What Do Customers Really Seek From Their Mobile Service Providers?

A thesis submitted in partial fulfillment of the requirements for the degree of
Masters of Science in Telecommunications

State University of New York (SUNY) Polytechnic Institute at Utica/Rome

By

Deepa Ramkrishna

December 2016
Declaration

I declare that this project is my own work and has not been submitted in any form for another degree or diploma at any university or other institute of tertiary education. Information derived from the published and unpublished work of others has been acknowledged in the text and a list of references is given.

________________________
Deepa Ramkrishna

December 2016
Approved and recommended for acceptance as a thesis in partial fulfillment of the requirements for the degree of Masters of Science in Telecommunications

Dec 17, 2016
DATE

Approved by:

Dr. Larry Hash

Dr. John Marsh
Abstract

With the number of smartphone and wireless internet users set to increase at a rapid pace over the next few years, there is an increased need for a next generation mobile wireless technology such as 5G. Before discussing 5G, it is important to understand consumer needs today. This paper includes findings from an online survey that was administered to students and alums of SUNY Polytechnic and other universities in the US to understand what drives choice of mobile service providers. Additionally, the challenges faced by consumers with respect to their mobile and wireless use were tested and the improvements they seek was sought. The author then uses secondary research to understand if 5G will address these consumer needs and facilitate other commercial applications. While consumers might be fairly satisfied with their mobile service providers today, there is still room for improvement on some aspects such as network coverage, call quality and data speed. Implementation of 5G through efficient spectrum use and technologies such as Massive MIMO and MmWave will help address the above and also facilitate broader commercial applications in multiple industries such as driverless cars, smart cities etc.
Acknowledgement

The research that has gone into this thesis has been thoroughly enjoyable. That enjoyment is largely a result of the interaction that I have had with my supervisors.

I feel very privileged to have worked with my supervisor Dr. Larry Hash, faculty, Master of Science in Telecommunications Program who served as the thesis advisor throughout the study. I would also like to thank Dr. John Marsh and other telecommunication faculty who supervised my research during the important phases.

Thanks to the Human Subjects Review Board at SUNY Institute of technology for verifying my survey for the human subject’s requirements.

Also, I am thankful the IT team of SUNY Polytechnic for sending out invites for my survey. More importantly, I am very thankful to all those who took the time to participate in my survey.
**Table of Contents**

Declaration .................................................................................................................. ii
Abstract ......................................................................................................................... iv
Acknowledgement ........................................................................................................ v
Table of Contents ........................................................................................................ vi
List of Tables ................................................................................................................ viii
List of Figures ................................................................................................................ viii
1. Introduction ............................................................................................................. 1
2. Thesis Statement ...................................................................................................... 2
3. Literature Review .................................................................................................... 3
   3.1 Factors Influencing Quality of Experience of Commonly Used Mobile Applications .................................................. 3
   3.2 4G Wireless Networks ......................................................................................... 6
   3.3 A Brief Overview of 5G Research Activities ....................................................... 8
   3.4 What Will 5G Be? ............................................................................................... 11
   3.5 5G Wireless Access: Requirements and Realization ......................................... 14
4. Uniqueness Claim ..................................................................................................... 17
5. Methodology ............................................................................................................ 18
   5.1 Survey - Understanding the factors that drive mobile service provider choice .... 18
      5.1.1 Population & Sample .................................................................................. 19
      5.1.2 Questionnaire development ....................................................................... 21
      5.1.3 Survey logistics ........................................................................................ 22
      5.1.4 Verification & Validation .......................................................................... 22
      5.1.5 Delimitations .............................................................................................. 23
      5.1.6 Limitations .................................................................................................. 24
      5.1.7 Analysis ..................................................................................................... 24
   5.2 Understanding whether 5G will address or potentially improve upon the key factors of choice identified in Survey ................................................................. 26
6. Analysis Of The Survey .......................................................................................... 27
7. Background About Evolution Of Communication Technologies ......................... 45
8. Applications, Objectives, Technology & Cost Of 5G ............................................ 53
8.1 Need for 5G ................................................................. 53
8.2 Market Demand for 5G .................................................. 55
  8.2.1 Mobile Broadband .................................................. 55
  8.2.2 Automotive ......................................................... 56
  8.2.3 Smart Cities/Smart Homes ....................................... 57
  8.2.4 Smart Grids ......................................................... 58
  8.2.5 Health ............................................................... 58
  8.2.6 Industrial Applications ........................................... 59
8.3 Brief Introduction about the Objectives for 5G ....................... 60
8.4 Brief Introduction about the Requirements for Successful 5G Use ....... 61
8.5 Technology to Deliver on 5G .......................................... 64
8.6 Cost of 5G ............................................................. 81
8.7 Regulatory framework for 5G ......................................... 83
8.8 Author’s perspective and conclusions on 5G ......................... 84
9. Conclusion .................................................................. 85
10. Recommendations For Additional Research .......................... 87
References .................................................................. 88
Appendix ................................................................... 92
List of Tables

1. Evolution of wireless technology in terms of service and performance ........................................... 51
2. Potential 5G Technologies that address consumer requirements .......................................................... 81

List of Figures

1. Current Mobile Service Provider Usage ........................................................................................................ 28
2. Features - Average Rank .............................................................................................................................. 29
3. Features - Percent Ranking in Top 3 .............................................................................................................. 29
4. Brand Satisfaction ........................................................................................................................................ 30
5. Likelihood to Recommend ........................................................................................................................... 31
6. Important Factors in Choice of Mobile Providers ....................................................................................... 32
7. Factors Influencing Choice – Avg Rank ......................................................................................................... 32
8. Factors Influencing Choice - Percent Ranked in Top 3 ................................................................................ 33
9. Correlation of Factors with Likelihood to Recommend ............................................................................... 35
10. Regression .................................................................................................................................................. 38
11. Challenges with Current Mobile Provider - Avg Rank .............................................................................. 39
12. Challenges with Current Mobile Provider - Percent Ranked in Top 2 ..................................................... 40
13. Familiarity with 5G ..................................................................................................................................... 41
14. Level of Improvement Desired from 5G ...................................................................................................... 41
15. Improvements Desired from 5G .................................................................................................................. 42
1. Introduction

Mobile communication technology has been developing over the past few decades to keep pace with an increased demand for speed and connectivity. Four generations of mobile technology have been adopted so far - 1G, 2G, 3G and 4G. Most consumers in the US currently use 4G compatible smart phones. If asked about the improvements in mobile technologies, they will tell us that it has been immense from 1G to 4G. As consumers become well-entrenched in the 4G mobile technology, the obvious question is what's next and how much of an improvement will that 'next' be over the already improved 4G? The ‘next’ generation will be 5G. Before understanding the potential benefits from 5G, the critical question is what drives consumer choice of their mobile phone service providers (4G compatible) and how satisfied they are with their service. Understanding the current drivers of choice and unmet needs will help better comprehend how the next generation 5G technology will help improve on those aspects that consumers currently seek. Thus, the intention of this thesis is to first understand what drives consumer choice of mobile phone service providers among a limited population of graduate students and alums from various universities in the US and then determine how the next generation 5G technology will improve upon the key aspects that drive choice today.

This thesis paper describes the above in detail in two parts The first part comprises findings from the online survey about what drives consumer choice of mobile service providers. The second part describes whether 5G technology will address and improve upon many of the top drivers determined in first part of the study.
2. Thesis Statement

Determine the factors that influence the choice of mobile service providers and the implications of these factors for 5G technology.

The thesis will help understand -

1) The factors that influence the choice of mobile service providers among the young and educated students and alums primarily from SUNY Polytechnic Institute who are aware of mobile technologies

2) Customer perceptions of current mobile service providers on those key factors

3) The factors that are not currently satisfactorily addressed by the mobile service providers (factors that are important yet currently unmet by the market)

4) Will the next generation fifth generation (5G) technology address those factors
3. Literature Review

3.1 Factors Influencing Quality of Experience of Commonly Used Mobile Applications

Ickin, S.; Wac, K.; Fiedler, M.; Janowski, L.; Jin-Hyuk Hong; Dey, A.K.


Abstract: There has been a rapid increase in the use of mobile application and services in
day to day life. The receptivity of users to mobile applications is dependent on the
experience using the application and the relevance of the application to the user. Despite
the increase in mobile application use, there is still a gap with respect to understanding
the end-user's quality of experience (QoE). This article provides the results of a study to
understand end-users' QoE based on use of popular mobile applications.

Introduction: Till date, any attempt to understand users' QoE has been in controlled
laboratory environments. Such experiments help understand usability issues with the
application but are not a barometer for measuring issues such as quality of service (QoS)
and network infrastructure performance that are relevant to real-world situations.
Additionally, mobile application designers employ their own perceptions and the volume
of users of an application to set QoE expectations. This article will suggest an approach
that combines the qualitative measure in the Human Computer Interaction (HCI)
community and the quantitative measures of QoS and the underlying infrastructure.
Methodology:

The researcher used a combination of Qualitative and Quantitative methodology for the 4-week user study. The study was carried out on the following factors:

- A weekly interview was conducted with users to analyze their experience using the Day Reconstruction Method (DRM)
- Feedback from the users on QoE with respect to mobile applications was collected using the Experience Sampling Method (ESM).
- Data was collected from the user’s mobile phone using the Context Sensing Software (CSS) application.

Summary: This article suggests an approach to measure QoE of mobile applications in real world environments in which the user becomes an active participant. There are 2 steps in measuring QoE - one is to gather spontaneous information about the user's mobile application experience using the experience sampling method (ESM) after each use and two is a retrospective analysis of the user's experience using the day reconstruction method (DRM). Based on this, it is determined that the app interface, performance, battery efficiency, mobile phone features, app and connectivity cost and end-user schedules and lifestyles influence the QoE. It is also observed that higher SRT (server response time) and RTT (round trip time) values and decreased throughput resulted in lower MOS (Mean opinion score) values and that for an MOS level of 3, SRT needs to be 950 ms. Future work based on this study will look at the user context as a factor in determining QoE.
**Relevance:** This paper is related to my thesis as the researcher has used a combination of quantitative and qualitative analysis. The analysis from the survey was considered for further qualitative analysis. The researcher has conducted a survey from customer (service provider users) standpoint.

**Critique:**

The positive point about this paper was the researcher has conducted a survey on self-selected users. The researcher had conducted the study in a very organized structure as the data from the quantitative analysis was further studied in qualitative analysis.

The negative point about this paper was that the study was conducted on users who self-selected themselves. The probability of the results being biased is higher. This study did not mimic real world situations, so the conclusions are contained and cannot be extrapolated to the real world.
3.2 4G Wireless Networks

Varshney .U, Jain .R


Abstract: 4G wireless networks are currently widely prevalent in the US and in many developed countries. This study provides a status update on what the original expectations from 4G were, how it has delivered on those expectations and what the future prospects are.

Introduction: The number of handheld wireless devices have grown five times from 2002 to 2010 worldwide with adoption rates at 100 percent. Wireless networks offer different levels of mobility support such as personal area networks, fixed wireless networks, wireless LAN's, country level (3G/4G) and satellite networks. Efforts are on to create even inter-planetary mobility networks. Wireless networks also vary in terms of bandwidth and speed such as a few kbps with 1G/2G to a few Mbps with 3G/4G. 4G has a lot of potential in terms of further improving coverage and speed and has many applications not originally envisioned such as telemedicine and mobile commerce applications.

Methodology: This paper has compared wireless technologies such as 1G, 2G, 3G and 4G and proposed another version of 4G network with existing 4G framework. The author has also compared the existing 4G networks in the US. This paper contains in it several existing networks used to provide 4G services and the next generation 5G.

Summary: 4G now has applications beyond what was originally envisioned. 4G networks have some issues such as upgrade costs, coverage and lost investments in 3G.
General barriers for adoption are lack of spectrum, highly active power users and applications that consumer bandwidth. Despite the barriers, the future looks bright as many carriers are moving to 4G LTE and subsequently to LTE advanced. 4G use will expand to accommodate more mobile applications, content rich e-commerce and high-end healthcare applications such as telemedicine and health monitoring.

**Relevance:** The paper clearly tries to explain the study on 4G and the need for 5G. In this paper the author has examined 4G technology, explained the reasons why it is not able to meet the existing high speed demands of mobile users from both the carriers and the mobile user’s perspective. The carriers are still using enhanced 3G networks to provide high speed Internet to reduce the expenses. The mobile users experience low data transfer and low coverage while roaming.

**Critique:** The paper "4G Wireless Networks" has been written in a very simple language where the researcher has explained the concepts of 4G, HSPA and existing wireless technologies etc. in a detailed format. A tabular format of the technologies in the paper provides a clear understanding about the technologies from 1G to 4G. Also, it gave many reasons for the need to implement 5G technology. The factors considered for this study were bandwidth, frequencies and the coverage area of 4G network.

The negative point in the paper was that the researcher has neglected significant factors that play a crucial role in the wireless networking. They are broadband, Network Access Points (NAP), transceivers and transmission delays. To support 4G the mobile devices should have high end antennas. Not all mobile devices are manufactured with high end antennas that support high data rate.
3.3 A Brief Overview of 5G Research Activities

1st International Conference on 5G for Ubiquitous Connectivity

Pekka Prrinen

IEEE Communications, 18th Dec 2014

Abstract: This paper demonstrates the various aspects of 5G wireless networks. The main purpose of this paper is to explain about 5G, its basic features, need for 5G, the steps to deploy 5G, the challenges with its deployment and steps to overcome those challenges. It also provides some information about the recent developments in 5G in the European Union (EU).

Introduction: The increase in the demand for wireless communication has led to the implementation of 3G and 4G technologies, however, there is always a demand for better and enhanced technologies. 5G is the latest technology in which research is being conducted and is expected to be launched in the year 2020. In addition to what 4G provides, the improvements in 5G would be as follows:

- 1000 times elevated mobile data/ area
- 10 times longer battery life
- 5 times minimized end-to-end latency
- 10 to 100 times increase in number of connected devices

A summary of ongoing European projects on 5G can be explained as below:
- Mobile and wireless communication Enablers for Twenty-twenty Information Society (METIS) is trying to build the foundation for 5G technology and standardize the requirements of 5G. METIS also is testing 5G on various aspects such as increase in data rate with minimal latency, clear network coverage in a densely populated area etc.

- Wireless technologies for isolated rural communities in developing countries based on cellular 3G femtocell deployments (TUCAN3G) project is trying to check the feasibility of 5G in rural areas by a combination of wireless access (3G to 4G femtocell (a small portion on mobile phone base station is connected to the network of the phone through internet in case of poor network clarity)) and various backhauling technologies such as Wi-Fi, WiMAX etc.

- Cognitive Radio for Satellite Communications (CoRaSat) project works on spectrum sharing by transmitting the cognitive radio techniques to satellite networks.

- Mobile Cloud Networking (MCN) project works on the lifecycle of packet systems with the help of cloud based flexible mobile networks system.

**Summary:** This paper provides a brief idea about what 5G is all about and various activities happening on 5G in the European Union. The concept of 5G is yet to materialize however, the common features which 5G would provide are improved spectral efficiency, improved network connectivity etc.

**Relevance:** The second phase of my project is to introduce 5G. This paper is very relevant to my topic because it explains about the ongoing projects and development in
5G technology from European markets point of view. The various development and projects happening in the field of 5G have been explained briefly.

**Critique:** The positive points about 'A Brief Overview of 5G Research Activities' paper are that the paper explains about the various projects on 5G clearly. It provides a brief overview on 5G.

However, a detailed explanation on 5G, technology used, tabular explanation about the difference between prior generations and 5G would be have been more beneficial.
3.4 What Will 5G Be?


IEEE Journal - Selected Areas in Communications, 32 (6), 1065-1078, 2014

Abstract: 5G will not be an advanced version of 4G. It will be a paradigm shift that works on a very high carrier frequency with immense bandwidth, extreme base station and device density and unmatched number of antennas. It will be compatible with existing Wi-Fi and LTE to allow high speed data sharing and seamless user experience. This paper explains about the road to 5G, future research on 5G to achieve high speed data rate, design issues for 5G and preliminary 5G standardization activities such as spectrum policy and regulation.

Introduction: LTE has now been completely deployed and is reaching its saturation level where a lot of traffic issues are being reported due to increase in the number users accessing data at the same place and time. Thus it is now giving road to implementation of the next generation technology called 5G. The amount of data handled by wireless networks will increase 100 fold in the next 10 years. This paper explains about the key technologies which will be used to implement 5G: ultra-densification, millimeter Wave (mmWave), and massive multiple-input multiple-output (MIMO).

1000x data rate will be achieved by a combination of the following 3 categories:

- Extreme densification and offloading to increase area spectral efficiency
• Increased bandwidth, by moving into mmWave spectrum and also by efficient use of Wi-Fi's unlicensed spectrum in the 5-GHz band
• Higher spectral efficiency, by using massive MIMO technology

**Massive MIMO:** This bold idea, initially termed “large-scale antenna systems” but now more popularly known as “massive MIMO,” offers enticing benefits such as:

• Massive enhancements in spectral efficiency without increasing BS densification.
• Leveled out channel responses due to vast spatial diversity.
• Simple transmit and receive structures because of the quasi orthogonal nature of the channels between each base station and the set of active users sharing the same signaling resources.

Thus, these contributing factors have elevated massive MIMO to a central position for providing high capacity universal coverage supporting tiers of small cells.

**Summary:** Demand for new requirements on 5G are already unlocking an outbreak of new ideas and urgency in converting innovative new technologies into reality. This article has highlighted that it is a long road ahead for 5G networks. The features of 5G is explained in brief.

**Relevance:** This paper is very relevant to my topic because I plan to write about the evolution of telecom technology culminating in 5G. This paper talks about how that end
goal of 5G is not easy and that certain challenges need to be overcome before it can be effectively implemented. This paper will be useful to me when I talk about the evolution.

**Critique:**

The positive points about this paper are that it explains the need for 5G in a simple language. The journey from 4G to 5G is also explained to show how 5G evolved from a prior technology in brief. This paper also explains about Massive MIMO in detail.

The negative points about this paper is there is not much information about the drawbacks of 4G or a tabular explanation about prior technologies for the researcher to have good understanding. A diagrammatic explanation would have given more clarity. Information about what were the difficulties faced in the earlier technologies is not mentioned clearly. The general applications, characteristics of 5G is not mentioned elaborately.
3.5 5G Wireless Access: Requirements and Realization

Erik Dahlman, Gunnar Mildh, Stefan Parkvall, Janne Peisa, Joachim Sachs, Yngve Selén, and Johan Sköld

IEEE Communications Magazine — Communications Standards Supplement, 52 (12), 42-47, December 2014

Abstract: The most awaited technology “5G” is expected to be launched in the year 2020. The basic principle of 5G is to provide information access and data sharing anytime and anywhere in the world. This paper describes the current status of implementing 5G. It also talks about the requirement and technical solutions needed for successful 5G implementation.

Introduction: The demand for high speed data access will continue to increase in future (expected to increase hundreds to thousands of times the current need in the next 10 years). The goal of 5G technology is to cater to such a demand at a cheaper cost and in an energy efficient manner (i.e. lower energy per bit transfer). 5G will provide speed in the range of 10 GB/s for offices and university campus. It will also attempt to provide universal connectivity of at least few Mb/s in remote locations and deep indoor environment.

The universal access to data will be provided by ITU-R Working Party (WP) 5D for the overall radio system aspects of International Mobile Telecommunications (IMT) systems. At present it consists of IMT-2000(3G) and IMT- Advanced (4G). The key features of IMT Vision with respect to 5G are not only to improve 3G and 4G capabilities but also to drive development of new capabilities which were not a part of 3G and 4G. The spectrum
for 5G needs to be designed in such a way that it is compatible with existing LTE technology. The additional technology solutions which are the key requirements for 5G wireless access are as below:

- **MASSIVE BEAMFORMING AND ADVANCED ANTENNAS**: Advanced antennas with multiple elements improve coverage for data sharing and increase in system capacity. This technique will be used by 5G in order to reduce radiofrequency imperfections and control interference in the network.

- **ULTRA-LEAN DESIGN**: The ultra-lean transmission enables wireless access in higher frequency bands in areas where the network is non-existent. It also results in an energy efficient network and reduces overall interference level. Thus it enables the network to reach remote areas of the world.

- **LOW LATENCY**: Lower latency over the radio link can be achieved by decreasing transmission-time intervals and broadening the bandwidth of resource blocks in which a specified amount of data is transmitted. This should be complemented by designing a physical-channel structure that allows for quick decoding at the receiver to reduce delays.

**Summary**: The basic goal of 5G technology is to enable anyone, anywhere and anytime to access information and share data. This will be achieved by integrating the existing LTE technology with new radio access technologies which operate at higher frequencies. Massive beam forming and advanced antennas will help increase sharing capacity while an Ultra lean design will ensure lesser interference and higher energy efficiency. Low latency and a highly networked society are other advantages of 5G.
**Relevance:** This paper is very relevant to my project as it illustrates the basic requirements needed for technology successful implementation of 5G. This will be one of the building blocks of my research as I’d like to show the evolution of wireless from 1G to 5G. This paper helps me understand the requirements of 5G that will make it far superior to earlier generation technologies.

**Critique:**

**Pro** - The researchers have done extensive research to find out the requirements of 5G and how they will help deliver on the promised benefits of 5G.

**Con** - What might be missing is a comparison to earlier generation technology requirements. A table comparing at least 4G if not earlier generation technology requirements with 5G would have been helpful.
4. **Uniqueness Claim**

Evidence from the literature reviews shows that this topic might have not been directly addressed before with this population. The study titled "Factors Influencing Quality of Experience of Commonly Used Mobile Applications" identifies the metrics to be used to measure mobile applications in the real world but does not directly address the drivers of choice of mobile phone service providers. The study titled "4G wireless networks" details the use of 4G beyond its original intended use but does not once again quantify the reasons consumers choose a 4G compatible mobile service provider. Additionally, there might be studies that mobile service providers have undertaken to obtain this information nationally or regionally, however, there have not been any quantitative studies focused only on SUNY Polytechnic students and alums who are knowledgeable about mobile technologies. The first part of this thesis will do exactly that - identify quantitatively the factors that drive mobile phone service provider choice.

The other 3 studies - 5G wireless access: Requirements and Realization, what will 5G be? and A brief overview of 5G research activities while providing insights into the potential and current happenings regarding 5G do not make a connection between 5G's potential and current unmet needs regarding 4G. The second part of this thesis will address this gap by tying in the key factors to the capabilities of 5G.
5. **Methodology**

The study comprised into 2 sections – First part includes an online survey and Second part includes study on 5G

5.1 **Understanding the factors that drive mobile service provider choice**

The purpose of this study is to understand what drives choice of mobile service provider choice. Before understanding the improvements that could be potentially delivered by 5G, the first step is to understand what sort of improvements are desired by the consumers. First section of this study will accomplish that. The next few pages provide a description of the methodology used to obtain these findings.

An 'Online Survey' approach was determined to be the best approach to obtain a quantitative understanding of what factors influence the choice of mobile service providers. The survey approach was deemed to be better because it provides a quantitative understanding while an interview or focus group would have only provided a qualitative understanding. Hence, a 4-5 minute closed-ended survey with 10-12 questions was conducted to force customers to rate and rank so that one can understand their key factors of choice. Only an online survey could have - 1) Handled such large sample 2) Obtained quantitative information through multiple data points 3) Provided the data needed to run advanced analyses such as a correlation and regression 4) Made respondents rank and/or rate.

A summary of the steps followed in this phase is as follows – 1) Candidate designed the paper version of the survey 2) Incorporated changes suggested by the thesis advisor 3)
Finalized paper version of the survey after final approval by the thesis advisor 4)
Obtained SUNY Polytechnic Human Resources Board (HRB) approval 5) Programed the survey 6) Obtained feedback from thesis advisor and fellow students 7) Invited students and alums to take the survey 8) Analyzed the data using Microsoft Excel and SPSS 9) Reported the findings.

5.1.1 Population & Sample

The population for this survey included -

- Young and educated students and alumni from primarily SUNY Polytechnic and other Universities in the US

- Most of them were pursuing or had completed an undergraduate or graduate degree in Telecommunications, Network and Computer Securities and Computer Science

- Most of them had graduated after 2010

- Owned and used mobile smart phones

- Were aware of the service provider they were using for their mobile phone

- Were involved in the decision of determining their mobile phone service providers (such as Verizon, AT&T, T-Mobile, Sprint, MetroPCS, Virgin Mobile, Boost Mobile etc.)

- The survey did not include using carrier services for tablets or notebooks, kindle etc.
Approximately 12,000 students enrolled in SUNY Polytechnic between 2010 and 2015. There could be overlaps as an undergraduate student could also have enrolled for graduate education within the same period. Most students carry smartphones but many might not be as savvy as telecommunications, computer science or network security students. In SUNY Polytechnic, those disciplines constitute about 10 percent of the student population. Applying that percentage to the whole student population, that would bring the qualifying population to approximately 1200. At 95 percent confidence interval and a 5 percent confidence level, the requisite sample was 291. This sample was determined using this sample size calculator tool - http://www.surveysystem.com/sscalc.htm. Unfortunately, this sample could not be achieved within the required time due to lower than expected response rates. Hence, the confidence level was adjusted to 7 percent thus bringing the required sample down to 169. Finally, the sample that was actually achieved was a robust 201. This sample is adequate to accurately report the factors that are important in driving mobile service provider choice.

The rationale for choosing a younger population was that they will be aware of the nuances of telecommunications and will be able to answer in a balanced manner on both the business and the technical factors. Being younger, they are also likely to be early adopters of 5G mobile technology when it is introduced. Hence, understanding their choices and pain points were critical inputs to this study.
5.1.2 Questionnaire development

The questionnaire was developed with the objectives of the study in mind. A draft paper version of the survey was prepared by the candidate. The thesis advisor reviewed and provided feedback. The candidate then incorporated the feedback and sent back the revised version. After a few rounds of back and forth, the paper version was approved by the thesis advisor. Once it was approved, the survey was programmed using Survey Gizmo. The candidate tested the survey multiple times to ensure the content matched with that of the paper version. The thesis advisor too reviewed the online version of the survey and suggested edits. The candidate also asked a few fellow students to take the survey to obtain feedback on the content and flow. After obtaining feedback from the thesis advisor and other students, the candidate made the requisite changes before sending the link to a wider audience.

Since the central question was about the factors driving choice, a list of factors was developed based on secondary research. The survey primarily consisted of closed ended questions. Ranking and ratings questions on the list of factors were asked. They were later used as the independent variables in the correlation. Questions around likelihood to recommend and satisfaction with current mobile service providers were also asked. The data from the likelihood to recommend question was later used as the dependent variable in the correlation. The above helped understand what drives choice. This indirectly also helped understand the current gaps in the mobile service providers’ offering.

The questions that were asked in the survey have been provided in the appendix.
5.1.3 Survey logistics

An online survey development tool called Survey Gizmo was used to develop the survey. Survey Gizmo is a website where surveys can be designed for free. Compared to other similar websites, Survey Gizmo allows to program more questions for free. Once the survey was programmed and tested, the survey invites were sent to the prospective respondents.

A snowballing technique was used to send the survey link out to students and alums through emails and social media. The survey link was also posted on the SUNY Polytechnic banner website and was also part of a mailer that went out to students and alums. The survey was conducted in February and March of 2016. The appendix provides the request that was sent to prospective respondents. The survey link is as below –


5.1.4 Verification & Validation

Before the online survey was programmed, a paper version of the survey along with a cover letter were sent to the SUNY Polytechnic Human Resources Board (HRB) for approval. After reviewing the petition, the SUNY Polytechnic HRB provided approval to proceed with fielding the survey. A copy of the email sent to HRB for approval is provided in the appendix. The survey was programmed after this approval.

Once the survey was programmed, two pilot survey tests were conducted among a subset of the population for checking the clarity of the survey. The candidate was present
on the phone when the respondents took the survey. The respondents were asked to 'think aloud' and provide feedback to the candidate as they were answering each question in the survey. Specific probes were asked by the candidate to ensure the questions were clear and to identify aspects of the survey that might potentially be confusing. Respondents were also probed on the survey duration and if they were paying attention throughout. Both the respondents who participated in the pilot tests indicated that the survey questions were easy to understand and the survey itself was easy to navigate. They took 4 minutes to complete the survey.

5.1.5 Delimitations

- The survey dealt only with mobile technologies for smartphones and did not cover the use of mobile technologies for tablets
- The survey focused only on 4G mobile technology smartphone users
- The survey consisted primarily only of students or alumni pursuing or completed a degree in Telecommunications, Network and Computer Securities and Computer Science
- The survey consisted majorly of students and alums from SUNY Polytechnic
- The survey was conducted only among respondents who are in the US
- Since the participants were not randomly selected, the results from this study cannot be generalized to the wider population
5.1.6 Limitations

- In an online survey, the body language of the person being interviewed or surveyed could not be observed.
- Respondents might take the survey fast and might not put as much thought into their answers.
- Survey responses might not necessarily reflect what consumers might do in real-life situation.
- Survey responses might not sometimes lend well to understand cause and effect.

5.1.7 Analysis

The Survey Gizmo platform on which the survey was programmed allowed for the data to be exported at any time in the Microsoft Excel format. Once fielding was completed, the final data was downloaded and analyzed using Microsoft Excel.

The survey had many questions. Since this was a closed ended survey with multiple options for each question, the data for all the questions were analyzed with the frequency of occurrence of each option for every question. Apart from the general frequency tables, a separate correlation was also run. This survey had a central question that asked respondents to rate the importance of key factors that drive their choice of a mobile service provider on a scale of 1-5. Each of these ratings were treated as independent variables. Factors included network coverage, bandwidth, data speed, call clarity, cost etc. Another question that got at how likely respondents are to recommend their mobile service provider was also asked on a scale of 1-5. This was used as a dependent variable. A correlation was then run between the dependent variable and each independent variable.
one at a time to understand which of the independent factors drive the likelihood to recommend and to what extent. Additionally, a regression was also run more as a confirmation between the same dependent variable and the independent variables.

The correlation was more preferred for this analysis when compared to a regression because a regression is not ideal when using discrete interval variables and also there is a greater chance of multi-co linearity between independent variables thus not providing ideal results. Hence, the regression was used more as a confirmatory analysis rather than as the primary analysis. Even though correlation does not imply causation, it was found to be the best approach as it was more likely to produce greater differentiation between independent variables than a regression. The correlation coefficient was calculated for each independent variable against each dependent variable. The magnitude of the coefficients indicated the extent to which each of the factors impacted the choice of mobile service providers.
5.2 **Understand if 5G will address or potentially improve upon the key factors of choice identified in Survey**

The second part of the research will explain in the detail the need for 5G and also tie in how 5G will improve upon some of the factors highlighted as being important by respondents in the first phase. The second phase of the study will primarily employ secondary research as a source of information. The secondary data for this study will be collected from literature reviews of scholarly articles, white papers and theses work/articles on 5G. The study will primarily cover the following points:

- **Market demand:** Before understanding the technical improvements of 5G, the first step would be to understand what applications in the market will drive the need and potential adoption of 5G. This section will focus in detail on the growth in applications of mobile technologies and the need for 5G to sustain this growth.

- **Technology:** The focus of this section will primarily be on how various technologies such as ultra-densification, mmWave (Milli meter wave), and massive multiple-input multiple-output (MIMO) will help fully realize the potential of 5G.

- **Infrastructure and Budget Requirements (i.e. Spectrum availability etc.):** In this section, the focus will be on what the infrastructure and budget requirements for implementing 5G and the optimum use of spectrum.
6. **Analysis Of The Survey**

The survey was conducted primarily to determine the factors that influence choice of mobile service providers among young and educated students and alumni of a few colleges (who use smartphones and are aware of mobile technologies) in the US.

A few key questions are listed as below -

1. What is the overall level of satisfaction with current mobile service providers?

2. How likely are current customers to recommend their mobile service providers to their friends/family?

3. Please rate the following factors depending on how important they are to you in influencing your choice of a mobile service provider.

4. What are some of the challenges that they face with current mobile service providers?

5. What are some of the improvements they seek from 5G technology?

This confidence interval for the data captured was 95 percent and the confidence level was 7 percent. Almost half of the sample comprised of respondents who were currently using AT&T as their mobile service provider. Verizon was #2 followed by Others, T-Mobile and Sprint. Others includes mobile service providers such as MetroPCS, Cricket Wireless, Lyca Mobile etc. The figure 1 below provides the distribution of current mobile service provider usage.
Finding #1 - Call, SMS/MMS and Email are the most important features of a smartphone

When asked to rank the top 5 features of their smartphone, a vast majority of the respondents indicated their top 3 to be - Call, Messaging (SMS/MMS) and Email. Social media and Web browsing completed the top 5 but were much farther behind the top 3. This indicates that despite the proliferation of the features of a smartphone to include various applications and uses, a vast majority still use their smartphones for their most critical and basic purposes. The figures 2 and 3 below show the ranking of the features in 2 ways - 1 sorted by average rank (lower the number higher is its importance) and percent of times the features were ranked in the top 3. Both the data points are consistent and support the above findings.
Fig 2: Features - Average Rank (N=201)

- Call: 2.80
- Messaging (i.e. SMS/MMS): 3.22
- Email: 3.58
- Web browsing: 5.33
- Social media: 6.35
- Take pictures: 6.96
- Watch the time and set alarms: 6.97
- Watching videos (i.e. YouTube, Netflix etc.): 8.09
- Reading news (i.e. using news apps): 8.64
- Schedule and review meetings on the calendar: 8.87
- Use other standalone applications (apps): 9.63
- Video chat: 9.64
- Play games: 10.43
- Shopping: 11.19
- Mobile wallet to pay for items at stores: 12.72

Fig 3. Features - percent Ranking in top 3 (N=201)

- Call: 71%
- Messaging (i.e. SMS/MMS): 64%
- Email: 61%
- Social media: 27%
- Web browsing: 22%
- Watch the time and set alarms: 14%
- Reading news (i.e. using news apps): 7%
- Take pictures: 7%
- Watching videos (i.e. YouTube, Netflix etc.): 6%
- Schedule and review meetings on the calendar: 5%
- Video chat: 3%
- Use other standalone applications (apps): 3%
- Play games: 2%
- Mobile wallet to pay for items at stores: 0%
- Shopping: 0%
Finding #2 - Respondents report high satisfaction with their providers but there is still room for improvement

When asked to rate their satisfaction with their current mobile service providers, users of AT&T, Verizon, T-Mobile and Others provided good ratings (percent of respondents rating 4 or 5 on a 5-point scale was greater than 65 percent). While these satisfaction ratings are very good with more than 2/3rds of the current users indicating satisfaction with their mobile service provider, the fact that the rest 1/3rd didn't think so suggests that there is room for improvement. Satisfaction ratings for Sprint are not provided because of low sample sizes. Satisfaction ratings are provided in figure 4 below.

![Fig 4. Brand Satisfaction](image)

Finding #3 - While satisfaction ratings are high, likelihood to recommend ratings are slightly lower validating that there is room for improvement

While the satisfaction ratings are very good across most of the mobile service providers, when asked how likely they will be to recommend their service providers to their friends and family, the top 2 box ratings (percent rating 4 or 5 on a 5-point scale)
reported is lower than their satisfaction ratings for all brands except for AT&T. Interestingly, AT&T reports significantly higher likelihood to recommend scores than the other brands. This indicates that while satisfaction with current brands is quite high, that enthusiasm is not carried over to recommending their brands to their friends and family. This proves that there is room for improvement in the offerings from these mobile service providers. Likelihood to recommend ratings for Sprint are not provided because of low sample sizes. Likelihood to recommend ratings are provided in figure 5 below.

![Fig 5. Likelihood to Recommend](image)

Finding #4 - 3 key factors in determining mobile provider choice are Network coverage, Call quality and Data speed

It was indicated before that call, SMS/MMS and Emails were the most used features of a smartphone. Consistent with that response, when asked what aspects are important to respondents in choosing a mobile service provider, a vast majority of the respondents indicated that network coverage, call quality, data speed and data plan were most important (percent rating 4 or 5 on a 5-point scale). Some of the relatively less important attributes
were - brand, recommendation of friends/family, store availability, promotions, availability of the phone with the service provider's plan and customer service. This clearly shows that the functional aspects of the mobile service provider are what respondents seek the most followed by the service aspects. This is also validated when respondents were asked to rank these factors. Network coverage, data speed and call quality were the top 3 factors. Figures 6, 7 and 8 depict the above in different ways.

**Fig 6. Important Factors in Choice of Mobile Providers (N=201)**

<table>
<thead>
<tr>
<th>Factor</th>
<th>% Unimportant (Rating 1-2)</th>
<th>% Neutral (Rating 3)</th>
<th>% Important (Rating 4-5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network coverage</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Call quality</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Data speed</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Data plan</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Customer service</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Phone is available with service provider's plan</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Promotions</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Store availability near my home</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Recommendation</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
<tr>
<td>Brand</td>
<td>% Unimportant (Rating 1-2)</td>
<td>% Neutral (Rating 3)</td>
<td>% Important (Rating 4-5)</td>
</tr>
</tbody>
</table>

**Fig 7. Factors Influencing Choice - Avg Rank (N=201)**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Avg Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network coverage</td>
<td>2.42</td>
</tr>
<tr>
<td>Data speed</td>
<td>3.17</td>
</tr>
<tr>
<td>Call quality</td>
<td>3.33</td>
</tr>
<tr>
<td>Data plan</td>
<td>3.96</td>
</tr>
<tr>
<td>Phone is available with provider's plan</td>
<td>6.54</td>
</tr>
<tr>
<td>Customer service</td>
<td>6.72</td>
</tr>
<tr>
<td>Brand</td>
<td>7.92</td>
</tr>
<tr>
<td>Promotions</td>
<td>8.24</td>
</tr>
<tr>
<td>Recommendation</td>
<td>8.47</td>
</tr>
<tr>
<td>Store availability near home</td>
<td>8.70</td>
</tr>
</tbody>
</table>
Finding #5 - Network coverage is the top factor that is correlated with likelihood to recommend; Leaving out the brand and other services aspect, call quality and data speed are the next 2 most correlated factors

In order to validate the above stated responses, a correlation was run between the Likelihood to recommend a brand and importance ratings on each of the above factors. The dependent and independent variables are as below -

**Dependent Variable** - Likelihood to recommend their mobile service provider (On a scale of 5-point likelihood scale)

**Independent Variables** - Rating the important factors that drive mobile service provider choice on a 5-point scale. The factors are as below -

1. Data speed
2. Call quality
3. Network coverage
4. Data plan (includes price)

5. Brand

6. Whether the phone you want is available with the service provider's plan

7. Customer service

8. Recommendation by friends and family

9. Availability of a store near my home

10. Promotions (i.e. deals etc.)

A correlation while not a measure of causality is a better a derived estimate than stated responses on what drives mobile service provider choice among respondents. While network coverage is still the top correlated measure (consistent with stated responses), it is noticed that a lot of brand, service and price aspects come up to the top. This indicates that while respondents place more importance on the functional aspects in stated responses, the derived correlations prove their latent need for brand, improved service and price.

Correlations are found to be significant at 99 percent and 95 percent confidence levels for all factors except for Recommendations by family/friends, Availability at a store near home, Promotions and Price. This indicates that consumers deem the functional attributes such as network coverage, data speed etc. to be more important than other factors such as recommendations by family/friends, availability at a store near home etc. Correlations and the actual outputs are provided in figure 9 below.
In addition to a correlation, a regression was also run to better understand causality. First, let’s look at the model fit which is determined by the R square. An R square of 0.086 implies that the independent variables explain only 8.6 percent of the variance in the dependent variable. The higher this number, the better is the model fit. While this is a low R square, there is no standard as to what is a good R square as it varies from one study to another and one domain to another. This could also be because we have a large number of independent variables.

![Fig 9. Correlation of Factors with Likelihood to Recommend (N=201)](image)

<table>
<thead>
<tr>
<th>Likelihood to Recommend</th>
<th>Data speed</th>
<th>Call quality</th>
<th>Network coverage</th>
<th>Data plan</th>
<th>Brand</th>
<th>Phone available with service provider plan</th>
<th>Customer service</th>
<th>Recommendation by friends/family</th>
<th>Availability at store near house</th>
<th>Promotions</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson Correlation</td>
<td>.147</td>
<td>.149</td>
<td>.239*</td>
<td>.165</td>
<td>.188*</td>
<td>.177</td>
<td>.157</td>
<td>.108</td>
<td>.026</td>
<td>.077</td>
<td>.005</td>
</tr>
<tr>
<td>Sig. (2-tailed)</td>
<td>.037</td>
<td>.035</td>
<td>.001</td>
<td>.020</td>
<td>.008</td>
<td>.012</td>
<td>.026</td>
<td>.129</td>
<td>.711</td>
<td>.276</td>
<td>.941</td>
</tr>
<tr>
<td>N</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
<td>201</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).
### Model Summary

<table>
<thead>
<tr>
<th>Mode</th>
<th>R</th>
<th>R Square</th>
<th>Adjusted R Square</th>
<th>Std. Error of the Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>.294a</td>
<td>.086</td>
<td>.033</td>
<td>1.101</td>
</tr>
</tbody>
</table>

*a. Predictors: (Constant), Q10_11, Q10_5, Q10_3, Q10_9, Q10_1, Q10_7, Q10_10, Q10_6, Q10_2, Q10_8, Q10_4*

The Sig value here indicates whether the model is statistically significant. If this number was less than 0.05, the model would have been statistically significant. However, in this case the sig number is 0.097 indicating that the model is not statistically significant.

### ANOVA*

<table>
<thead>
<tr>
<th>Model</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>21.521</td>
<td>11</td>
<td>1.956</td>
<td>1.614</td>
<td>.097b</td>
</tr>
<tr>
<td>Residual</td>
<td>227.874</td>
<td>188</td>
<td>1.212</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>249.395</td>
<td>199</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*a. Dependent Variable: Q09  
b. Predictors: (Constant), Q10_11, Q10_5, Q10_3, Q10_9, Q10_1, Q10_7, Q10_10, Q10_6, Q10_2, Q10_8, Q10_4*

The next step is to interpret the relationship between the dependent and the independent variables.

First and foremost, the fact that the sig value is not less than 0.05 for any of the independent variables suggests that no single variable has a significant influence on the likelihood to recommend a service provider.

Increase in importance of data speed by 1 unit results in 0.02 reduction in the likelihood to recommend. Increase in importance of call quality by 1 unit results in 0.007 reduction in the likelihood to recommend. These indicate that call quality and data speed have almost no influence on the likelihood to recommend.
Increase in importance of network coverage by 1 unit results in 0.335 increase in the likelihood to recommend. Increase in importance of data plan by 1 unit results in 0.053 increase in the likelihood to recommend. Increase in importance of brand by 1 unit results in 0.086 increase in the likelihood to recommend. Increase in importance of the availability of the phone with the service provider by 1 unit results in 0.065 increase in the likelihood to recommend. Increase in importance of customer service by 1 unit results in 0.077 increase in the likelihood to recommend. Increase in importance of promotions by 1 unit results in 0.029 increase in the likelihood to recommend. Increase in importance of recommendations of family/friends by 1 unit results in 0.005 increase in the likelihood to recommend.

Increase in importance of the availability of a store near home by 1 unit results in 0.09 reduction in the likelihood to recommend. Increase in importance of price by 1 unit results in 0.052 reduction in the likelihood to recommend.

Negative scores on these regression coefficients indicates that there might be multi-collinearity i.e. that the independent variables are closely related to each other.

So, the conclusion is that many of these independent variables are closely related to each other and for a successful 5G implementation, all these factors especially the functional ones must be taken into account. Regression coefficients are provided in figure 10 below.
### Fig 10

**Coefficients**

<table>
<thead>
<tr>
<th>Model</th>
<th>Unstandardized Coefficients</th>
<th>Standardized Coefficients</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>1.696</td>
<td>.813</td>
<td>2.086</td>
<td>.038</td>
</tr>
<tr>
<td>Data speed</td>
<td>-.020</td>
<td>.136</td>
<td>-.145</td>
<td>.885</td>
</tr>
<tr>
<td>Call quality</td>
<td>-.007</td>
<td>.150</td>
<td>-.047</td>
<td>.962</td>
</tr>
<tr>
<td>Network coverage</td>
<td>.335</td>
<td>.185</td>
<td>.172</td>
<td>.072</td>
</tr>
<tr>
<td>Data plan</td>
<td>.053</td>
<td>.146</td>
<td>.037</td>
<td>.717</td>
</tr>
<tr>
<td>Brand</td>
<td>.086</td>
<td>.088</td>
<td>.093</td>
<td>.333</td>
</tr>
<tr>
<td>Phone available with service provider plan</td>
<td>.065</td>
<td>.071</td>
<td>.079</td>
<td>.361</td>
</tr>
<tr>
<td>Customer service</td>
<td>.077</td>
<td>.093</td>
<td>.071</td>
<td>.409</td>
</tr>
<tr>
<td>Recommendation by friends/family</td>
<td>.005</td>
<td>.094</td>
<td>.005</td>
<td>.959</td>
</tr>
<tr>
<td>Availability at store near house</td>
<td>-.090</td>
<td>.079</td>
<td>-.105</td>
<td>.260</td>
</tr>
<tr>
<td>Promotions</td>
<td>.029</td>
<td>.080</td>
<td>.031</td>
<td>.715</td>
</tr>
<tr>
<td>Price</td>
<td>-.052</td>
<td>.108</td>
<td>-.481</td>
<td>.631</td>
</tr>
</tbody>
</table>

a. Dependent Variable: Q09
Finding #6 - Consistent with the above findings, lack of network coverage at all places, slow data speed and lack of call clarity are the top challenges respondents face with current mobile service providers.

In order to validate the above, a separate stated question was also asked to understand the current challenges that they face with their current mobile service providers. Consistent with their stated responses on the important factors of choice and correlation, lack of network coverage at all places was indicated to be the most important challenge. Slow data speed, lack of call clarity, call dropping, communication delay and the inadequacy of mobile technologies to use all apps were the next most critical challenges. The above is once again proved using the average rank and percent of respondents rating that challenge in the top two. Figures 11 and 12 depict the above.

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Avg Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of network coverage at all places</td>
<td>2.38</td>
</tr>
<tr>
<td>Slow data speed</td>
<td>3.03</td>
</tr>
<tr>
<td>Lack of call clarity even in locations with signal</td>
<td>3.39</td>
</tr>
<tr>
<td>Call dropping</td>
<td>3.62</td>
</tr>
<tr>
<td>Communication delay</td>
<td>3.96</td>
</tr>
<tr>
<td>Mobile/wireless technologies are inadequate to facilitate use of all apps</td>
<td>4.36</td>
</tr>
</tbody>
</table>

Fig 11. Challenges with Current Mobile Provider - Avg Rank (N=201)
Finding #7 - Familiarity with 5G is low but more than half the respondents seek improvements from the next generation technology

When asked about the respondents' familiarity with 5G technology, a majority of the respondents indicated low levels of familiarity (Figure 13). This is expected as not all of them were from the Telecommunications space. Moreover, the intent was to understand what their current drivers of choice were, what challenges they face with current mobile services and what they seek from a new technology.
Even if a majority were not very familiar with 5G, more than a 50 percent indicate that they still seek improvement from a new 5G technology (Figure 14).
Finding #8 - Data speed, Smarter internet and Bandwidth are the top 3 most desired improvements from 5G

The 3 most desired improvements they seek from 5G technology are data speed, smarter internet (i.e. when person is streaming, 5G will provide even faster speeds etc.) and the bandwidth for multiple devices to be connected to the internet (Figure 15). Even though coverage, data speed, communication clarity and latency/communication delay were at the bottom of the list relative to other options, more than 50 percent still seek improvement on those aspects.
Author’s perspective on Survey results

From the survey findings, it is clear that while most consumers are satisfied with their mobile service providers, their likelihood to recommend is lower indicating room for improvement. Fairly good satisfaction ratings don’t tell the full story as switching barriers such as contracts and hassle make it difficult for consumers to switch even if they want to. Consumers might also be comparing today’s technology with what they were used to getting a few years ago. Today’s 4G technology are clearly an improvement over earlier technologies. When asked to elaborate further on challenges with their service, consumers bring up lack of network coverage, data speed and call quality as the key ones. Interestingly, these are also the key technical drivers of choice. Brand, price and the availability of their choice of handset was also important but the key technical factors are the ones that are most interesting from a 5G standpoint. While many are not aware of 5G, they seek improvements in terms of data speed, smarter internet and bandwidth. This tells us that even consumers have started thinking about advanced applications of mobile technologies. While they might not be aware of the potential of mobile technologies, it is clear that any improvement will be welcome. The current state can be equated to that of the use of CD players prior to the advent of the iPod. While most users were satisfied with CD players which were improvements over the Walkman, they didn’t know it could be improved any further. However, today we notice that the CD’s have become obsolete and iPod’s have been adopted widely. Similarly, consumers might be seeking basic improvements today because they might not be aware of the full potential of mobile technologies.
Before proceeding to discuss about how 5G will address some of the improvements sought by consumers, the next section will provide a brief background of the evolution of mobile and wireless technologies as a primer.
7. Background About Evolution Of Communication Technologies

There has been a great development in communication technologies over the past 2 decades. This has primarily been achieved by the enhanced functionalities of wireless protocols. Wireless communication technology has been developing tremendously and there have been increased demand for improvement in speed and connectivity. The wireless technologies usage is increasing among users and strongly changed the background of telecommunications globally. The wireless standards of generations implemented so far include 1G, 2G, 3G, 4G and upcoming 5G [2] [5]. Through this background, I intend to briefly describe the evolution of earlier generation mobile and wireless technologies leading up to the future – 5G.

First Generation (1G)

1G was an analog system used for mobile communication. The technology was based only for voice communications. The primary limitations were -

1. It was a narrow band technology which deployed analog mobile network. Hence, only voice calls and text messages were allowed.

2. Moreover, the network was only available within the premises of a particular region [4].
Second Generation (2G)

2G networks used digital rather than analog technology. The digital network brought better communication clarity than 1G. It also provided more services when compared to 1G such as short message service, web access to certain extent and digital voice calling. 2G networks included GSM, CDMA, and TDMA. Even with this improvement, there were a few limitations:

1. It offered low data transfer rates.
2. There was low efficiency in packet switched services as a result of which wireless internet could not be executed efficiently.
3. It restricted roaming capabilities in the area outside the home network due to which it was semi-globally recognized [3].

2.5G

2.5G was an intermediary generation technology to bridge the gap between 2G and 3G. The mid generation 2.5G was introduced mainly for plugging bandwidth issues with 2G. The two network types of 2.5G were General packet radio services (GPRS) and high-speed circuit switched data (HSCSD). Deploying GPRS was an attempt to fix all the loop holes that exist in 2G. 2.5G standard of wireless communication is called EDGE technology [1] [3]. 2.5G was a marginal speed improvement over 2G.
Third Generation (3G)

3G wireless technology provided substantial increase in the speed of wireless communication. 3G deploys Wide Band Wireless Network with which a better clarity is achieved in real conversation. The data transferred in 3G is achieved by combination of Packet Switching and Circuit Switching. It provides services including voice, data, video and multimedia. It provides a larger bandwidth and high speed capacity. But this too has a few limitations:

1. 3G does not include features like interactive multimedia services, teleconferencing, wireless Internet, etc.
2. The bandwidth is less as compared to 4G [1].

Fourth Generation (4G)

4G is the advanced version of 3G mobile communication. It is a comprehensive and secure IP based system offering speed in giga-bits, Internet access, IP telephony and streamed multimedia. Remarkable improvements using 4G have been made in services such as video-streaming, global-mobility, multimedia and global-access with various types of devices. The 3G technology uses combination of packet switching and circuit switching networks but 4G utilizes packet switching network only. Despite such advancements, demands unfulfilled by 4G are:

1. Poor network coverage in rural areas and many buildings in metropolitan cities.
2. As it operates on new higher frequencies, new components in cell tower are required.
3. Battery consumption of cell phones is high due to which hardware becomes complicated.

4. Each time the user is forced to buy new devices to support 4G [4].

We notice that from analog to 4G, each generation of mobile technology has been motivated by the requirement to plug the loopholes in the earlier technology. With that in mind, a brief summary of the futuristic 5G which will not only be an improvement over 4G LTE, but will take mobile and wireless communication to a changed level.

**Fifth Generation (5G)**

In the US, we are currently on 4G. The next generation mobile technology that is in development is called 5G. It has not been commercialized yet. Today, the world is craving for videos, social media and other types of entertainment on their mobile devices. Many companies such as Samsung, Fujitsu, AT&T, NTT Docomo etc. are rushing to be the first to offer superfast mobile wireless technologies to consumers so that they access all the above much faster. This need for faster access has propelled service providers who in turn are looking towards equipment manufacturers such as Ericsson and Huawei to build the necessary infrastructure. 5G research is being conducted in isolated pockets globally such as the University of Surrey because there is a need to test this on a local area before widening its reach. Moreover, countries are yet to agree on a standard on how the different networks in various countries talk to each other. A truly global standard for 5G is not expected till 2019. Only then can 5G even start to be deployed globally without any telecommunication gap for people travelling from one country to another. Hence, the full-fledged global rollout is not expected till 2025. Additionally, we can see from the Phase one results that while customers are fairly satisfied with their current service
providers, they do seek some improvements. They are not able to articulate it more strongly because they haven’t perceived the improvements yet. It is creditable to note that the industry is able to have the foresight to develop a new mobile wireless technology even though consumer needs might only be latent at this point. It won’t be long when consumer needs become stronger and at that point the industry will be able to full satisfy this need with 5G.

The most distinguishing feature of 5G is that it is more consumer and industry oriented. 5G will provide a very high bandwidth, speed of 10 Gb/s in addition with very low latency and reaction times. 5G will be an incremental version of (4G, LTE, HSPA, Wi-Fi and GSM) and radio access technology (RAT). The two visions of 5G can be explained as below:

**The existing extended vision:** In this outlook, 5G creates a blend of pre-existing 2G, 3G, 4G, Wi-Fi and other technologies providing better coverage and network availability. The distinguishing feature is stronger connectivity between multiple machine services and Internet of Things (IoT). This enables conservation of power and devices with extended battery life.

**Radio access technology:** In this assessment, 5G will provide a wide range of solutions to satisfy the requirements of consumers. Some of the requirements are higher system capacity (1000 times capacity/km²), reduced latency (Radio Access Network less than 1ms), energy and cost efficiency as the implementation infrastructure cost is inexpensive, higher data rates (100 times available data rate) and large number of connected devices in a small area (100 times connected devices).
Overall, we have come a long way from 1G and there is an even greater scope for improvement in the form of 5G. The next few sections will focus on the market demand for 5G, its applications and how multiple technological approaches will bring to life the idea of 5G. Before we proceed to that section, a summary of the evolution of various generations of mobile wireless technologies are summarized in table 1.
<table>
<thead>
<tr>
<th>Generation</th>
<th>Primary Service</th>
<th>Key Differentiator/Improvement</th>
<th>Weakness (Addressed by Subsequent generation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1G</td>
<td>Voice calling</td>
<td>Mobility within the area</td>
<td>Poor spectral efficiency</td>
</tr>
<tr>
<td>2G</td>
<td>Voice Calling, Short message service</td>
<td>Secure, global access</td>
<td>Limited data rates, unable to support internet/e-mail</td>
</tr>
<tr>
<td>2.5G</td>
<td>Internet access</td>
<td>Better bandwidth than 2G</td>
<td>Weak data connection</td>
</tr>
<tr>
<td>3G</td>
<td>Video, data, voice, Multimedia</td>
<td>Better internet experience</td>
<td>failure to support Wireless Access Protocol for internet access</td>
</tr>
<tr>
<td>4G</td>
<td>All IP services, global mobility</td>
<td>Faster broadband internet, lower latency</td>
<td>High speed internet, high definition streaming.</td>
</tr>
<tr>
<td>5G</td>
<td>Enhanced connectivity all around the world</td>
<td>More secure, better coverage and high data rates.</td>
<td>?</td>
</tr>
</tbody>
</table>

*Table 1*: Evolution of wireless technology in terms of service and performance
Certain commercial trials for 5G are planned for the latter part of this decade. Megafon in Russia is planning to trial 5G in 2018 in some cities that will host the soccer world cup. The 2018 winter Olympics in South Korea will see a trial run. NTT Docomo in Japan has even more ambitious plans with a 5G rollout for the 2020 summer Olympics in Tokyo. There are also other trials that are planned in France, Germany, US, Australia and Brazil.¹²
8. Applications, Objectives, Technology & Cost Of 5G

8.1 Need for 5G

As discussed in the background section, mobile and wireless technologies have come a long way from 1G to the current 4G LTE. But there is a need for a next generation mobile technology such as 5G to broaden mobile and wireless access across the world. 5G, which is expected to be implemented between 2020 and 2030 will help connect all humans with each other and with all machines at any place and at any time. The increased capacity associated with 5G will offer such large bandwidths and speeds that the virtual distance between any human and machine will sink to zero.

There are 2 things that are driving the deployment of 5G – the demand for many kinds of services to be delivered over the broadband mobile networks and the evolution of the internet of things (IoT).

Mobile Broadband

The significant increase in the volume of information being carried by mobile networks is due to consumers’ demand for video and other applications. So far, the industry has been able to manage this spurt through data traffic optimization and offloading to other networks. However, as the demand continues to increase, there will be the need for efficient use of current spectrum, use of new spectrum, network innovation and innovation in wireless technologies.
Internet of Things (IoT)

There are 2 broad types of IoT –

**Massive machine type communications**

This includes a large number of connections and end points such as mobile devices, smart and connected homes, smart meters etc. While many of these can be handled using 4G, the sheer volume increase on this front over the next few years will need a next generation standard such as 5G.

**Mission critical applications**

These include mostly commercial applications such as remote surgery and some personal applications such as driverless cars. These are areas that will need high reliability and low latency. Driverless cars especially will require flexible systems that can exchange data in real-time with other vehicles and the infrastructure around them. In addition to driverless cars, there are other transportation applications such as wireless networks in ports, airports, other transportation hubs, in-transport real-time entertainment systems etc. that will require more bandwidth. There is also a new term called Industrial IoT. This includes smart factories that need real-time capabilities for process control. In the case of the utility sector, there is the drive towards smart grids that will go beyond the meters to devices within the household. In the healthcare area, there is a clear trend towards wearable fitness devices and smartphone based applications for monitoring long-term medical conditions. In the developed markets, more advanced techniques such as remote robotic surgery is in the realm of the near future. In the case of the developing and underdeveloped countries where health facilities are sparse, mobile services have enabled
the move towards remote diagnosis. With the advent of many virtual reality and augmented reality companies such as Oculus, VR and AR are quickly becoming a reality in gaming and even in retail. In some of the developing markets like India, Smart Cities are expected to become a reality as the country tries to optimize infrastructure consumption. In such cases, data from multiple sources are brought together to lead to better city planning in areas such as traffic planning, parking, energy management, lighting, waste management etc.

Each of the above are explained in detail in the below section.

8.2 Market Demand for 5G

Forecasts for the start of 5G have actually accelerated much before the 2020 timeframe. The use cases for 5G will be mobile broadband, automotive, smart society, smart grids, health, industrial and logistics/freight tracking. All of these applications will need high reliability, larger bandwidth and low latency. Only a fully functional 5G technology can deliver effectively on these applications. Provided below is a description of potential applications of 5G. Benefits of some of these applications will be directly observed by the consumers while others will be perceived in an indirect manner.

8.2.1 Mobile Broadband

This will go above and beyond basic internet applications to cover interactive work, media and entertainment applications in the cloud. Voice communication will still be an integral component but it will be handled as an application. Data is expected to grow between 25-50 percent annually till 2030 leading to about 10,000 times the traffic we are
experiencing today. This growth will be due to applications that require high data rates such as streaming services. Moreover, a lot of the applications are moving into the cloud both on the work and the personal front. Before, a lot of documents were only downloaded but nowadays there are large number of uploads as well. With many companies such as Amazon and Microsoft offering cloud services to businesses to run their emails and storage and with cloud gaming becoming a reality, the need for connectivity is becoming insatiable. While LTE might be able to handle 1000 times more traffic than what is experienced today, 10,000 times more traffic will require a paradigm shift in the technology. Today, ~45 percent of the world population has access to internet. By 2020, that penetration will be close to 100 percent. Moreover, the number of smartphone users will go up to 6.1 billion by 2020 which would constitute about 70 percent of the world population. This is an application that directly impacts consumers and is probably the most urgent and immediate of consumer needs. The author’s option is that when 5G is fully implemented, this is one application that will be the most direct and easily observed by consumers.

8.2.2 Automotive

The automotive industry will also be a significant driver of 5G with real-time passenger entertainment, augmented reality dashboards and driverless vehicles. By 2020, it is expected that about 250 million vehicles globally will be connected thus boosting the infotainment market. Even today, some automotive brands such as Chevrolet provide mobile and internet connectivity by partnering with mobile service providers. Connectivity in cars will also help with augmented reality dashboards which will help identify objects in the dark and identify distances between the car and other objects etc.
These 2 use cases will help passengers access information. But a much more futuristic application is that of driverless cars which will involve cars communicating with each other, with other infrastructure objects and with devices carried by individuals. It is expected that about 10 million driverless cars will be on the roads by 2020. The author’s option is that while real-time in car entertainment and augmented reality dashboards will be widely deployed within this decade, driverless cars while already in pilot mode in a few cities around the world will probably become a norm in the 2030’s.

### 8.2.3 Smart Cities/Smart Homes

Smart homes and in turn Smart cities will be comprised of dense enmeshed networks. In a smart home, all appliances such as lights, TV’s, heating, air conditioning, computers, entertainment systems, burglar alarms etc. can be controlled remotely through a computer or a mobile phone. This offers homeowners lower costs, security and convenience. The number of smart homes just in the USA is expected to be around 46 million. Smart city is a term that is used to refer to how cities of the future will manage all their assets such as healthcare, traffic signals, power plants, waste management, transportation systems etc. For example, a city could remotely control traffic signals, use video sensors to detect crowds and manage them etc. The market for smart cities to be $1.5 trillion by 2020. India alone has plans to develop 100 smart cities over the next 15 years. Smart homes are already a reality today and as consumers adopt the same, the expense of such connected homes will reduce. Smart cities however are a much larger project and will require significant investment and governmental commitment. The author’s option is that while there will be a few smart cities in certain developed countries soon, in developing
countries such as India where even basic amenities are yet to be city, ready, smart cities are a distant dream.

8.2.4 Smart Grids

A smart grid is just an intelligent way of managing the diverse power systems that are available at the disposal of cities, states and countries. The main challenge of the smart grid is controlling the demand and supply of power generated by diverse power producers. These power producers could be renewable energy sources, coal power plants etc. It basically uses communications technology to adapt to changes in power usage. A smart grid comprises of multiple sensors such as voltage sensors, fault detectors, power meters etc. which communicate back and forth with the command center and help utility companies and in turn cities make efficient energy decisions. The smart grid market is expected to touch $400 billion by 2020. Smart grids are already in place today and actually had investments coming in through the stimulus program in late 2009. Once again, the author’s option is that wide deployments will take time.

8.2.5 Health

The health sector has various applications that can benefit from improved mobile communications. Telemedicine is important especially in less developed countries where access to healthcare is limited. Some of the applications of telemedicine include acquiring medical data and transmitting data to the doctor or medical specialist for his/her assessment. Remote patient monitoring by tracking parameters such as blood pressure, heart rate etc. even when the patient is not at a hospital or a doctor’s office is also possible. Remote patient consultation is also possible especially if the patient is not able
to go to the doctor’s office or unable to afford going to the doctor’s office regularly. Other applications include telenursing (assistance by nurses via conferencing etc.), telepharmacy (remote connection with pharmacists from areas where no access is available; can be used for drug therapy monitoring, refills and prior authorization of certain prescription drugs) and teletrauma care (doctors can interact with emergency personnel on the scene and determine the severity of the injuries and what the emergency personnel should or should not do). Telemedicine is expected to be worth $30 billion globally by 2020. These health applications are already in place in many countries and as per the author, will only become faster and better with the implementation of 5G.

8.2.6 Industrial Applications

The application of 5G in industries include remote industrial automation and process control and fleet management and logistics. Heavy machinery can be controlled from remote centers while performing dangerous tasks such as excavating mines or clearing forests. Critical to perform such tasks is the availability of high quality audio, video and other real-time sensory information. Moreover, in various industries wiring is becoming obsolete as they install wireless sensors that monitor equipment in factories in real-time. Other applications include freight and logistics that help track packages using location based systems rather than when they reach a certain hub. Once again, as per the author, these applications are already in place in the industry and logistics and will be fully exploited with the implementation of 5G.

All of these applications were sourced from an executive report presented at the GSA (Global Mobile Suppliers Association) by Ericsson, Huawei and Qualcomm. This proves
that even beyond mobile broadband, 5G has great potential to make many commercial applications more efficient.

The above applications translate into 2 kinds of requirements from 5G – user driven requirements and network driven requirements. User driven requirements include – improved battery life or reduced energy consumption, improved latency, robust networks, increased mobility and seamless user experience with minimal interruptions. Network driven requirements include – increased scalability, improved network capacity, improved cost efficiency and enhanced security. The following sections will discuss about the objectives, the above mentioned requirements and what technology will be employed to address those requirements.

8.3 Brief Introduction about the Objectives for 5G

In order to deliver on the above demand, 5G needs to meet the following objectives –

- **Significantly faster data speeds.** For example, with 5G, download speeds of 10 GB/s could be achieved as opposed to 1 Gb/s with current 4G technology thus leading to a large high definition movie to be downloaded in as fast as 6 seconds vs. 7 minutes.

- **Very low latency** thus increasing the speed with which data packets are sent from one device to another. For example, latency rates with 5G will be as low as 1 millisecond as opposed to 50 milliseconds with 4G.
• **Facilitate a completely connected world** i.e. the Internet of Things (IoT) such as wearables, smart home appliances, smart homes, connected cars etc. For example, if there is a car accident ahead, the sensors on the road can detect the accident and communicate back to other driverless cars to slow down or detour.

The above 3 objectives of 5G are consistent with the 3 key drivers of mobile service provider choice from the Phase one survey – data speed, call quality and network coverage. This is also consistent with what current smartphone users seek from 5G – improved data speed, smarter internet and bandwidth for multiple devices. This indicates that consumers drive market demand which in turn drives the goals for 5G. But, only goals and objectives are not enough, certain requirements need to be fulfilled to successfully implement 5G.

### 8.4 Brief Introduction about the Requirements for Successful 5G Use

5G in itself cannot meet the above objectives. In order for 5G to fully deliver on the above objectives and in turn satisfy the market demand, it needs certain requirements to be satisfied –

- Building of the capability to support a large capacity (**Large Network requirements**)
- Support for facilitation of large number of devices across both personal and industrial settings (**Massive Connectivity**)
- Potential use of all available spectrum for different network scenarios (**Efficient Spectrum Usage**)
Provided below is a brief explanation of the above key requirements -

- **Large Network Requirements**: The basic requirements of 5G are higher capacity (primary goal of 5G is to provide high speed data starting from 100Mb/s to 10 Gb/s), increased bits/Hz/km², fast delivery (the time taken for data to reach the required destination quickly), support maximum devices (the maximum number of devices supported by 5G at the same time in a small area will be 100 times extra), least delay (the latency is as low as possible as <1ms), strong network coverage (the number of base stations are closely located to provide strong network access in remote areas), cost and energy efficient (the infrastructure implementation cost involved is low and involves low energy apparatus).

- **Massive Connectivity**: The wireless technology 5G network merges with the existing 4G, LTE-Advanced, HSPA+ and Wi-Fi in addition to latest technologies to meet the detailed requirements. For example, to facilitate huge amount of data in a concentrated area, deploying unprecedented number of base stations cannot be achieved by making modifications in the existing LTE but requires fundamental changes to resource allocation strategies. Thus, it leads to a new requirement to operate in an improved spectrum of greater than 6GHz and application of new radio techniques, signaling protocols and architecture.
- **Efficient Spectrum Usage**: The operating frequency of 5G recommended is between 6GHz to 300 GHz. Spectrum utilization in 5G can be broadly categorized in 3 categories -

  - Low frequencies, <1GHz (for countryside and coverage inside houses)
  - Core frequencies, between 1GHz to 6GHz (for coverage and capacity for hot-spots carriers)
  - High frequencies, between 6GHz to tens of GHz (for high capacity e.g. in schools and corporate offices)

To satisfy the above requirements, 5G’s design must –

- Attempt to use frequencies higher than what is being used today
- Attempt to consolidate spectrum across multiple bands
- Develop new air interfaces and multiple access schemes
- Reduce the number of network layers and consolidate resources on the cloud

As higher frequency bands provide small cell radii, it would be difficult to deliver widespread network coverage with the current topology model. Hence a widely accepted gigantic ‘beam-forming’ approach needs to be used. The radio interface into a beam provides wider area for network coverage over long distances which uses 6GHz or higher spectrum bands. 5G utilizes this technology to deploy on a wide area, as each cell supports hundred individual beams at one time and tracks end users in a three dimensional space. Massive MIMO (Multiple-input, Multiple-Output) is the technique by which the increase in bandwidth can be achieved. In this technique, an array of antennas
are installed in a device and multiple radio connections are established between base station and a cell to provide high quality connectivity in the given network area.

The big 3 technologies that will be used in the implementation of 5G are massive multiple-input multiple-output (MIMO), mmWave and network slicing. Massive MIMO and mmWave are interconnected and belong to the concept of ultra-densification. Apart from the big 3, a few other technologies might help 5G implementation such as simultaneous transmission and reception, Multi-RAT integration, Device-to-device communication, Small data transmission, Wireless backhaul integration, Flexible mobility and Moving networks. Each of these are described in detail in the below section.

8.5 Technology to Deliver on 5G

8.5.1 Massive MIMO

Network coverage is a top driver of mobile service provider choice. In order to effectively make 5G work, telecommunication companies will have to improve capacity between mobile phones and the base stations that are present every few miles. This doesn't mean just building more base stations but also tapping into the currently unused radiowave frequency territory spectrum and working on better antenna technologies. Building more base stations closer to each other to improve mobile phone coverage is a definite option and is something that service providers have been doing for years in order to improve connectivity. Generally, base stations include what are known as macrocells which can provide coverage for up to 20 miles or so. But in order to truly deliver the benefits of 5G to the consumers, mobile service providers will have to build small cells at every pole on the street having coverage of a few hundreds of feet. The massive MIMO
technology requires the use of a large number of antenna units that are scattered around a wide geographical area. These antenna units in turn have hundreds of antennas. These antenna units are installed at the base stations and are connected to the base stations using optical fibers. Mobile users who are outside of the buildings have small antennas within their cellphones which when in touch with antennas from the base stations form a virtual massive MIMO network. As indicated before, every building or pole will be installed with smaller cells that communicate with the outside base stations. Mobile phones of users inside the building will either be connected to their wireless or to the mobile network. If they are connected to the wireless network in the building, that network will be connected to the outside antenna through cables. Thus, this antenna technology ensures that at least in populated areas where network providers tend to build a lot of base stations, there are no gaps in terms of coverage.

Another potential improvement with massive MIMO is that the antennas within the mobile phones communicate with each without the need for the by the base station. This circumvents the current method whereby a signal from 1 mobile phone reaches the base station and then is transmitted to another phone. In such cases, the mobile phones themselves will act as the base station. Once security issues are overcome with such an approach, this should lead to significant improvement in network coverage.

Traditionally, there is one antenna in the receiver and one in the transmitter. With MIMO (multiple inputs and multiple outputs), the receiver and the transmitter will each have tens or even hundreds of antennas. This leads to better data rates as a large number of antennas are enable many independent data streams with more devices being served simultaneously. It also leads to greater reliability as the large number of antennas result in
more distinct paths. It also enables efficient energy usage as the base station can focus its energy on specific identified locations where the devices are located. Reduced interference also results as the base station can opt not to send any signals in the direction where communications are already happening. MIMO is something that is happening today but most base stations today have only about 8 antennas but for fully achieving the potential of 5G, many more antennas need to be installed at the base station. This means elevating the utility of the MIMO technology to a higher level called massive MIMO. These will be systems with hundreds of antennas serving multiple terminals at the same time.

Massive MIMO systems can increase energy efficiency and also increase the capacity significantly. Capacity increase can be attributed to the concept of spatial multiplexing. With the large number of antennas, energy can be directed towards small regions with extreme accuracy. By shaping the signals from the base station antennas, the station ensures that all wave fronts from the antennas are consolidated constructively at the terminals of the destination and destructively everywhere else. Energy consumption of base stations is becoming a challenge and with massive MIMO being energy efficient it will reduce the load. Moreover, the base stations that require less power due to massive MIMO can be powered by renewable sources such as solar or wind.

Massive MIMO can also be built with inexpensive components. Massive MIMO systems do not have the more expensive 50 watt amplifiers, they are comprised of many low cost amplifiers. This avoids the need to use coaxial cables. This design also reduces the impact of a single amplifier on the entire system. The noise and interference is zoned out when signals from multiple antennas are combined together in the air.
Massive MIMO will also reduce latency. Latency generally occurs when the signal from a base station takes many paths before reaching the terminal. These multiple paths create fading and interference. If a destination terminal is under the influence of an interference or fading dip, it will have to wait till the interference passes before any further data can be received. Massive MIMO relies on the fact that signals are emitted from a large number of antennas and then forming beams to decrease the probability of latency.

Intentional blocking of signals is also becoming a significant security issue. Simple jammers can be bought easily and even sophisticated jammers can be assembled using components available off-the-shelf. In the current scenario, if a jammer is used, all signals in the area will be blocked with no transmission happening as signals cannot be broadcast through other frequencies. With massive MIMO, there are large degrees of freedom which will minimize interference from intentional jammers.

Ultimately, 5G technology will not necessarily improve network coverage but it is the other way around as to properly deliver the benefits of 5G, service providers will have to be innovative with improving network coverage. And Massive MIMO is one such approach. The information about Massive MIMO has been primarily sourced from a paper called A Survey of 5G Network: Architecture and Emerging Technologies; Akhil Gupta and Rakesh Kumar Jha, School of Electronics and Communication Engineering, Shri Mata Vaishno Devi University, Katra 182320, India. This approach is doable on a wider scale assuming the necessary outlay is available as antenna technology has improved significantly.
8.5.2 Mm Wave

One other way to fully deliver on the promises of 5G will be to move to higher spectrum bands such as 6 GHz, 28 GHz and 38 GHz. The higher end of frequencies in excess of 30 GHz is called millimeter wave. Using spectrum at lower frequencies does not result in high bandwidth but helps transmit data over long distances while on the other hand with Mm wave, bandwidth is large but distances over which it can be transmitted is low. One advantage of mm wave is that beamforming is possible with signals being sent directly to the device rather than being broadcasted and received from multiple places. The comparison between the traditional frequencies and Mm wave is equivalent to many people shouting at one place thus causing disturbance vs. many people focusing their voice through a megaphone only at places they want.

Initially, it was studied that at 60 GHz, there was weakening of signal over long distances because of the oxygen in the air. Hence, this had always been avoided. But later studies are providing evidence that at 28, 38 and even 70 GHz, the oxygen absorption seen at 60 GHz is not observed. It seems as though the mm wave is obtaining the same level of weakening as the frequencies used for today’s communication due to rain.

One way to tide over some of these challenges is to use small cells as antennas. These are portable base stations that are adapted to transmissions over a shorter range. With such small cells, high frequency spectrum can be reused by multiple cells in the network thus increasing spectrum usage efficiency. Additionally, antenna size is inversely proportional to frequency size, thus smaller antennas would be ideal to use high
frequency bands. By packaging more antennas into devices, steering of signals in a particular direction is possible.

Today, small cells have been used in business premises and in some residential buildings to improve spotty mobile coverage. With 5G, the goal is to build a lot of small cells in urban densely populated areas to improve coverage. Unlike base stations, these small cells with not be conspicuous i.e. they can be installed on roof tops or street corners without people noticing them. As the name suggests, these small cells can help with communications only over short distances. So, there is an issue with handover. For example, if someone is travelling by train, he/she is moving fast through multiple small cells and there needs to be a handover across these cells with the movement resulting in potential loss of data packets. Some workarounds to this issue are using small cells for data only or identifying users who are moving and placing them on the usual base station larger cell.

The other challenge with smaller cells is energy consumption. While macrocells consume a lot of energy, there are only a finite number of macrocells. But in moving to small cells, there could potentially be billions of them especially in dense areas. The best way to move to smaller cells and yet conserve energy is by keeping the plane that determines how the data moves through the network different from the plane that governs the actual data moving. This separation enables shutting down a few cells but at the same time keeping the anchor source on. Today’s cellular systems always keep transmitting information but the above discussed separation will cut down significantly on always-on transmissions. Thus, this design will lead to lesser interference and lesser energy consumption.
Thus mmWave will help improve the other driver of choice from the Phase one survey of call quality. This information on mmWave has been primarily sourced from a paper called mmWave Communications in 5G; Isabelle Tardy and Jan Erik Håkegård; SINTEF, Norway. Similar to Massive MIMO, this technological approach will also require significant investment and might take longer to be fully functional.

8.5.3 Network slices

Since the application of 5G will be so diverse, network slicing will be important. For example, mobile broadband will require a different network slice from that for massive machine to machine communication such as traffic regulation. Network slicing is an approach by which operators can support multiple virtual networks behind the air interface. This can be accomplished through software designed networks (SDN) and Network functional virtualization (VFN).

SDN helps move the control plane away from the switches and enable control of data through a centralized controller. SDN describes the components, their functionality and the protocol to manage them using a controller through a secure channel. This enables the controller to function as a network manager thus allowing easy handling of network behavior. In this case, the devices that receive the information need not understand the different protocols since the controller does it for them. The value of SDN for 5G lies in its ability to offer new capabilities such as NFV.

NFV is complementary to SDN and helps virtualize network functions by placing them into software packages which can then be assembled. Conventionally, network operators dedicated network equipment to deploy their networks. This increased their
capital spending and also needed people to manage this equipment leading to higher operational spending. NFV plans to consolidate heterogeneous networks by shifting functions from hardware to computer platforms such as servers. Moving network functions to data servers will also help with resource management and distribution. This will in turn improve energy efficiency by allocating only the necessary amount of resources.

From a practical standpoint, what this ensures is that different applications even within a single equipment or area use different network slices thus reducing the chances of interference and in turn leading to better call and data quality. For example, network slicing will allow a driverless car to report back road conditions etc. to other cars while at the same time using a different slice to run high speed streaming video.

8.5.4 Spectrum & 5G

Electromagnetic spectrum is a band of frequencies at which radio waves can be transmitted without a wire. Radio spectrum refers to the entire range of frequencies available for communications – 3KHZ to 300GHz. The primary issue with spectrum is interference i.e. at low frequencies the radio waves can be transmitted between the source and the receiver with lesser interference from unwanted radio signals while at higher frequencies, interference is higher.

Spectrum is a resource of a country just like water, land etc. To promote efficient use of the spectrum and to minimize interference, each country allocates spectrum for different usage purposes. For example, 88-108 MHz is used for radio while 300-500 MHz is used for aeronautical operations. Till the later part of the 20th century, the
allocation of spectrum was easier as the usage was limited to certain core applications such as phone calls, radio, TV etc. But with the explosion of the internet and smartphones, the need for spectrum has ballooned creating an apparent scarcity. This becomes a greater challenge as we move to the 5G technology in order to satisfy a fast growing wireless world.

For a finite set of devices, the entire spectrum band of 3KHz to 300 GHz is ample. With the fast increase in the demand of wireless technologies every year, the industry has become more efficient in packing more data into the same amount of available spectrum using less power. The improvement in radio and antenna design have led to the same level of communications with lesser power. There are also potential improvements in wireless technologies that can operate in noisy environments via beam forming with multiple antennas. In the world of 5G, it is possible that spectrum usage might be driven more by the above mentioned techniques adopted by the industry rather than the governments’ allocation of more spectrum. Strict regulatory controls of the bands to be used for certain applications have actually led to inefficient usage of spectrum. Deregulating spectrum usage will allow the new technologies such as CR and dynamic spectrum sharing to work to their full potential thus enabling more efficient usage of spectrum. Apart from the above, there is still spectrum available in the higher bands greater than 10 GHz that are still underutilized.

In order for 5G technology to fully deliver on its capabilities, spectrum usage will be key. This will not only necessitate extending usage of current bands but also operate in newer bands. In order to do this, spectrum is to be made available in vertical (centralized) and horizontal (distributed) sharing approaches.
The primary approach of distributed sharing is to address only those transmissions that create interference between systems. They fall under the purview of the standards and do not need contracts between mobile service providers. In this approach, the systems transmit recognizable signals that can be employed by other systems to adjust their spectrum usage. Thus, in this approach the systems communicate with each other on an equal basis.

The primary approach of centralized sharing is ideal for systems that can share at a higher level. In this approach, there is a spectrum broker in which distributed sharing systems communicate with a centralized spectrum management unit for obtaining permission to use spectrum. The other way to do this is through geospatial location whereby systems communicate with a database to identify spectrum resources that are available for use at a particular location.

While interference is a reality, it is not a property of a spectrum, it is the byproduct of inefficient transmitters and receivers. An improved receiver will pick up a transmission clearly while an improved transmitter will also transmit appropriately by avoiding interferences from devices that are close by. Smart radios today can sense the gaps in the spectrum and make decisions on occupying those gaps. The closeness of devices to each other can also make a big difference as 2 devices can communicate without interfering with the transmission of other devices in the network. Thus a distributed spectrum sharing approach has intelligent cognitive radios that communicate with each without interfering with other communications in the vicinity. They don’t need a centralized command control and are smart enough to mutually cooperate and use the spectrum. In the centralized approach, there is a spectrum conditioner that will maintain the use of air.
waves in an area. This is a device used to sense the spectrum availability without any manual intervention and to also ensure disciplined use of spectrum in an area by multiple devices. It will have the capability to silence malfunctioning radios.

But recent studies have found that despite the demands exceeding supply, most of the times the existing spectrum is not being used efficiently. This has led to an approach called Cognitive Radio (CR) that allows detection of an unused spectrum channel and use it. It is a smart radio that is designed to use the best wireless band in its realm. It can detect if any portion of the spectrum is in use and dynamically use it without interfering with the transmissions of other users. CR requires Cognitive Network (CN) to help facilitate this process. CN is a smart network that understands the scope of its realm and uses artificial intelligence to allocate the unused bands to the appropriate CR.

There is another area for spectrum sharing that is known as device relaying and cooperative communication. In this approach, the devices in a network act as relays for each other thus creating a large mesh network. This is a simpler explanation for the distributed method of spectrum sharing. This approach is opposite to the traditional approach where there are wired links between identified nodes with an allocated spectrum. In this distributed method, the utilized spectrum and the devices to function as relays are opportunistically determined by their availability at that point to form a wireless link. This approach works better with a larger network because it offers more opportunities to identify devices within the network that can act as relays.

In traditional systems, devices are not allowed to communicate with each other as all communication is routed via the base stations. For 5G, device to device communication
will be important. This means creating a network that is entirely device centric in which a device has the entire spectrum to be operated through a community of intelligent devices. These smart devices have an intelligent algorithm to find the best devices in the vicinity that they can communicate with. Spectrum negotiations are done based on availability whereby each device selects a frequency band based on availability of other devices in the vicinity. This approach needs a proper handover of wireless links. The intermediate devices function as wireless repeaters. A new wireless device that enters the area will need frequency handovers while an intermediate device that leaves the area will necessitate handover to new wireless links that can continue the session. In this case, a base station will be treated only as another wireless intermediary.

Thus, efficient use of spectrum will be key to provide a larger capacity which in turn will dramatically improve network coverage which was one of the top drivers of choice. The information for this paper was primarily sourced from a paper called Spectrum Scarcity - An alternate view, Sajeev Manikoth, IonIdea, Bangalore, India; Novel Spectrum Usage Paradigms for 5G; Special Interest Group Cognitive Radio in 5G; IEEE. While all the above approaches to efficiently use spectrum are possible, policy generally does not keep pace with ideas and might take longer for obtaining permissions to use different spectrum bands for mobile purposes.

8.5.5 Simultaneous Transmission and Reception

Currently wireless networks dedicate spectral and temporal resources to UL and DL channels. But simultaneous transmission and reception would enable resource sharing in both directions. This will also lead to effective spectrum usage and increase capacity. The
challenge with using the same channel for UL and DL is interference. But, research over the years have reduced the interference but not to the level where they can be used with current cellular networks. But with 5G which will use mmWaves, this level of interference can be tolerated due to lower transmission powers. As research continues in the area of interference cancellation, this technological approach might be useful in a 5G context but might not be encouraging as the major 3 technologies that we discussed before.

8.5.6 Multi-RAT Integration\textsuperscript{17}

The large increase in Radio Access Technologies (RAT) means it is important to think about multi-RAT integration with the introduction of 5G. The aim is to ensure consistent multi-RAT integration between different technologies such as 3GPP and non-3GPP. With the advent of 5G, it will be extremely important to route certain devices to the correct RAT. This will enhance user experience. With the different types of RAT’s such as 5G, 4G, 3G, Wireless and Bluetooth, there needs to be a separation of the user and control planes whereby there will be an entity that controls to which RAT a certain signal needs to be opportunistically routed.

8.5.7 Device-to-Device (D2D) Communication\textsuperscript{13}

The macrocell level of communication refers to the communication between a device and the base station. The device level refers to the communication between 2 devices. This will be extremely important to fully obtain the benefits of 5G. Normally, device to device communication happens through the base station but it is possible for devices to communicate with each other without every signal having to be sent to the base station.
This is possible if all the devices are within the range of the base station and also are near to each other thus creating an enmeshed network. There are multiple ways in which this can happen –

Device relaying with the base station still in control – In this case, a device that is just outside or at the periphery of a base station range can communicate with the base station by relaying its signal to the base station through a device that is within the range of the base station. This ensures uninterrupted signal even in areas that might be outside of the general coverage area.

Device to device communication with the base station only providing control – In this case, the base station provides only the controlling to the 2 devices but the devices communicate with each other directly without having to send the signals back to the base station. This will free up the space of on the base station to support even larger volume of mobile operations.

Device to device communication with no involvement of the base station but using other devices as relays – In this case, the base station is neither involved in control nor communication. An array of devices form an enmeshed network and can communicate with each other directly. The 2 devices will use another device as the relay for control.

Device to device communication with no involvement of the base station or other devices – This is the most perfect form of device-to-device communication whereby the 2 devices communicate with each without the need for a base station or another intermediary device.
In order to successfully implement the above, there is a need for a closed approach to security whereby the signals are relayed through only those devices which are trusted by 1 of the 2 devices which want to communicate with each other. If the relaying device or one of either the destination or the source is not a known or a trusted device, device-to-device communication will not be allowed. Moreover, in the world of perfect device-to-device communication, in the absence of a controlling authority such as a base station which determines when D2D can be allowed, the devices will have to constantly signal each other to obtain the permission to form a channel.

8.5.8 Small Data Transmission

Small data transmission can be done through connectionless access. In this scenario, a device sends a small data burst to the 5G network which in turn transmits it to the base station. This is done through a connectionless access which consumes less energy and does not need the security authentication of a regular communication. This frees up the network for other longer data transmissions. Hence, smartphones which are compatible with both scheduled and connectionless access can send short data bursts through connectionless access and longer ones through the scheduled access.

8.5.9 Wireless Backhaul Integration

Backhaul is generally done through wireless means and it is how an end-user connects to a larger network such as the internet. Currently, point-to-point wireless backhaul is predominant but the goal is to move towards licensed point to multipoint backhaul which will aggregate the signals from multiple base stations to a single hub.
which will then connect to the larger network. This will free up bandwidth. Additionally, there is also an effort to ensure the access and the backhaul link use the same spectrum.

8.5.10 Flexible Mobility

This concept can be fulfilled through 2 means – No idle mode and no active mode. No idle mode means that the state information for tracking the device need not be stored on the network thus saving resources in a sensor based network. The device may not have an idle mode or might have a sleep mode whereby the device hibernates till it a network transaction has to be started. This ensures that the device need not be constantly connected to the network and saves its own battery and also the resources on the network. For stationary devices, the no active mode works better because there is no need for the network to store the state information of the device. Addresses are allocated to the device locally by the base station thus enabling lower latency due to the presence of direct routing.

For flexible mobility to happen, the network should be aware of the context. A network cannot offer the resources needed for each device unless it knows the context of the device. An aware network is a hybrid of both a dumb and an intelligent network where a network can adapt to the needs of a device. The ability of the network to know the usage history, location history etc. of a device would lead to very efficient network usage. Context information can be collected from the device or the network monitors or elements. Once a device connects to the network, it services the device based on its history.
8.5.11 Moving Networks\textsuperscript{17}

5G might have to support communications even when the device is moving at a very high speed. For that to happen, instead of the current concept where the moving device has to keep up with the network, the network must keep pace with a moving device for better connectivity.

5G will require one or more of the above of the above mentioned technologies to be executed to be successfully implemented. Of the ones discussed Massive MIMO, mmWave and efficient use of spectrum seem to be the most important approaches. However, even these approaches are a long way from being proven to be successful in wide implementations. Hence, a successful implementation of 5G will require concerted effort by the scientific community from a technological standpoint, the industry from an investment standpoint and the government from a regulatory standpoint.

A summary of which of the above described technologies address the consumer needs from the survey is provided in the below table.
<table>
<thead>
<tr>
<th>Key Consumer Requirements</th>
<th>Technology that addresses the requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network coverage</td>
<td>Efficient Spectrum Usage, Simultaneous Transmission and Reception, Small Data Transmission, Wireless Backhaul Integration, Flexible Mobility, D2D Communication</td>
</tr>
<tr>
<td>Data speed</td>
<td>Massive MIMO, Network Slices, Moving Networks, Multi-RAT Integration</td>
</tr>
<tr>
<td>Call Quality</td>
<td>Mm Wave, Moving Networks, Multi-RAT Integration</td>
</tr>
</tbody>
</table>

Table 2: Potential 5G Technologies that address consumer requirements

8.6 Cost of 5G\textsuperscript{18} & \textsuperscript{19}

5G will be a paradigm shift in mobile wireless technology. This means it will be more challenging to estimate the cost outlay that will be needed. As indicated in the prior sections, there are many technological approaches to developing the 5G network and all of those approaches need significant investment. By some estimates $100 billion will be spent over the next 10 years in the US alone to upgrade the existing 4G infrastructure and build new infrastructure for 5G. That $100 billion will be almost equally split between the upgrades for 4G and new infrastructure for 5G with the new infrastructure holding a slight edge. The new infrastructure costs will primarily include RAN upgrades, creation of small cell sites and data centers. The upgrades to 4G will include new antennas and radios at
existing cell tower sites, activation of more network fibers that will be built by that time and upgrades to existing data centers. It is also expected that the mobile service providers will pay for these costly investments. This will be significant at a time when these providers have not yet completely deployed LTE yet in the US. Additionally, for the mobile service providers to invest such a huge amount of money, there needs to be an economic case. Expecting consumers to pay more for ultra-high speed video will not work as is evident from the competitive pricing war going on between mobile service providers.

The question is how does this cost translate into price for consumers. The average mobile phone bill has increased from ~$50 just before smartphones were widely introduced to ~$75 now. By the end of this decade, it is expected to grow to ~$120. This monthly bill should have increased at a faster clip if the rates per data bytes had stayed constant because there has been a massive increase in data usage. What has kept the average monthly bill manageable is that mobile service providers have reduced their rates per data bytes. This is not to say that the bill hasn’t increased, it has but not as much as it would have if the mobile service providers had kept the rates per data bytes constant. It has been indicated that for consumers to hold their current average monthly bill and yet take advantage of 5G, the rate per data byte needs to be reduced a 1000 times. This in itself will be the most significant challenge for a faster adoption of 5G. Hence, the estimates are that there will continue be isolated roll-outs of 5G with a wide roll-out taking at least till mid to late of the next decade at the minimum.
Since 5G is a next generation technology, regulatory standards are critical to ensure seamless working. Standards are needed on the 5G network and the radio interfaces and for the specific applications in every industry.

The Federal Communications Commission in the USA has begun to create a regulatory framework for 5G that will enable greater use of higher band spectrum. But European Telecommunications Standards Institute (ETSI) is slightly ahead with a worldwide initiative to the use the V band (57-66 GHz), E band (71-76 and 81-86 GHz) and higher frequency bands up to 300 GHz. The digital single market (DSM) initiative in Europe calls for the right regulatory environment to be created for 5G. The focus is to make national regulatory authorities to think in terms of incentivizing industry participants to invest in connectivity and innovation rather than just focusing on lower prices for consumers. This means fewer and simpler rules, flexibility through risk sharing agreements between industry participants to reduce burden and adequate spectrum licensed in time at reasonable prices.

While efforts are underway in the US and Europe to develop a worldwide initiative to create a regulatory framework in which 5G can develop and thrive, a lot more discussions and meetings need to happen between the government and the industry to finalize a framework. Apart from the regulatory framework, the standards bodies such as 3GPP, IEEE and ITU-T/ITU-R also have timetables to develop standards for 5G before 2020 in order for a successful commercial application.
8.8 Author’s perspective and conclusions on Phase two (5G)

In phase two of this study, the need and demand for 5G were analyzed, then the technologies that can help 5G become a reality were discussed and finally the cost and regulatory factors were analyzed. From this analysis, it is clear that the need for a next generation wireless mobile technology is definitely there, if not now but in the next decade with the burst of wireless and mobile use globally. It is not just the volume of general wireless and mobile use that will drive the demand, it is also the wide variety of applications such as increased streaming video use, applications such as driverless cars, smart cities, smart grids, smart homes, industrial automation etc. In order to meet this demand, there is a need for a faster, wider and more powerful next generation wireless mobile technology such as 5G. The industry is working on multiple technologies to make 5G a reality. Of the multiple technologies that were discussed, Massive MIMO, MmWave and efficient spectrum use were the three key ones that are more prominent and will improve network coverage, latency and speed. Significant investments will be required by telecommunication providers to implement these technologies. This will mean that 5G like with any other new technology will be expensive for the consumers to start with but will become reasonably priced over time. Finally, 5G’s successful implementation is dependent on developing global regulatory frameworks and standards. Various governments and standards authorities have developed a timetable for 5G regulatory frameworks and if they stick to those timelines, 5G’s first commercial roll-out might occur in the early part of the next decade.
9. Conclusion

From the Phase one survey results, we can see that current smartphone users are fairly satisfied with their mobile service providers. But there does seem to be a marginal room for improvement. Despite being fairly satisfied, more than half report the lack of network coverage at all places and ~40 percent report slow data speeds. Lack of call clarity, call drops and communication delays are also reported but to a smaller extent. But when specifically asked what improvements they seek from a next generation mobile technology, ~3/4ths suggested improved data speeds, smarter internet and bandwidth for all the devices they use. A majority also sought improvements on communication delay, call clarity, call dropping and coverage. These numbers indicate that while the need for improvement is marginal today, it is bound to become stronger as consumers start realizing that today’s 4G network cannot keep up with their increasing demands. While the immediate drive for 5G from a consumer standpoint might be nascent today, like with all technological revolutions, it is the industry that has to think forward. Consumers in many instances in the past have only been able to communicate their needs, it is the duty of the telecommunication industry to crystallize these needs into a technology that will satisfy their current and future demands.

Based on the findings from Phase two, it is clear that there are a wide variety of futuristic applications that will be made possible with the advent of 5G. Those applications go beyond satisfying the needs of an average smartphone user to a larger number of commercial applications. Ultimately, all these commercial applications such self-driving cars, smart homes, remote patient services, smart grids etc. will in some way or the other
end up benefiting the consumer. But for an average consumer, the greatest immediate benefits they will see will still be in applications that are more apparent such as data speeds, call clarity, lack of communication delays etc. Overall, consumers will perceive a faster, smarter and all-time connected mobile and wireless technology. While 5G might not be a necessity today, it will be one in the not very distant future as demands from consumers and industry balloons to a level where the current 4G LTE technology just cannot satisfy it any longer.

But implementing 5G on a wide scale is not going to be easy. It will require significant investment by the industry and a consistent standard by the regulators. The various technological approaches which are experimental at this point will also need to be proven in wider implementations. While efforts are already on to target localized deployments by the end of this decade, a full-fledged active roll-out is not expected till at least till 2025. Various technologies are being explored and smarter ways to use spectrum are being devised to successfully implement 5G. With a concerted and unified effort from the industry and countries, it is hoped that 5G will emerge as a paradigm shift that will be well placed to satisfy the ever growing needs of the consumer at an affordable price.
10. **Recommendations For Additional Research**

As a follow-up to this research, additional research is recommended to better understand this space. A few suggestions are as below -

- Research to understand what's the optimal price consumers will be willing to pay for the improvements with 5G

- Research on every technological approach to 5G in detail i.e. each student takes one technological approach and delves in detail

- Once 5G is commercially rolled out, research needs to be conducted to understand customer satisfaction and compare that with 4G
  
  o Objective will be to understand if an ordinary consumer can perceive the differences

- Research to understand if with 5G we have reached the maximum possible improvements that could be obtained from a mobile technology standpoint


References


Computer Applications in Industry and Engineering. Retrieved from
https://scholarworks.bridgeport.edu/xmlui/bitstream/handle/123456789/1459/Cost
%20Analysis%20of%205th%20Generation%20Technology.pdf?sequence=1

http://money.cnn.com/2015/05/18/technology/5g-cost-wireless-data/


Retrieved from http://www.wsj.com/articles/fcc-proposes-rules-for-5g-network-
1445533829

http://telecoms.com/wp-
content/blogs.dir/1/files/2016/07/5GManifestofortimelydeploymentof5GinEurope.pdf
Appendix

A. Survey Questionnaire

I, Deepa Ramkrishna, am a graduate student enrolled in the Masters program in Telecommunications at SUNY Polytechnic Institute, Utica, NY. As part of the requirements of this program, I am pursuing a thesis related to a Telecommunications topic of my interest.

My thesis is about understanding what affects how a person selects a mobile service provider and understand if the next generation 5G technology will improve upon those factors.

As part of this research I am conducting a short survey on what might be important to you in choosing your mobile service provider.

This survey should take no more than 5 minutes.

You are requested to complete this survey in 1 sitting. Your participation in this survey is voluntary and can stop at any point of time. The individual answers to the survey will be kept confidential.

It will be very helpful if you can complete this survey by March 15, 2016.

Thanks for your participation.

______________________________

Q01. Please specify the university at which you completed your most recent degree.

______________________________

______________________________

Q02. Please identify the type of your most recent degree.

(Please select one answer)

[1] Bachelors
[3] Doctorate
[4] Other (Please specify___________)

______________________________

Q03. Please indicate the area of focus of your most recent degree.
(Please select all that apply)

[1] Telecommunications  
[2] Computer Science  
[5] Other (Please specify__________)

Q04. Please indicate your year of graduation for your Bachelor’s degree (for current students - expected year of graduation).

(Please select one answer)

[1] Before 2010  
[2] 2010  
[9] 2017  
[10] After 2017

Q05. Please rank the top 5 among the following features of your smartphone depending upon how important they are to you.

Assign a rank of 1 to the most important feature, rank of 2 to the second most important feature and so on.

1. Social media (i.e. Facebook, Instagram, LinkedIn etc.)
2. Messaging (i.e. SMS/MMS)
3. Email
4. Call
5. Reading news (i.e. using news apps)
6. Web browsing
7. Watching videos (i.e. YouTube, Netflix etc.)
8. Take pictures
9. Play games
10. Video chat
11. Use other standalone applications (apps)
12. Shopping (Amazon, eBay or any other store apps etc.)
13. Watch the time and set alarms
14. Schedule and review meetings on the calendar
15. Mobile wallet to pay for items at stores (Apple Pay, Android Pay etc.)
16. Other 1 (Please specify___________)
17. Other 2 (Please specify___________)
18. Other 3 (Please specify___________)

Q06. Which of the following companies is your smartphone's mobile service provider?
(Please select one answer)
[1] AT&T
[2] Sprint
[4] Verizon
[5] Other (Please specify___________)

Q07. Please choose an option from the below list that best describes your participation with respect to choosing your smartphone's mobile service provider.
(Please select one answer)
[1] I personally evaluated the options and chose the mobile service provider
[2] I was not responsible for evaluating the mobile service providers but made the final choice
[3] I was responsible for evaluating the mobile service providers but did not make the final choice (someone else made the final decision)
[4] I was not involved in either evaluating or choosing the mobile service provider

Q08. How satisfied are you with your current mobile service provider?

<table>
<thead>
<tr>
<th></th>
<th>1= Very Dissatisfied</th>
<th>2= Dissatisfied</th>
<th>3= Neither Satisfied nor Dissatisfied</th>
<th>4= Satisfied</th>
<th>5= Very Satisfied</th>
</tr>
</thead>
</table>

94
Q09. How likely are you to recommend your current mobile service provider to your family/friends?

<table>
<thead>
<tr>
<th>1= Very Unlikely</th>
<th>2= Somewhat Unlikely</th>
<th>3= Neither Unlikely nor Likely</th>
<th>4= Somewhat Likely</th>
<th>5= Very Likely</th>
</tr>
</thead>
</table>

Q10. Please indicate how important the following factors are in your choice of a mobile service provider.

<table>
<thead>
<tr>
<th>1= Not at all important</th>
<th>2= Somewhat Unimportant</th>
<th>3= Neither Unimportant nor Important</th>
<th>4= Somewhat Important</th>
<th>5= Very Important</th>
</tr>
</thead>
</table>

1. Data speed 
2. Call quality 
3. Network coverage 
4. Data plan (includes price) 
5. Brand 
6. Whether the phone you want is available with the service provider's plan 
7. Customer service 
8. Recommendation by friends and family 
9. Availability of a store near my home 
10. Promotions (i.e. deals etc.) 
11. Other (Please specify______________)

Q11. Please think about the challenges or issues that you face with your current service provider. Rank the below issues/challenges based on how critical they are.

Assign a rank of 1 to the most critical issue, rank of 2 to the second most critical issue and so on.

1. Slow data speed 
2. Call dropping 
3. Lack of network coverage at all places
4. Lack of call clarity even in locations with signal
5. Mobile/wireless technologies are inadequate to facilitate use of all apps
6. Communication delay (while using Skype or calling etc.)
7. Other (Please specify___________)

Q12. Please continue to think about the factors that influence your choice of a mobile service provider. Kindly rank the top 5 based on how important they are to you.

Assign a rank of 1 to the most important factor, rank of 2 to the second most important factor and so on.

1. Data speed
2. Call quality
3. Network coverage
4. Data plan (includes price)
5. Brand
6. Whether the phone you want is available with the service provider's plan
7. Customer service
8. Recommendation by friends and family
9. Availability of a store near my home
10. Promotions (i.e. deals etc.)
11. Other (Please specify___________)

Q13. Please rate the performance of your current service provider on the following factors.

<table>
<thead>
<tr>
<th>1= Very poor performance</th>
<th>2= Somewhat poor performance</th>
<th>3=Neither poor nor good performance</th>
<th>4= Somewhat good performance</th>
<th>5= Very good performance</th>
</tr>
</thead>
</table>

1. Data speed
2. Call quality
3. Network coverage
4. Data plan (includes price)
5. Brand
6. Whether the phone you want is available with the service provider's plan
7. Customer service
8. Recommendation by friends and family
9. Availability of a store near my home
10. Other (Please specify___________)

Q14. Please indicate your level of familiarity with the concept of next generation mobile technology “5G”?

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Not at all familiar</td>
<td>Not very familiar</td>
<td>Somewhat familiar</td>
<td>Moderately familiar</td>
<td>Very familiar</td>
</tr>
</tbody>
</table>

Q15. How much of an improvement do you think 5G will be over current mobile technologies out there in the market today?

| 1 = No improvement | 2 | 3 | 4 | 5 = Significant improvement |

Q16. How much of an improvement do you expect from 5G on the below items?

<table>
<thead>
<tr>
<th>Data speed</th>
<th>1 = No improvement</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5 = Significant improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
<td>------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Call dropping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network coverage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication clarity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latency/Communication delay</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spectrum usage</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smarter internet (i.e. when person is streaming, 5G will provider even faster speeds etc.)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bandwidth to accommodate multiple devices connected to the internet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Thank you for participating in this survey.
B. Letter for SUNY Poly IRB Approval

Dear Dr. Thistleton (IRB Chair),

I am a graduate student enrolled in the Masters program in Telecommunications at SUNY Polytechnic Institute, Utica, NY. As part of the requirements of this program, I am pursuing a thesis related to Telecommunications. My thesis is about determining the factors that influence choice of mobile service providers among young and educated students and alumni (who use smart phones and are aware of mobile technologies) and how the next generation fifth generation (5G) technology will address those factors.

I am conducting a survey among students and alums belonging to the Telecommunications, Network and Computer Securities, Electrical Engineering and Computer Science disciplines. All responses will be kept confidential and will be analyzed only in aggregate. The identity of the respondents will also be kept confidential.

I seek permission to conduct this survey at the earliest as this is an integral part of my thesis.

If you have any questions or comments, please feel free to contact me.

Regards,

Deepa Ramkrishna

2035 Finch Drive,
Bensalem, PA - 19020
Contact No. 1-214-872-0649
Email: ramkrid1@sunyit.edu

Feb 1, 2016
C. Application for SUNY Poly IRB Approval

Research may be exempt from IRB review if the activities involve no more than minimal risk, and the only involvement of human subjects falls within one or more of the exemption categories listed below. Research that does not fulfill the ethical principles of the Belmont Report will not be considered exempt.

1. **Respect for persons** – Individuals should be treated as autonomous agents, and persons with diminished autonomy are entitled to protection.
2. **Beneficence** – Minimize risk and maximize benefit.
3. **Justice** – Risks and benefits of research must be distributed fairly.

*Use this form to identify the category of research which may qualify for exempt status. Submit the completed form electronically to irb@sunyit.edu. Scan, fax (315-792-7278), or submit a paper copy of the required signatures to Deborah Tyksinski, Rm B234 Kunsela Hall.*

**NOTE:** The following research cannot be exempt:

- Research involving prisoners
- Research involving survey or interview of children
- Research involving the observation of public behavior of children unless the investigators do not participate in the activities being observed.

**Instructions:** Please complete the information in sections A, B and C below.

**Section A**
**Principal Investigator Name** - Deepa Ramkrishna

Principal Investigator Signature________________________________________________________

**Student Researcher Name** - Deepa Ramkrishna

Student Researcher Signature__________________________________________________________

**Student Faculty Advisor Name** - Dr. Larry Hash

Student Faculty Advisor Signature______________________________________________________

**Title of Research Project** - What do customers really seek from their mobile service providers?

For IRB Use Only

☐ **Accepted, Exempt Category**  Click here to enter text.

☐ **Denied, Reason**  Click here to enter text.

1st Reviewer Signature_________________________ Date________________________

2nd Reviewer Signature_________________________ Date________________________
To be eligible for exemption, **ALL** of the research activities for the project must fit into one or more of the six categories listed below.

*Indicate by checkmark which of the following categories describes the research project:*

□ 1. Research conducted in established or commonly accepted educational settings, involving normal educational practices, such as
   - Research on regular or special educational instruction strategies, or
   - Research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods (45CFR46.101(b)(1))

X 2. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement) survey procedures, interview procedures or observation of public behavior, unless
   - Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; AND
   - Any disclosure of the human subjects responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects’ financial standing, employability, or reputation. (45CFR46.101(b)(2))

□ 3. Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph 46.101(b)(2) if:
   - The human subjects are elected or appointed public officials or candidates for public office; or
   - Federal statutes require without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter. (45CFR46.101(b)(3))

X 4. Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available or if the information is recorded by the investigator in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. (45CFR46.101(b)(4))

*Explanatory Note (OHRP Guidance Sheet): The following criteria must exist:*
   - A. Data must exist PRIOR to research proposed to IRB for determination.
   - B. There can be NO direct or indirect identifiers (demographic information).

□ 5. Research and demonstration projects which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine
   - Public benefit or service programs
   - Procedures for obtaining benefits or services under those programs
   - Possible changes in or alternatives to those programs or procedures; or
   - Possible changes in methods or levels of payment for benefits or services under those programs. (45CFR46.101(b)(5))
**Definition:** Department or Agency head means the head of any federal department or agency; or any other office or employee of any department or agency to whom authority has been delegated.

**Explanatory Notes** (OHRP Guidance): The following criteria must be satisfied to be exempt:

A. The program under study must deliver a public benefit (financial or medical benefits as provided under the Social Security Act) or service (social, supportive, or nutrition as provided under the Older Americans Act).

B. The research/demonstration project must be conducted pursuant to specific federal statutory Authority.

C. There must be no statutory requirement that the project be reviewed by an IRB.

D. The project must not involve significant physical invasion or intrusions upon the privacy of participants.

E. The funding agency must concur with the exemption.

☐ 6. Taste and food quality evaluation and consumer acceptance studies,

   - If wholesome foods without additives are consumed or
   - If a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the Food and Drug Administration or approved by the Environmental Protection Agency or the Food Safety and Inspection Services of the US Department of Agriculture. (45CFR46.101(b)(6)

**Section C**

1. Please describe the nature of the research project. Include a sufficient level of detail so that the IRB may make a determination about the nature of the interaction with human subjects. Please be specific about which of the above criteria you are applying to your research activities in order that the SUNYIT IRB may make a determination that the research is exempt.

The topic of my thesis is "What do customers really seek from their mobile service providers?". The thesis will have 2 phases. As part of Phase 1, I plan to conduct a 5 minute online survey among undergraduate and graduate students belonging to the Network & Computer Securities (NCS), Computer Science and Telecommunications fields to understand from them the factors that drive their choice of a mobile service provider. This will fall under category 2 of the prior page as I will be conducting a survey but will not be capturing any identifiable information. Phase 2 will employ secondary research to understand how the next generation 5G mobile technology will improve upon the key factors obtained in the survey. This will fall under category 4 of the prior page whereby I will be collecting information from publicly available secondary sources.

2. Describe the subject population, such as number to be enrolled, age range, gender, ethnic background and health status. Include how the population will be recruited. Identify inclusion and exclusion criteria.

The population for this survey will include - Young and educated students and alumni (grads and undergrads) from multiple universities with knowledge of mobile technologies, Pursuing or have completed a graduate degree in Telecommunications, Network and Computer Securities and Computer Science, Own and use mobile smart phones with 4G technology, Are aware of the service provider they are currently using for their mobile phone, Are involved in the decision of determining their mobile phone service providers (such as Verizon, AT&T, T-Mobile, Sprint, MetroPCS, Virgin Mobile, Boost Mobile, US Cellular etc.). The survey does not include using carrier services for tablets or notebooks, kindle etc. An enhanced version of Survey Monkey or
Survey Gizmo will be used to develop the survey. Snowball technique will be used to roll out the survey through social media and friends.

3. Describe any potential risks – physical, psychological, social, legal or other risks. 
   **There are no physical, psychological, social, legal or other risks to conducting this study.**

4. Provide a description of how information acquired during your project will be managed and how confidentiality will be safeguarded. 
   **At no point during the survey will I be collecting any identifiable or demographic information about any respondent. All data will be collected through an online survey and will be analyzed in aggregate.**

5. If a survey is to be used, please provide a copy of the survey instrument. 
   **The survey document titled ”DeepaRamkrishna_ThesisSurvey_Jan282016” is attached with the email to HRB.**
D. Invitation to take the survey

Hi,

Hope you are doing well.

I am Deepa Ramkrishna and am currently pursuing a Masters in Telecommunication technology at SUNY Poly. I am working on my thesis, the key objective of which is to understand what drives mobile service provider choice.

As part of my thesis, I have developed a 5 min online survey that I would like you to take. Your answers will be kept confidential and will be analyzed only in aggregate.

I need a lot of people to take my survey to obtain enough data to analyze accurately. Hence, your time and opinion are very valuable to me and will go a long way in helping me collect the data and complete my thesis on time.


It will be very helpful if you can complete this survey by April 5, 2016. I also request you to please forward this email to "at least 2 of your friends" from either SUNY Poly or other universities so that I can improve my chances of getting more data.

Thanks a lot for your time and help.

Regards,

Deepa
E. Curriculum Vitae

Deepa Ramkrishna
Born in Mumbai, India on 27th October 1988
Address: 3108 Wildwood Court, Monmouth Junction, NJ -08852
Mobile: (214) 872 0679, E-mail: ramkrid1@sunyit.edu
LinkedIn Profile https://www.linkedin.com/pub/deepa-ramkrishna/1b/21a/b59

EDUCATION
Masters in Telecom, State University Of New York (SUNY) Polytechnic Institute, Utica, NY
Currently Enrolled - Expected Graduation Dec 2016, Scholarship Recipient
Pursuing a thesis on ‘What do customers really seek from their mobile service providers?’

B.E. in Electronics and Telecommunication Engineering, Atharva College of Engineering, Mumbai; August 2006 to May 2010

PROFESSIONAL EXPERIENCE
✓ Designed and implemented cutting-edge solutions to improve and enhance the Polaris software
✓ Authored Test Cases and Test Plans, executed test suites and analysed test results
✓ Defined test details, executed using Manual testing and where applicable implement automation
✓ Worked with onshore and offshore teams to conduct the above tasks

HRMantra Pvt Ltd. - Project Executive – June 2012 - Nov 2013, Mumbai, India (hrmantra.com)
✓ Client liaison for projects that involved implementation and support for the HRMS ERP (i.e. Entire Software Development Lifecycle (SDLC))
✓ Requirement capturing from clients to implement the HRMantra application
✓ Implementing the HRMantra application for various clients as per their requirements
✓ Maintenance of the implemented software
✓ Quality control of HRMantra application
✓ Troubleshooting and providing technical support on HRMantra application

Tech Mahindra - Technical Associate – Mar 2011 – May 2011, Mumbai, India (techmahindra.com)
✓ Provided technical support to IT Infrastructure Client and other Enterprise applications

SUNY Polytechnic Institute - Graduate Assistant - Aug 2010 – Dec 2010, Utica, NY
✓ Assisted Telecommunication faculty members in the development of new material for their courses, reading papers and grading student assignments, supplementing faculty instruction by facilitating a discussion session or tutorial, assisting with classroom supervision, preparing answer keys and notes

OTHER ACTIVITIES
Academic Activities (Atharva College of Engineering, Mumbai)
✓ Developed a pilot vehicle tracking system using GSM technology that offered effective real-time location monitoring, mapping and reporting via a mobile phone
✓ Certified for volunteering in inter-collegiate technical festival Techithon ’07