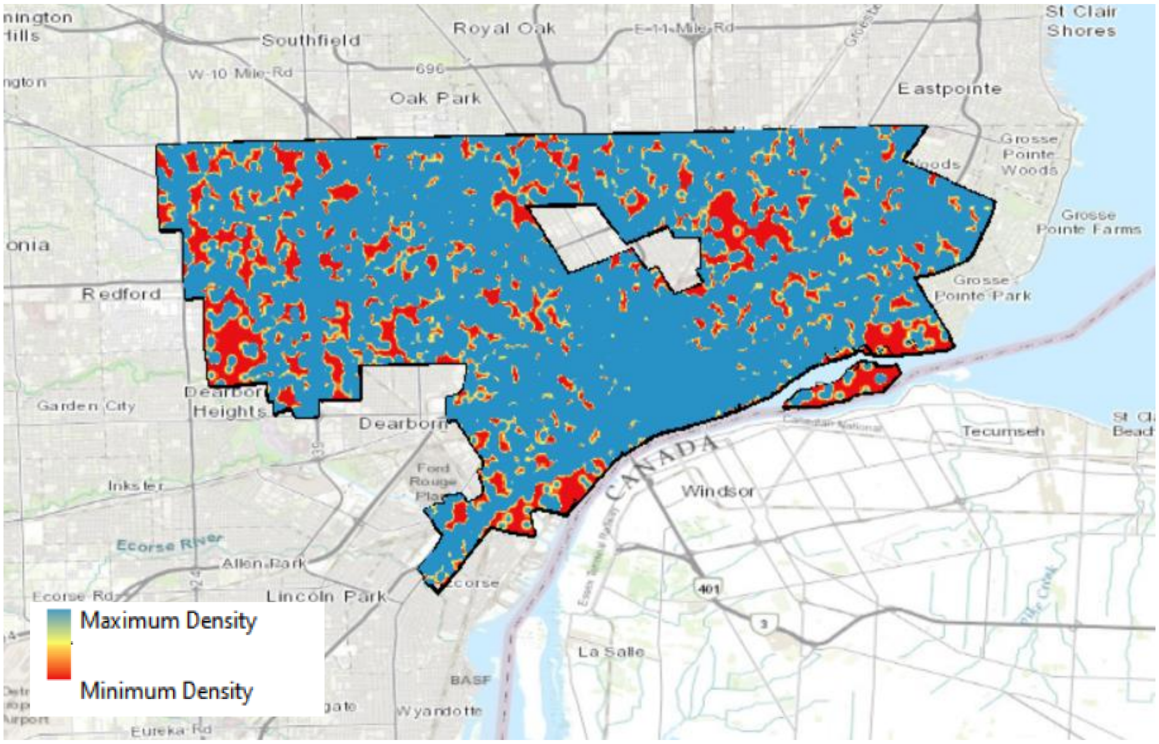


**Figure 2. 4G Signal Density in the City of Detroit**: Signal density results plotted in 9 $m^2$ map cells throughout the city of Detroit. Warm colors indicate low signal density while cool colors indicate high signal density within individual map cells.

Signal density for 5G technologies is very low within the city of Detroit, represented by the abundance of warm colors plotted on the map (Figure 3). Signal density near major roadways was very high for 5G technologies. This indicates that by replacing existing 4G cell towers with 5G cell tower technology would not provide enough signal throughout the city. Low signal density observed throughout most of the city would indicate that 5G signal is scarce and that minimal users would be connected to the network and would struggle with smooth data use and transfer.

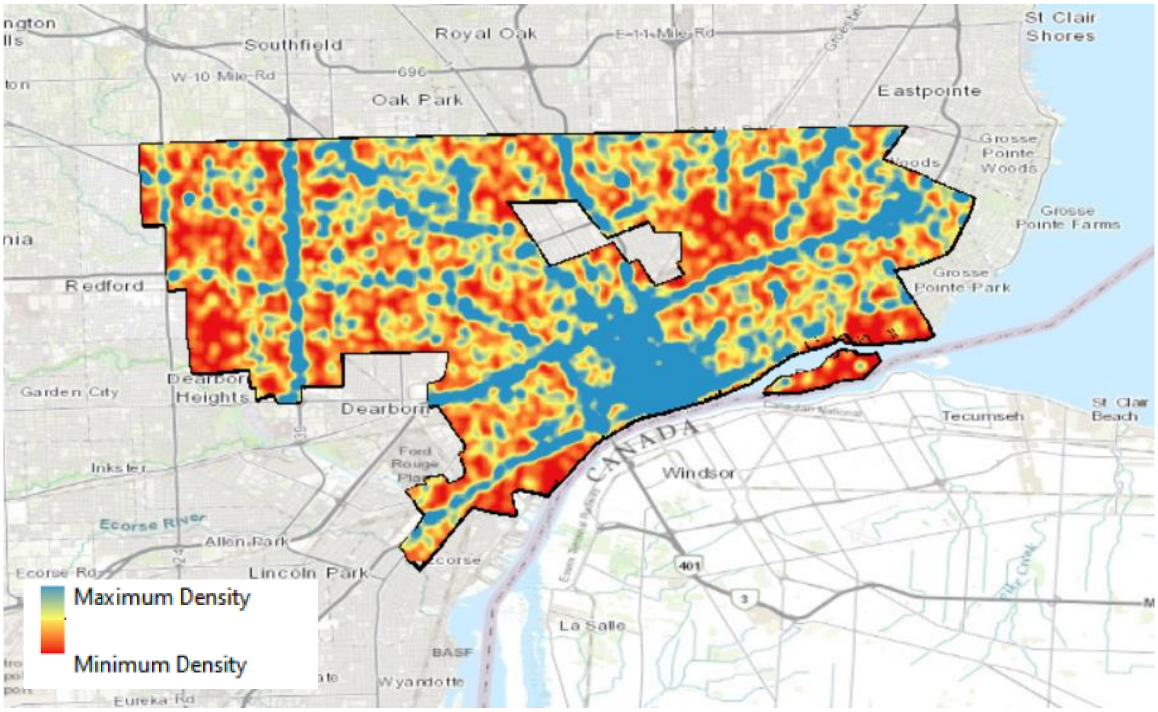


**Figure 3. 5G Signal Density in the City of Detroit**: Signal density results plotted in 9 $m^2$ map cells throughout the city of Detroit. Warm colors indicate low signal density while cool colors indicate high signal density within individual map cells.

## 3.2 Predicted 5G Cellular Coverage in Detroit, MI

Cellular coverage was calculated as described in Chapter 2.4. This metric is an average of cell signal density multiplied by cell signal redundancy and represents the real-world capability of wireless devices to connect and transfer data relative to the power of the signal provided by existing cell towers for 4G (Figure 4) and 5G (Figure 5) technologies. Cell tower locations are not plotted on the maps. Again, cellular coverage is plotted within 9 $m^2$ map cells within the city of Detroit. Warm colors represent poor cellular coverage while cool colors represent strong cellular coverage.

Cellular coverage for 4G technologies is average throughout the majority of Detroit, as represented by the predominance of yellow map cells in Figure 4. There are areas near major roadways or meeting places with stronger cellular coverage and areas near the edge of the city with poorer cellular coverage (Figure 4). Again, the results for 4G technology confirm our understanding of 4G wireless coverage and indicate that the methods used to estimate cellular coverage are accurate and will provide a good representation of what cellular coverage will be for 5G technology. We expect that cellular coverage should be average throughout most of the city, with certain locations having better or worse coverage respectively. The results show in Figure 4 confirm these expectations and indicate that wireless cellular devices should perform well within the city of Detroit.

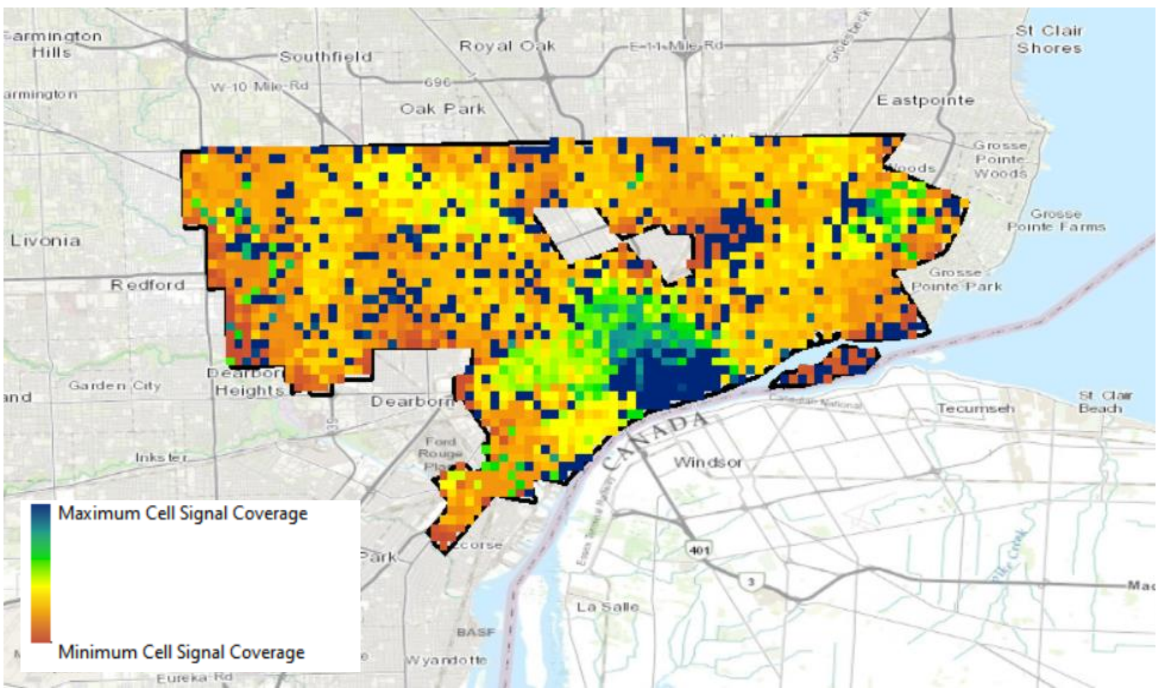


**Figure 4. 4G Cell Signal Coverage in the City of Detroit**: Cellular signal coverage results plotted in 9 $m^2$ map cells throughout the city of Detroit. Warm colors indicate poor coverage while cool colors indicate strong coverage within individual map cells.

Cellular coverage for 5G technology is extremely poor throughout the city of Detroit. This is indicated by the nearly complete coverage of the map by red dots, which indicate 9 $m^2$

map cells that would obtain poor cellular coverage (Figure 5). There are a few locations near major roadways and meeting places in the city where cellular coverage would be considered average, indicated by yellow map cells (Figure 5). In addition to this there are areas on the map where cellular coverage could not even be quantified, which is represented by areas showing the base map (Figure 5). This would mean that there would be minimal to zero 5G coverage in those locations. Overall, this map indicates that simply replacing 4G nodes with 5G nodes on existing cellular towers will not be sufficient to produce average to excellent cellular coverage throughout the city of Detroit.

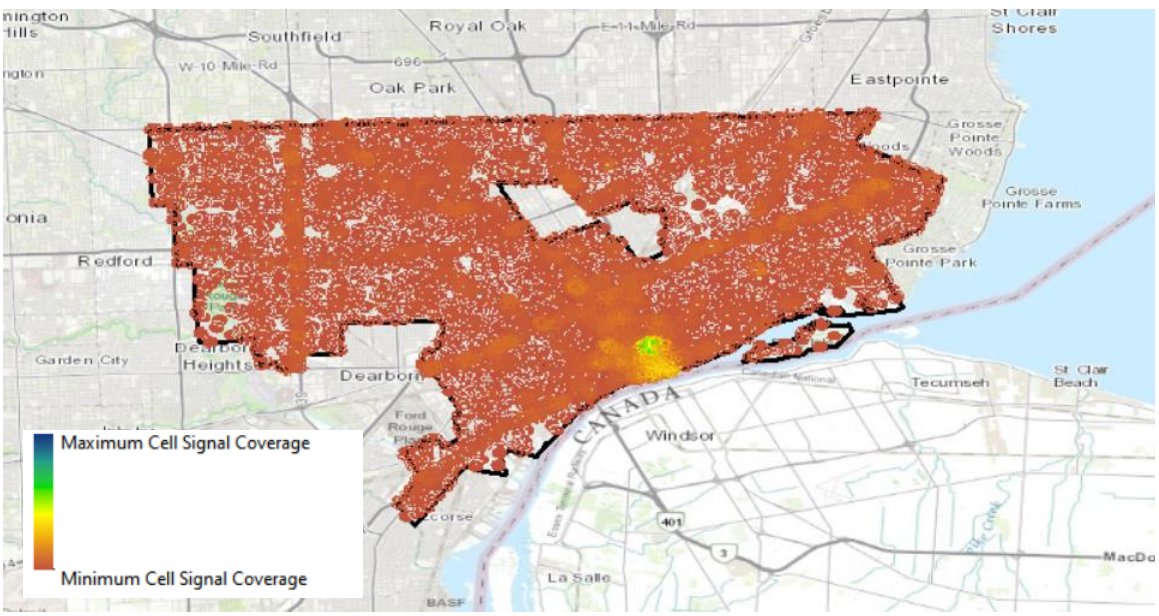


**Figure 5. 5G Cell Signal Coverage in the City of Detroit**: Cellular signal coverage results plotted in 9 $m^2$ map cells throughout the city of Detroit. Warm colors indicate poor coverage while cool colors indicate strong coverage within individual map cells.

# 4 Discussion and Conclusions

Signal density and cellular signal coverage results indicate that the existing cellular tower infrastructure used for 4G technology will not be enough to support a 5G network within the city of Detroit. This means that a significant investment to build and improve wireless network infrastructure will be necessary in order to implement a successful 5G network. This result is not necessarily surprising based on the higher frequency and shorter wave lengths that make 5G technology significantly faster than 4G technologies (Chang et al., 2014; Delmade et al., 2018). Ultimately this results in a smaller signal range radius for 5G technologies as compared to 4G, which means that more cellular towers will be required to create the signal density and redundancy required to generate sufficient and consistent cell signal coverage.

## 4.1 Implications for 5G Network Implementation

Results from this study have important implications for the roll out of the 5G network. While telecommunications companies may have anticipated a certain degree of infrastructure development in order to obtain sufficient signal density and cellular coverage due to the anticipated smaller signal radius of 5G technologies, they likely did not anticipate how extensive this would need to be. 5G cellular coverage could not be quantified in many areas of the map, and average cellular coverage was only achieved on major roadways and the cultural center of the city (Figure 5).

A calculation subtracting the 5G cellular coverage results from the 4G cellular coverage results in each map (Figures 4 & 5) cell indicates that an estimated 166% more 5G nodes would need to be installed throughout the city in order to meet the current level of 4G signal present in the city. This will require a significant investment in infrastructure solely within the city of Detroit that will take years to complete. In addition to this, these poor 5G coverage results were obtained within a city that likely has greater 4G coverage as compared to suburban and rural areas. The effort and cost that would be required to create a 5G network in these less densely populated areas is difficult to imagine.

Ultimately, it appears that the implementation of a 5G network will require total infrastructure overhaul, not unsimilar to what was required when implementing the 3G and 4G networks in recent decades (Gozde et al., 2015; Hui & Yeung, 2003; Sigle et al., 2009). While this has been achieved in the past, more 5G nodes at closer proximity will be required in order to generate a comprehensive network, which differs from the wireless network overhauls of the past (Hui & Yeung, 2003). There is also the possibility that the necessary density of 5G nodes may be spatially challenging within our current cities and towns (Ge et al., 2016; Liu et al., 2017).

Due to these challenges the implementation of a 5G network across the country may not be logistically feasible. As such, the targeted use of 5G in major cities, and select technological applications may be necessary. How to successfully do this in a cost-effective manner will need to be considered in light of the challenges discovered during initial attempts to implement the 5G network.

## 4.2 Limitations of the Study

The analyses performed in this study were meant to provide reasonable estimates of 5G signal density and cellular coverage. While we consider the estimates obtained in this study as highly accurate based on results that confirm our current knowledge of the 4G network in Detroit, there are of course factors that could not be accounted for in the calculations, but that could affect the final results.

The first and likely most important limitation of this study was the assumption that 5G towers have a fixed signal radius. Signal ranges for 5G nodes in a variety of settings have not been well quantified to our knowledge. 4G signal ranges are known to vary, but this given how different 4G and 5G signal waves are assuming the same type of variation in 5G signal ranges would be inappropriate. More work needs to be done in order to determine factors that increase or decrease 5G signal range. This could then be incorporated into the study in order to obtain finer resolution and more accurate results.

Related to signal range variance, this study did not consider the effect that obstacles like buildings, atmospheric conditions, or changes in topography may have on 5G signal ranges and coverage. This will ultimately become important when designing 5G network nodes and networks in city areas as compared to rural areas, and in high elevation mountainous areas as compared to flat areas at sea level. Similar to variance in signal range, the effects of these factors are not known and could not be incorporated into the study. They will be important to quantify though, as they will significantly impact infrastructure cost, needs, and designs as 5G is implemented in more places throughout the country.

A final limiting assumption in this study is that population density was assumed to be equally distributed throughout the study area. This is an assumption that we know is not true but is the best current option as small scale variations in population density are not well documented for these purposes. This is important when considering 5G network performance, as better cellular coverage is needed to support the use of more devices per unit area. This may mean that high population and high traffic areas may require more 5G nodes than what may be anticipated as the result of this work. Better assessment of population fluctuations and high traffic areas would improve the results of this work.

## 4.3 Conclusions

In general, the results of this study show that 4G coverage has finally reached acceptable cellular coverage levels within the city of Detroit. This is likely the case for most other cities, and many suburban and rural areas, although there is still probably some development necessary in rural areas. 4G was introduced nearly a decade ago, and we are just not reaching acceptable coverage levels throughout the nation. This is important to keep in consideration as we try to understand the amount of work required to implement 5G throughout the nation. Due to how many more 5G nodes will be required in order to implement 5G it seems likely that it may take a decade if not longer until 5G has reached acceptable coverage ranges within most major metropolitan areas in the nation.

This work showcases how different the infrastructural design of a 5G network is as compared to 4G. It is quite clear that 5G will not be able to be implemented by simply swapping out 5G nodes on 4G cellular towers. This will not provide sufficient cell signal density or coverage. More resources need to be used to properly plan and design the infrastructural needs and design for the implementation of 5G in order to avoid excess costs and decrease the amount of time needed to establish a 5G network in different areas.

## References


Andrews, J. G., Buzzi, S., Choi, W., Hanly, S. v., Lozano, A., Soong, A. C. K., & Zhang, J. C. (2014). What will 5G be? *IEEE Journal on Selected Areas in Communications*, *32*(6), 1065–1082. https://doi.org/10.1109/JSAC.2014.2328098

Botev, Z. I., Grotowski, J. F., & Kroese, D. P. (2010). Kernel Density Estimation via Diffusion. *The Annals of Statistics*, *38*(5), 2916–2957. https://doi.org/10.1214/10

Bryn, A., Dourojeanni, P., Hemsing, L. Ø., & O'Donnell, S. (2013). A high-resolution GIS null model of potential forest expansion following land use changes in Norway. *Scandinavian Journal of Forest Research*, *28*(1), 81–98. https://doi.org/10.1080/02827581.2012.689005

U.S. Census Bureau (2012). 2010 Census of Population and Housing: Population and Housing Unit Counts, CPH-2-24, Michigan. *U.S. Government Printing Office*.

Chang, G. K., Cheng, L., Xu, M., & Guidotti, D. (2014). Integrated fiber-wireless access architecture for mobile backhaul and fronthaul in 5G wireless data networks. *2014 IEEE Avionics, Fiber-Optics and Photonics Technology Conference, AVFOP 2014*, *4*, 49–50. https://doi.org/10.1109/AVFOP.2014.6999461

Delmade, A., Browning, C., Farhang, A., Marchetti, N., Doyle, L. E., Koilpillai, R. D., Barry, L. P., & Venkitesh, D. (2018). Performance analysis of analog if over fiber fronthaul link with 4G and 5G coexistence. *Journal of Optical Communications and Networking*, *10*(3), 174–182. https://doi.org/10.1364/JOCN.10.000174

ESRI. (2011). *ArcGIS Desktop: Release 10.7 Redlands, CA: Environmental Systems Research Institute.*

Ge, X., Tu, S., Mao, G., Wang, C.-X., & Han, T. (2016). 5G Ultra-Dense Cellular Networks. *IEEE Wireless Communications*, *February*, 72–79.

Gozde, H., Taplamacioglu, M. C., Ari, M., & Shalaf, H. (2015). 4G / LTE Technology For Smart Grid Communication Infrastructure. *IEEE*, 2–5. https://doi.org/10.1109/SGCF.2015.7354914

Gupta, A., & Jha, R. K. (2015). A Survey of 5G Network: Architecture and Emerging Technologies. *IEEE Access*, *3*, 1206–1232. https://doi.org/10.1109/ACCESS.2015.2461602

Huang, J., Qian, F., Gerber, A., Mao, Z. M., Sen, S., & Spatscheck, O. (2012). A close examination of performance and power characteristics of 4G LTE networks. *MobiSys'12 - Proceedings of the 10th International Conference on Mobile Systems, Applications, and Services*, 225–238. https://doi.org/10.1145/2307636.2307658

Hui, S. Y., & Yeung, K. H. (2003). Challenges in the Migration to 4G Mobile Systems. *IEEE Communications Magazine*, *41*(12), 54–59. https://doi.org/10.1109/MCOM.2003.1252799

Kardaras, G., Soler, J., Brewka, L., & Dittmann, L. (2010). Fiber to the Antenna : A Step towards Multimode Radio Architectures for 4G Mobile Broadband Communications. *2010 IEEE 4th International Symposium on Advanced Networks and Telecommunication Systems*, 85–87. https://doi.org/10.1109/ANTS.2010.5983537

Krenik, B. (2008). 4G Wireless technology: When will it happen? what does it offer? *Proceedings of 2008 IEEE Asian Solid-State Circuits Conference, A-SSCC 2008*, 141–144. https://doi.org/10.1109/ASSCC.2008.4708715

Liu, J., Sheng, M., Liu, L., & Li, J. (2017). Network Densification in 5G: From the Short-Range Communications Perspective. *IEEE Communications Magazine*, *55*(12), 96–102. https://doi.org/10.1109/MCOM.2017.1700487

Oshima, I. (2016). Development of base station antennas for 5G mobile communication systems. *2016 IEEE International Workshop on Electromagnetics, IWEM 2016 - Proceeding*, 6–7. https://doi.org/10.1109/iWEM.2016.7504923

Sigle, R., Blume, O., Ewe, L., & Wajda, W. (2009). Multi-Radio Infrastructure for 4G. *IEEE*, *13*(4), 257–276. https://doi.org/10.1002/bltj

Silverman, B. W. (1981). Using Kernel Density Estimates to Investigate Multimodality. *Journal of the Royal Statistical Society*, *43*(1), 97–99.

Sule, P., & Joshi, A. (2014). Architectural Shift from 4G to 5G Wireless Mobile Networks. *International Journal of Computer Science and Mobile Computing*, *3*(9), 715–721. www.ijcsmc.com