IMPACT ASSESSMENT OF INTRODUCING 4G TECHNOLOGY FOR WIRELESS COMMUNICATION IN BANGLADESH

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Impact Assessment of Introducing 4G Technology for Wireless Communication in Bangladesh

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Certificate of Approval

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I hereby declared that this thesis or any part of it has not been submitted elsewhere for award of any degree or diploma.

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Abstract

New era of wireless communication is upon us. The approaching 4G (fourth generation) mobile communication systems are projected to handle higher data rates and mobile internet for rich media collaboration allowing faster and more reliable connectivity. Bangladesh telecommunication sector already entered into the 3G mobile data wave and its immediate sequence is 4G.

This study is designed for the analysis of the technological preferences for selecting the Fourth Generation (4G) wireless communication technology in Bangladesh. An empirical analysis and relevant ranking is performed using Analytical Hierarchical Process (AHP) model rather than finding the causal relationship among the variables. A Technology Assessment (TA) on Fourth Generation (4G) telecommunication technology is presented here in terms of its appropriateness in Bangladesh considering quality, cost effectiveness, social value, environmental and economic impact.

With the study of technology assessment tools and techniques, it is presented that experts and general users preferred Fourth Generation (4G) wireless communication technology as the most appropriate technology for wireless communication technology in Bangladesh among existing and upcoming technologies. Thesis subsequently relates with the study of Cost Benefit and Scenario Based Analysis that 4G network is cost effective andits power consumption reduction in wireless communication network being environmental sustainable and friendly. Based on that result from the evaluation we determine that 4G can satisfy the upcoming multi-dimensional data and internet demand, making 4G as appropriate for wireless communication in Bangladesh.

Contents

List of Figures

List of Tables

Terminology

2G	Second Generation
3G	Third Generation
3GPP	Third Generation Partnership Project
4G	Fourth Generation
AHP	Analytical Hierarchy Process
AHP-OS	Analytical Hierarchy Process-Online Software
AMPS	Advance Mobile Phone System
AMTOB	Association of Mobile Phone Operators in Bangladesh
ARO	Application Resource Optimizer
ARIB	Association of Radio Industries and Businesses
ATSI	Alliance for Telecommunication Industry Solutions
BSS	Base-Station Subsystem
BTRC	Bangladesh Telecommunication Regulatory Commission
CBA	Cost-Benefit Analysis
CIA	Cross Impact Analysis
CI	Consistency Index
CR	Consistency Ratio
CCSA	China Communications Standards Association
CDMA	Code Division Multiple Access
CSD	Circuit-Switched Data
CSV	Comma Separated Value
DL	Download
DT	Delphi Technique
EDGE	Enhanced Data rates for GSM Evolution
ETSI	European Telecommunications Standards Institute
EUL	Enhanced Uplink
FDD	Time Division Duplex
FDMA	Frequency Division Multiple Access

FHDM	Fuzzy Hierarchical Decision Making
GIM	General Intuitive Method
GPRS	General Packet Radio System
GSM	Global System for Mobile Communications
HSCSD	High Speed Circuit-Switched Data
HSPA	High-Speed Packet Access
HSDPA	High-Speed Downlink Packet Access
HSUPA	High-Speed Uplink Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IP	Internet Protocol
IPv6	Internet Protocol Version 6
ITU	International Telecommunication Union
LAN	Local Area Network
LTE	Long Term Evolution
M2M	Machine to Machine
MCDM	Multi-Criteria Decision Making
MP3	Music Player 3
MS	Mobile Station
NAT	Network Address Translation
NMT	Nordic Mobile Telephone
NSS	Network and Switching Subsystem
OPEX	Operational Expenditure
OSS	Operation and Support Subsystem
PDA	Personal Digital Assistant
QAM	Quadrature Amplitude Modulation
RI	Random Index
RT	Relevance Tree
SMS	Short Message Service
TA	Technology Assessment
TDD	Time Division Duplex

TDMA	Time Division Multiple Access
TTA	Telecommunications Technology Association
TTC	Telecommunication Technology Committee
TTI	Transmission Time Interval
UE	User Equipment
UL	Upload
UMTS	Universal Mobile Telecommunication Services
UTRA	Universal Terrestrial Radio Access
UTRAN	Universal Terrestrial Radio Access Network
VAS	Value Added Service
WAN	Wireless Area Network
WCDMA	Wideband Code Division Multiple Access
Wi-Fi	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

Introduction

Chapter 1

1.1 Problem Statement

The fourth generation of mobile technology - known as 4G and also referred to as Long Term Evolution (LTE) - is the next step in the evolution of mobile network convergence technology which is the efficient coexistence of multimedia, voice and data communication within a single network [1-3]. 4G technology is usually described by the term MAGIC—Mobile multimedia, anytime anywhere, Global mobility support, integrated wireless solution, and customized personal service. This advanced technology is built specifically to handle higher data rates and mobile internet for rich media collaboration allowing faster and more reliable connectivity. As a promise for the future, 4G systems have been attracting much interest in the mobile communication arena. 3.9G technology has been launched in Bangladesh and its immediate advanced technology is 4G. As this technology is completely new in Bangladesh, its full-fledge assessment yet not done with any technology management as well as technology assessment process. It was felt the impact assessment of 4G technology is required considering different broad aspect of cost factors, ripple effects and telecommunication requirement.

Developing nations like Bangladesh where the demand for mobile internet, data and VAS are rapidly increasing by the service delivery across the area of m-banking, m-healthcare, m-educating, m-agriculture, e-transaction, e-commerce, e-billing, e-governance etc. [4-5]. Telecom sector in Bangladesh has seen exponential growth in mobile penetration that has exceeded all expectations with over 111 million subscribers and over 36 million internet subscribers at the end of year 2013 [6-7]. The rapid growth in mobile telephony has undoubtedly a transformative impact on the economy in terms of aggregate investment, foreign direct investment, tax revenue and catalytic effect on increasing the quality of life of tens of millions of people [8]. In order to meet this multi-dimensional demand, 4G could be a best possible technology which will bring super-high-speed connectivity for the first time in Bangladesh and help to compete on a global scale. Hence choosing an appropriate telecommunication technology with reliable quality of service as well as cost effective wireless communication is still a challenge for developing countries like Bangladesh. Thus a proper technology assessment on fourth generation telecommunication technology is required to predict different context of wireless communication in Bangladesh.

1.2 Objective

(i) The primary objective of this study is to apply Analytical Hierarchy Process (AHP) as a Multi-Criteria Decision Making (MCDM) Technology Assessment (TA) tool for proper selection of appropriate telecommunication technology.

(ii) Specific objective of this study is to analyze the data based on expert opinion from academy and industry for 4G technology impact analysis.

(iii) To formulate some recommendations and develop a set of indicators in relation to present telecommunication technologies and appropriateness of 4G technology for Bangladesh scenario.

(iv) The outcome of this research is a technology assessment of the wireless communication systems in Bangladesh for the purpose of selecting appropriateness of 4G telecommunication technology with the aid of some technology assessment tools and techniques.

1.3 Outline of Methodology

(i) In this study, data available from Bangladesh Telecommunication Regulatory Commission (BTRC) will be considered as the primary source of data for telecommunication technology in Bangladesh.

(ii) The secondary data will be taken through the internet, books, journals, related studies and other sources of information.

(iii) Based on the above study structured questionnaires will be prepared by the ways of interviews and interactions of relevant experts, observation and document review by following the principles of different tools and strategies of TA.

(iv) An expert opinion will be conducted as a General Intuitive Method (GIM) of TA. This intuition-based methodology of TA will be done by a participatory method by involving expert, academician etc. of the relevant field.

(v) A Relevance Tree (RT) will be developed to depict linkages between the effects and the chain effects that would emerge with the introduction of each telecommunication technology.

(vi) Analytical Hierarchy Process (AHP) analysis will be conducted as a Multi Criteria Decision Making (MCDM) tool, for technology assessment and appropriateness of 4G technology selection for wireless communication system.

(vii) Next a cost-benefit analysis (CBA) and will be performed to evaluate the economic features of different telecommunication technology of wireless communication.

(viii) A scenario based analysis will be presented to evaluate the environmental features of different telecommunication technology of wireless communication.

(ix) Final analysis will facilitate in formulation of an appropriate telecommunication technology strategies for choosing the appropriateness of 4G technology for wireless communication system in Bangladesh.

1.4 Thesis Outline

The thesis is organized in five chapters. The first chapter is Introduction to the thesis work conducted. The second chapter contains Technical background, Features of 4G and related works which act as basis for understanding the thesis. The third chapter describes Research questions, Experimental methodology and Experimental setup. The fourth chapter presents result generated by answering the research questions and data analysis. The fifth chapter provides conclusion to work carried out and gives an outline for future work.

1.5 Contribution of the Thesis

Telecommunication service helps improve the functioning of the market, reduce transaction costs and increase productivity through better management in public and private sector. These issues are more acute in developing economies like Bangladesh than developed economies. According to World Bank analysis of 120 countries, for every 10 percent point increase in the penetration of mobile phones, there is an increase in economic growth of 0.81 percentage points in developing countries, versus 0.6 percentage points in developed countries [9]. In 2008 study, Deloitte estimated that in aggregate, including direct and indirect employment, more than 1, 11,790 jobs have been created by the industry to date. The largest category of employment relates to retailers who sell airtime, SIMs and handsets [10].

Bangladesh has just entered into the mobile data wave, although 3G operation is delayed with regulatory issue. Operators are implementing desired network infrastructure phase by phase. The main drivers for increased activity on the mobile devices are three-fold; better networks in the form of 3G and sequentially 4G (and future upgrades of 4G+), higher processing power devices being available for mass-market prices and fact that consumers are not only consuming but also producing content at an exponential pace.

It is felt that the opportunity for telecom sector is convergence which, as a theme has a profound effect on telecoms markets. Telecoms sector has an opportunity to diversify revenues into new areas such as content development for data and VAS, even in the sectors of enterprises and corporate. With the arrival of 4G with faster data network will be a bigger potential source of revenue giving sector with significant impact on economy of Bangladesh as well. This advance technology has built for the purpose of handling higher data rates, enhance media collaboration and can fulfill the future data demand which increasing with technological advancement of wireless communication [11-14]. In the context of delivering a Digital Bangladesh, ensuring a 4G network and infrastructure for fast and broader data availability through all over the country could be the coming technological future need.

In this context research carried out to contribute and find the answer which telecommunication technologies will be appropriate for Bangladesh amongst existing and coming advanced telecommunication technology. Thus research conducted and contributed as a technology assessment for wireless communication technologies and their appropriateness.

Brief Background of Wireless Communication

Chapter 2

2.1 Literature Review

A worldwide telecommunications service industry for the past several years has grown tremendously by the combination of telecommunications deregulation, an exponential increase in IP services, and mobile services. In consequence of unexpected demand for network infrastructure, telecommunications equipment manufacturers also enjoyed sales and revenue growth. The growth of next telecommunications industry will be accelerated by many telecom services converged with others, new network architecture, technology and requirements evolved, and the demand for next generation telecommunication technology surged.

One strand focuses that the service quality of telecom operators helped to create competitive advantage by being an effective differentiating factors. Different service quality factors of telecom operators are essential and important to maintain cost effective and quality services to customers as well as appropriate telecommunication of its surrounding (Leisen and Vance) [15].

According to Anckar and D'Incau, besides voice call and network coverage the value added services (i.e., games, icons, ringtones, messages, web-browsing, SMS coupons, and electronic transaction) provided by telecom operators with different telecommunication technology is beneficial for operator and subscriber [16].

Rahman et al. mentioned some variables as important criteria for selecting telecommunication technologies. These variables are service quality, data rate and security [17]. Shah mentioned customer care service, per call charges, network, tariff schemes, value added service (VAS), billing system, voice clarity as some of important variables that operator should consider while developing their preference for technology choices [18].

This study further categorizes service quality factors into four dimensions, cost factors into three dimensions and effects of other dimension. From the previous studies now we can draw a conclusion in a form of taking variables from these related studies. Since the main objective of this study is to comparative analysis of different telecommunication technologies in terms of cost parameters and reliable quality of services and their effect in surrounding.

2.2 Technology Evolution Path

Wireless telecommunication history can be classified into different generations of network. Each generation has been a giant stride which revolutionized the field of mobile communication. The era of telecommunication started with 1G in 1980 where all the systems where based on analog radio signal technology. Voice was considered to be the main traffic. Various 1G standards defined were Advance Mobile Phone System (AMPS), Nordic Mobile Telephone (NMT), Time Division Multiple Access (TDMA) and Frequency Division Multiple Access (FDMA). In 1990, 1G was replaced by 2G which provided rich set of services such as high voice quality and global mobility based on the digital radio signal technology. Here also voice was considered to be the main traffic. 2G includes standards such as Global System for Mobile Communications (GSM), General Packet Radio System (GPRS). Both 1G and 2G are based on circuit-switched technology for data communication at low speed. 2G was a huge success [19].

2G was followed by 2.5G which is an intermittent between 2G and 3G. It is based on both circuit switched and packet switched technologies providing high data rate with low power consumption. It uses the infrastructure of Global System for Mobile communications (GSM) and Code Division Multiple Access (CDMA) to provide its services.

In the present generation, 2.5G is replaced by 3G which includes standards from 2.5G and also some other technologies such as WiMAX (Worldwide Interoperability for Microwave Access). It is totally based on the packet switching technology providing broad range of high quality services to the end user to meet the demand of high data rate and increasing rate of network users. But 3G was unable to repeat the success story of 2G as it provided only few new features over 2G.

Before 3G was deployed all over the world, the idea of technology beyond 3G started evolving. This idea was beyond the imagination of ordinary mobile user promising “connect anytime, anyhow, anywhere” [20]. This ubiquitous network access will be achieved by seamlessly integrating the available and new networks using a core IP based network layer. This vision is called as the 4thgeneration of communication (4G).

In 1998, a collaboration agreement known as the 3rd Generation Partnership Project (3GPP) was established. 3GPP brings together several telecommunications standards bodies in the USA, Europe, Japan, South Korea and China and currently, 3GPP counts over 400 member companies and institutions. The current organizational partners are the Association of Radio Industries and Businesses (ARIB), the China Communications Standards Association (CCSA), the European Telecommunications Standards Institute (ETSI), the Alliance for Telecommunication Industry Solutions (ATIS), Telecommunications Technology Association (TTA) and the Telecommunication Technology Committee (TTC).The original scope of 3GPP was to produce technical specifications and technical reports for a 3G Mobile System based on evolved GSM core networks and the radio access technologies that they support which included the Universal Terrestrial Radio Access (UTRA) in both Frequency Division Duplex (FDD) and Time Division Duplex (TDD) modes. Later, the scope was revised to take into account the maintenance and development of the Global System for Mobile communication (GSM) technical specifications and technical reports including evolved radio access technologies like General Packet Radio Service (GPRS) and Enhanced Data rates for GSM Evolution (EDGE). Figure 01 shows a timeline for 3GPP technology evolution. In the rest of this chapter, a brief review of the different 3GPP technologies and their enhancements are presented up to and including Long Term Evolution (LTE). In a subsequent part of this thesis, it will be discussing the features of IMT-Advanced and have an opportunity to consider the latest 3GPP technology, LTE, which is deemed to meet and even surpass the requirements for IMT-Advanced as stipulated by International Telecommunication Union (ITU) [21]. Figure 1 showing the wireless technology evolution path with time span.

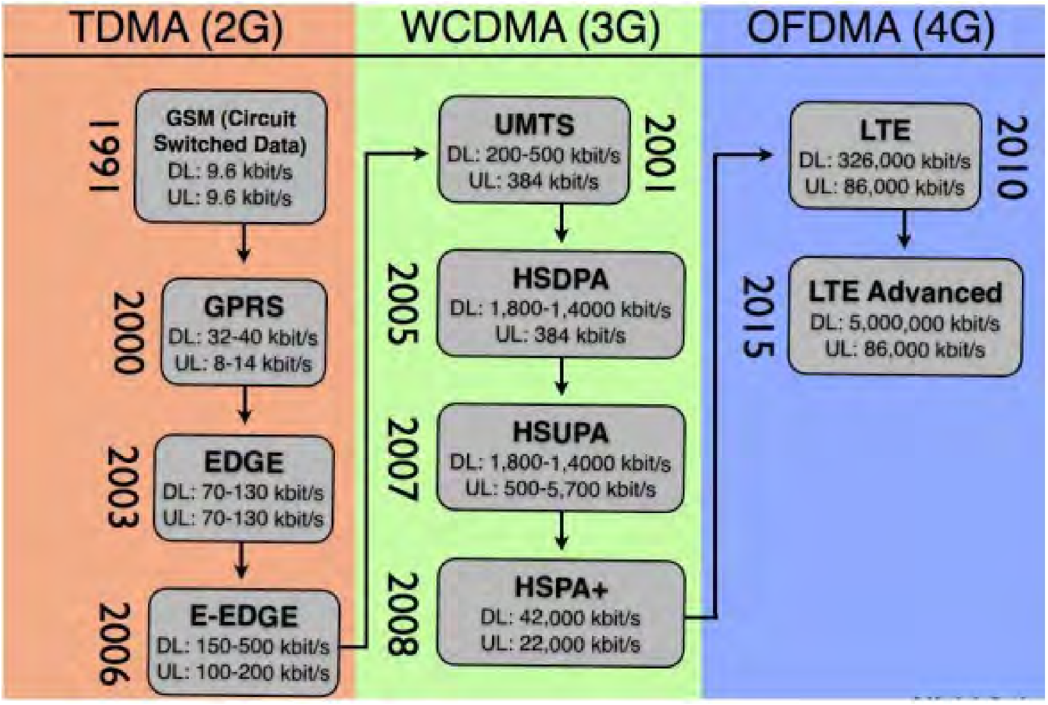

Figure 1: 3GPP technology evolutionary path

2.3 GSM Technology -2G Systems

The GSM system is the most widely used cellular technology in the world today. According to market data supplied by the GSM Association, which promotes GSM worldwide, about 80% of the global mobile market uses this standard. The success enjoyed by the GSM standard was due to a variety of reasons amongst which was the fact that a user had the ability to roam worldwide with the certainty of being able to operate on GSM networks in exactly the same way - provided that billing agreements are in place. The term GSM originally meant Group Special Mobile, but was changed to Global System for Mobile Communications when it became apparent that this technology was being used worldwide. The GSM network architecture as defined in the GSM specifications can be grouped into four main areas, namely: Mobile Station (MS), Base Station Subsystem (BSS), Network and Switching Subsystem (NSS) and the Operation and Support Subsystem (OSS) [22].

2.4 GSM to IMT-2000: The road to 3G Systems

3GPP technologies have evolved from GSM, through EDGE and UMTS-HSPA-HSPA+ to provide increased capacity and user experience, and the evolution will continue in the coming years with further enhancements to HSPA+ and the introduction of LTE and LTE-Advanced. The path from 2nd generation systems to 3G is broad, depending on the starting point. For instance, CDMA-based systems have a very different road to IMT-2000 than their TDMA counterparts. Such systems point to 'CDMA 2000' systems as equivalent to '3G', while for TDMA systems (including GSM), the Ericsson-proposed W-CDMA standard represents attainment of '3G'. It is interesting to note that, CDMA-based carriers believe that their migration path will be more inexpensive than that of GSM/TDMA-based carriers, because many will have only to change channel cards in the base stations and upgrade the network software as opposed to implementing entire network overlays. That notwithstanding, the focus of this section of the thesis remains the path of GSM towards 3G [23].

2.4.1 HSCSD (High-Speed Circuit Switched Data)

HSCSD is an improvement on the Circuit-Switched Data (CSD) capability of the GSM network. GSM encoding techniques provided for 9.6 Kbps (or 14.4 Kbps with improved encoding techniques) maximum CSD speeds. Up to 8 time slots are available per user frequency in the GSM TDMA interface, but these are not always all occupied hence making it possible to extend the CSD into a much faster HSCSD having data rates of up to 38.4 Kbps as a result of increased data throughput. Apart from the use of multiple time slots at the same time to greatly improve data and transfer rates, HSCSD also allowed 8different correction methods to be used for data transfer based on the quality of the radio link. This means that in the best conditions 14.4 Kbps can be put through a single time slot that under CSD would only carry 9.6 Kbps, for a 50% improvement in throughput. Due to the increased charges for the user per connection time, probably as a result of more time slots allocated than normal, HSCSD was considered too expensive. An alternative technology GPRS which will be discussed next, became more attractive due to its comparatively lower pricing based on amount of data transferred rather than duration of connection [24].

2.4.2 GPRS (General Packet Radio Service)

GPRS as the name suggests, is a packet-based and overlay technology which essentially acts as an enhancement to the CSD services discussed earlier as well as in short message rates in the range 56-114 Kbps as well as continuous connection to the internet for phone and PC users. This is made possible by the fact that the GPRS packet-switching technology allows for radio resources to be potentially shared and used only when data is actually being transmitted by users. Several users can be served by a single cell, sharing the same bandwidth due to efficient use the available radio resources. GPRS also uses TDMA as in GSM but will improved the peak time capacity as it can simultaneously direct traffic that was sent using the original CSD through the overlay and at the same time, reduce the SMS Centre and signaling channel loading. This ability of GPRS in combination with the fact that the communication channels are shared between users based on packet needs, will bring down the overall cost for the users [24].

2.4.3 EDGE (Enhanced Data rates for GSM Evolution)

EDGE which is also referred to sometimes as “Enhanced Data rates for Global Evolution” and even “Enhanced GPRS” by some, is a radio-based high-speed mobile data standard which is capable of achieving data transmission speeds of 384 Kbps when using all available 8 time slots. By using EDGE, operators can handle three times more subscribers than GPRS and triple their data rate per subscriber, or add extra capacity to their voice communications. This will only involve the addition of one extra EDGE transceiver unit to each cell. Originally developed for operators who failed to win spectrum for 3G networks, EDGE provides a cost-efficient way of jumping into complete 3G services while at the same time allows legacy GSM operators to offer their users high speed data services comparable to those of UMTS. EDGE uses the same structure as in GSM networks, which allows it to be overlaid directly onto an existing GSM network and is a simple software upgrade for many existing GSM/GPRS networks. The focus here is to improve capacity and efficiency over the air interface by ensuring more data is transferred per time slot with the help of more advanced coding schemes. By efficiently implementing modulation changes that might be required later by UNMT, EDGE can provide an evolutionary migration path from GPRS to UMTS. The main idea behind EDGE was to squeeze out even higher data rates on the 200 kHz GSM radio carrier, by changing the type of modulation used, whilst still working with circuit-and packet-switched approaches [24]. EDGE was deployed on GSM networks beginning in 2003.

2.5 IMT-2000 Technology – 3G Systems

The concept of IMT-2000 (International Mobile Telecommunications) was discussed in the mid-1980s followed by several years of negotiations. In the year 2000, new technical specifications for third generation (3G) systems under the brand IMT-2000 were unanimously approved with spectrum allocation in the range 400-3000 MHz. The basic architecture of 3G networks is based on two main principles: mobile cellular networks should be structured to maximize network capacity and multimedia services should be offered independently of the place of the end-users.

The 3G umbrella encompasses a range of competing mobile wireless technologies, namely CDMA-2000 and WCDMA. ITU's IMT-2000 vision of a global 3G mobile communication systems family included the Universal Mobile Telecommunications System (UMTS) which was standardized by the European Telecommunications Standards Institute (ETSI). WCDMA is a radio access scheme in the UMTS standard and was the next technology step in the path of 3GPP, created in 1998 to continue with the technical specification work [25].

2.5.1 WCDMA (Wideband Code-Division Multiple Access)

W-CDMA (or WCDMA) which stands for Wideband Code-Division Multiple Access was the radio technology chosen by 3GPP in implementing UTRA (Universal Terrestrial Radio Access). W-CDMA is a spread-spectrum modulation technique and uses channels with much larger bandwidths compared to that of the data being transferred. This modulation technique encodes each channel such that a decoder, with knowledge of the code, can selectively pick out the desired signals from all other signals in the same band. Additionally, since knowledge of the code is required in order to identify separate channels, W-CDMA is therefore very secure from eavesdropping. By making use of wide frequency band, the system is by design resistant to many of the aspects of radio communication which plague narrow band systems, such as noise, multipath reflections, and other interfering transmissions [25]. Other key operational features in W-CDMA include

- High data rate transmission: 384 Kbps (wide area coverage), 2 Mbps (local coverage).
- Service flexibility: support of multiple parallel variable rate services on each connection.
- Support for Frequency Division Duplex (FDD) and Time Division Duplex (TDD).
- Built-in support for future capacity and coverage enhancing technologies like adaptive antennas, advanced receiver structures and transmitter diversity.
- Support for inter frequency hand over and hand over to other systems, including GSM.
- Efficient packet access.

2.5.2 HSPA (High-Speed Packet Access)

The key enhancement in WCDMA 3GPP Release 6 was a new transport channel in the uplink: enhanced uplink (EUL), also sometimes called HSUPA (High-Speed Uplink Packet Access). The combination of HSDPA (High-Speed Downlink Packet Access) and EUL is known as HSPA, referring to High-Speed Packet Access which extends and improves the performance of WCDMA protocols. HSPA specifications for the DL and UL and contained in the 3GPP s Release 5 [26] and Release 6 [27] specifications respectively. This enhancement improved throughput, reduced latency and increased capacity. HSPA improves the end-user experience by increasing peak data rates up to 14 Mbps (DL) and 5.8 Mbps (UL). In 2008, Evolved HSPA (or HSPA+) was released with subsequent adoption worldwide in 2010. HSPA improvements in UMTS spectrum efficiency are obtained by:

- Shared-channel transmission, leading to efficient use of available code and power resources in WCDMA.
- Shorter Transmission Time Interval (TTI), hence shorter round-trip time and improvement in tracking of fast channel variations.
- Link adaptation, which maximizes channel usage and enables the BS to operate close to maximum cell power.
- Fast scheduling which prioritizes users with the most favorable channel conditions.

- Fast retransmission and soft-combining, resulting in further increase in capacity.
- 16QAM (Quadrature Amplitude Modulation), yielding higher bit-rates.

To further boost the peak data rate and capacity, 3GPP Release 7 introduced HSPA evolution (also called HSPA+), which supports MIMO, 64QAM in the downlink, and 16QAM in the uplink. Release 8 supported two ways to give downlink bitrates of 42Mbps, one of which involves a combination of 64QAM and MIMO while the other is by using dual carriers with 64QAM modulation.

2.6 LTE, WiMAX– 4G Systems

Long Term Evolution: LTE is the natural upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks. LTE is, therefore, anticipated to become the first truly global mobile phone standard, although the different LTE frequencies and bands used in different countries will mean that only multi-band phones will be able to use LTE in all countries where it is supported. The unprecedented take-up and demand for mobile broadband around the world, seeing connections jump from a few thousand in late 2006 to nearly 100 million in early 2009, has been the real driver and the need now for ever higher data rates and capacities [28]. In 2004, 3GPP started the investigation of Universal Mobile Telecommunication Services (UMTS) Terrestrial Radio Access Network (UTRAN) Long-Term Evolution (LTE) by identifying the requirements from different players in the field [29]. These requirements included the following:

- Packet-switched domain optimization.
- Server to User Equipment (UE) round-trip time under 30ms and access delay below 300ms.
- Peak rates uplink/downlink 50/100 Mbps.
- Good level of mobility and security ensured.
- Improved terminal power efficiency.
- Frequency allocation flexibility with 1.25/2.5, 5, 10, 15 and 20 MHz allocations; possibility to deploy adjacent to WCDMA.

- High capacity compared with the Release 6 HSDPA/HSUPA reference case, in the downlink throughput 3 to 4 times and in the uplink 2 to 3 times reference scenario capacity.

The overall objective for LTE is to provide an extremely high performance radio-access technology that offers full vehicular speed mobility and that can readily coexist with HSPA and earlier networks. LTE will make the user experience even better by enhancing more demanding applications such as interactive TV, mobile video blogging, advanced games and professional services. LTE offers several important benefits for users and operators, including the following:

Performance and capacity–With LTE built to provide downlink peak rates of at least 100Mbps and allowance for speeds of more than 300Mbps as well as Radio access network (RAN) round-trip times of less than 10ms, LTE meets key 4G requirements compared to other comparable technologies

Simplicity–Flexible carrier bandwidths ranging from 1.4MHz up to 20MHz as well as Frequency Division Duplexing (FDD) and Time Division Duplexing (TDD) are supported by LTE. 3GPP has already identified fifteen paired and eight unpaired spectrum bands for LTE and with many more to come, operators will be able to introduce LTE in new bands where it is easiest to deploy 10MHz or 20MHz carriers and eventually deploy LTE in all bands. Features such as self-configuration and self-optimization will simplify and reduce the cost of network roll-out and management, hence simplifying the building and management of next generation LTE radio networks in the future. These will be deployed in parallel with simplified, IP-based core and transport networks that are easier to build, maintain and incorporate new services [30].

Wide range of terminals–LTE modules can be embedded into devices like mobile phones, computers and other consumer electronic devices, such as notebooks, ultra-portables, gaming devices and cameras. These devices can have universal coverage from the onset as a result of LTE supporting handover and roaming to existing mobile networks.

Worldwide Interoperability for Microwave Access: WiMAX is a wireless communications standard by the WiMAX Forum, formed in June 2001 to promote conformance and interoperability of the IEEE 802.16 [31] standard. Mobile WiMAX is a broadband wireless solution that enables convergence of mobile and fixed broadband networks through a common wide area broadband radio access technology and flexible network architecture. Mobile WiMAX systems offer possibilities for future upgrades in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and services offered. Mobile WiMAX supports a full range of smart antenna technologies to enhance system performance [32]. Mobile WiMAX also supports adaptive switching between different techniques to maximize the benefit of smart antenna technologies under different channel conditions.

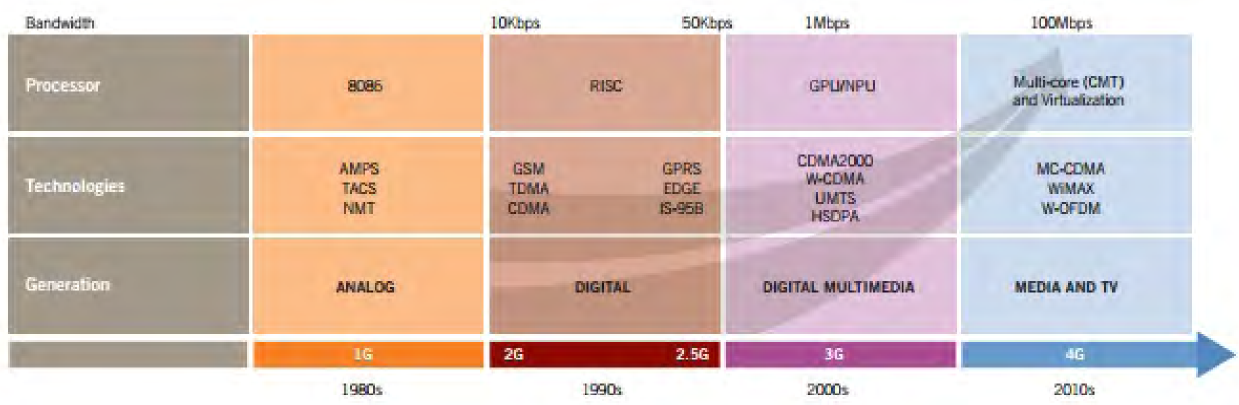

Figure 2: Evolution of processors and DSP technology for 4G

Figure 2 shows the wireless communication technology evolution and advancement with time. In 1980 1G launched with limited data speed capability after that 2G, 3G and 4G launched respectively in 1990, 2000, 2010 having significant speed, data transfer rate and lot of advanced features.

Table 1 provides the evolution of the cellular networks generation in terms of Maximum Speed and Features.

Table 1: Representation of cellular network generation [33]

Specifications	Protocol	Maximum Speed	Features
1G analog networks	AMPS	N/A	• Voice service only (analog) • No data service
	DataTAC		
	FDMA		
	Mobitex		
	NMT		
	TACS		
2G	CDMA	Up to 20Kbps	• Digital voice service • Push-to-Talk (PTT) • Short Message Service (SMS) • Conference calling • Caller ID • Voice mail • Simple data applications such as email and Web browsing
	GSM		
	iDEN		
	PCS		
	TDMA		
2.5G	CDMA2000 1xRTT	Up to 144Kbps (typical 60-80Kbps)	All 2G features plus: • MMS (Multimedia Message Service) • Web browsing • Real-time location-based services such as directions Basic multimedia, including support for short audio and video clips, games and images
	GPRS	Up to 114Kbps (30-40Kbps)	
	HSCSD	Up to 64Kbps	
	EDGE	Up to 384Kbps	
	WiDEN	Up to 100Kbps	
2.75G	EGPRS 2	473Kbps (uplink) to 1.2Mbps (downlink)[2]	Better performance for all 2/2.5G services
3G (DSL speeds)	CDMA2000 EVDO (data only) Rev 0	Up to 2.4Mbps	Support for all 2G and 2.5G features plus: • Full motion video • Streaming music • 3D gaming • Faster Web browsing
	CDMA2000 EVDV (simultaneous voice and data)	Up to 2.4Mbps	
	UMTS	Up to 2Mbps	
	WCDMA	Up to 2Mbps	
	CDMA2000/ EVDO-Rev A	Up to 3.1Mbps	
3.5G (cable speeds)	HSDPA	Up to 14.4Mbps	Support for all 2/2.5/3G features plus: • On-demand video • Video conferencing • Faster Web browsing (especially graphics intensive sites)
	CDMA2000/ EVDO Rev B	Up to 46Mbps	
4G (wired networking equivalent)	WiMAX	100+Mbps	Support for all prior 2G/3G features plus: • High quality streaming video • High quality videoconferencing • High quality Voice-over-IP (VoIP)
	UMB	35Mbps	
	LTE	100Mbps	

Reflects evolution of CDMA network — Reflects evolution of GSM network

2.7 Why the Leap Towards 4G

The vision which considers 4G as an extension to 3G cellular services is called as the linear 4G vision. But the extent of 4G capabilities goes beyond the cellular services. Envisioning 4G as high speed delivery of services via the most efficient network available from the pool of wireless networks is called as the concurrent 4G vision [34]. One of the major reasons of 3G being unable to repeat the success story of 2G was the provision of only few additional services over 2G. It was not encouraging enough for the customer's to change their equipment. User-centric approach for the design of 4G is to avoid mismatch between the user's expectations and the services provided by 4G. Features of 4G which cater to the end-user's expectations and the problems of the current generation networks can be listed as follows:

User friendliness: 4G aims at providing myriad of services to the end users at high speed. The applications developed to avail these services should be highly user friendly minimizing the interaction between the application and the user. For example, integration of speech recognition technology in the user interfaces would ease the use of the applications for every layman.

User personalization: High data transfer rates and ubiquitous coverage of4G networks would provide users access to large repository of data and services. Users should have flexibility to filter these data and services as per his preferences by configuring the operational mode of their devices, so that he can preselect the service features he wants to use. For an example, user in a mall interested in buying clothes should receive alerts about various discount offers on clothes rather than about the other accessories.

Terminal and Network heterogeneity: Terminal heterogeneity refers to the different types of terminals in terms of the size, weight, display features, power consumption, etc. Network heterogeneity means the different types of access networks like WiMAX, Wi-Fi, UMTS and so forth which differ in their coverage area, data rate, latency and data loss rate. Each of these terminals and services cater to different user requirements. In 4G, all these terminals and networks will provide common services independent of their capabilities. This is also called as service personalization [35].

High Performance: Low transfer rates of 3G restrict the user's ability to take advantage of the rich multimedia contents across the wireless networks. 4G is expected to provide wireless download speeds of about 1Gbps in local area network (LAN) and 100 Mbps in wide area network (WAN), about 260 times greater than the 3G wireless networks.

Interoperability: Multiple standards of 3G restrict the user's mobility and interoperation across different networks. 4G targets at providing a unified global standard which will facilitate global mobility and service portability. In other words, end user can subscribe to different services from different service providers using the same mobile device.

Intelligent Networking: 3G is based primarily on cell or base station WAN design. 4G aims at building hybrid networks utilizing both the Wireless LAN concept and WAN design. Thus, the world would have base stations everywhere providing ubiquitous network coverage to users at high speed. For example, a user walking on road is browsing internet using GPRS. The moment he enters a mall with Wi-Fi (LAN design), seamless hand-over from GPRS to Wi-Fi would take place without the user's knowledge [36].

Network Convergence: Network convergences the efficient coexistence of multimedia, voice and data communication within a single network [37]. Currently the telecommunication environment is divided into wireless and fixed line communication. To avail these different kinds of services, the end user require different devices such as cellular phones, fixed line phones, laptops and PDA's. Once the fixed mobile convergence is in place in 4G, the distinction between these services will disappear. The current 3G technology is not able to capture the market share as done by the fixed line services partly because of its low bit rates of 384kbps and because of the high costs associated with these services. But with the emergence of 4G aiming at global integrated IP based network, the wireless sector will be able to match the fixed line sectors in terms of both costs and speed. 4G will lead to convergence in terms of both devices and services. Thus, handset capabilities, MP3, camera, mobile broadband services would be made available in a single device. Service convergence will result from availability of telecommunication and internet on a single platform. This would force the fixed line sector to jump in the competitive wireless market. In response, the wireless operators will also jump into the fixed line sector. Thus slowly the boundaries between these markets will disappear. Thus, the end user will benefit from one business providing variety of services. He will experience high quality service at affordable prices. Thus fixed mobile convergence will act as a catalyst for stimulating markets to come up with new innovative and cost effective ideas.

Scalability: Scalability in mobile networks is the ability to handle the increasing numbers of users and services. 4G will use IPv6 addressing scheme which will support large number of wireless devices eliminating the need for Network Address Translation (NAT). NAT is technique of sharing limited number of addresses among large number of devices. The huge expanse of current internet world signifies the scalability support of IP. Thus, the use of IP as core network layer will make 4G easily scalable.

Lower power consumption: Battery technology has not been able to keep pace with the growing telecom industry. 2G devices required one battery while 3G required two batteries. Battery drain is a persistent problem of wireless devices. 4G aims at breaking this directly proportional rule. Shorter communication links is one of the few solutions proposed to cater to this requirement.

Low costs: 4G is designed to be spectrally efficient with no requirement to buy costly extra spectrum. It is not development of a completely new system rather built on the top of the existing networks. 4G will also support backward compatibility with 2G and 3G devices. All these factors will make 4G much cheaper than the current generation networks.

2.8 Global Subscriber Base of 2G, 3G & 4G System

The rate of LTE network commitments and roll-outs at an all-time high, network and device vendors have significantly improved their position to offer products and solutions to network operators. Total mobile subscriptions in Q1 2014 were around 6.8 billion. This included the addition of 120 million new subscriptions during the first quarter. Global mobile subscriptions have continued to grow 7 percent year-on-year and 2 percent quarter-on-quarters. Global mobile penetration reached 93 percent in Q1 2014. Global mobile broadband subscriptions grew by around 35 percent year-on-year and reached 2.3 billion in Q1 2014 [38].

LTE continues to grow strongly and has reached 240 million subscriptions, with around 35 million additions in Q1 2014. WCDMA/HSPA had the highest net additions during the quarter at around 70 million. Almost all of these 3G/4G subscriptions have access to GSM/EDGE as a fallback. The number of GSM/EDGE-only subscriptions remained flat [38].

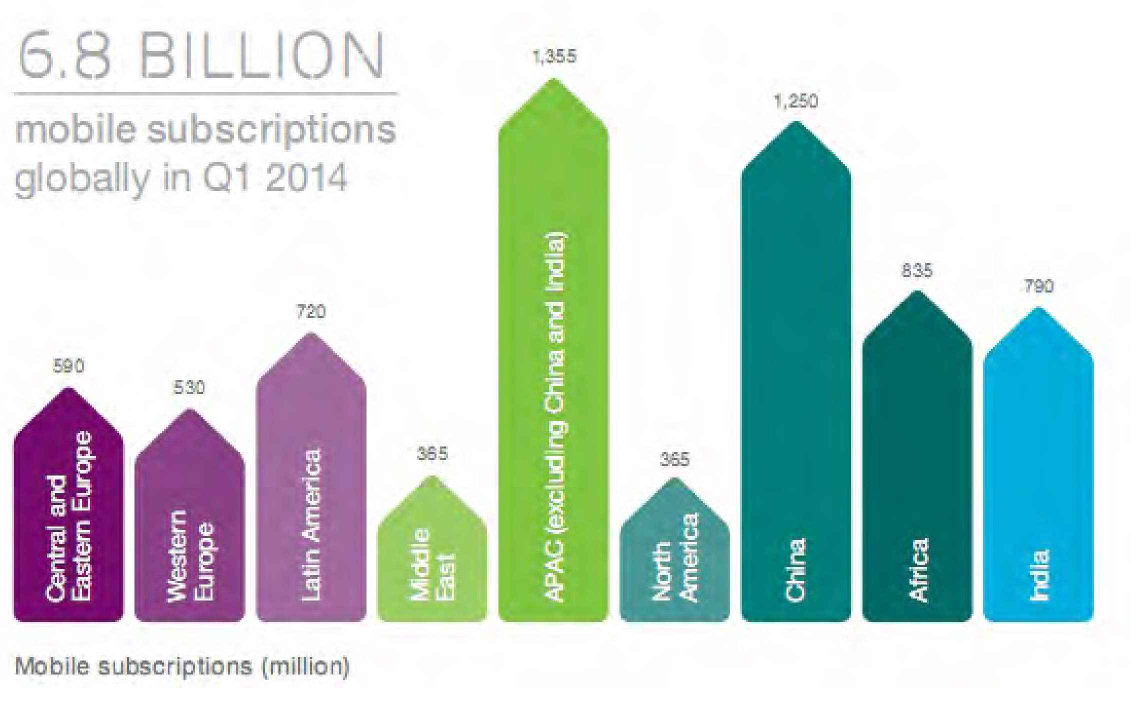

Figure 3: Global mobile subscriber base [38]

Figure 3 represents that total mobile subscriptions are expected to grow from 6.8 billion in Q1 2014 to 9.2 billion by the end of 2019. Global mobile broadband subscriptions are predicted to reach 7.6 billion by 2019 and will gain an increasing share of the total mobile subscriptions over time. By the end of 2019, mobile broadband subscriptions are expected to account for more than 80 percent of all mobile subscriptions, compared to around 30 percent in 2013. Mobile broadband will also gain a larger share of total broadband subscriptions in many markets, complementing fixed broadband, and in certain segments replacing it. In developing ICT markets, smart phones already provide consumers with their first internet contact. This is due to limited access to fixed internet, combined with the influx of cheaper smart phones. The majority of mobile broadband devices is, and will continue to be, smart phones [39].

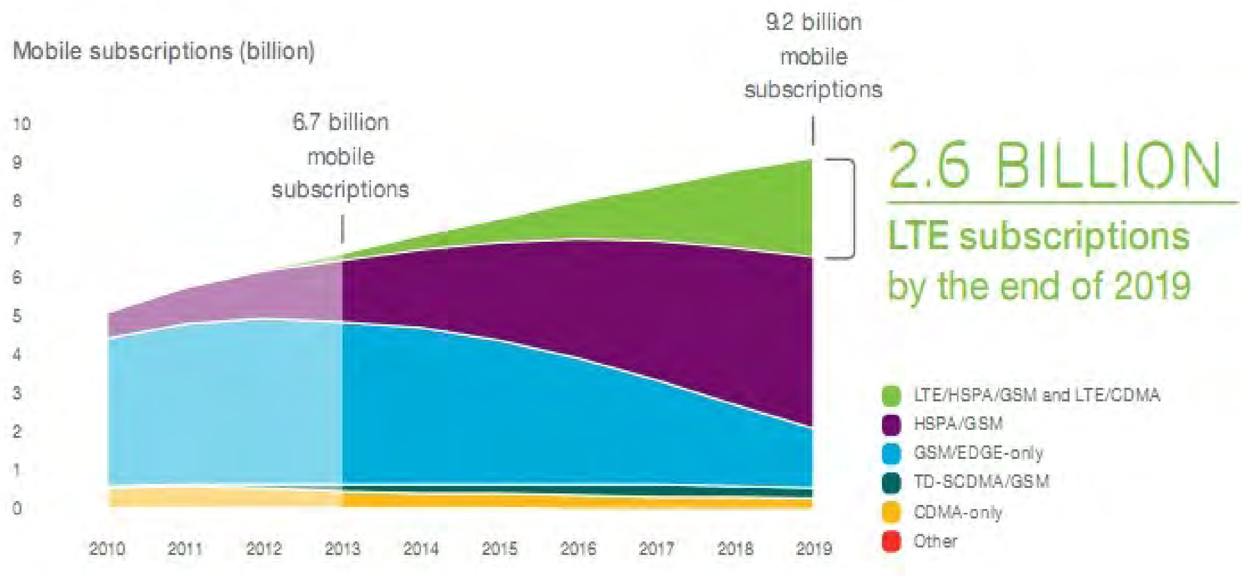

Figure 4: 2G, 3G & 4G mobile subscriber base globally [39]

As in figure 4, 2G (GSM/EDGE)-only subscriptions represent the largest share of mobile subscriptions today. In developed markets there has been rapid migration to more advanced technologies, resulting in a decline in 2G (GSM/EDGE)-only subscriptions. Despite this, 2G will continue to represent a large share of total mobile subscriptions. This is because new, less affluent users in developing markets will likely choose a low-cost mobile phone and subscription. In addition, it takes time for the installed base of phones to be upgraded. 2Gnetworks will also continue to be important in complementing 3G (WCDMA/HSPA) and 4G

(LTE) coverage in all markets. Today, LTE is being deployed in all regions, and subscriptions for this technology are predicted to reach 2.6 billion by 2019, representing around 30 percent of total mobile subscriptions [39].

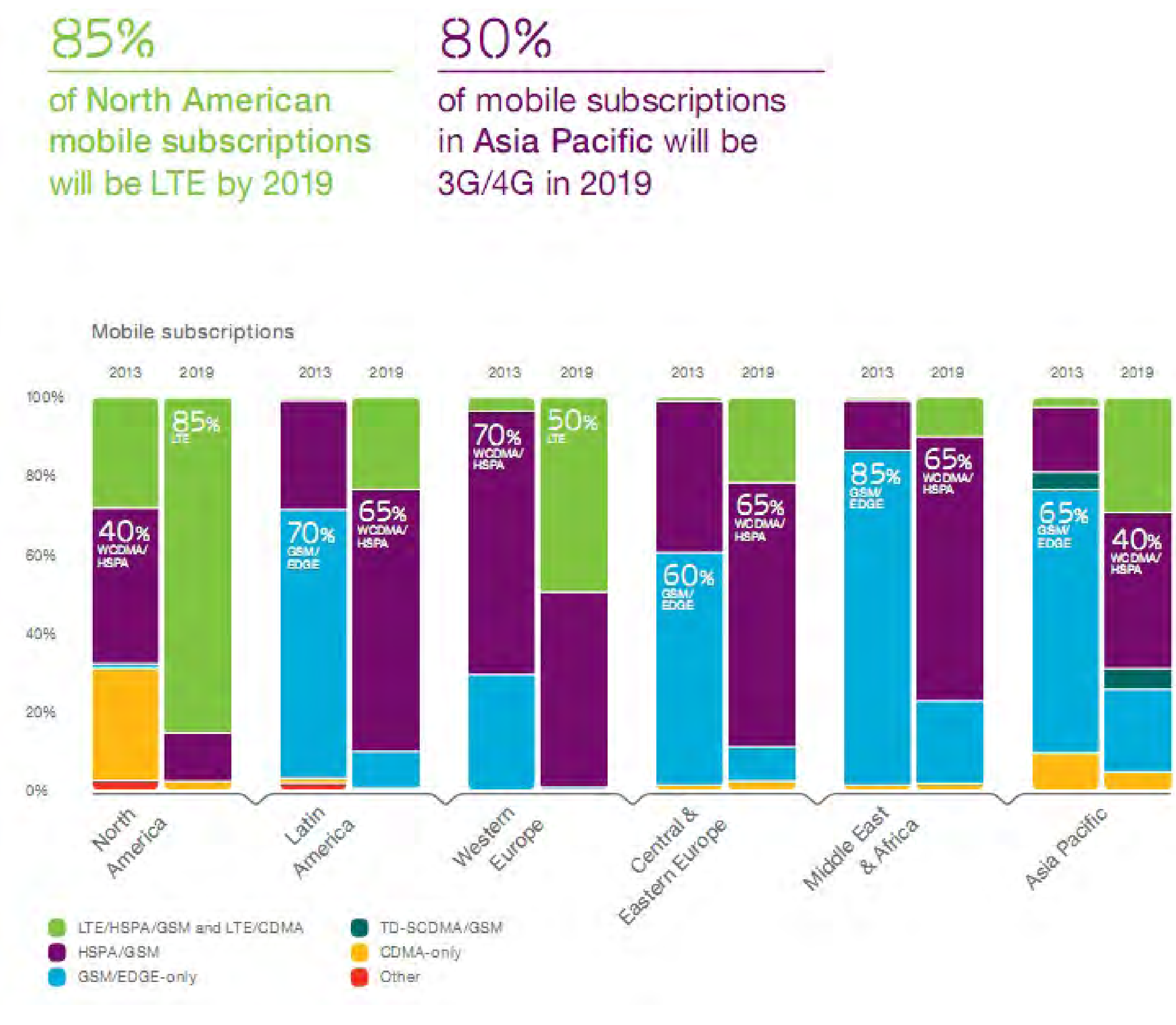

Figure 5: Region wise mobile subscription base [39]

In figure 5 represents region wise mobile subscriber base as well as it also represents region wise telecommunication technology preferences. Each region’s maturity level is reflected in its radio technology mix. Developing regions are dominated by 2G technologies like GSM/EDGE, while developed ones are dominated by WCDMA/HSPA. LTE is rapidly being embraced by both operators and subscribers, particularly in North America. In all regions, 2G networks (GSM/EDGE, CDMA 1X) remain as fallback technology for 3G and 4G subscriptions where coverage is missing [39].

In North America, LTE will represent the majority of subscriptions by 2015, growing to around 85 percent in 2019. This rapid growth in LTE subscriptions is driven by strong competition, consumer demand and CDMA operators' early decisions to migrate to LTE. Mobile subscriptions in Latin America will reach around 900 million in 2019. The strong growth in subscriptions in this region will be driven by economic development and consumer demand. Latin America currently has a large GSM/EDGE subscriber base. In 2019, WCDMA/HSPA will be the dominant technology and LTE subscriptions are expected to be more than double the number for GSM/EDGE-only [39].

In Europe, every country has WCDMA/HSPA networks and more than half have launched LTE. In Western Europe, WCDMA/HSPA is the dominant technology today. By the end of the forecast period, LTE will make up around 50 percent of the subscriptions base. Data services were rolled out early in this region, initially accessed via dongle or mobile PC. Western Europe is at the forefront of mobile broadband uptake, but the drive for LTE has not yet been as strong in the region as in North America, due to factors such as having many well-developed 3G networks. Central and Eastern Europe shows a strong increase in HSPA subscriptions. LTE will initially grow in the most developed parts of the region and will be present in almost all countries by 2015 [39].

The Asia Pacific market continues to see a significant increase in mobile subscriptions with 1.4 billion net additions by the end of 2019. This market represents more than 50 percent of mobile subscription additions globally. Markets such as Japan and South Korea took up LTE subscriptions earlier than emerging markets. By the end of 2013, LTE penetration had already reached over 30 percent in Japan and over 50 percent in South Korea – the highest in the world. It is estimated that Japan and South Korea will account for around 25 percent of the world's LTE subscriptions at the end of 2014. Mainland China has started to roll out LTE and will add a significant number of LTE subscriptions during the forecast period, reaching over 700 million by the end of 2019. This means that China will represent more than 25 percent of total global subscriptions for LTE. The Indian telecom sector registered among the strongest growth rates in the world with regard to mobile subscription during years. 3G subscriber base of India to cross the 200 million mark by 2014 and 4G subscribers will reach 5 million by 2014 in Indian telecom market. It will be the take-off period with 3G subscriber growth achieving a compound annual growth rate of 106%. Beyond 2014, growth will slow because of the introduction of faster technologies, such as 4G and relative market maturation. In 2013, around 75 percent of mobile subscriptions in Asia Pacific were 2G, whereas in 2019 around 80 percent will be 3G/4G [39].

In 2013, the Middle East and Africa was dominated by GSM/EDGE, which represented around 85 percent of mobile subscriptions in the region. Mobile subscriptions will grow from 1.2 billion in 2013 to 1.9 billion in 2019. By this time WCDMA/HSPA will be the dominant technology with 65 percent of total mobile subscriptions. However, GSM/EDGE-only subscriptions will still be significant. In Sub-Saharan Africa, for example, GSM will remain the dominant technology until 2018, due to the dominance of lower income consumers using 2G-enabled handsets [39].

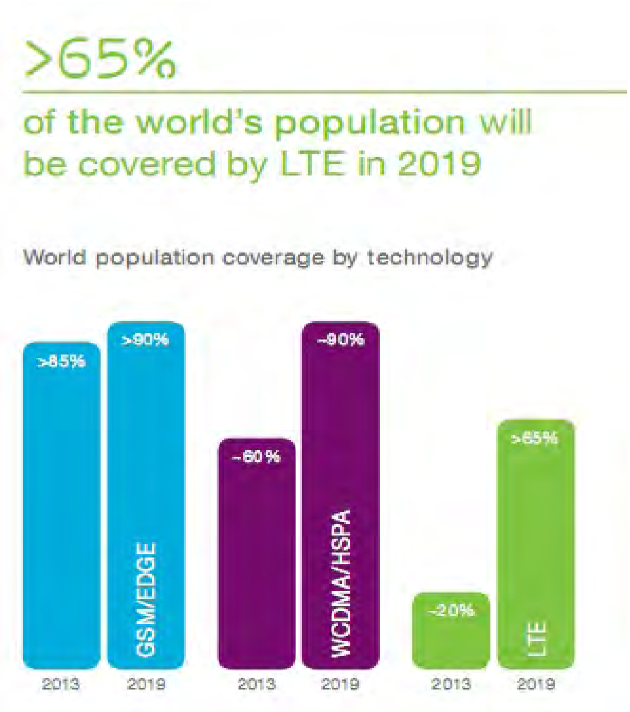

Figure 6: Network coverage by 2G, 3G and 4G [40]

Today's markets are highly competitive and subscribers expect a high-quality user experience, as well as continuous enhancements to their services. As more base stations are deployed, the population coverage of the world's mobile networks constantly increases. As presented in figure 6, at the end of 2013, 2G (GSM/EDGE) technology has the widest reach and covers over 85 percent of the world's population. 3G (WCDMA/HSPA) covered approximately 60 percent of the world's population. This is an increase of around 10 percent worldwide on 3G population coverage compared to 2012.LTE covered around 20 percent of the world's population at the end of 2013. This was a doubling of LTE population coverage compared to 2012. It is predicted that this will increase to over 65 percent by 2019 [40].

Methodology and Experimentation

Chapter 3

3.1 Technology Assessment

Technology Assessment (TA) is a systematic attempt to foresee the consequences of introducing a particular technology in all spheres it is likely to interact with. The essential meaning of technology assessment is that making technological choices should be proceeded by a thorough analysis of all consequences the choice might have, not just the immediate or sought for consequences. Technologies often have had unintended effects which, on occasion, have proved highly undesirable. Some of these might have been foreseen and avoided if an attempt to look for them had been made. TA on Fourth Generation (4G) wireless communication is to consider the technology in its full context, with all the opportunities, possibilities and consequences and the environment in which it operates. TA helps to

- Gain competitive advantage of Technology
- Technology assessment is a tool
- Questions regarding technical & social purpose
- Identification of Positive & Negative effects of Technology
- Selecting a Technology

Many different types of TA and their tool have been available for analysis, depending on the technologies or problems to be assessed, and on the ground to be converted, i.e., the scope of the assessment. Some popular TA techniques are Relevance Tree (RT), Cross Impact Analysis (CIA), Fuzzy Hierarchical Decision Making (FHDM), Delphi Technique (DT), Analytical Hierarchical Process (AHP), etc. Among the methods, AHP provides a framework for rational choice of technology by identifying the relevant criteria, measuring the performance of each alternative on each criterion, determining the importance weight of each criterion and finally evaluating a weighted score for each alternative that reflects strength of preference of an alternative. Hence, because of its inherent capability to handle both quantitative and qualitative attributes and data uncertainty, AHP is widely applicable as technology assessment tool.

3.2 Research Tool: AHP, CBA, SWOT

In this research I have used Analytical Hierarchy Process (AHP) for the empirical analysis. It's a Multi criteria decision making tool which is using worldwide for its inherent capability for both handling quantitative and qualitative data. Its functionality is to breaking down the problem into hierarchy and finally generates rating for each alternative of technological choices. Cost Benefit Analysis (CBA) presented here to predict the functional requirement/benefit for the technological choices. It is a systematic process for calculating and comparing benefits and costs of a technology project and choices and decision. After that a tool used, SWOT analysis to evaluate the strength, weaknesses, opportunities and threats for the telecommunication technologies. For telecommunication technology assessment it determines and identifies the internal and external factors that are favorable and unfavorable for each wireless communication technology. SWOT analysis frequently using for technology planning, technology assessment, technology forecasting, technology decision making etc.

3.2.1 Analytical Hierarchy Process (AHP)

Over the last three decades, a number of methods have been developed which use pair wise comparisons of the alternatives and criteria for solving Multi-Criteria Decision-Making (MCDM) [41] between finite alternatives. The analytic hierarchy process (AHP) proposed by Saaty [42-43] is a very popular approach to multi-criteria decision-making (MCDM) that involves qualitative data. It has been applied during the last twenty-five years in many decision-making situations and has been used on a wide range of applications in many different fields. The method uses a reciprocal decision matrix obtained by pair wise comparisons so that the information is given in a linguistic form. The pair wise comparison method was introduced by Fechner [44] in 1860 and developed by Thurstone [45] in 1927. Based on pair wise comparison, Saaty proposes the analytic hierarchy process (AHP) as a method for multi-criteria decision-making. It provides a way of breaking down the general method into a hierarchy of sub-problems, which are easier to evaluate.

AHP belongs to the multi-criteria decision making methods (MCDM) group. AHP is a decision-making process in which a problem is first broken down to a hierarchy of interrelated decision elements and then uses the pair wise comparisons of the user to give the order in which factors affect a decision, consistency of the respondent, and (depending on the particular problem) a prioritized list of the decisions to be made. Mathematically, the method is based on the solution of an “eigenvalue problem. The results of the pair-wise comparisons are arranged in a matrix. The first (dominant) normalized right Eigen vector of the matrix gives the ratio scale (weighting), the Eigen value determines the consistency ratio. The core of AHP is the comparison of pairs instead of sorting (ranking), voting (e.g. assigning points) or the free assignment of priorities. Validation of the method in practical testing shows surprisingly good agreement with actual measured values.

AHP has been used successfully in many institutions and companies, although the method is so universal. Using AHP as a supporting tool for decision making will help to gain a better insight in complex decision problems. As need to structure the problem as a hierarchy, it forces to think through the problem, consider possible decision criteria and select the most significant criteria with respect to the decision objective. Using pair wise comparisons helps to discover and correct logical inconsistencies. The method also allows to "translate" subjective opinions, such as preferences or feelings, into measurable numeric relations. AHP helps to makes decisions in a more rational way and to make them more transparent and better understandable [46]. There are several advantages of using AHP.

- Ease of use.
- Specification of judgment.
- Built-in consistency tests.
- Appropriate measurement scales.
- Applicability in the elicitation of utility functions.
- Inherent capability to handle both qualitative and quantitative attributes.

This study presents an empirical analysis of technology assessment on fourth generation technology. The empirical analysis is being made just to rank the telecommunication technologies based on technological choices and preferences, not to identify the causal relationship among the variables. Therefore, this study is a descriptive research with some empirical evidences. An Analytical Hierarchical Process (AHP) is performed as a technology assessment tool to determine the appropriateness of this new technology. The steps to be followed while implementing the AHP process are illustrated as follows.

- Step1: Define the goal of the decision
- Step2: Structure the decision problem in a hierarchy
- Step3: Pair comparison of criteria in each category
- Step4: Calculate the priorities and a consistency index
- Step5: Evaluate alternatives according to the priorities identified
- Step6: Research result analysis

3.2.2 Cost Benefit Analysis (CBA)

Cost Benefit Analysis (CBA), sometimes called benefit–cost analysis (BCA), is a systematic approach to estimating the strengths and weaknesses of alternatives that satisfy transactions, activities or functional requirements for a business. It is a technique that is used to determine options that provide the best approach for the adoption and practice in terms of benefits in labor, time and cost savings etc. The CBA is also defined as a systematic process for calculating and comparing benefits and costs of a technology project, decision or government policy [47].

Broadly, CBA has two purposes:

- To determine if it is a sound investment/decision (justification/feasibility).
- To provide a basis for comparing projects. It involves comparing the total expected cost of each option against the total expected benefits, to see whether the benefits outweigh the costs, and by how much.

3.2.3 SWOT Analysis (SWOT)

SWOT Analysis is strategic planning technique used to evaluate strength, weaknesses, opportunities and threats for particular technological alternatives. Each box in Figure 3 indicating the internal and external factors of strength, weaknesses, opportunities and threats for any technological choices. It involves specifying the objective of the technology project or technology assessment and identifying the internal and external factors that are favorable and unfavorable to achieve that objective. The technique is credited to Albert Humphrey, who led a convention at the Stanford Research Institute in the 1960s and 1970s using data from Fortune 500 companies. The degree to which the internal environment of the firm matches with the external environment is expressed by the concept of strategic fit [48].

Figure 7: SWOT Analysis

Setting the objective should be done after the SWOT analysis has been performed. This would allow achievable goals or objectives to be set for the organization.

- **S**trengths: characteristics of the technology project that give it an advantage over others.

- **W**eaknesses: characteristics that place the technology project at a disadvantage relative to others
- **O**pportunities: elements that the project could exploit to its advantage
- **T**hreats: elements in the environment that could cause trouble for the technology project.

The usefulness of SWOT analysis is not limited to profit-seeking organizations. SWOT analysis used in any technology decision-making situation when a desired end-state has been defined. Examples include: non-profit organizations, governmental units, and individuals. SWOT analysis may also be used in pre-crisis technology planning and preventive crisis technology management. SWOT analysis may also be used in creating a recommendation during a viability study/survey for ant technological assessment and forecasting.

3.3 Research Model

In this study, Analytical Hierarchy Process (AHP) has been chosen for the analysis of fourth generation wireless technology assessment. For the analytical purposes ranking of the telecom technologies are being made using the Analytical Hierarchy Process (AHP) model. The empirical analysis is being made to rank the telecom operators based on variables relating to Academy and Industry expert's preferences, not to identify the causal relationship among the variables.

With AHP, Cost Benefit Analysis (CBA) has been chosen for requirement/benefit analysis for telecom technologies. Here considered abroad scenario and data for CBA. A SWOT Analysis also considered in research model for evaluating each and every telecom technologies internal and external features considering strategic fit of strength, weakness, opportunity and threat.

3.3.1 Source of Data

The required data for empirical analysis are collected from Bangladesh Telecommunication Regulatory Commission (BTRC) which considered as the primary sources of data for telecommunication technology in Bangladesh. The secondary sources for data and information have been taken through the internet, books, journals, related studies and other sources of information. Based on the above study structured questionnaires were prepared by the ways of interviews and interactions of relevant experts from Academy and Industry, observation and document review by following the principles of different tools and strategies of TA. An expert opinion has conducted as a General Intuitive Method (GIM) of TA. GIM is an intuition-based methodology of TA has done by a participatory method by involving expert, academician, etc. of the relevant field.

3.3.2 Sampling Design

For the purpose of the study and for empirical research, experts are selected from telecommunication industry and academy using judgmental sampling techniques. Firstly, I have requested the experts from Academy and experts from Industry for their valued feedback on selecting telecommunication technologies based on their industry experience and expertise. Secondly General users have been chosen based on telecommunication facilities usage experience. The sampling design is summarized in Table 2.

Table 2: Summary of sampling design

Expert Opinion	Academy personnel & Telecom industry expert General User
Number of Experts	Twenty Five
Sampling Technique	Judgmental
Scaling Technique	AHP 1-9 Scale
Extent	Dhaka, Bangladesh 2014

3.3.3 Model Development

AHP model uses four stages for data hierarchy. First stage contains the research goals, second stage contains the criteria of ranking, third stage contains sub-criteria and fourth stage contains the alternatives. For empirical analysis, three criteria and ten sub-criteria are selected in this study for ranking three telecommunication technologies as alternatives. The stages of AHP model are summarized in Table 3.

Table 3: Stages of AHP hierarchy

Stage-1: Goal	Selection of Technology for Wireless Communication in Bangladesh
Stage-2: Criteria	Cost Component Quality Features Ripple Effect
Stage-3: Sub-Criteria	Licensing Cost Upgradation Cost Maintenance Cost Data Rate Spectral Efficiency & Mobility Security Features Integration Scalability Environmental Issue Economic Impact Social Impact
Stage-4: Alternatives	2G (GSM/GPRS/EDGE) 3G (UMTS/ HSDPA/ HSPA) 4G (LTE/ WiMAX)

The criteria and sub-criteria are the building blocks of AHP for 4G technology assessment is shown in Table 03. Decision making is depends on those criteria and sub-criteria for each alternatives. AHP method uses a hierarchy with several levels, structured in objectives, criteria, sub criteria, alternatives. It is used to derive relative priorities on absolute scales from both discrete and continuous paired comparisons in multilevel hierarchic structures [49]. Using the AHP method, the first step is to identify the weights of the criteria factors of the telecommunication technologies. Consequently, a four level hierarchy has been considered as framework for the telecommunication technology selection. Based on those criteria and sub-criteria, a relevance tree (RT) was formed in Figure 8.

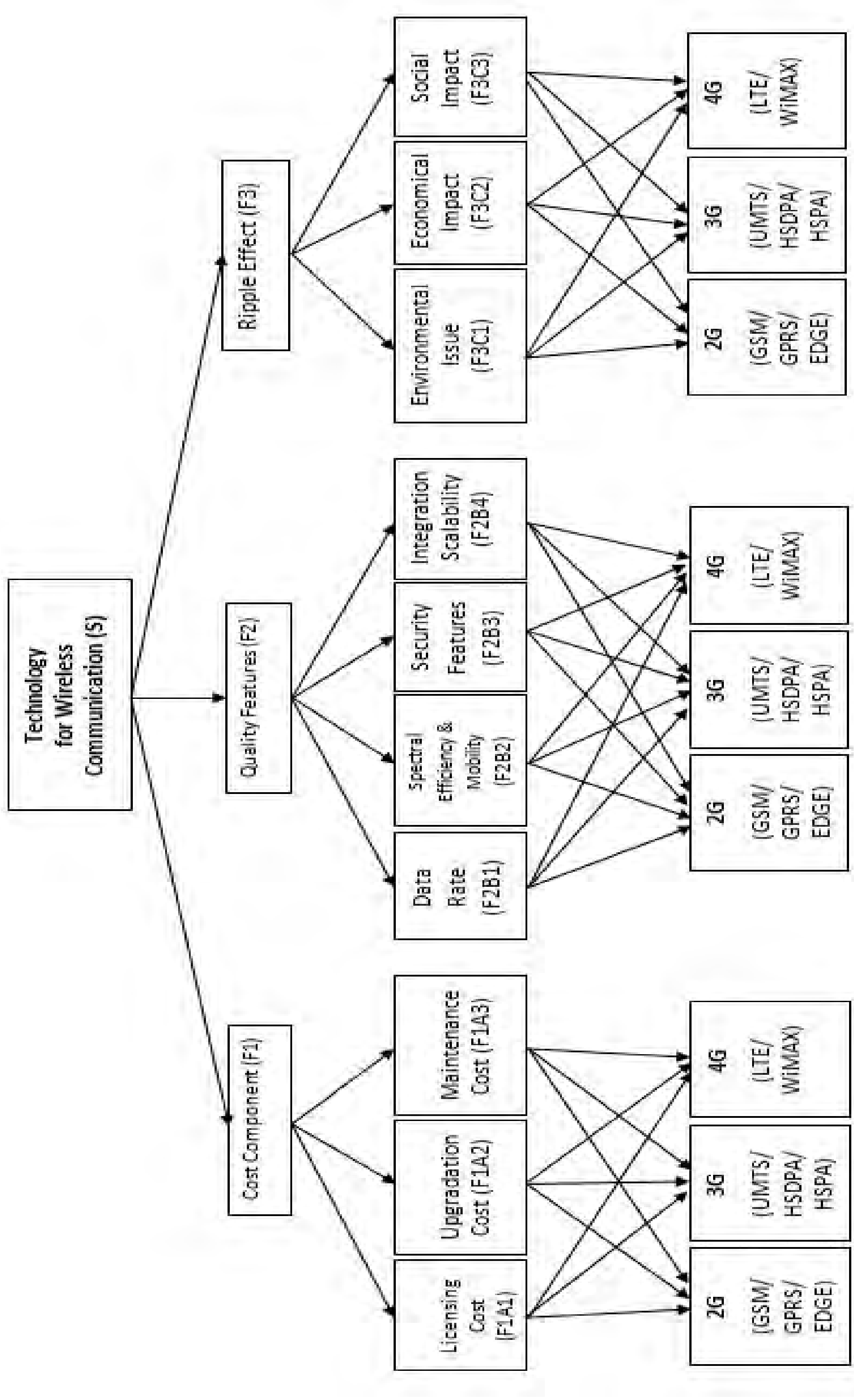

Figure 8: AHP relevance tree based on Criteria and Sub-criteria

3.3.4 Questionnaire Development

The questionnaire was formed based on the relevance tree considering the main goal of this research. Initially the questionnaire has been prepared for general criteria, then for sub-criteria and alternatives. The questionnaire and scale considered for this research is from 1 (Equally Preferred) to 9 (Extremely Preferred). AHP Standard Preference Table 4 is given below for the detail of scale 1-9. Detail questionnaire has been presented in Appendix section.

Table 4: Pair-wise comparison scale for AHP preferences

AHP (Analytical Hierarchy Process) Standard Preference Table	
Judgments of preference	Numerical Rating
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

Questions are formulated in comparative term, as presented below:

1(a) Given the Technology selection, what do you think is more important: the factor of <u>Cost Component (F1)</u> or the factor of <u>Quality Features (F2)</u>? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

2(a) Given the Technology selection, what do you think is more important: the factor of Cost Component (F1) or the factor of Ripple Effect (F3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

3(a) Given the Technology selection, what do you think is more important: the factor of Quality Features (F2) or the factor of Ripple Effect (F3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

4(a) Given the Factor (F1), what do you think is more important: the sub factor of Licensing Cost (F1A1) or the sub factor of Upgradation Cost (F1A2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

5(a) Given the Factor (F1), what do you think is more important: the sub factor of Licensing Cost (F1A1) or the sub factor of Maintenance Cost (F1A3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

6(a) Given the Factor (F1), what do you think is more important: the sub factor of Upgradation Cost (F1A2) or the sub factor of Maintenance Cost (F1A3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

13(a) Given the Factor (F3), what do you think is more important: the sub factor of Environmental Issue (F3C1) or the sub factor of Economic Impact (F3C2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

14(a) Given the Factor (F3), what do you think is more important: the sub factor of Environmental Issue (F3C1) or the sub factor of Social Impact (F3C3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

15(a) Given the Factor (F3), what do you think is more important: the sub factor of Economic Impact (F3C2) or the sub factor of Social Impact (F3C3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

16(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 2G [GSM/GPRS/EDGE] (T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

17(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 2G [GSM/GPRS/EDGE] (T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

18(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

43(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 2G [GSM/GPRS/EDGE] (T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

44(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 2G [GSM/GPRS/EDGE] (T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

45(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

3.3.5 Data Analysis Tool and Techniques

Hierarchy is constructed by stating the goal/objective and identifying the criteria and alternatives. Pair-wise comparison constructs matrices for all the criteria and alternatives. Table 04 shows the pair-wise comparison scale for AHP preferences. The matrix is determined through a number of different career scoring experts in the relevant fields as follows:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \qquad (1)$$

Where $A = (a_{ij})$, $a_{ij}>0$, *and* $a_{ji} = 1/a_{ij}$

The weights of the criteria and local weights of the alternatives are determined from the above matrices by using Normalization Procedure. The criteria and local weight of the alternatives are determined by the following equations:

Calculating the sum of the data of each row,

$$\overline{\omega}_i = \sum_{j=1}^{n} a_{ij}, i = 1,2, \dots\dots n \qquad (2)$$

Normalizing the local weights

$$\omega_i = \frac{\sum_{j=1}^{n} a_{ij}}{\sum_{k=1}^{n}\sum_{j=1}^{n} a_{kj}}, i = 1,2, \dots\dots n \qquad (3)$$

Normalized local weighted vector is determined by

$$w = [\omega_1, \omega_2, \dots\dots, \omega_n]^T \qquad (4)$$

The Global weights of the alternatives is obtained by synthesizing the local weights,

$$B \text{ x } V = \begin{bmatrix} b_{11} & b_{12} & \dots & b_{1n} \\ b_{21} & b_{22} & \dots & b_{2n} \\ \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots \\ b_{n1} & b_{n2} & \dots & b_{nn} \end{bmatrix} \text{x} \begin{bmatrix} v_1 \\ v_2 \\ \dots \\ \dots \\ v_n \end{bmatrix} \qquad (5)$$

Matrix B represents the local weights of the alternatives and each column represents the local weight under each criterion. The V matrix represents transpose of the local weight of criteria. Global weight is determined by multiplying the matrices B and V [50].

3.3.6 Consistency Analysis

The purpose for doing Consistency Analysis is to make sure that the original preference ratings are consistent and check these values. There are 3 steps to arrive at the consistency ratio:

- Calculate the consistency measure.
- Calculate the consistency index (CI).

$$CI = \frac{\lambda\text{max} - n}{n - 1}$$

Where, λmax = The maximum eigenvalue of the matrix

n = Matrix size

- Calculate the consistency ratio (CR)

$$CR = \frac{CI}{RI}$$

Where, RI=Random Index

For each matrix of size n, Saaty's team generated random matrices and computed their mean CI value and called it the Random Index. The Random Index (RI) table [51] presented in Table 05.

Table 5: Random Index table for corresponding matrix size

Random Index (RI) table										
n	1	2	3	4	5	6	7	8	9	10
Random Index (RI)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

In practice, a CR of 0.1 or below is considered acceptable. Any higher value at any level indicates that the judgments warrant re-examination. Larger values require the decision maker to reduce the inconsistencies by revising judgments. Determining the Consistency Index and the Consistency Ratio should have been done on the initial "pair-wise" comparisons. With AHP, we can measure the degree of consistency; and if unacceptable, we can revise pair wise comparisons. If we are perfectly consistent, then the consistency measures will equal n and therefore, the CIs will be equal to zero and so will the consistency ratio [52].

Using above equations the data (available from data source e.g. expert opinion) were administered in the matrix named as general criteria. Then under these general criteria there are numbers of sub-criteria. These sub-criteria were compared under each general criterion. The data were administered for every sub-criterion under every general criterion. Then each sub-criterion contains three alternatives. Considering the sub-criteria under general criteria the alternatives were compared pair wise and administered in the matrix. All the comparison gives several tables of corresponding matrix and their values. At each stage I have checked consistency for the authentic result. Finally, the data analysis is made using Microsoft Excel spread sheet and AHP Online Software (AHP-OS) [53].

3.4 Description of AHP Online Software

BPMSG (Business Performance Management Singapore) provides AHP online software (AHP-OS). It is a non-commercial website, and information is shared in this site for educational and research purposes.

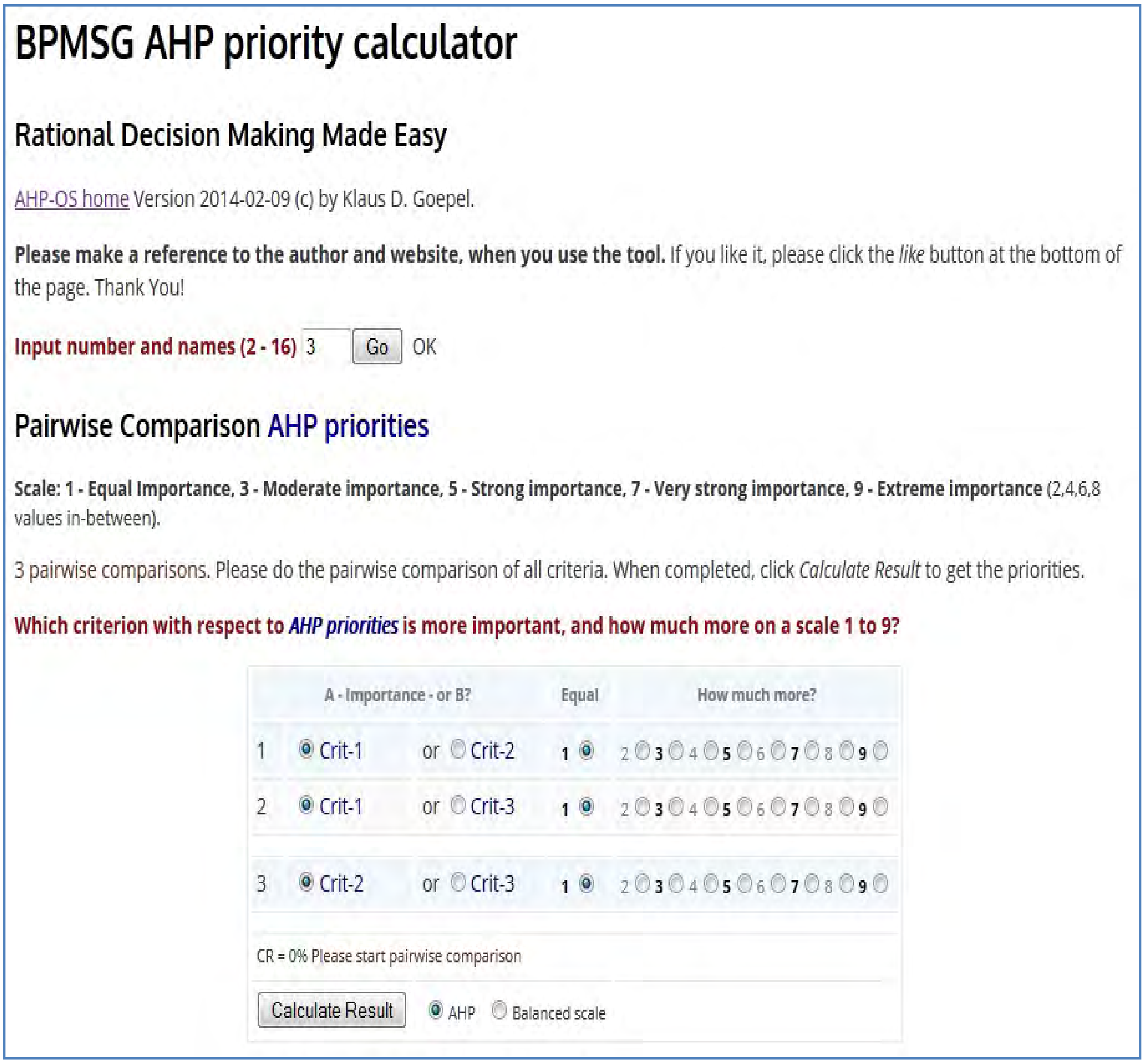

Figure 9: AHP Online Software web view [54]

The latest version (V. 2014-05-15) of AHP online software (AHP-OS) has now additional features to manage complete AHP projects. AHP stands for Analytic Hierarchy Process, and is a decision support tool. It can store complete decision hierarchies, use them to estimate the weights of criteria and sub-criteria and evaluate up to seven decision alternatives. AHP is also helpful to support group decision making; participants can input their individual judgments and a consolidated group result is calculated. With the AHP online system it can even define complete AHP hierarchies and evaluate alternatives. For both programs the results can now be exported as .csv (Comma Separated Values) files for further processing in spreadsheet programs [54].

Results and Analysis

Chapter 4

4.1 Result Calculation (Expert Opinion)

The data analysis has been made using Microsoft Excel Spread Sheet and AHP Online Software. All the data were administered in the matrix named as general criteria. The matrices have a diagonal of unity. The lower triangles were made just reversing the corresponding component using equation (1). We need to develop pair wise comparison matrix for Criteria. This matrix can be developed through expert opinion. After that we need to normalize the value of resulting matrix. Averaging the values in each row will give the corresponding rating. Final step is to calculating and checking the consistency ratio. Similar steps have to be done for Sub-criteria. Last step is to calculate global weight by calculating the weighted average rating for each decision alternative. Highest score will indicate the appropriate telecommunication technology for Bangladesh considering given criteria (Quality Features, Cost Factors and Ripple Effects) and sub-criteria (Licensing Cost, Upgradation Cost, Maintenance Cost, Data Rate, Spectral Efficiency & Mobility, Security Features, Integration Scalability, Environmental Issue, Economic Impact and Social Impact).

4.1.1 AHP Calculation for Expert-1

The matrix of pair wise comparisons represents the intensities of the expert's preference between individual pairs of alternatives. Let's construct a matrix for criteria's considering Expert-1 feedback in Table 6.

Table 6: Pair wise comparison matrix for Technology Selection criteria

Absolute judgments amongst Criteria	F1	F2	F3
Cost Component (F1)	1	1/8	1/4
Quality Factor (F2)	8	1	5
Ripple Effect (F3)	4	1/5	1

Normalized value and priorities of pair wise comparison have been calculated for above matrix for wireless technology selection using equations (2)-(5). Parallel Consistence ratio calculated through consistency ratio equations. Table 7 presents normalized values and priorities.

Table 7: Priorities vector for pair wise comparison matrix of criteria

Criteria	Priorities
Cost Component (F1)	0.067538
Quality Factor (F2)	0.733351
Ripple Effect (F3)	0.19911
Consistency Ratio (CR)	**0.098**

Matrix and calculation result presented in Table 6 and Table 7 respectively. These have been accomplished using AHP-OS. The online view of tool is presented in Figure 10.

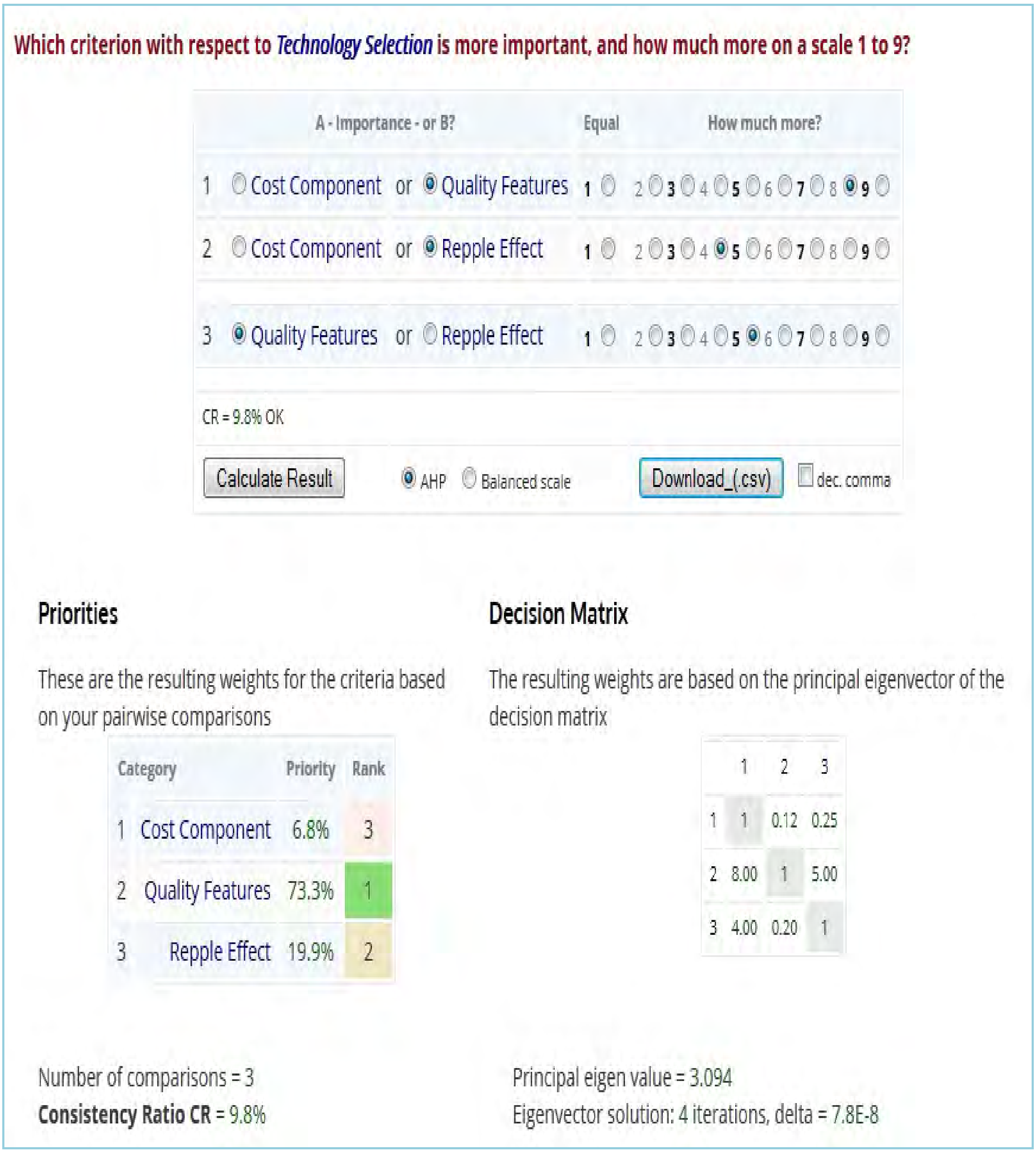

Figure 10: Priorities calculation for technology selection criteria using AHP-OS

Calculating priorities and consistency ratio (CR) for Sub-criteria under each criteria for selecting wireless communication technology.

Table 8: Pair wise comparison matrix for Technology Selection Cost sub-criteria

Absolute judgments amongst Sub-Criteria of Cost	F1A1	F1A2	F1A3
Licensing Cost (F1A1)	1	4	7
Upgradation Cost (F1A2)	1/4	1	4
Maintenance Cost (F1A3)	1/7	1/4	1

Table 9: Priorities vector for pair wise comparison matrix of Cost sub-criteria

Sub-Criteria of Cost	Priorities
Licensing Cost (F1A1)	0.6955
Upgradation Cost (F1A2)	0.229075
Maintenance Cost (F1A3)	0.075425
Consistency Ratio (CR)	**0.080**

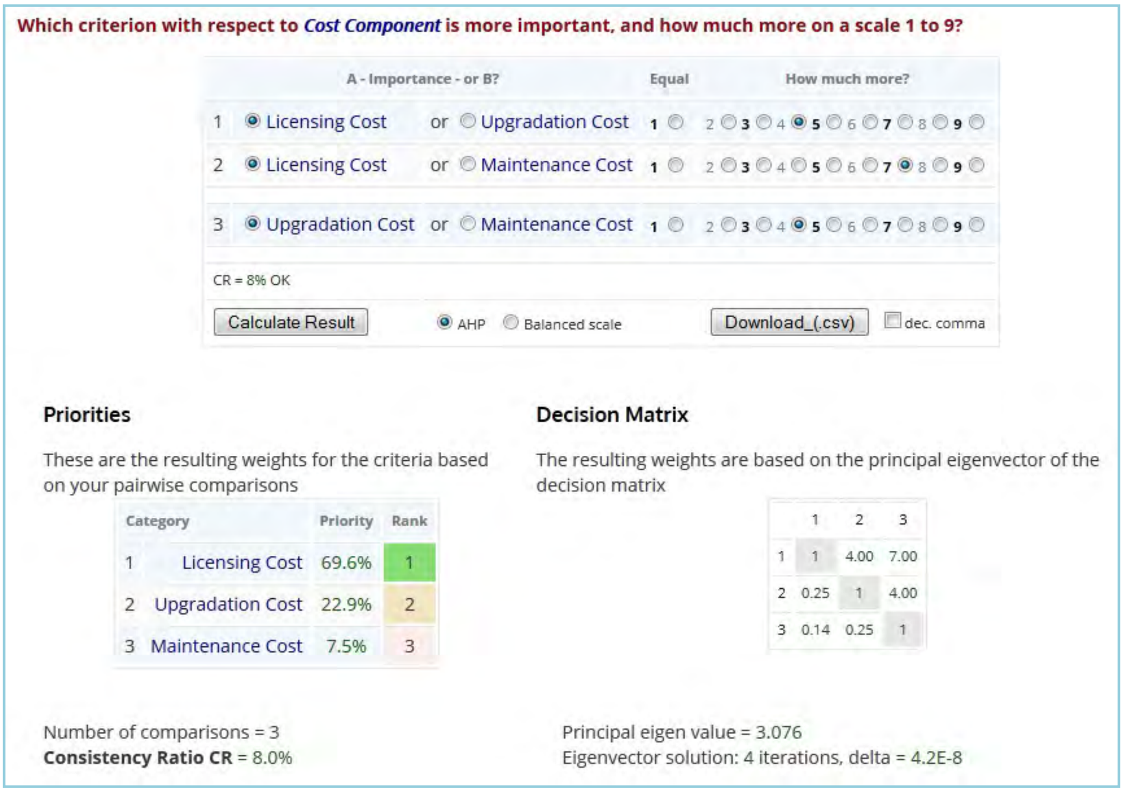

Figure 11: Priorities calculation for technology selection Cost sub-criteria using AHP-OS

Table 10: Pair wise comparison matrix for Technology Selection Quality sub-criteria

Absolute judgments amongst Sub-Criteria of Quality	F2B1	F2B2	F2B3	F2B4
Data Rate (F2B1)	1	4	8	8
Spectral Efficiency and Mobility (F2B2)	1/4	1	7	3
Security Features (F2B3)	1/8	1/7	1	1/4
Integration Scalability (F2B4)	1/8	1/3	4	1

Table 11: Priorities vector for pair wise comparison matrix of Quality sub-criteria

Sub-Criteria of Cost	Priorities
Data Rate (F2B1)	0.629167
Spectral Efficiency and Mobility (F2B2)	0.229797
Security Features (F2B3)	0.041873
Integration Scalability (F2B4)	0.099162
Consistency Ratio (CR)	**0.093**

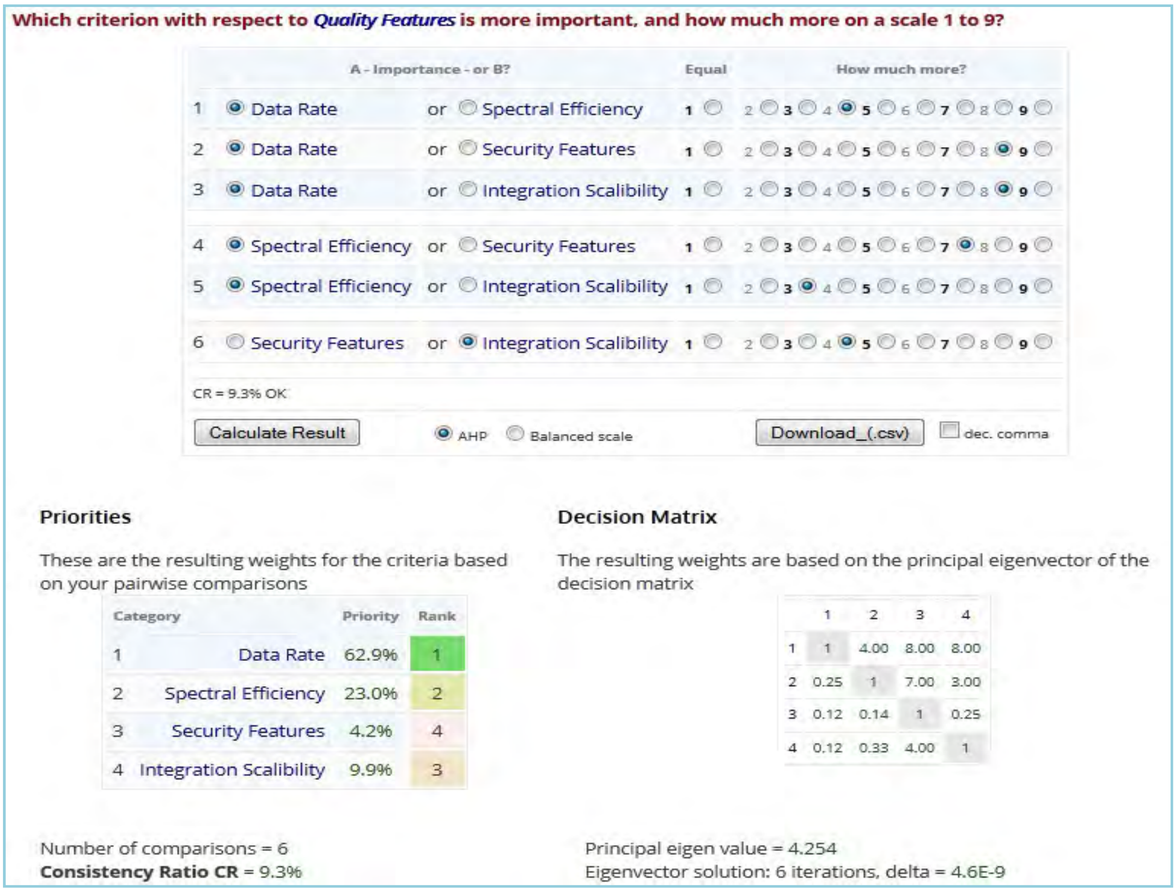

Figure 12: Priorities calculation for technology selection Quality sub-criteria using AHP-OS

Table 12: Pair wise comparison matrix for Technology Selection Ripple Effect sub-criteria

Absolute judgments amongst Sub-Criteria of Ripple Effect	F3C1	F3C2	F3C3
Environmental Issue (F3C1)	1	1/6	1/3
Economical Impact (F3C2)	6	1	5
Social Impact (F3C3)	3	1/5	1

Table 13: Priorities vector for pair wise comparison matrix of Ripple Effect sub-criteria

Sub-Criteria of Ripple Effect	Priorities
Environmental Issue (F3C1)	0.088068
Economical Impact (F3C2)	0.717214
Social Impact (F3C3)	0.194718
Consistency Ratio (CR)	**0.098**

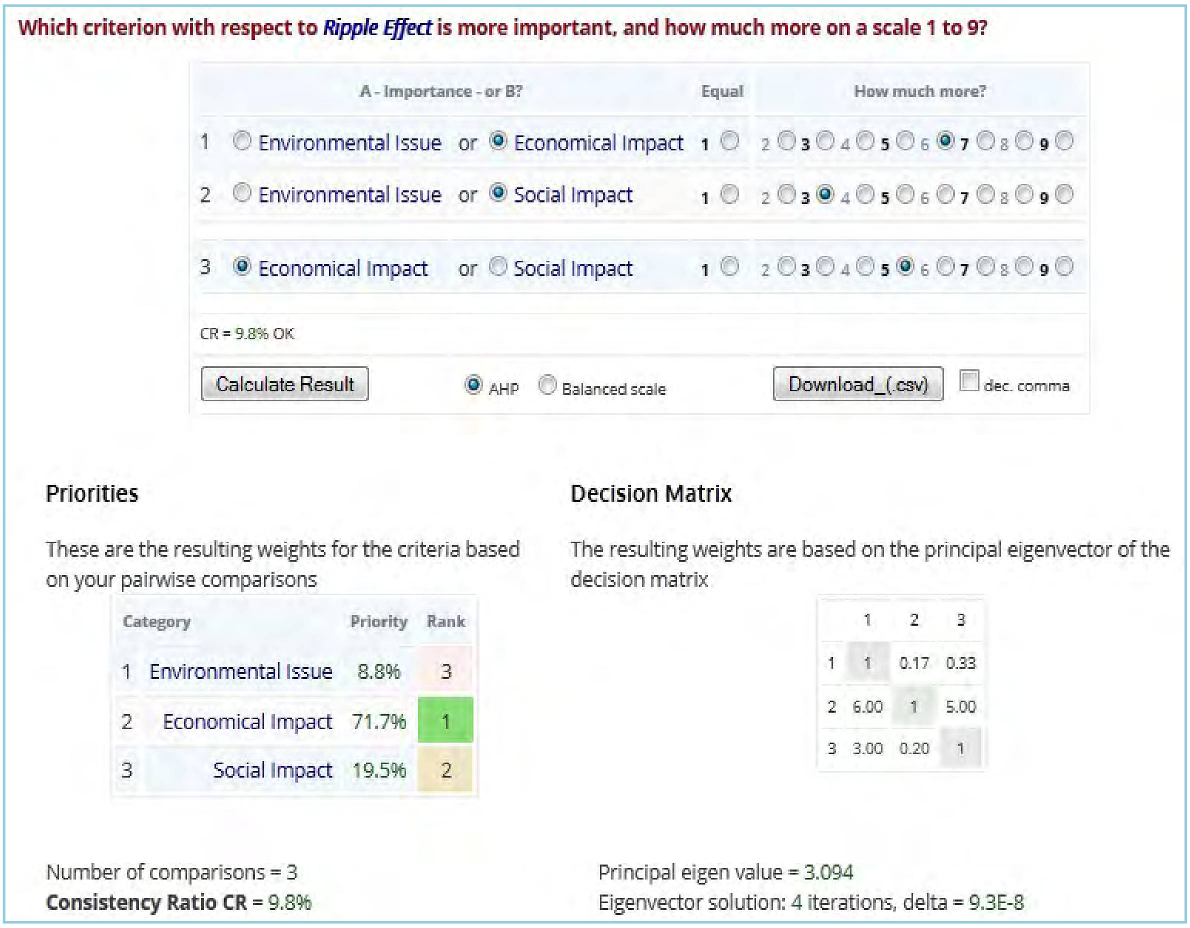

Figure 13: Priorities calculation for technology selection Ripple Effect sub-criteria using AHP-OS

Table 14: Pair wise comparison matrix for Technology Alternatives of Licensing Cost

Absolute judgments amongst Technology Alternatives of Licensing Cost (F1A1)	T1	T2	T3
2G Technology (T1)	1	1/4	4
3G Technology (T2)	4	1	7
4G Technology (T3)	1/4	1/7	1

Table 15: Priorities vector for pair wise comparison matrix of Technology Alternatives for Licensing Cost

Technology Alternatives of Licensing Cost (F1A1)	Priorities
2G Technology (T1)	0.229075
3G Technology (T2)	0.695500
4G Technology (T3)	0.075425
Consistency Ratio (CR)	**0.080**

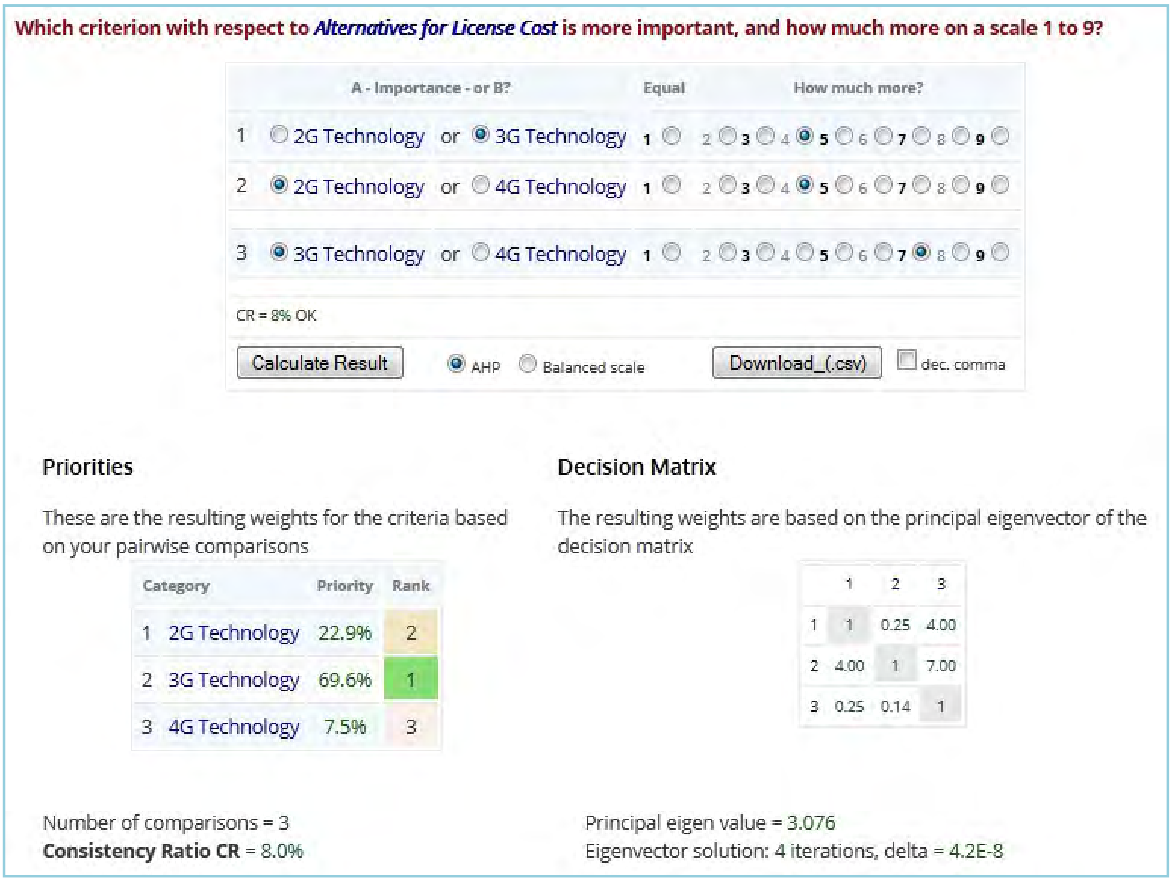

Figure 14: Priorities calculation for Technology Alternatives of Licensing Cost using AHP-OS

Table 16: Pair wise comparison matrix for Technology Alternatives of Upgradation Cost

Absolute judgments amongst Technology Alternatives of Upgradation Cost (F1A2)	T1	T2	T3
2G Technology (T1)	1	1/9	1/3
3G Technology (T2)	9	1	7
4G Technology (T3)	3	1/7	1

Table 17: Priorities vector for pair wise comparison matrix of Technology Alternatives for Upgradation Cost

Technology Alternatives of Licensing Cost (F1A2)	Priorities
2G Technology (T1)	0.065789
3G Technology (T2)	0.785378
4G Technology (T3)	0.148833
Consistency Ratio (CR)	**0.084**

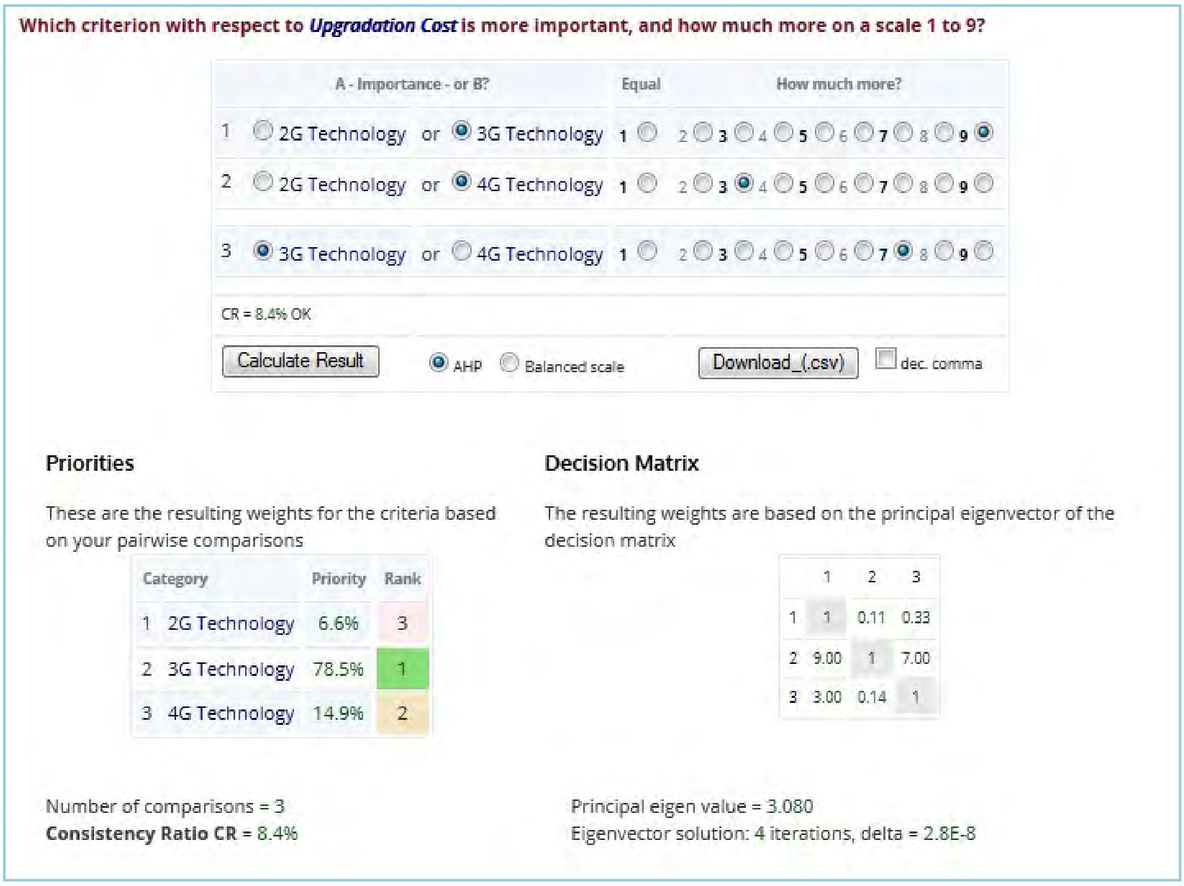

Figure 15: Priorities calculation for Technology Alternatives of Upgradation Cost using AHP-OS

Table 18: Pair wise comparison matrix for Technology Alternatives of Maintenance Cost

Absolute judgments amongst Technology Alternatives of Maintenance Cost (F1A3)	T1	T2	T3
2G Technology (T1)	1	1/8	1/4
3G Technology (T2)	8	1	5
4G Technology (T3)	4	1/5	1

Table 19: Priorities vector for pair wise comparison matrix of Technology Alternatives for Maintenance Cost

Technology Alternatives of Licensing Cost (F1A3)	Priorities
2G Technology (T1)	0.067538
3G Technology (T2)	0.733351
4G Technology (T3)	0.199110
Consistency Ratio (CR)	**0.098**

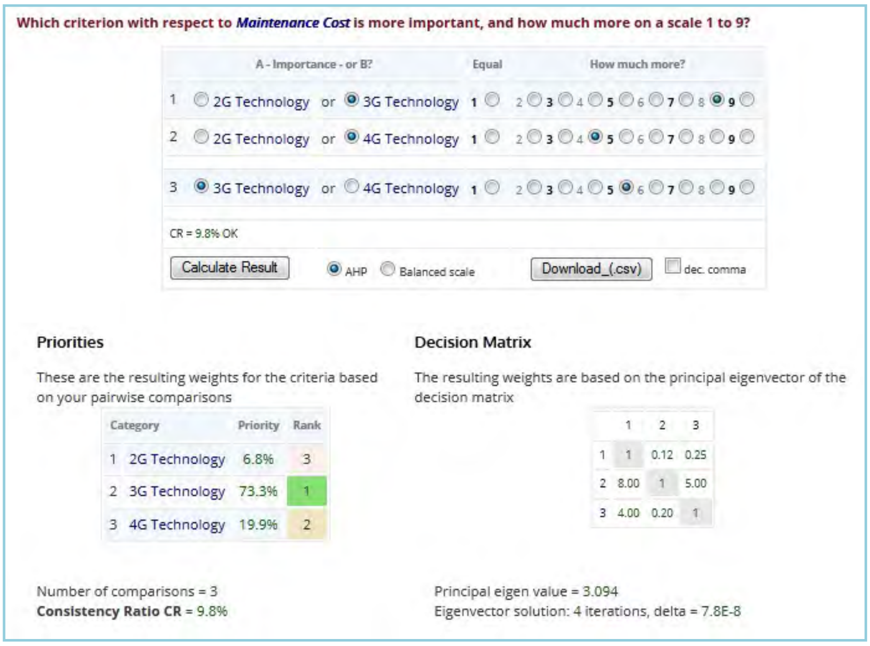

Figure 16: Priorities calculation for Technology Alternatives of Maintenance Cost using AHP-OS

Same calculations have been conducted for Technology Alternatives of Data Rate (F2B1), Spectral Efficiency & Mobility (F2B2), Security Features (F2B3), Integration Scalability (F2B4), Environmental Issue (F3C1), Economic Impact (F3C2) and Social Impact (F3C3). These calculations not been presented here as those are calculated same above manners. But matrix priorities for these Technology Alternatives has shown and considered for the final calculation. Finally, alternatives are scored by checking off their respective ratings under each criterion and summing these ratings for all criteria.

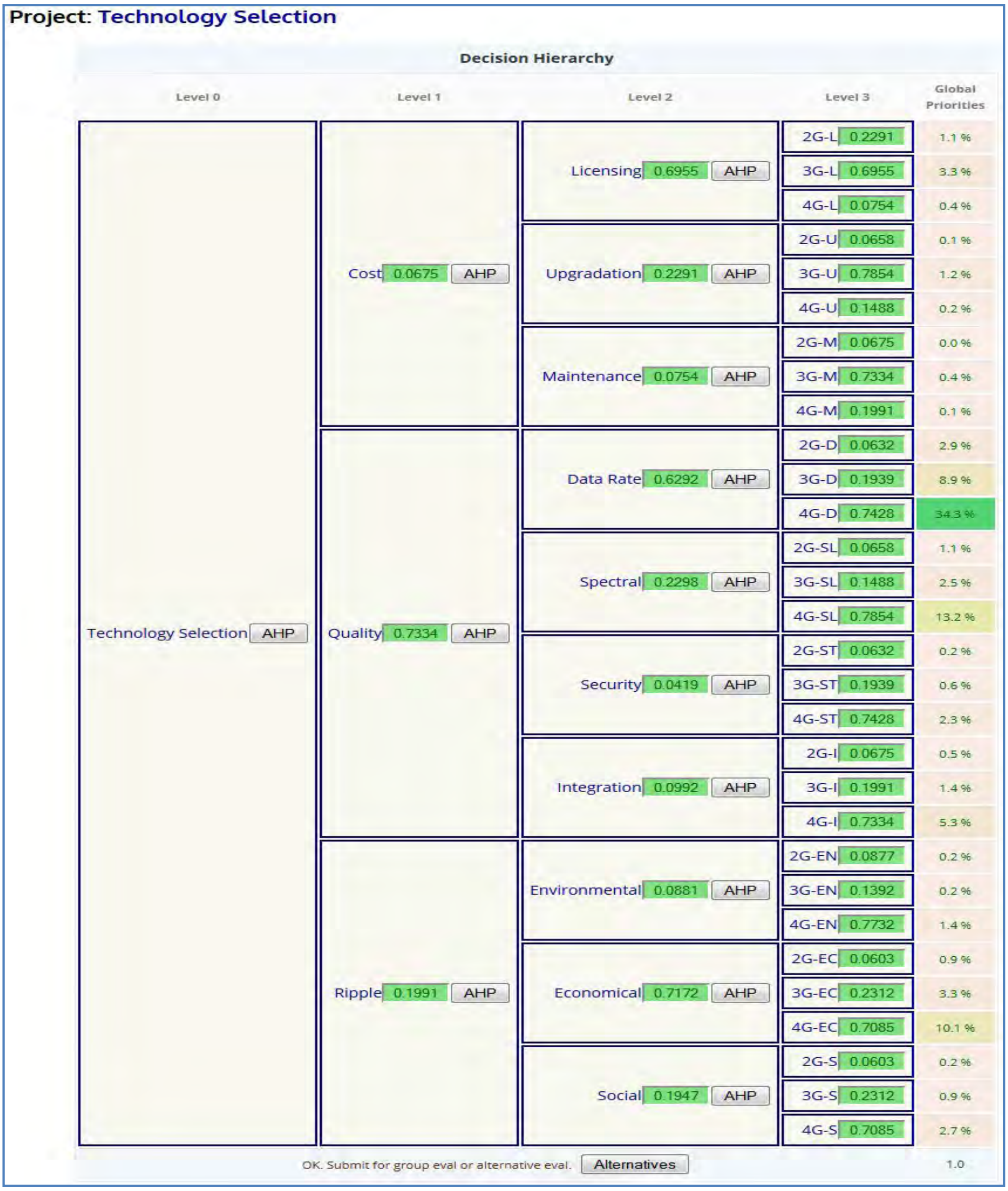

Figure 17: Priorities for Telecommunication Technology Selection Alternatives for expert-1 using AHP-OS

From above calculations by AHP-OS in Figure 17, I have calculated final result for Expert-1 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. Calculating all priorities and weight, I have prepared the Table20 for the final score of telecommunication technology selection.

Table 20: Global weights of the Telecommunication technology alternatives and final ranking (Expert-1)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.072	7.20%	3
3G (UMTS/HSDPA/HSPA)	0.227	22.70%	2
4G (LTE/WiMAX)	**0.701**	**70.10%**	**1**

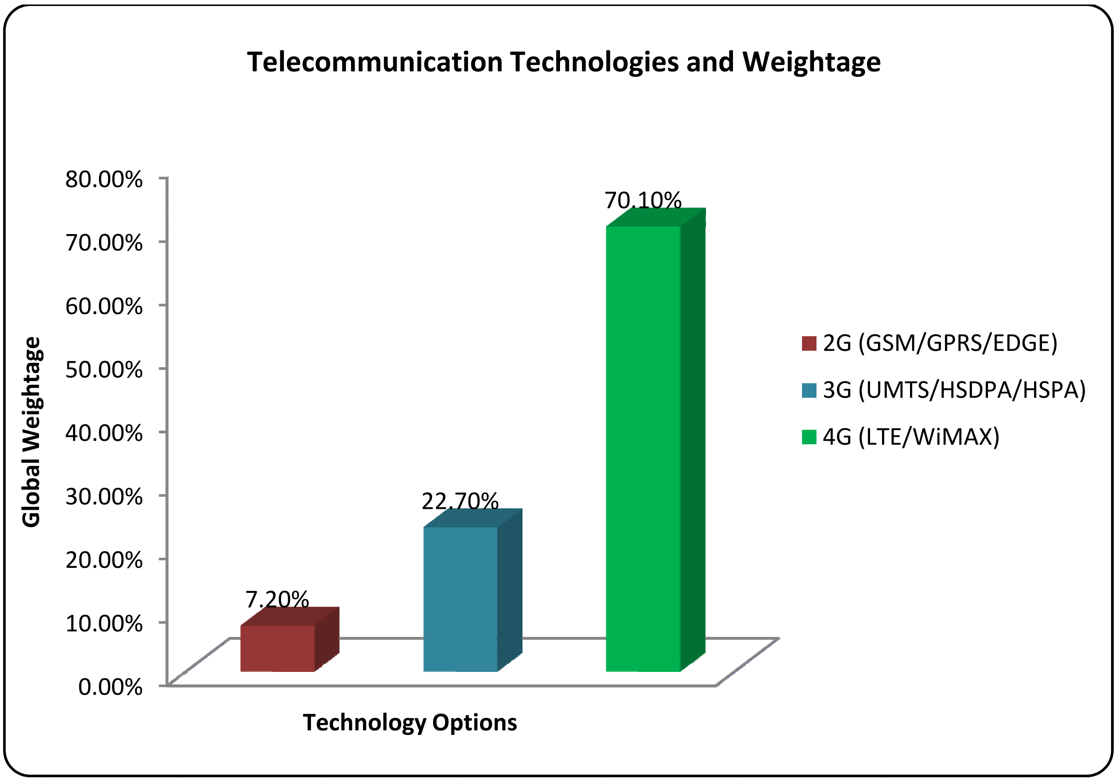

Figure 18: The result of telecommunication technology alternatives from expert-1 feedback

From Figure 17, the results of the empirical analysis show that the expert-1 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 20 and Figure 18 show that expert-1 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 70.10% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 22.70% and 2G (GSM/GPRS/EDGE) technology with 7.20%.

4.1.2 AHP Calculation for Expert-2

Similar data analysis has been conducted by AHP-OS tool for the expert-2 feedback. Detail result presented in Figure 19 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

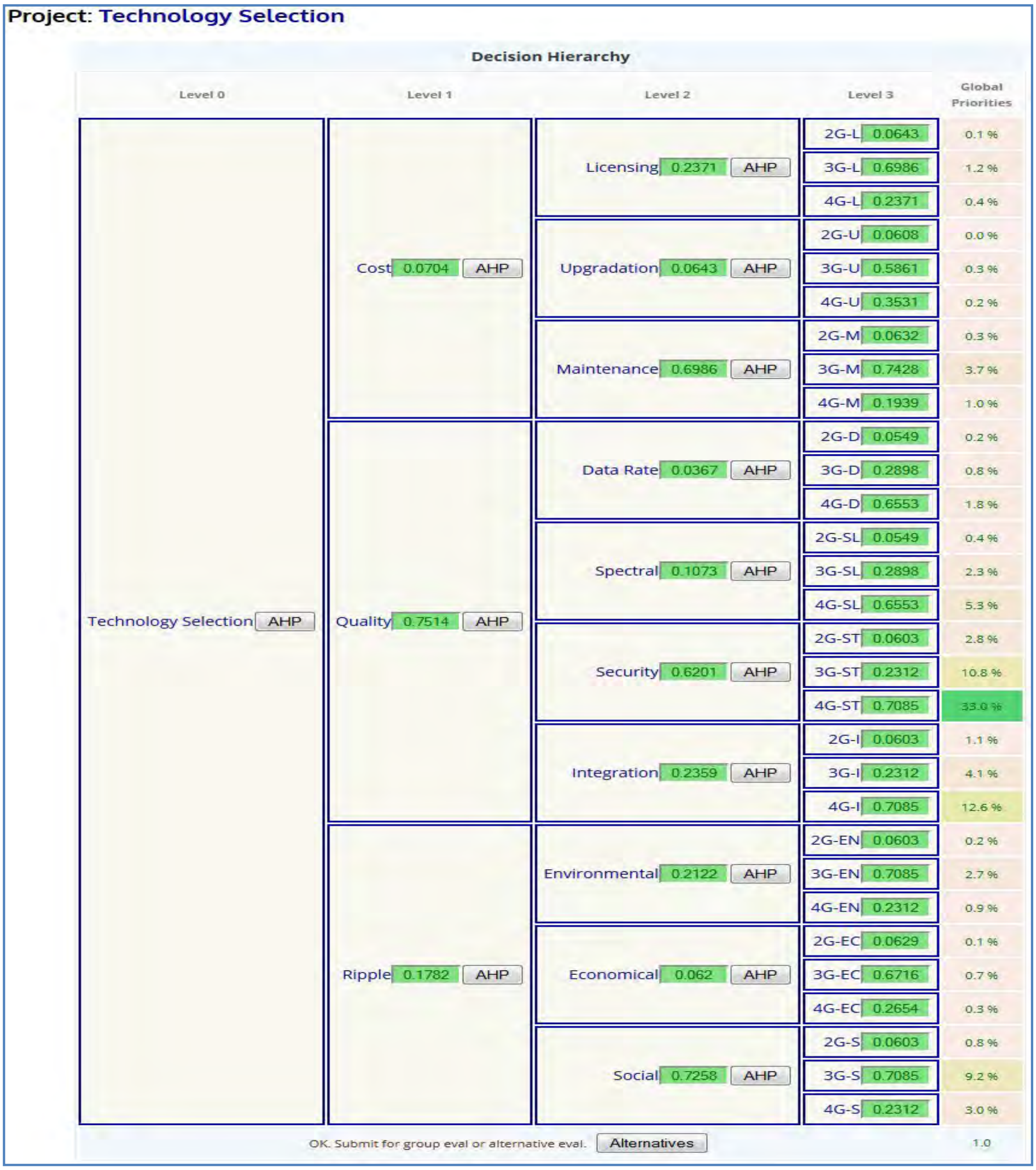

Figure 19: Priorities for Telecommunication Technology Selection Alternatives for expert-2 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for Expert-2 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 21 for the final score of telecommunication technology selection.

Table 21: Global weights of the Telecommunication technology alternatives and final ranking (Expert-2)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.060	6.00%	3
3G (UMTS/HSDPA/HSPA)	0.356	35.60%	2
4G (LTE/WiMAX)	**0.584**	**58.40%**	**1**

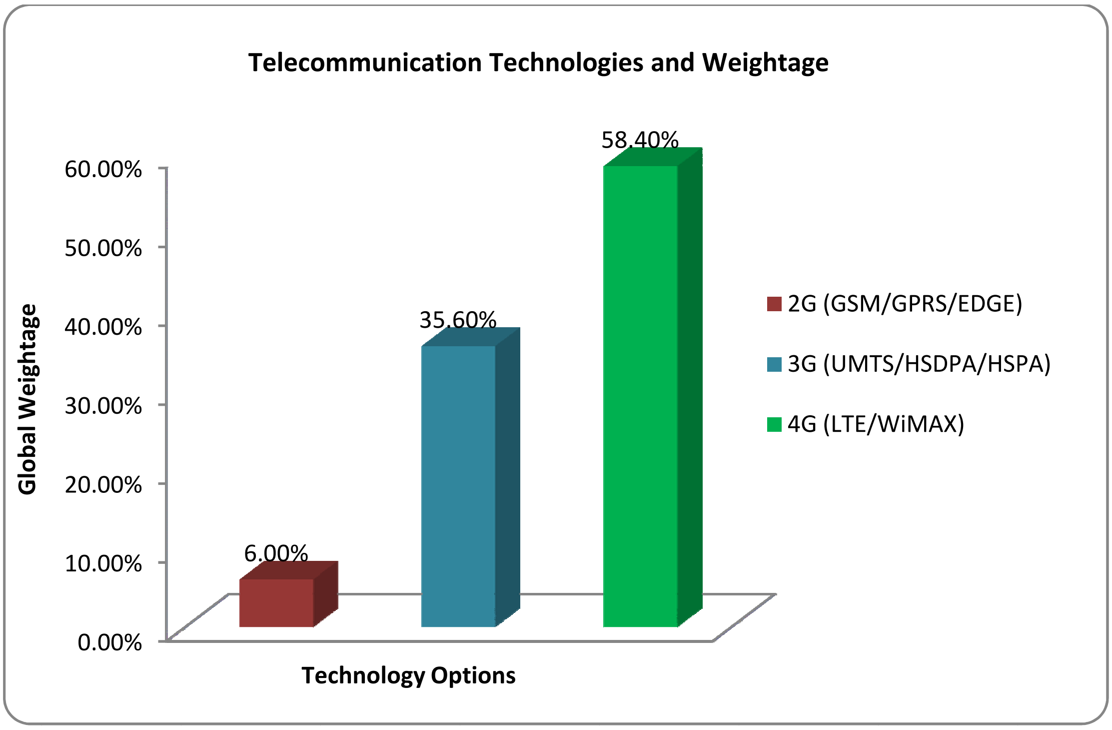

Figure 20: The result of telecommunication technology alternatives from expert-2 feedback

From Figure 19, the results of the empirical analysis show that the expert-2 preferred the Quality Features criterion as most important criterion and Security Features as most important sub-criteria. Table 21 and Figure 20 show that expert-2 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 58.40% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 35.60% and 2G (GSM/GPRS/EDGE) technology with 6.00%.

4.1.3 AHP Calculation for Expert-3

Similar data analysis has been conducted by AHP-OS tool for the expert-3 feedback. Detail result presented in Figure 21 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

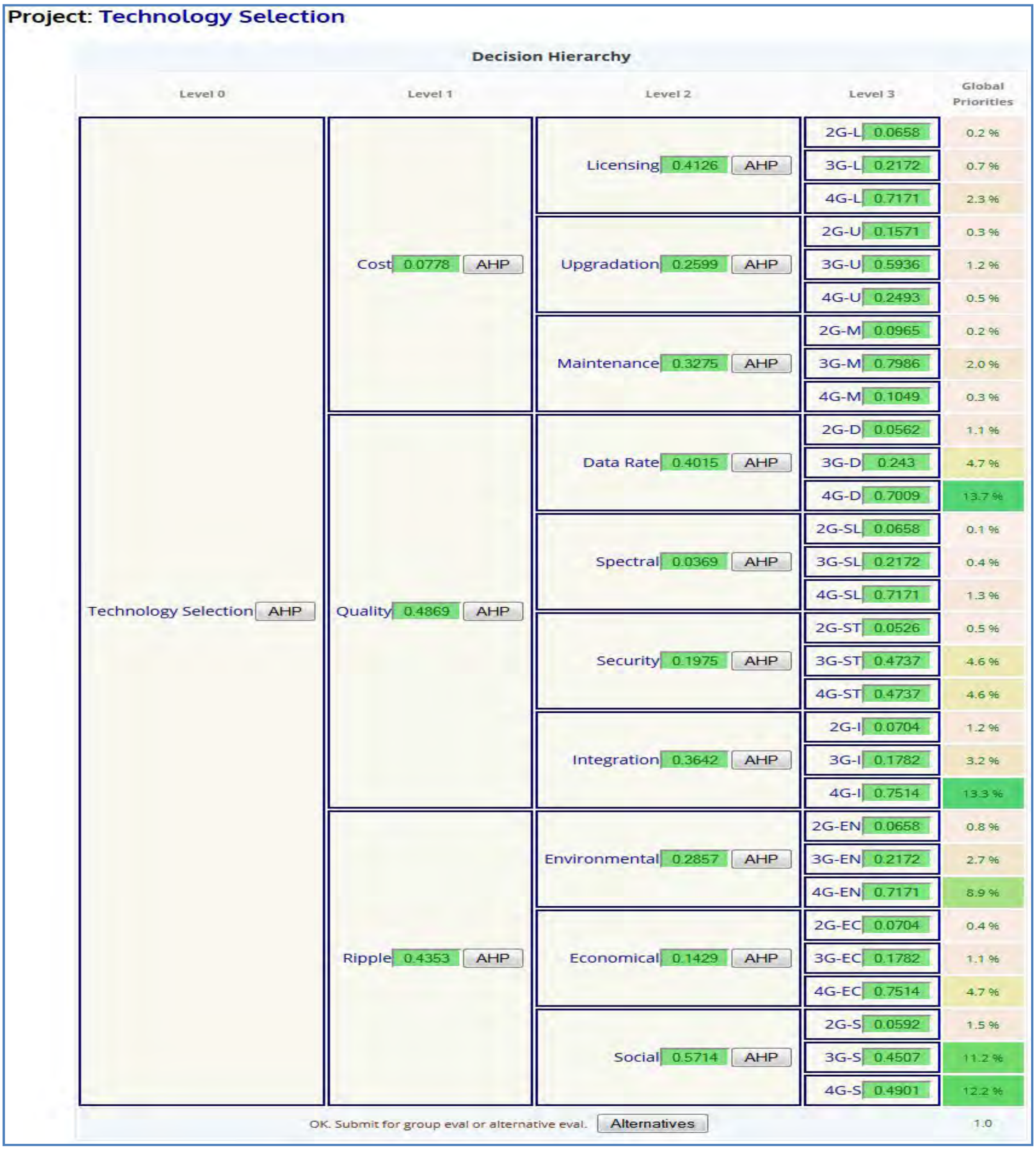

Figure 21: Priorities for Telecommunication Technology Selection Alternatives for expert-3 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for expert-3 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 22 for the final score of telecommunication technology selection.

Table 22: Global weights of the Telecommunication technology alternatives and final ranking (Expert-3)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.063	6.30%	3
3G (UMTS/HSDPA/HSPA)	0.318	31.80%	2
4G (LTE/WiMAX)	**0.619**	**61.90%**	**1**

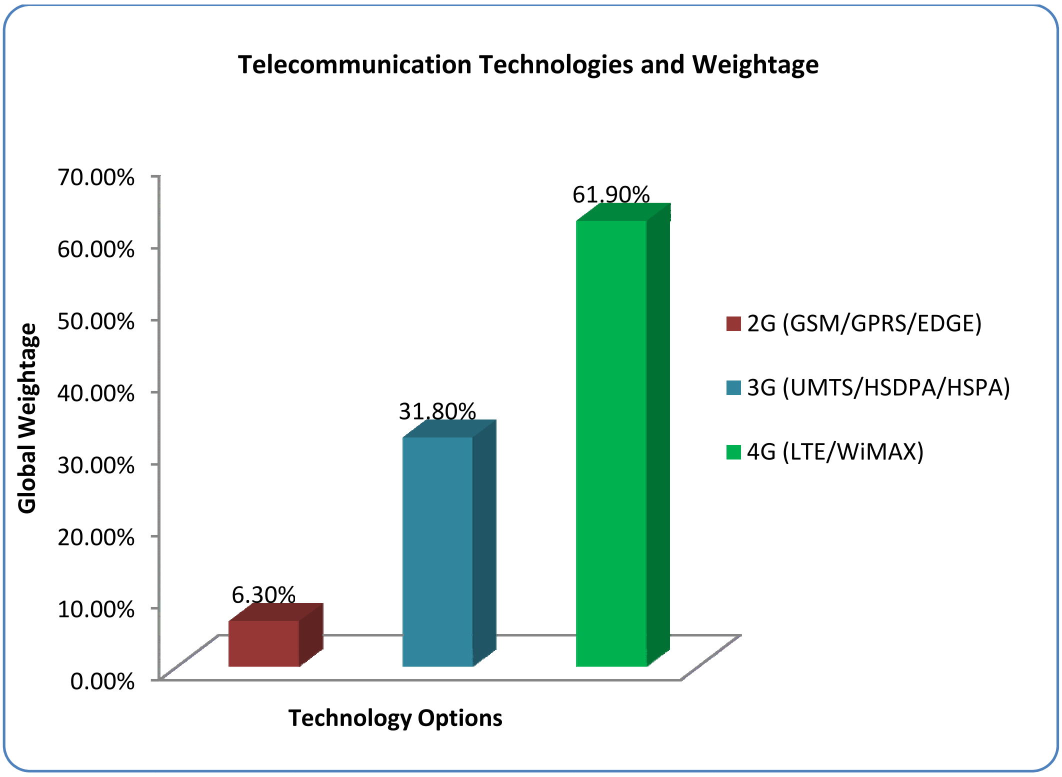

Figure 22: The result of telecommunication technology alternatives from expert-3 feedback

From Figure 21, the results of the empirical analysis show that the expert-3 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 22 and Figure 22 show that expert-3 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 61.90% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 31.80% and 2G (GSM/GPRS/EDGE) technology with 6.30%.

4.1.4 AHP Calculation for Expert-4

Similar data analysis has been conducted by AHP-OS tool for the expert-4 feedback. Detail result presented in Figure 23 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

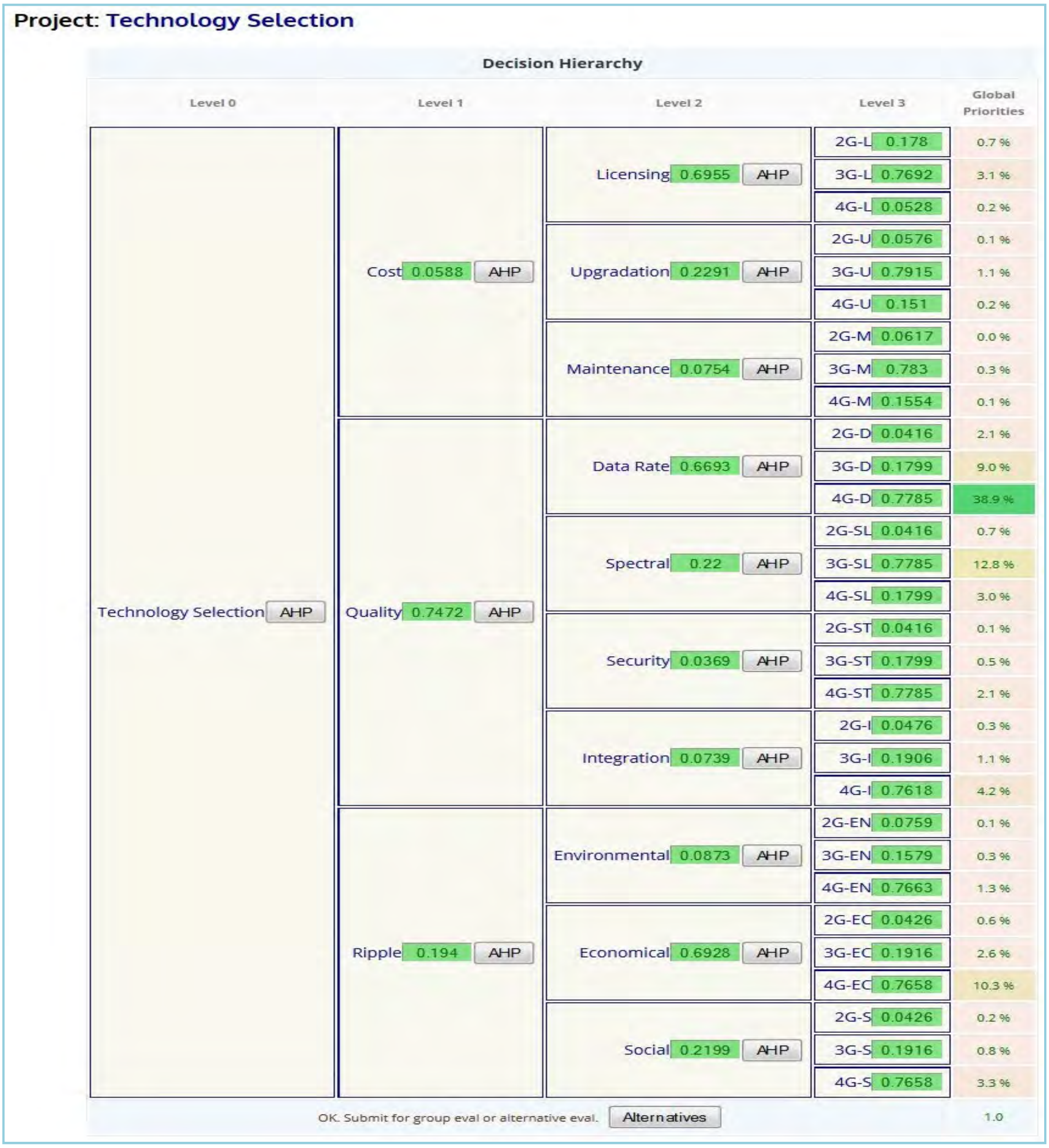

Figure 23: Priorities for Telecommunication Technology Selection Alternatives for expert-4 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for expert-4 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 23 for the final score of telecommunication technology selection.

Table 23: Global weights of the Telecommunication technology alternatives and final ranking (Expert-4)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.049	4.90%	3
3G (UMTS/HSDPA/HSPA)	0.316	31.60%	2
4G (LTE/WiMAX)	**0.635**	**63.50%**	**1**

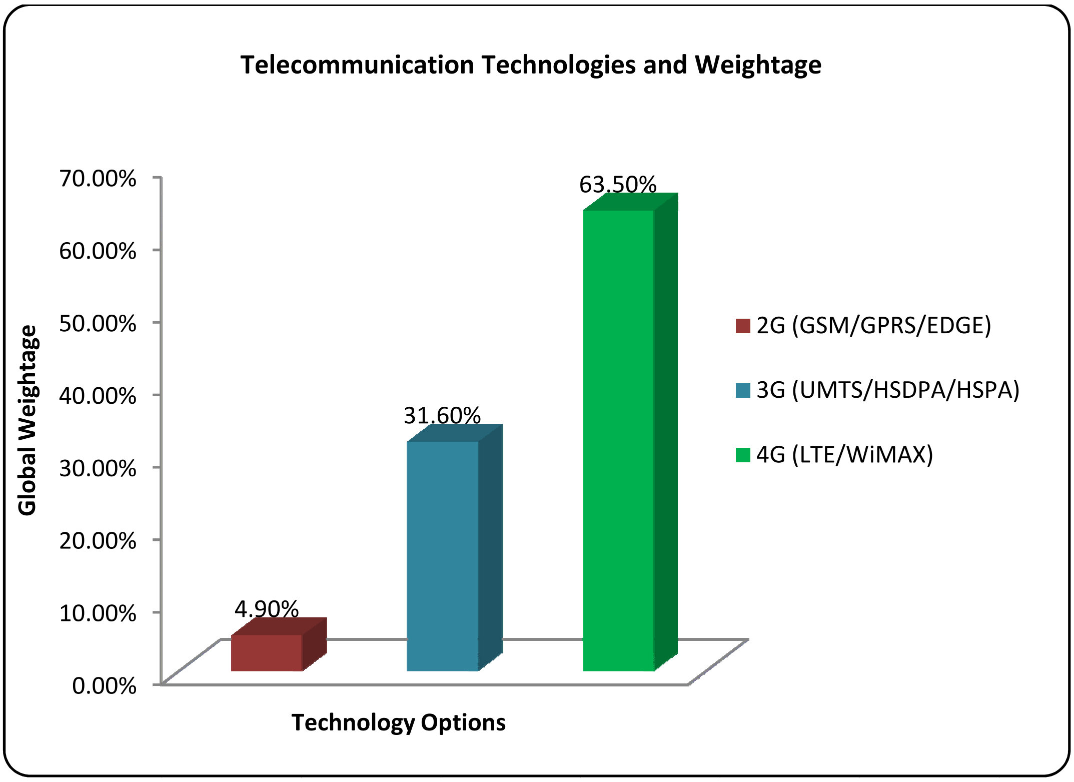

Figure 24: The result of telecommunication technology alternatives from expert-4 feedback

From Figure 23, the results of the empirical analysis show that the expert-4 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 23 and Figure 24 show that expert-4 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 63.50% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 31.60% and 2G (GSM/GPRS/EDGE) technology with 4.90%.

4.1.5 AHP Calculation for Expert-5

Similar data analysis has been conducted by AHP-OS tool for the expert-5 feedback. Detail result presented in Figure 25 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

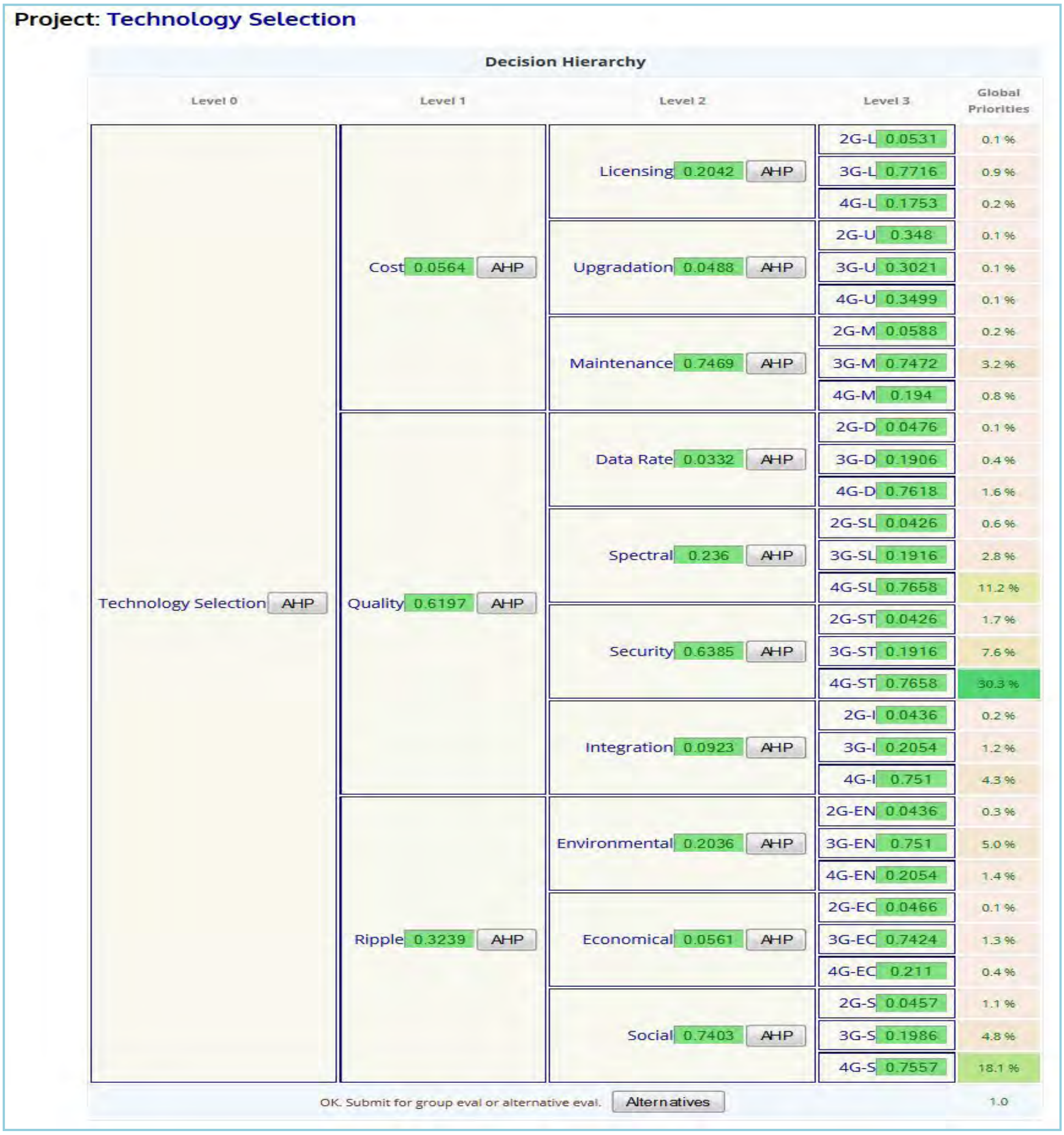

Figure 25: Priorities for Telecommunication Technology Selection Alternatives for expert-5 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for Expert-5 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 24 for the final score of telecommunication technology selection.

Table 24: Global weights of the Telecommunication technology alternatives and final ranking (Expert-5)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.045	4.50%	3
3G (UMTS/HSDPA/HSPA)	0.272	27.20%	2
4G (LTE/WiMAX)	**0.683**	**68.30%**	**1**

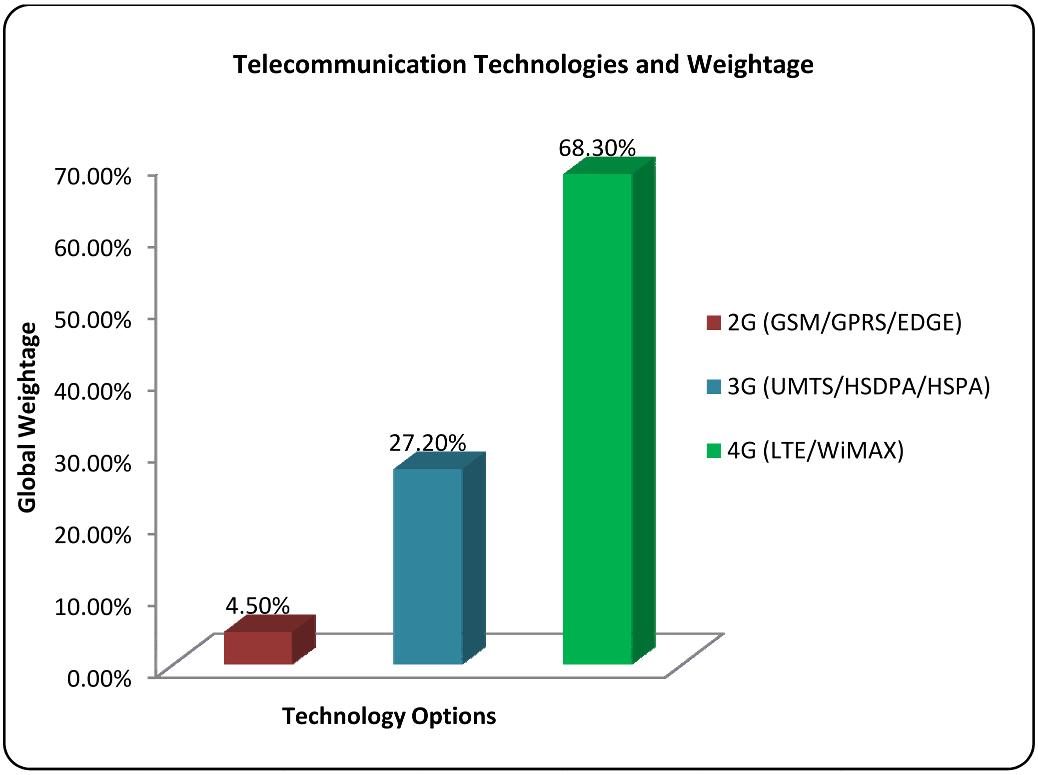

Figure 26: The result of telecommunication technology alternatives from expert-5 feedback

From Figure 25, the results of the empirical analysis show that the expert-5 preferred the Quality Features criterion as most important criterion and Security Features as most important sub-criteria. Table 24 and Figure 26 show that expert-5 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 68.30% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 27.20% and 2G (GSM/GPRS/EDGE) technology with 4.50%.

4.1.6 AHP Calculation for Expert-6

Similar data analysis has been conducted by AHP-OS tool for the expert-6 feedback. Detail result presented in Figure 27 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

Figure 27: Priorities for Telecommunication Technology Selection Alternatives for expert-6 using AHP-OS

From above calculations by AHP-OS I have calculated final the result for expert-6 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 25 for the final score of telecommunication technology selection.

Table 25: Global weights of the Telecommunication technology alternatives and final ranking (Expert-6)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.101	10.10%	3
3G (UMTS/HSDPA/HSPA)	0.263	26.30%	2
4G (LTE/WiMAX)	**0.636**	**63.60%**	**1**

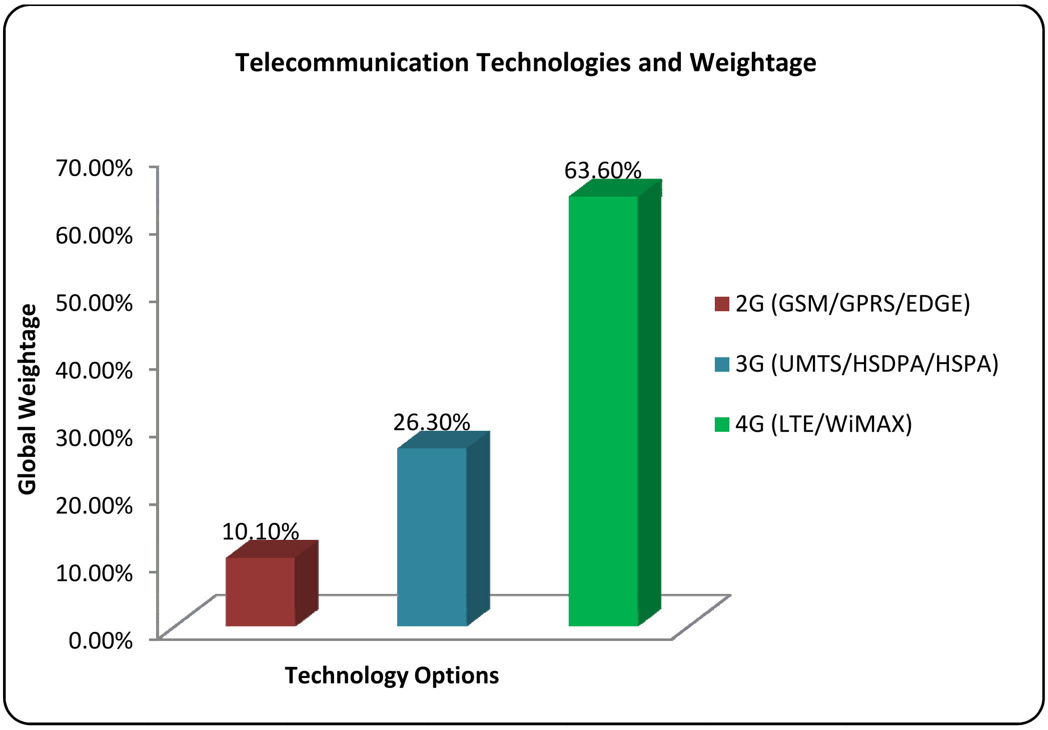

Figure 28: The result of telecommunication technology alternatives from expert-6 feedback

From Figure 27, the results of the empirical analysis show that the expert-6 preferred the Quality Features criterion as most important criterion and Spectral Efficiency & Mobility as most important sub-criteria. Table 25 and Figure 28 show that expert-6 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 63.60% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 26.30% and 2G (GSM/GPRS/EDGE) technology with 10.10%.

4.1.7 AHP Calculation for Expert-7

Similar data analysis has been conducted by AHP-OS tool for the expert-7 feedback. Detail result presented in Figure 29 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

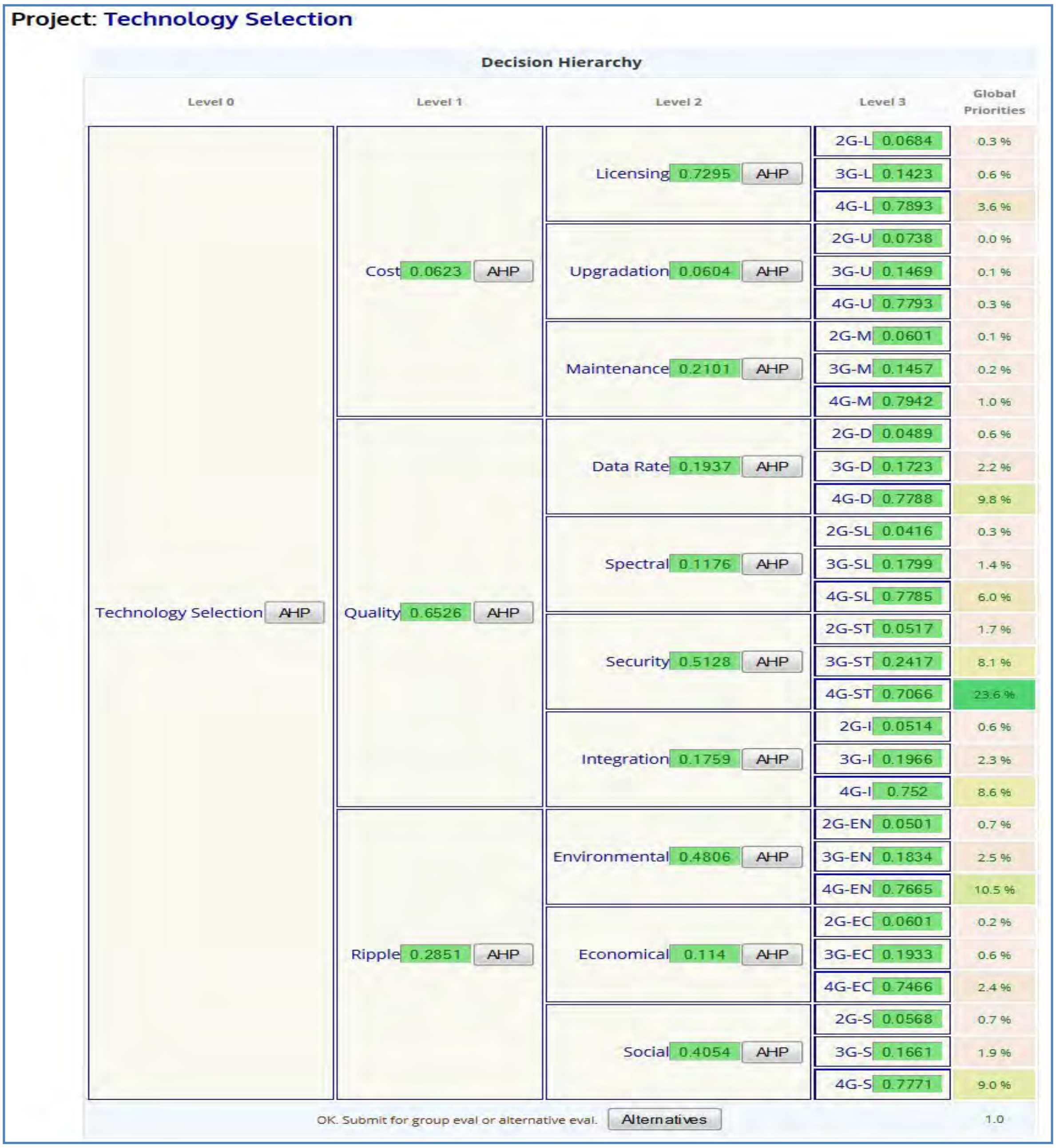

Figure 29: Priorities for Telecommunication Technology Selection Alternatives for expert-7 using AHP-OS

From above calculations by AHP-OS I have calculated final the result for expert-7 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 26 for the final score of telecommunication technology selection.

Table 26: Global weights of the Telecommunication technology alternatives and final ranking (Expert-7)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.052	5.2%	3
3G (UMTS/HSDPA/HSPA)	0.213	21.30%	2
4G (LTE/WiMAX)	**0.735**	**73.50%**	**1**

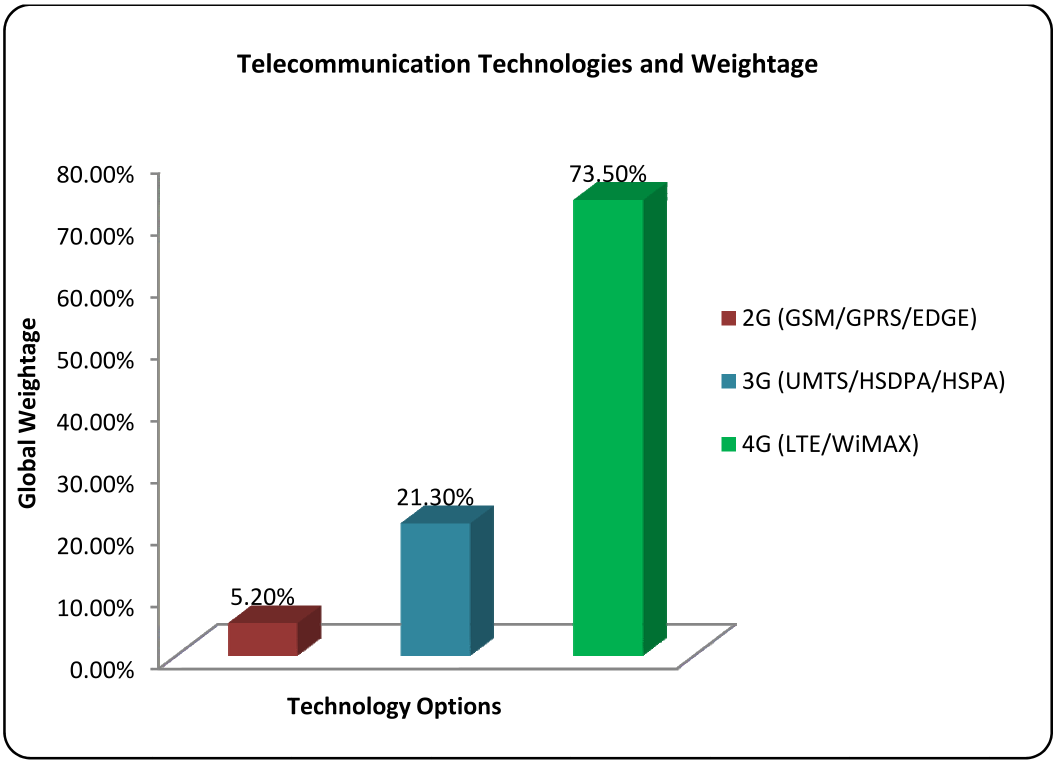

Figure 30: The result of telecommunication technology alternatives from expert-7 feedback

From Figure 29, the results of the empirical analysis show that the expert-7 preferred the Quality Features criterion as most important criterion and Security Features as most important sub-criteria. Table 26 and Figure 30 show that expert-7 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 73.50% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 21.30% and 2G (GSM/GPRS/EDGE) technology with 5.20%.

4.1.8 AHP Calculation for Expert-8

Similar data analysis has been conducted by AHP-OS tool for the expert-8 feedback. Detail result presented in Figure 31 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

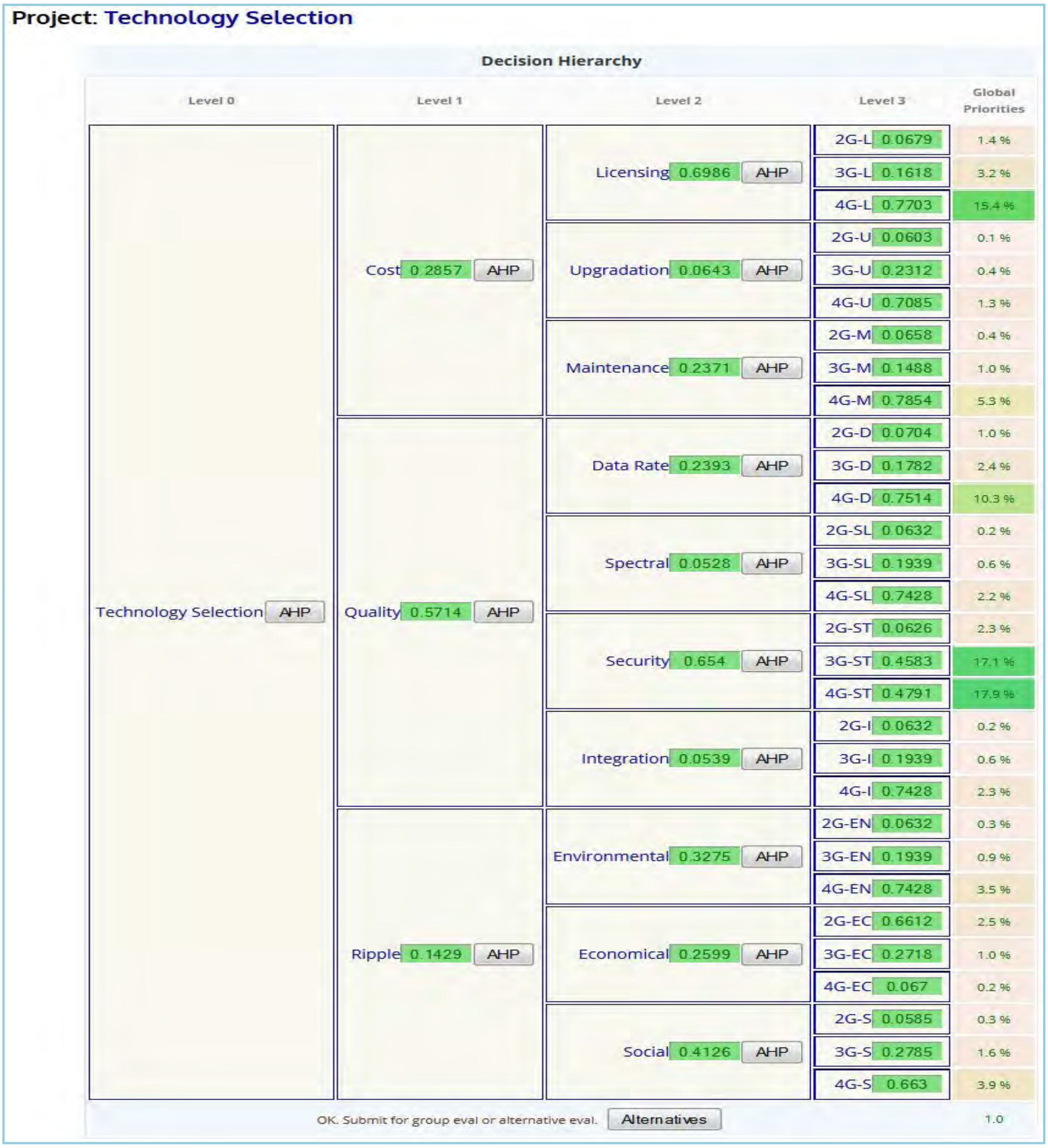

Figure 31: Priorities for Telecommunication Technology Selection Alternatives for expert-8 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for expert-8 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 27 for the final score of telecommunication technology selection.

Table 27: Global weights of the Telecommunication technology alternatives and final ranking (Expert-8)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.087	8.70%	3
3G (UMTS/HSDPA/HSPA)	0.289	28.90%	2
4G (LTE/WiMAX)	**0.624**	**62.40%**	**1**

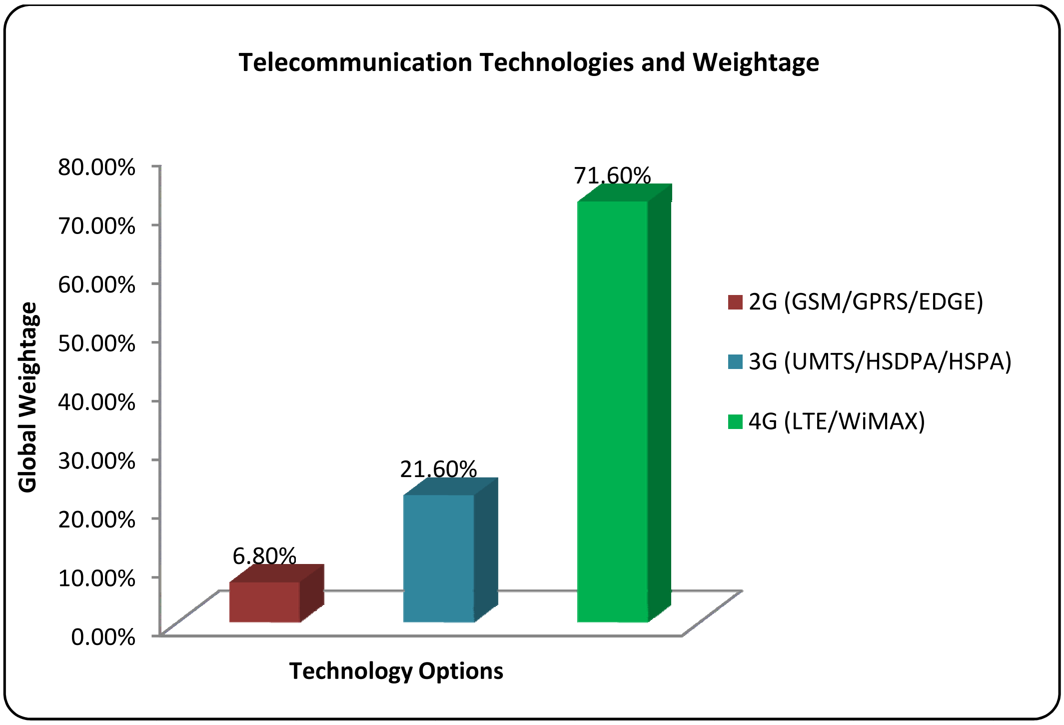

Figure 32: The result of telecommunication technology alternatives from expert-8 feedback

From Figure 31, the results of the empirical analysis show that the expert-8 preferred the Quality Features criterion as most important criterion and Security Features as most important sub-criteria. Table 27 and Figure 32 show that expert-8 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 62.40% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 28.90% and 2G (GSM/GPRS/EDGE) technology with 8.70%.

4.1.9 AHP Calculation for Expert-9

Similar data analysis has been conducted by AHP-OS tool for the expert-9 feedback. Detail result presented in Figure 33 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

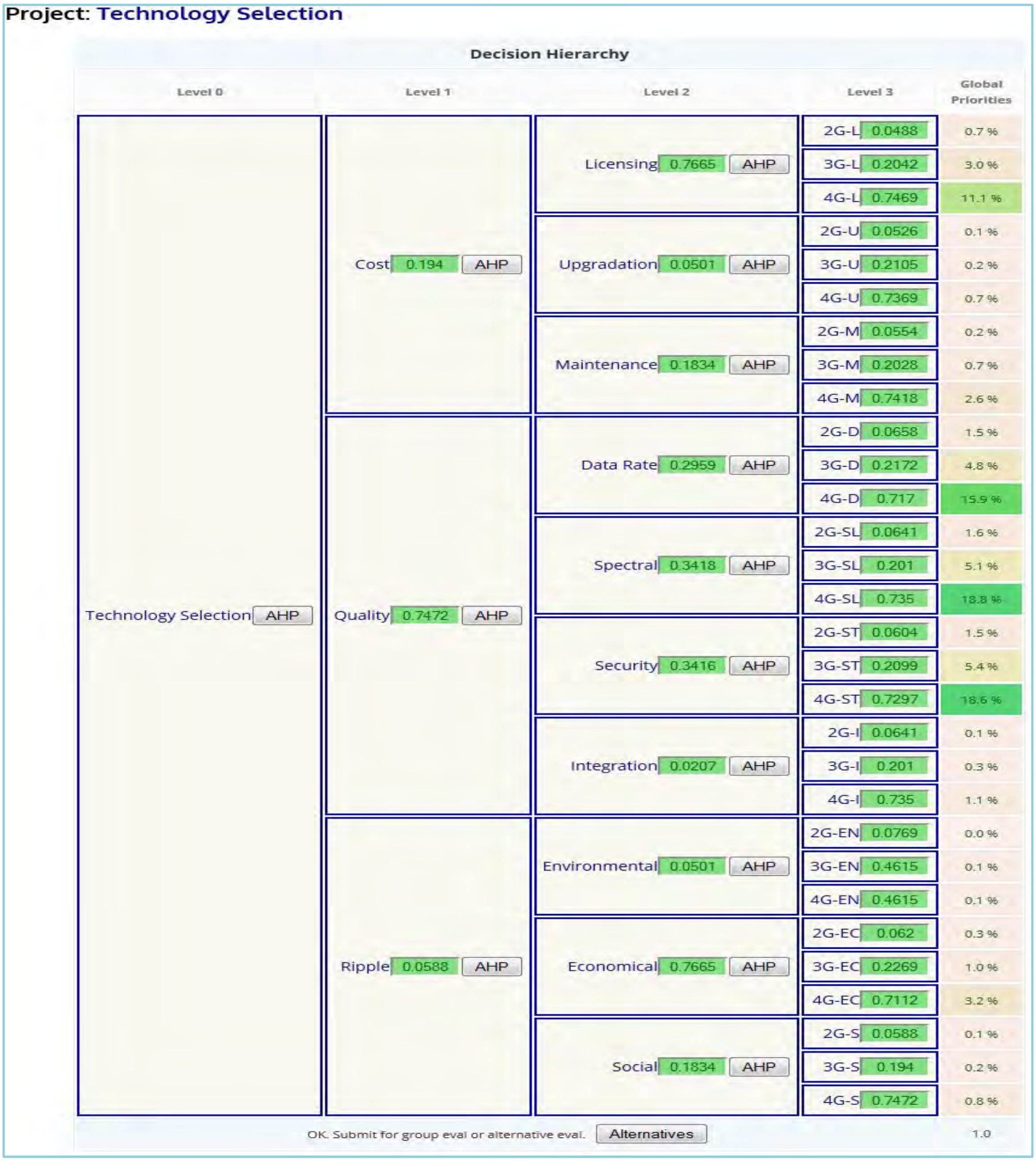

Figure 33: Priorities for Telecommunication Technology Selection Alternatives for expert-9 using AHP-OS

From above calculations by AHP-OS, I have calculated final the result for expert-9 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 28 for the final score of telecommunication technology selection.

Table 28: Global weights of the Telecommunication technology alternatives and final ranking (Expert-9)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.061	6.10%	3
3G (UMTS/HSDPA/HSPA)	0.208	20.80%	2
4G (LTE/WiMAX)	**0.731**	**73.10%**	**1**

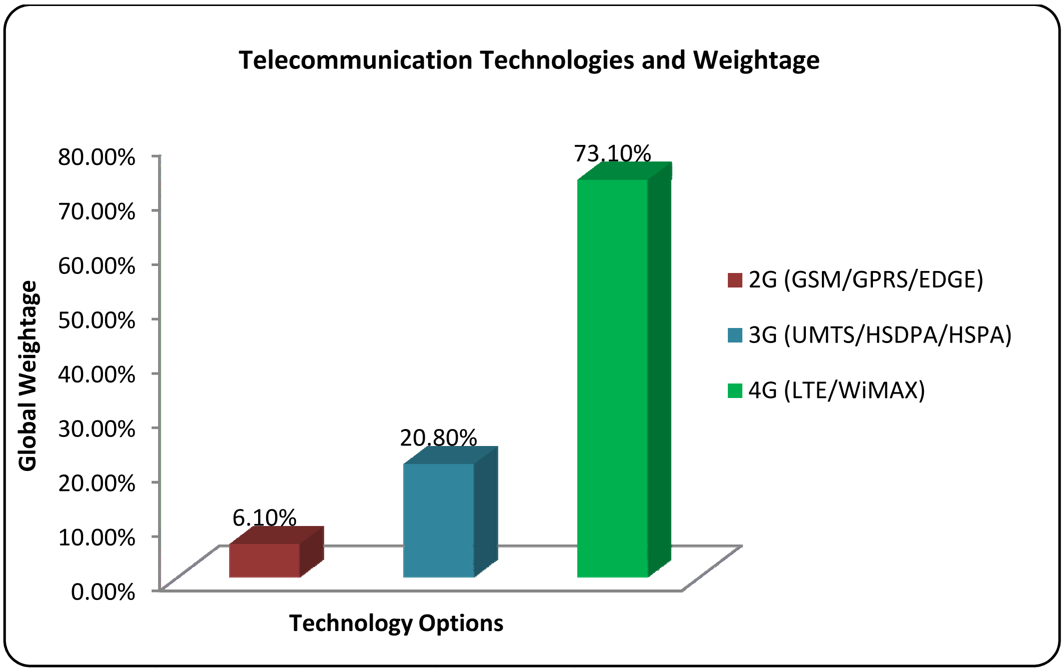

Figure 34: The result of telecommunication technology alternatives from expert-9 feedback

From Figure 33, the results of the empirical analysis show that the expert-9 preferred the Quality Features criterion as most important criterion and Spectral Efficiency & Mobility as most important sub-criteria. Table 28 and Figure 34 show that expert-9 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 73.10% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 20.80% and 2G (GSM/GPRS/EDGE) technology with 6.10%.

4.1.10 AHP Calculation for Expert-10

Similar data analysis has been conducted by AHP-OS tool for the expert-10 feedback. Detail result presented in Figure 35 for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

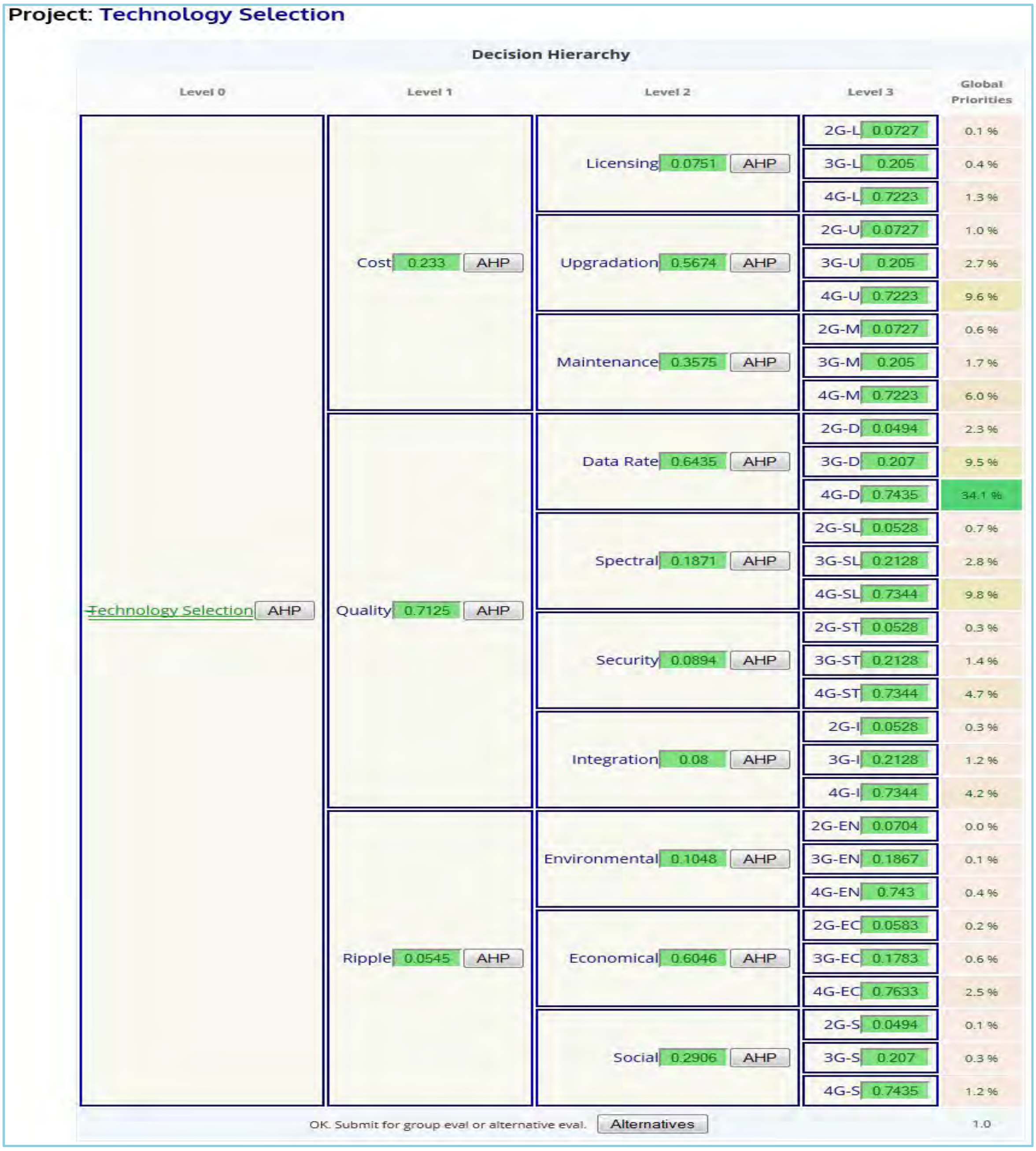

Figure 35: Priorities for Telecommunication Technology Selection Alternatives for expert-10 using AHP-OS

From above calculations by AHP-OS, I have calculated the final result for expert-10 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 27 for the final score of telecommunication technology selection.

Table 29: Global weights of the Telecommunication technology alternatives and final ranking (Expert-10)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.056	5.60%	3
3G (UMTS/HSDPA/HSPA)	0.207	20.70%	2
4G (LTE/WiMAX)	**0.737**	**73.70%**	**1**

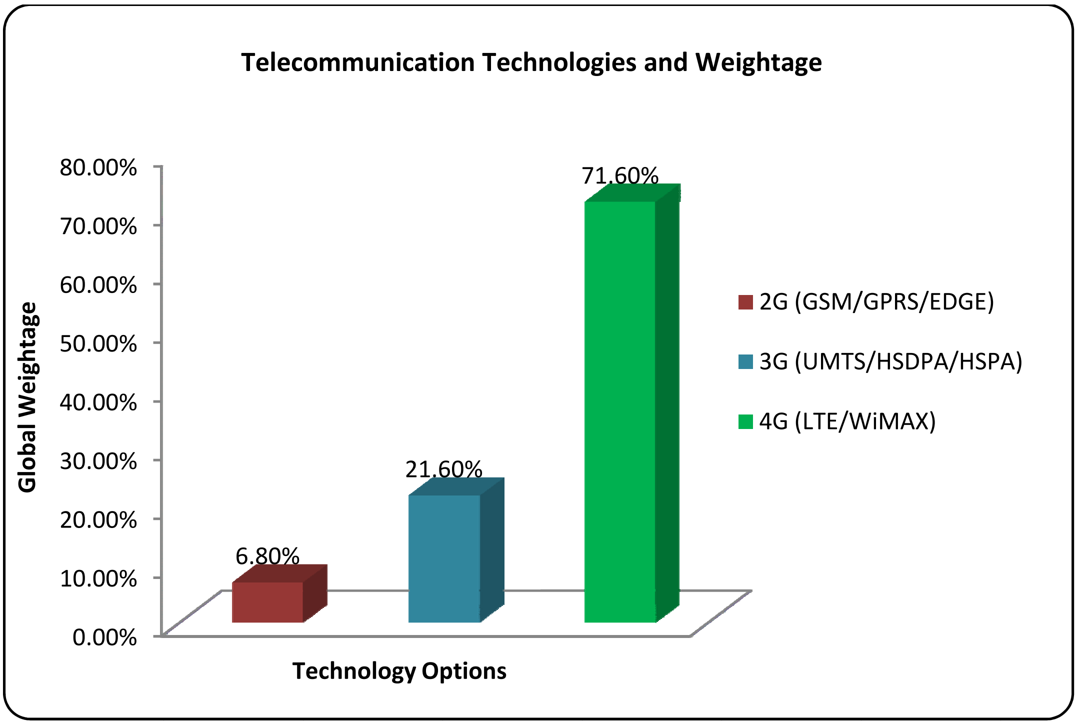

Figure 36: The result of telecommunication technology alternatives from expert-10 feedback

From Figure 35, the results of the empirical analysis show that the expert-10 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 29 and Figure 36 show that expert-10 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 73.70% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 20.70% and 2G (GSM/GPRS/EDGE) technology with 5.60%.

4.1.11 ResultConsolidationandSimulation (Expert Opinion)

For result consolidation I have taken all the global weight of Expert-1 to Expert-10 feedback and have been plotted in Table 30. By averaging these values got final result in Table 30 also. Final result has been presented by using Microsoft Excel Spreadsheet and plotted in Figure 37.

Table 30:Global weights of the Telecommunication technology alternatives and final ranking (Expert Opinion)

Telecommunication Technology selection						
Telecommunication Technologies	Global Weight (Expert-1)	Global Weight (Expert-2)	Global Weight (Expert-3)	Global Weight (Expert-4)	Global Weight (Expert-5)	Global Weight (Expert-6)
2G (GSM/GPRS/EDGE)	7.20%	6.00%	6.30%	4.90%	4.50%	10.10%
3G (UMTS/HSDPA/HSPA)	22.70%	35.60%	31.80%	31.60%	27.20%	26.30%
4G (LTE/WiMAX)	**70.10%**	**58.40%**	**61.90%**	**63.50%**	**68.30%**	**63.60%**
Telecommunication Technology selection						
Telecommunication Technologies	Global Weight (Expert-7)	Global Weight (Expert-8)	Global Weight (Expert-9)	Global Weight (Expert-10)	**Average Weight**	**Final Ranking**
2G (GSM/GPRS/EDGE)	5.2%	8.70%	6.10%	5.60%	**6.46%**	**3**
3G (UMTS/HSDPA/HSPA)	21.30%	28.90%	20.80%	20.70%	**26.69%**	**2**
4G (LTE/WiMAX)	**73.50%**	**62.40%**	**73.10%**	**73.70%**	**66.85%**	**1**

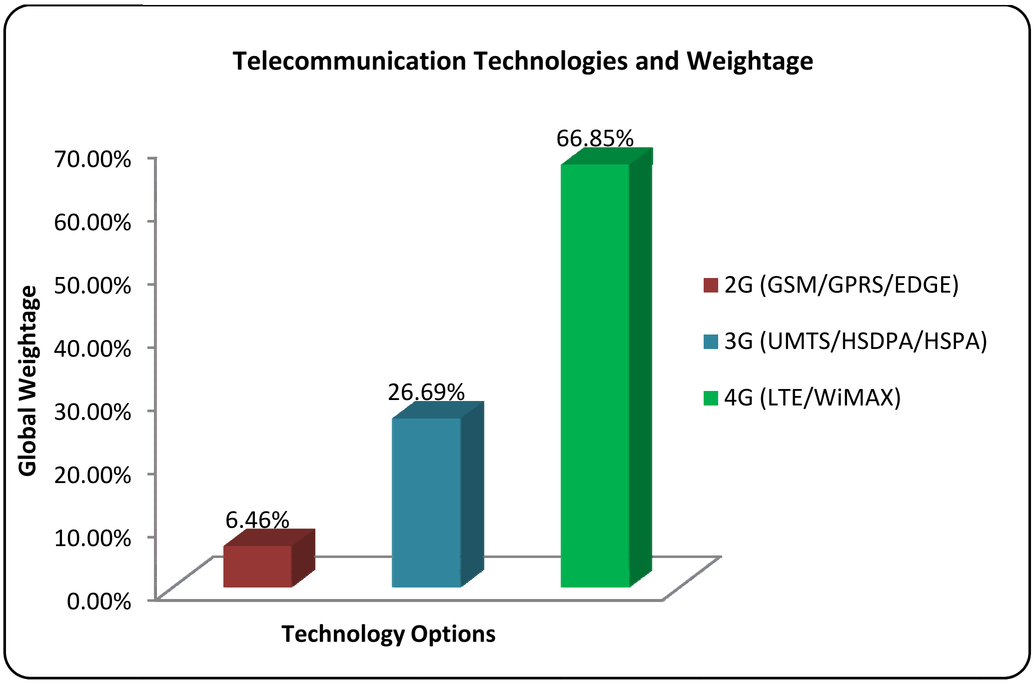

Figure 37: The result of telecommunication technology alternatives (Expert Opinion)

The final results of the empirical analysis show that all the experts preferred Quality Features criterion as most important criterion. In terms of sub criteria expert-1, expert-3, expert-4 and expert-10 preferred Data Rate as most important sub criterion. Whereas expert-2, expert-5, expert-7 and expert-8 preferred Security Features as most important sub criterion. Another side only expert-6 and expert-9 preferred Spectral Efficiency and Mobility as most important sub criterion. As for overall result, Table 30 and Figure 37 show that experts preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 66.85% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 26.69% and 2G (GSM/GPRS/EDGE) technology with 6.46%.

4.2 Result Calculation (General User Feedback)

The data analysis has been made using Microsoft Excel Spread Sheet and AHP Online Software. All the data were administered in the matrix named as general criteria. The matrices have a diagonal of unity. The lower triangles were made just reversing the corresponding component using equation (1). We need to develop pair wise comparison matrix for Criteria. This matrix can be developed through general user feedback. After that we need to normalize the value of resulting matrix. Averaging the values in each row will give the corresponding rating. Final step is to calculating and checking the consistency ratio. Similar steps have to be done for Sub-criteria. Last step is to calculate global weight by calculating the weighted average rating for each decision alternative. Highest score will indicate the appropriate telecommunication technology for Bangladesh considering given criteria (Quality Features, Cost Factors and Ripple Effects) and sub-criteria (Licensing Cost, Upgradation Cost, Maintenance Cost, Data Rate, Spectral Efficiency & Mobility, Security Features, Integration Scalability, Environmental Issue, Economic Impact and Social Impact).

4.2.1 AHP Calculation for General User-1

Similar data analysis has been conducted by AHP-OS tool for the general user-1 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

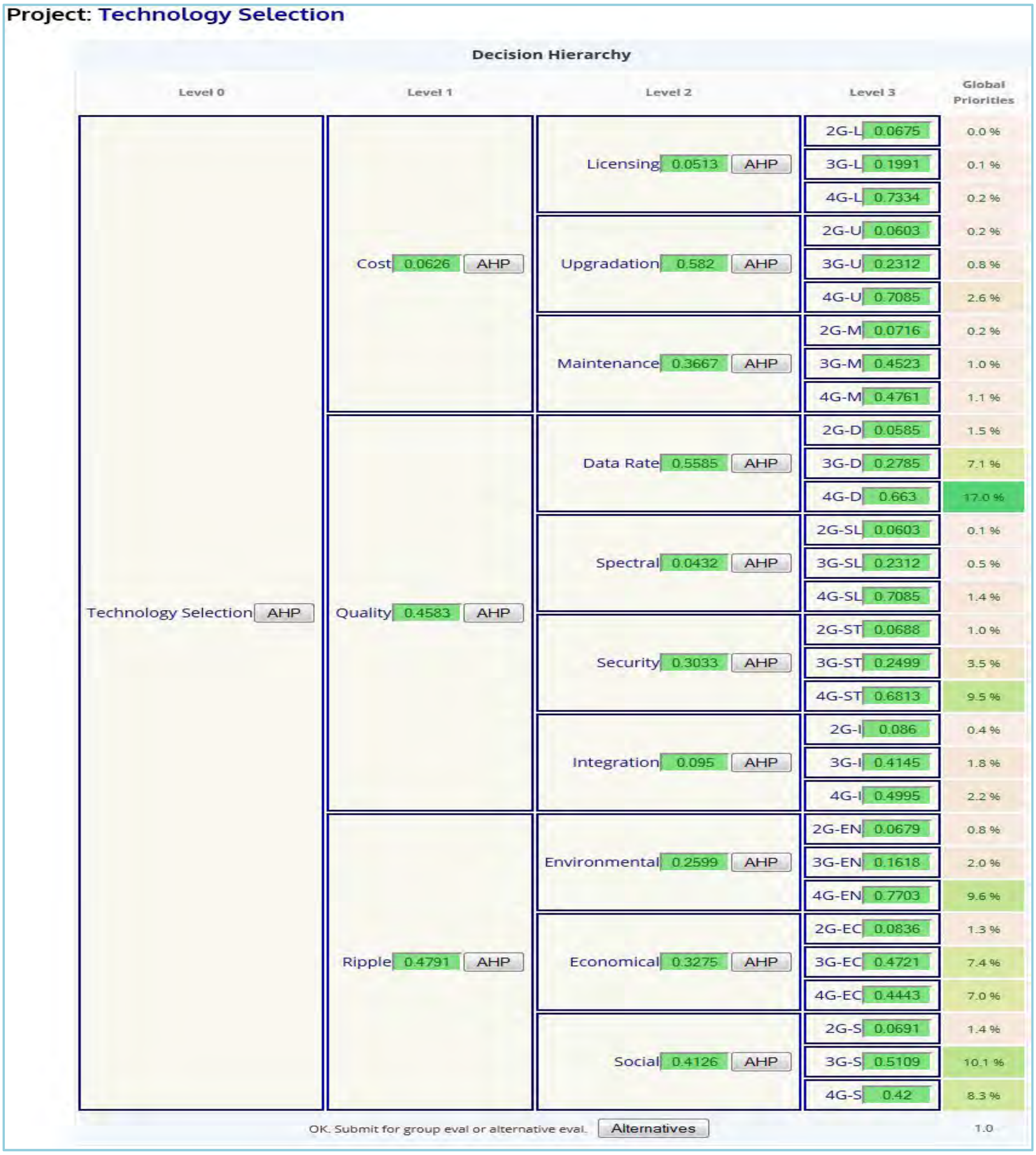

Figure 38: Priorities for Telecommunication Technology Selection Alternatives for general user-1using AHP-OS

From above calculations by AHP-OS, I have calculated the final result for general user-1 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 31 for the final score of telecommunication technology selection.

Table 31: Global weights of the Telecommunication technology alternatives and final ranking (General User-1)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.069	6.90%	3
3G (UMTS/HSDPA/HSPA)	0.343	34.30%	2
4G (LTE/WiMAX)	**0.588**	**58.80%**	**1**

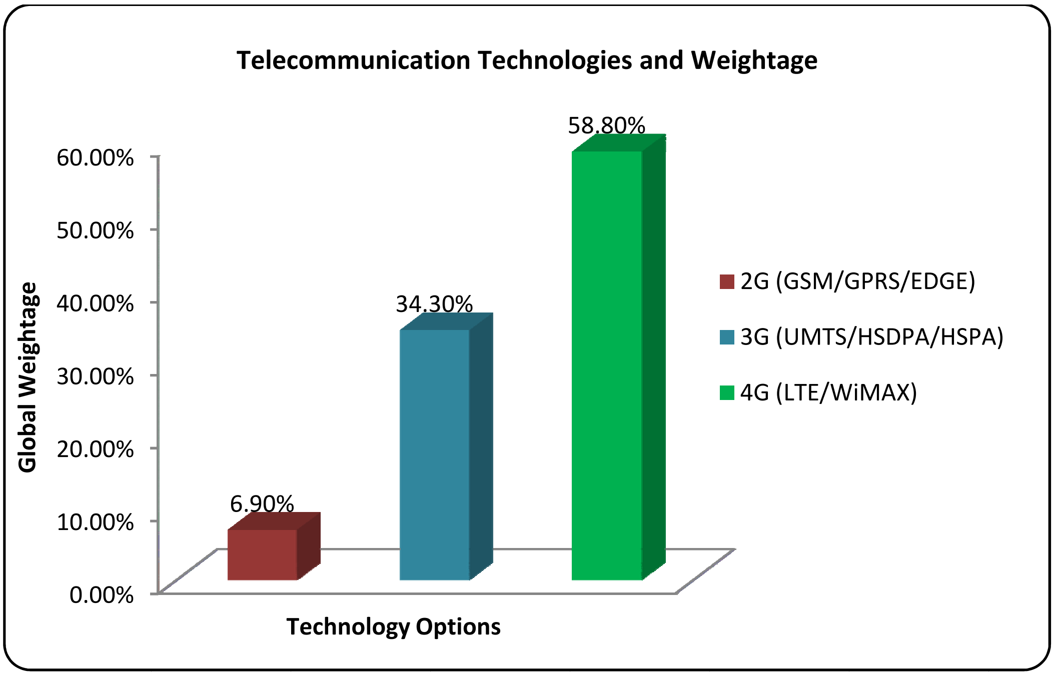

Figure 39: The result of telecommunication technology alternatives from general user-1 feedback

From Figure 38, the results of the empirical analysis show that the general user-1preferred the Ripple Effect criterion as most important criterion and Data Rate as most important sub-criteria. Table 31 and Figure 39 show that general user-1 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 58.80% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 34.30% and 2G (GSM/GPRS/EDGE) technology with 6.90%.

4.2.2 AHP Calculation for General User-2

Similar data analysis has been conducted by AHP-OS tool for the general user-2 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

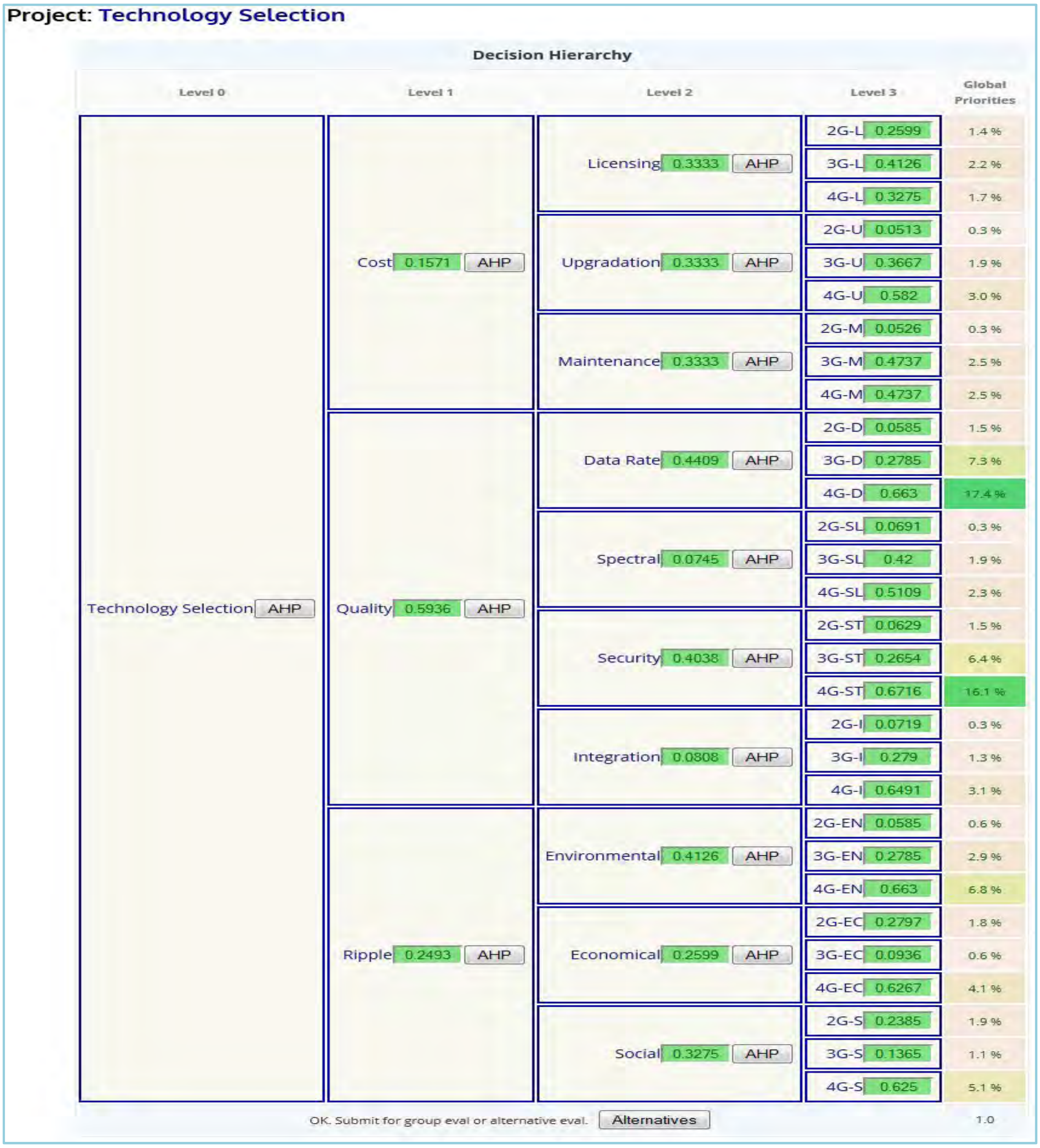

Figure 40: Priorities for Telecommunication Technology Selection Alternatives for general user-2 using AHP-OS

From above calculations by AHP-OS, I have calculated the final result for general user-2 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 32 for the final score of telecommunication technology selection.

Table 32: Global weights of the Telecommunication technology alternatives and final ranking (General User-2)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.099	9.90%	3
3G (UMTS/HSDPA/HSPA)	0.281	28.10%	2
4G (LTE/WiMAX)	**0.620**	**62.00%**	**1**

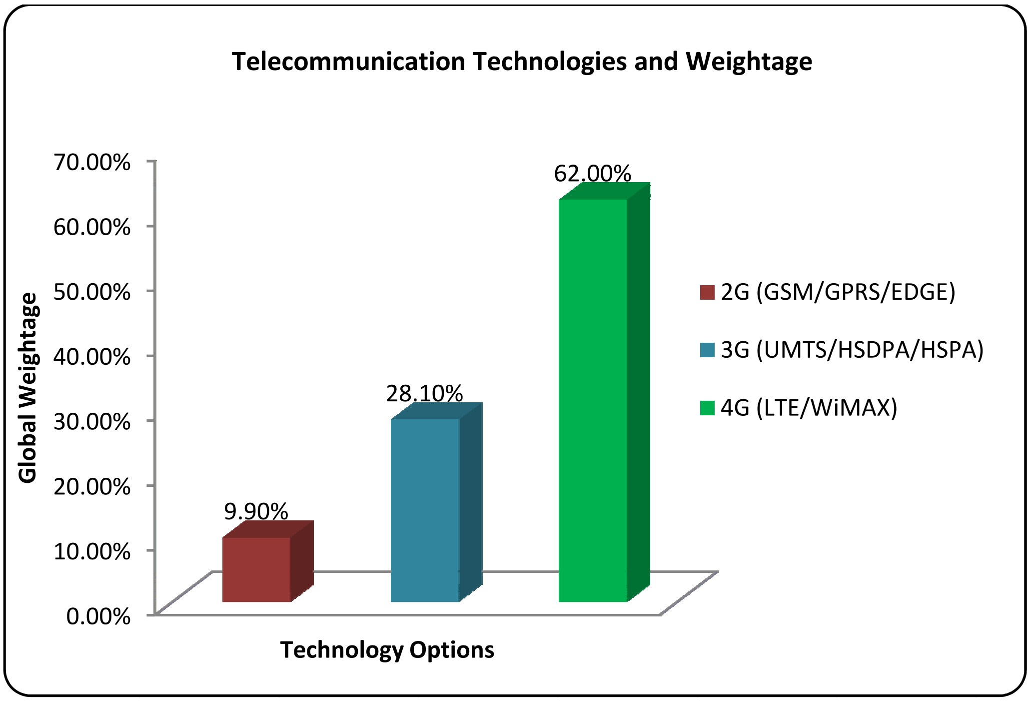

Figure 41: The result of telecommunication technology alternatives from general user-2 feedback

From Figure 40, the results of the empirical analysis show that the general user-2 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 32 and Figure 41 show that general user-2 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 62.00% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 28.10% and 2G (GSM/GPRS/EDGE) technology with 9.90%.

4.2.3 AHP Calculation for General User-3

Similar data analysis has been conducted by AHP-OS tool for the general user-3 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

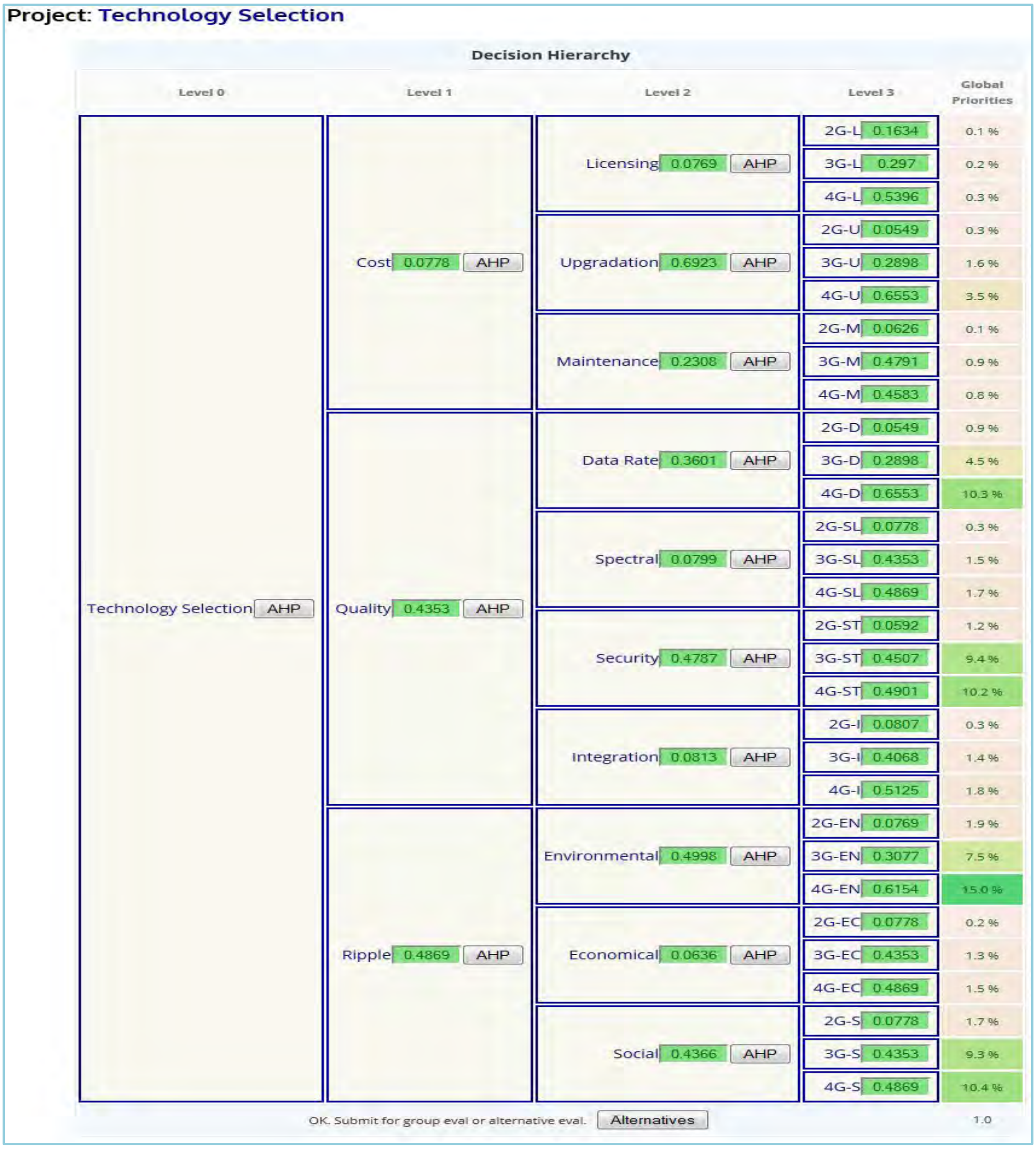

Figure 42: Priorities for Telecommunication Technology Selection Alternatives for general user-3 using AHP-OS

From above calculations by AHP-OS, I have calculated the final result for general user-3 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 33 for the final score of telecommunication technology selection.

Table 33: Global weights of the Telecommunication technology alternatives and final ranking (General User-3)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.070	7.00%	3
3G (UMTS/HSDPA/HSPA)	0.376	37.60%	2
4G (LTE/WiMAX)	**0.554**	**55.40%**	**1**

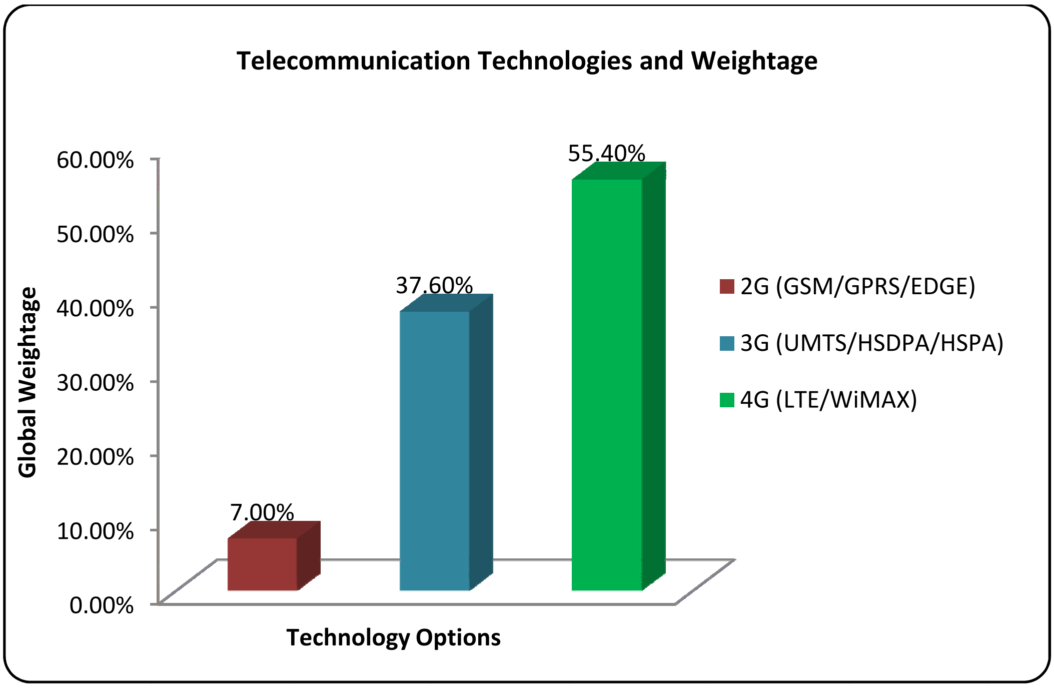

Figure 43: The result of telecommunication technology alternatives from general user-3 feedback

From Figure 42, the results of the empirical analysis show that the general user-3 preferred the Ripple Effects criterion as most important criterion and Environmental Issues as most important sub-criteria. Table 33 and Figure 43 show that general user-3 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 55.40% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with37.60% and 2G (GSM/GPRS/EDGE) technology with 7.00%.

4.2.4 AHP Calculation for General User-4

Similar data analysis has been conducted by AHP-OS tool for the general user-4 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

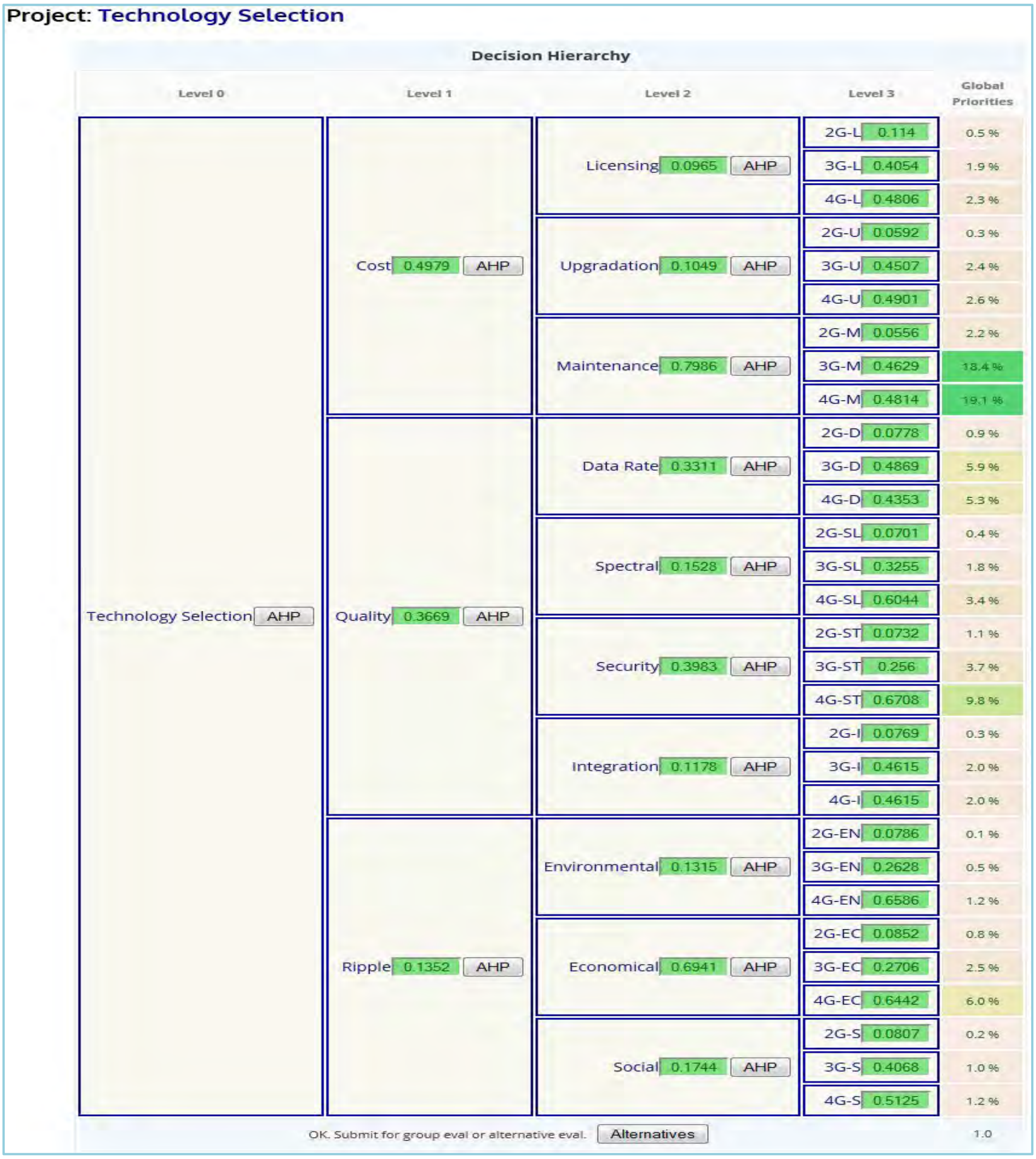

Figure 44: Priorities for Telecommunication Technology Selection Alternatives for general user-4 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-4 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 34 for the final score of telecommunication technology selection.

Table 34: Global weights of the Telecommunication technology alternatives and final ranking (General User-4)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.068	6.80%	3
3G (UMTS/HSDPA/HSPA)	0.401	40.10%	2
4G (LTE/WiMAX)	**0.531**	**53.10%**	**1**

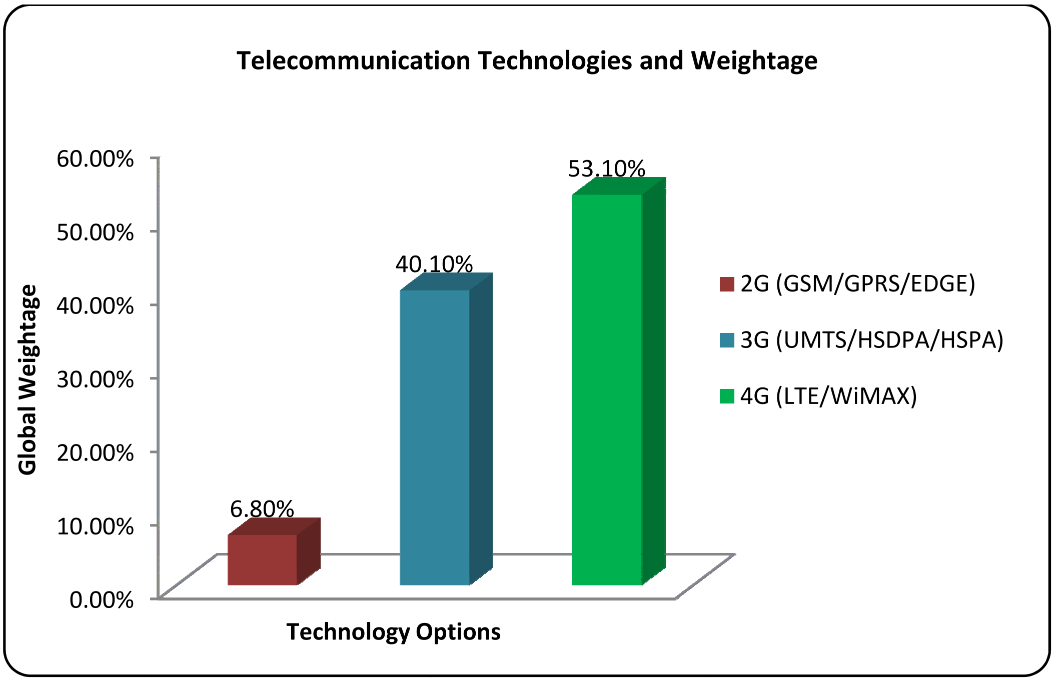

Figure 45: The result of telecommunication technology alternatives from general user-4 feedback

From Figure 44, the results of the empirical analysis show that the general user-4 preferred the Cost Components criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 34 and Figure 45 show that general user-4 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 53.10% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 40.10% and 2G (GSM/GPRS/EDGE) technology with 6.80%.

4.2.5 AHP Calculation for General User-5

Similar data analysis has been conducted by AHP-OS tool for the general user-5 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

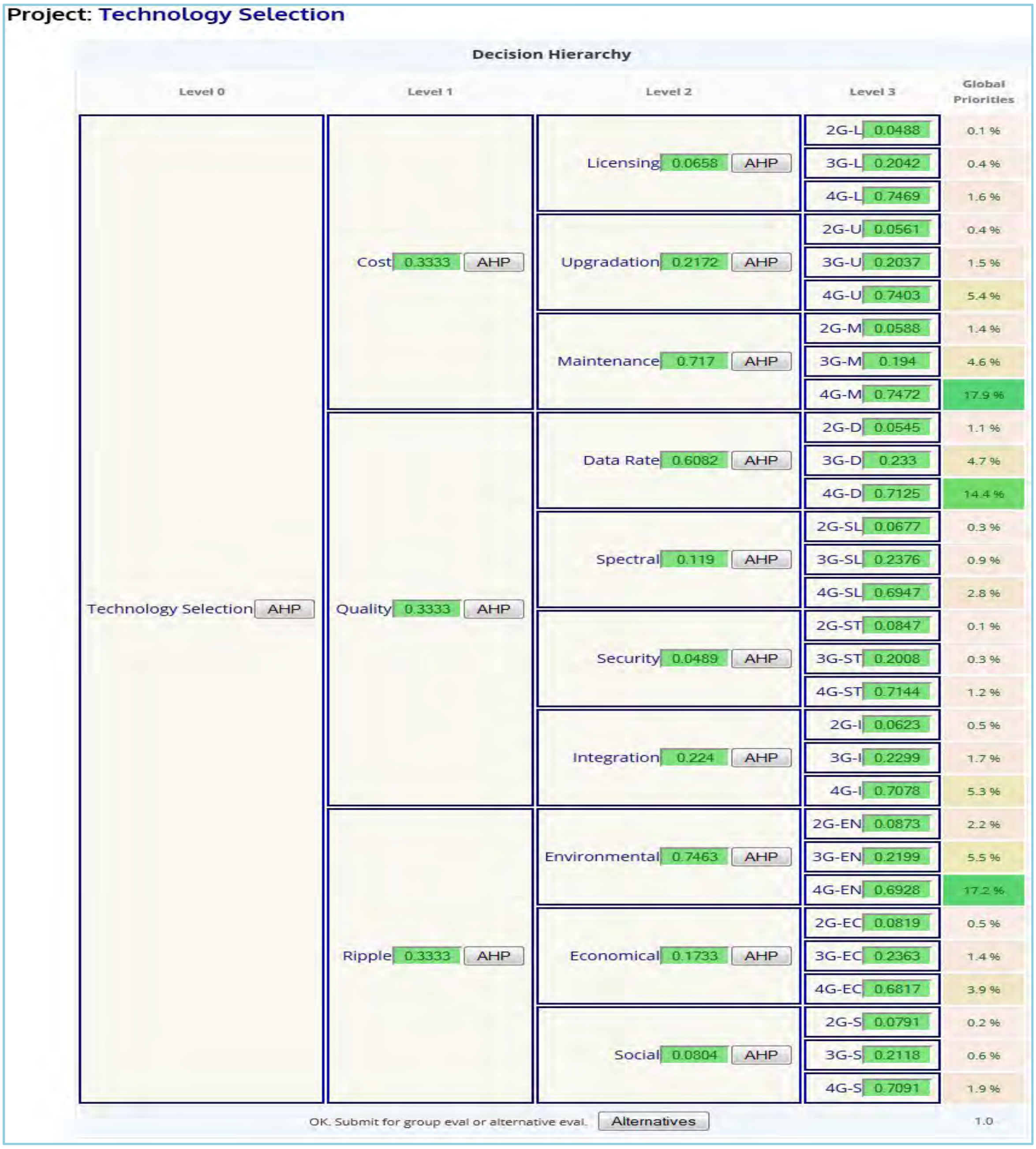

Figure 46: Priorities for Telecommunication Technology Selection Alternatives for general user-5 using AHP-OS

From above calculations by AHP-OS I have calculated the final result for general user-5 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 35 for the final score of telecommunication technology selection.

Table 35: Global weights of the Telecommunication technology alternatives and final ranking (General User-5)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.068	6.80%	3
3G (UMTS/HSDPA/HSPA)	0.216	21.60%	2
4G (LTE/WiMAX)	**0.716**	**71.60%**	**1**

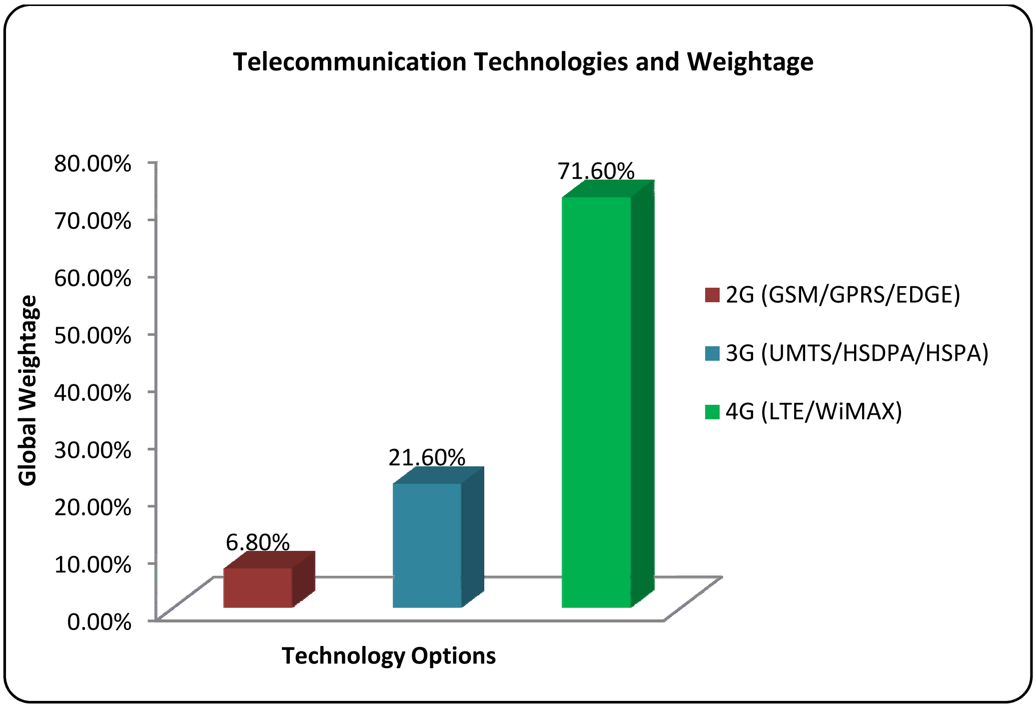

Figure 47: The result of telecommunication technology alternatives from general user-5 feedback

From Figure 46, the results of the empirical analysis show that the general user-5 preferred three criterions equally and Maintenance Cost as most important sub-criteria. Table 35 and Figure 47 show that general user-5 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 71.60% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 21.60% and 2G (GSM/GPRS/EDGE) technology with 6.80%.

4.2.6 AHP Calculation for General User-6

Similar data analysis has been conducted by AHP-OS tool for the general user-6 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

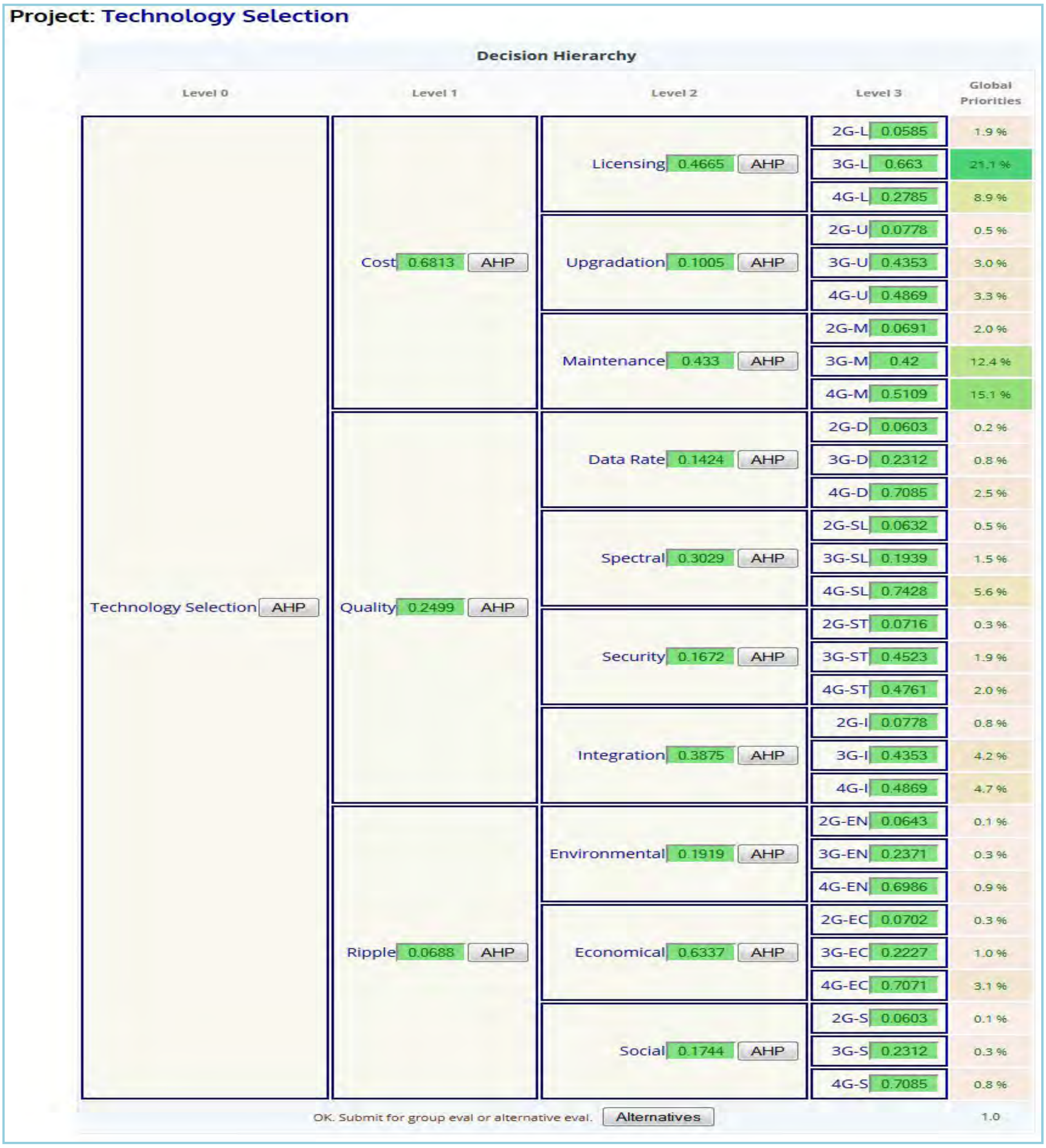

Figure 48: Priorities for Telecommunication Technology Selection Alternatives for general user-6 using AHP-OS

From above calculations by AHP-OS, I have calculated the final result for general user-6 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 36 for the final score of telecommunication technology selection.

Table 36: Global weights of the Telecommunication technology alternatives and final ranking (General User-6)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.067	6.70%	3
3G (UMTS/HSDPA/HSPA)	0.465	46.50%	2
4G (LTE/WiMAX)	**0.468**	**46.80%**	**1**

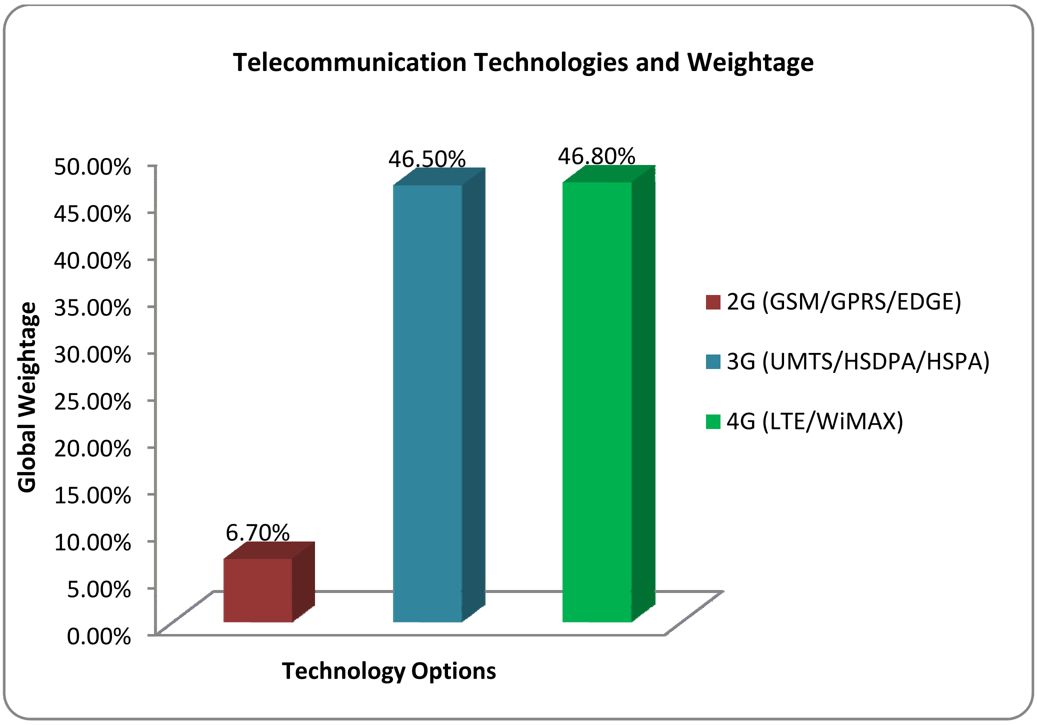

Figure 49: The result of telecommunication technology alternatives from general user-6 feedback

From Figure 48, the results of the empirical analysis show that the general user-4 preferred the Cost Components criterion as most important criterion and Licensing Cost as most important sub-criteria. Table 36 and Figure 49 show that general user-6 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 46.80% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 46.50% and 2G (GSM/GPRS/EDGE) technology with 6.70%.

4.2.7 AHP Calculation for General User-7

Similar data analysis has been conducted by AHP-OS tool for the general user-7 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

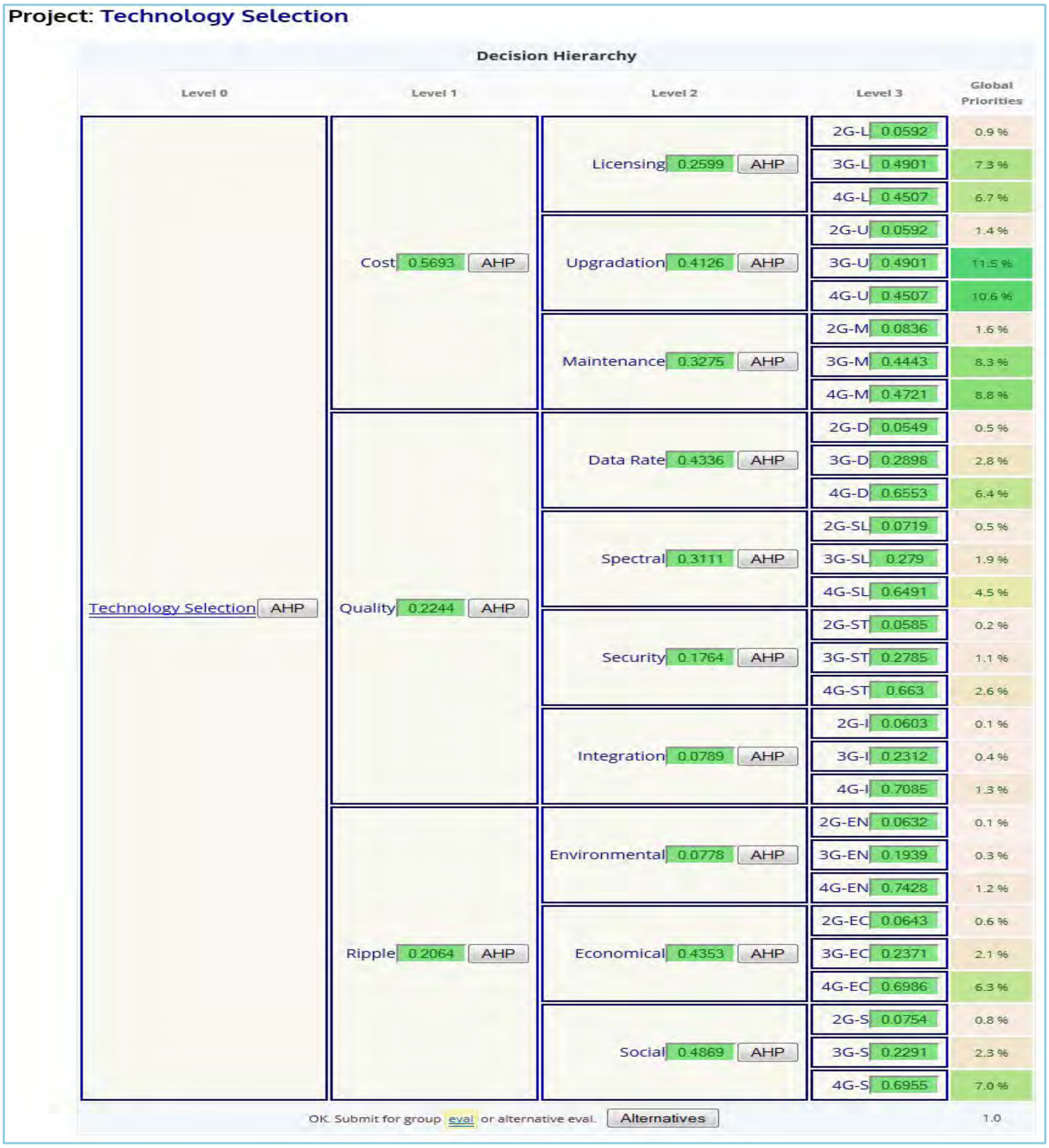

Figure 50: Priorities for Telecommunication Technology Selection Alternatives for general user-7 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-7 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 37 for the final score of telecommunication technology selection.

Table 37: Global weights of the Telecommunication technology alternatives and final ranking (General User-7)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.067	6.70%	3
3G (UMTS/HSDPA/HSPA)	0.380	38.00%	2
4G (LTE/WiMAX)	**0.553**	**55.30%**	**1**

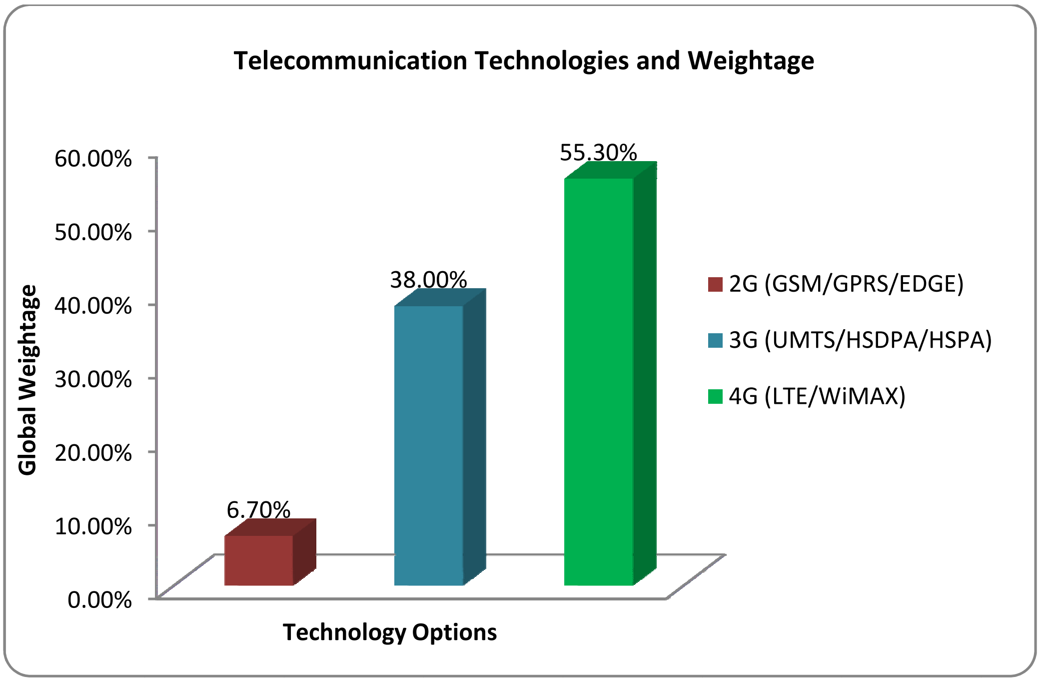

Figure 51: The result of telecommunication technology alternatives from general user-7 feedback

From Figure 50, the results of the empirical analysis show that the general user-7 preferred the Cost Components criterion as most important criterion and Upgradation Cost as most important sub-criteria. Table 37 and Figure 51 show that general user-7 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 55.30% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 38.00% and 2G (GSM/GPRS/EDGE) technology with 6.70%.

4.2.8 AHP Calculation for General User-8

Similar data analysis has been conducted by AHP-OS tool for the general user-8 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

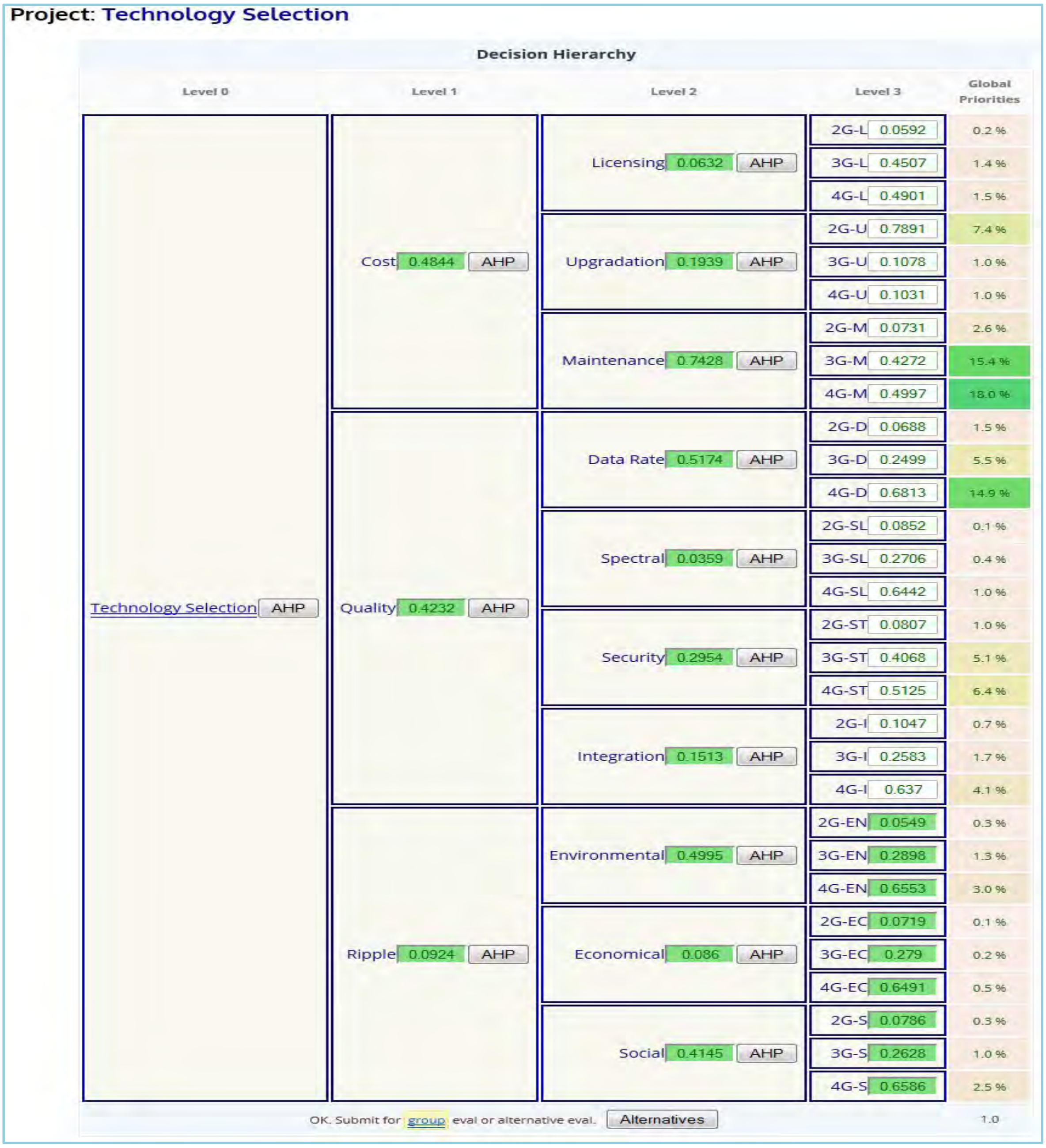

Figure 52: Priorities for Telecommunication Technology Selection Alternatives for general user-8 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-8 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 38 for the final score of telecommunication technology selection.

Table 38: Global weights of the Telecommunication technology alternatives and final ranking (General User-8)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.142	14.20%	3
3G (UMTS/HSDPA/HSPA)	0.330	33.00%	2
4G (LTE/WiMAX)	**0.528**	**52.80%**	**1**

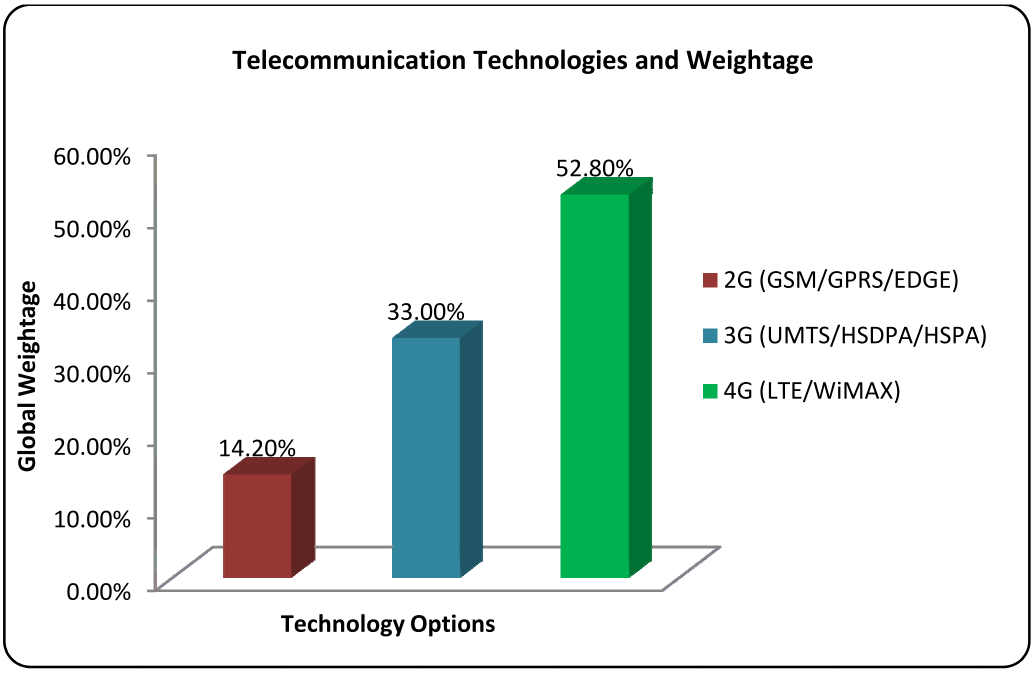

Figure 53: The result of telecommunication technology alternatives from general user-8 feedback

From Figure 52, the results of the empirical analysis show that the general user-8 preferred the Cost Components criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 38 and Figure 53 show that general user-8 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 52.80% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 33.00% and 2G (GSM/GPRS/EDGE) technology with 14.20%.

4.2.9 AHP Calculation for General User-9

Similar data analysis has been conducted by AHP-OS tool for the general user-9 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

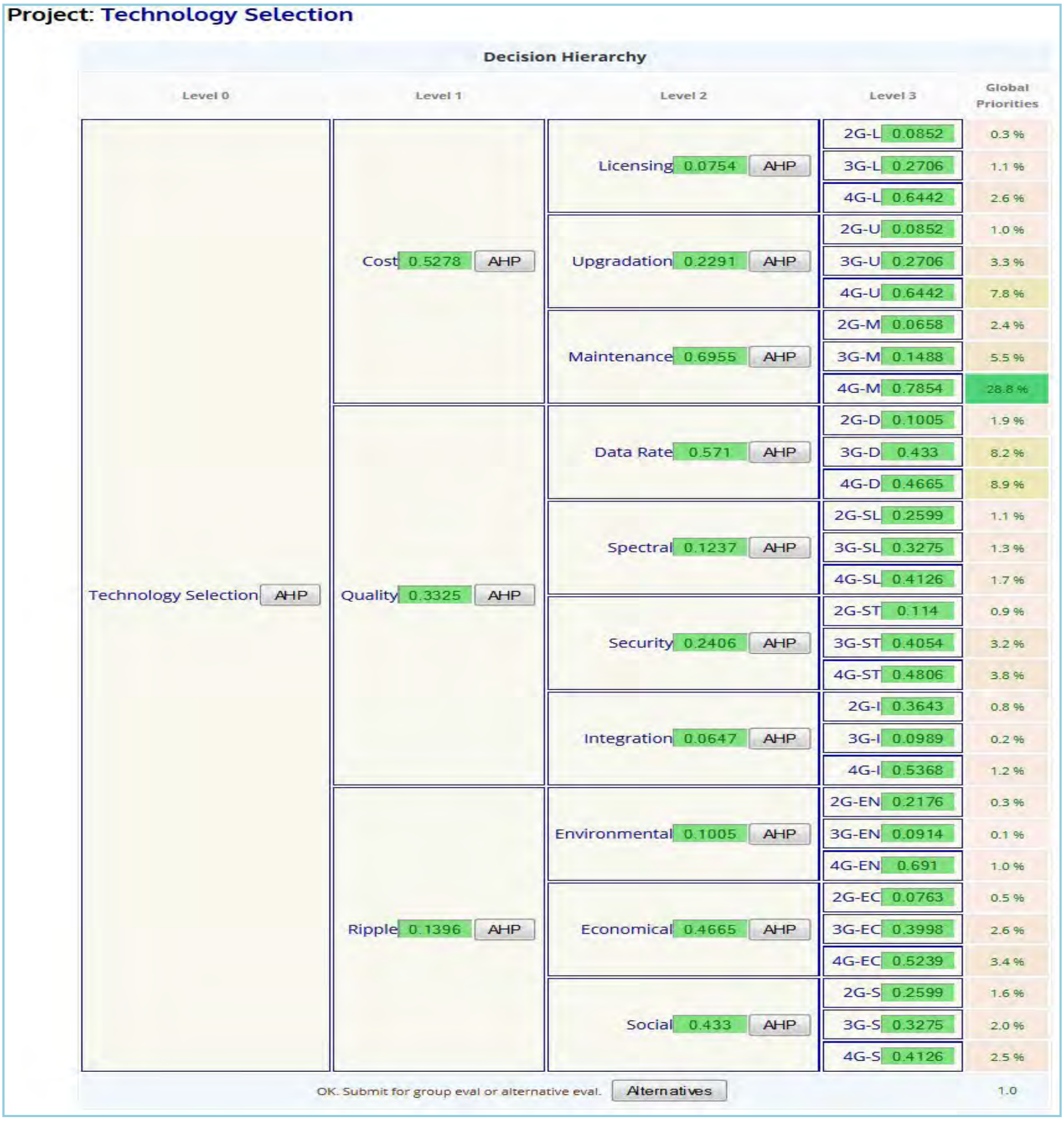

Figure 54: Priorities for Telecommunication Technology Selection Alternatives for general user-9 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-9 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 39 for the final score of telecommunication technology selection.

Table 39: Global weights of the Telecommunication technology alternatives and final ranking (General User-9)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.108	10.80%	3
3G (UMTS/HSDPA/HSPA)	0.275	27.50%	2
4G (LTE/WiMAX)	**0.617**	**61.70%**	**1**

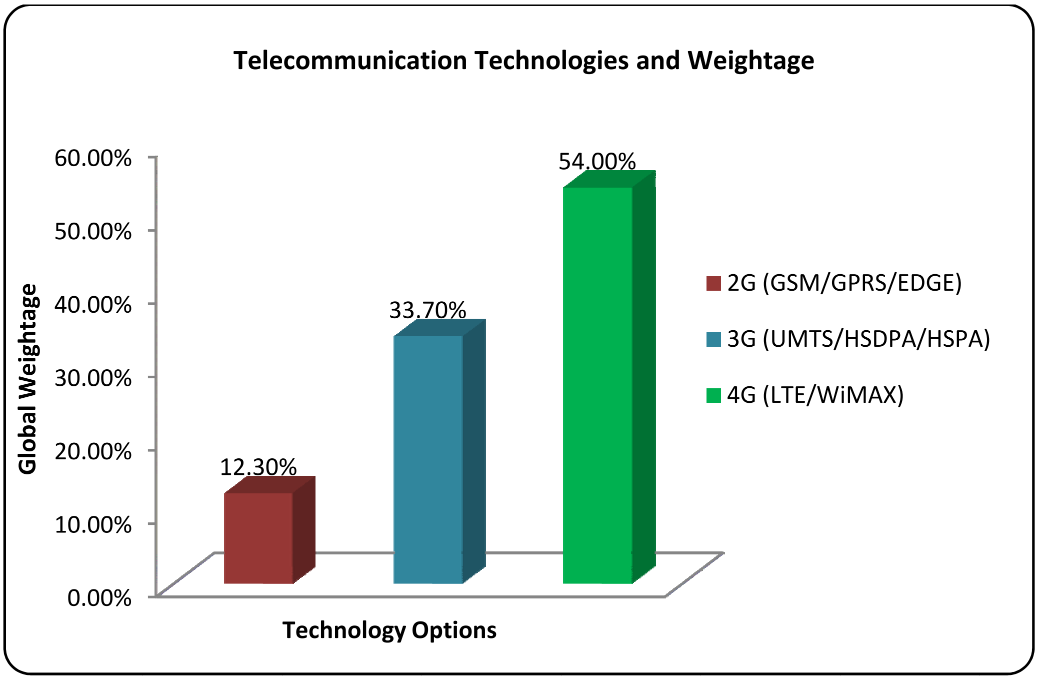

Figure 55: The result of telecommunication technology alternatives from general user-9 feedback

From Figure 54, the results of the empirical analysis show that the general user-9 preferred the Cost Components criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 39 and Figure 55 show that general user-4 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 61.70% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with27.50% and 2G (GSM/GPRS/EDGE) technology with 10.80%.

4.2.10 AHP Calculation for General User-10

Similar data analysis has been conducted by AHP-OS tool for the general user-10 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

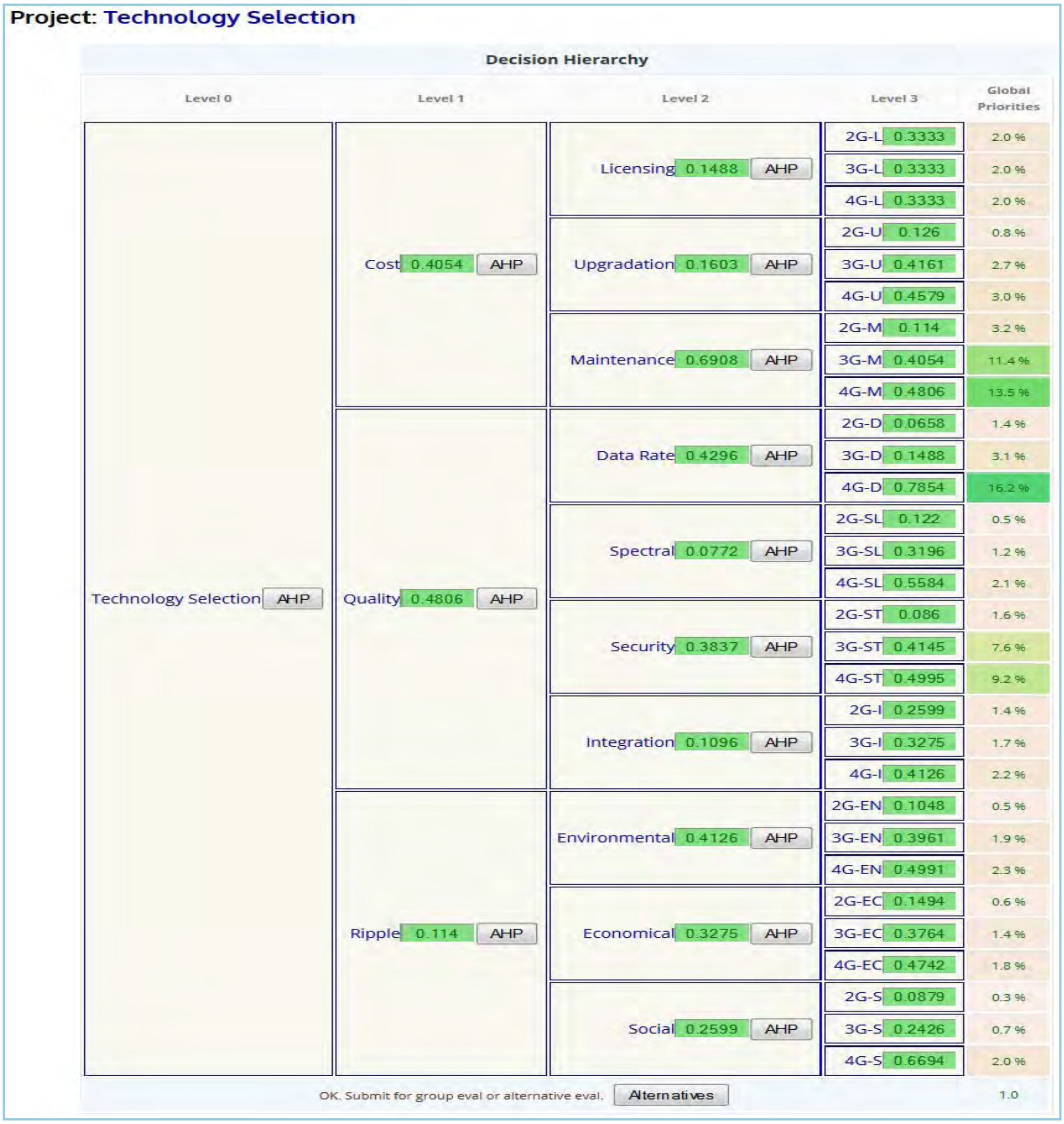

Figure 56: Priorities for Telecommunication Technology Selection Alternatives for general user-10 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-10 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 40 for the final score of telecommunication technology selection.

Table 40: Global weights of the Telecommunication technology alternatives and final ranking (General User-10)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.123	12.30%	3
3G (UMTS/HSDPA/HSPA)	0.337	33.70%	2
4G (LTE/WiMAX)	**0.540**	**54.00%**	**1**

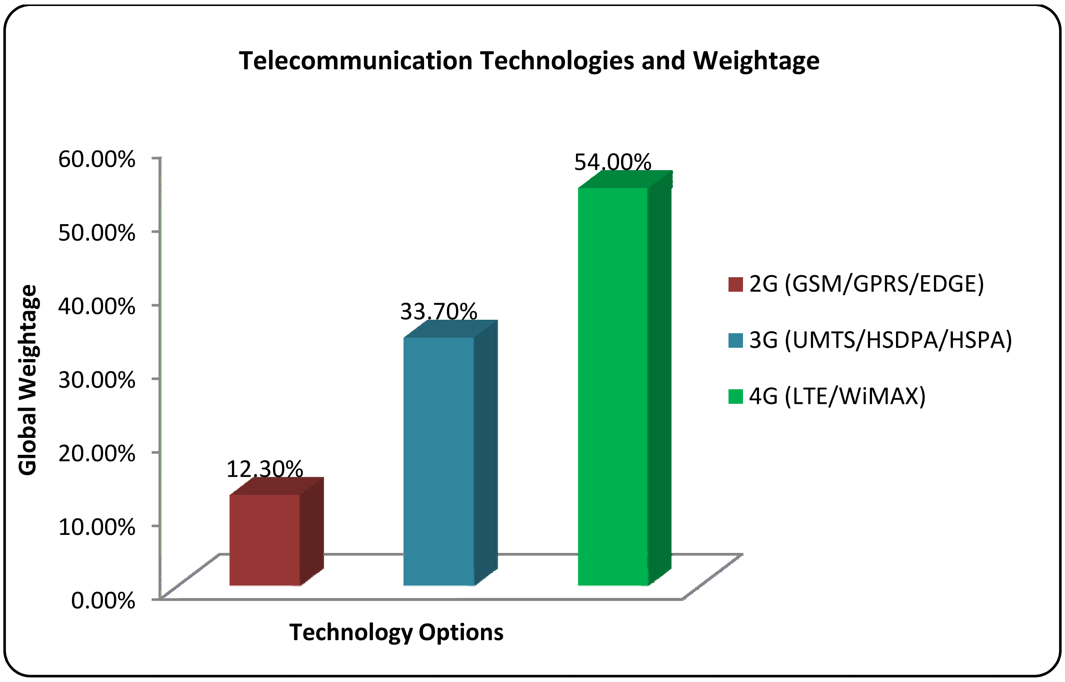

Figure 57: The result of telecommunication technology alternatives from general user-10 feedback

From Figure 56, the results of the empirical analysis show that the general user-10 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 40 and Figure 57 show that general user-10 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 54.00% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 33.70% and 2G (GSM/GPRS/EDGE) technology with 12.30%.

4.2.11 AHP Calculation for General User-11

Similar data analysis has been conducted by AHP-OS tool for the general user-11 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

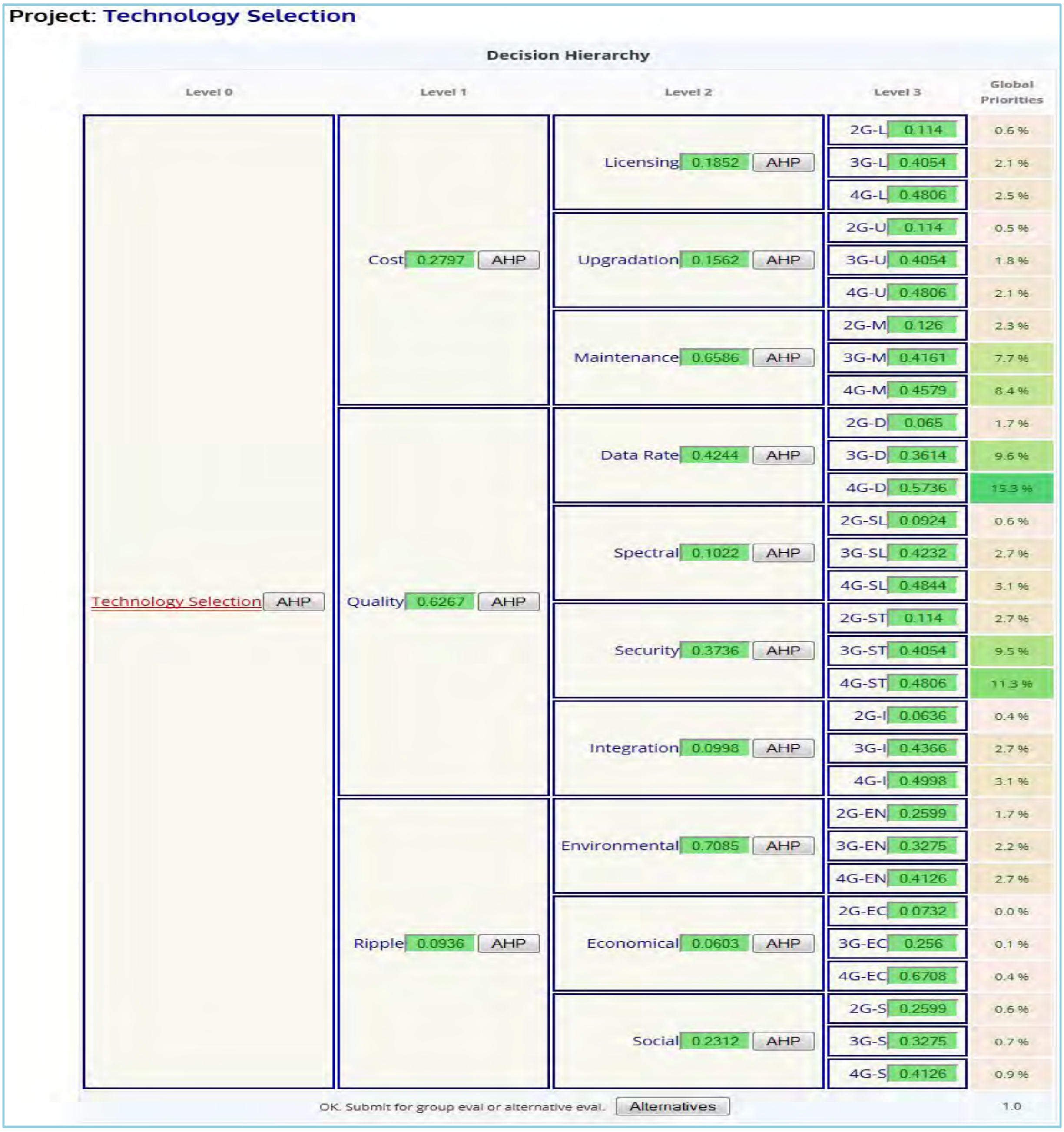

Figure 58: Priorities for Telecommunication Technology Selection Alternatives for general user-11 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-11 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 41 for the final score of telecommunication technology selection.

Table 41: Global weights of the Telecommunication technology alternatives and final ranking (General User-11)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.111	11.10%	3
3G (UMTS/HSDPA/HSPA)	0.391	39.10%	2
4G (LTE/WiMAX)	**0.498**	**49.80%**	**1**

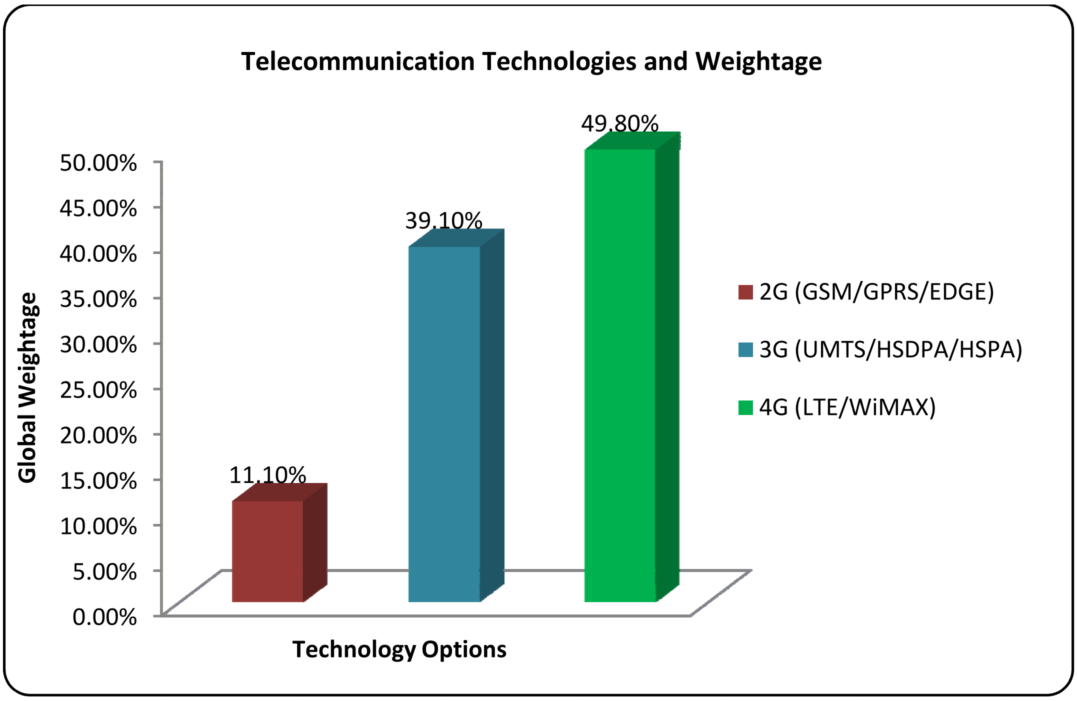

Figure 59: The result of telecommunication technology alternatives from general user-11 feedback

From Figure 44, the results of the empirical analysis show that the general user-11 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 41 and Figure 59 show that general user-11 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 49.80% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 39.10% and 2G (GSM/GPRS/EDGE) technology with 11.10%.

4.2.12 AHP Calculation for General User-12

Similar data analysis has been conducted by AHP-OS tool for the general user-12 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

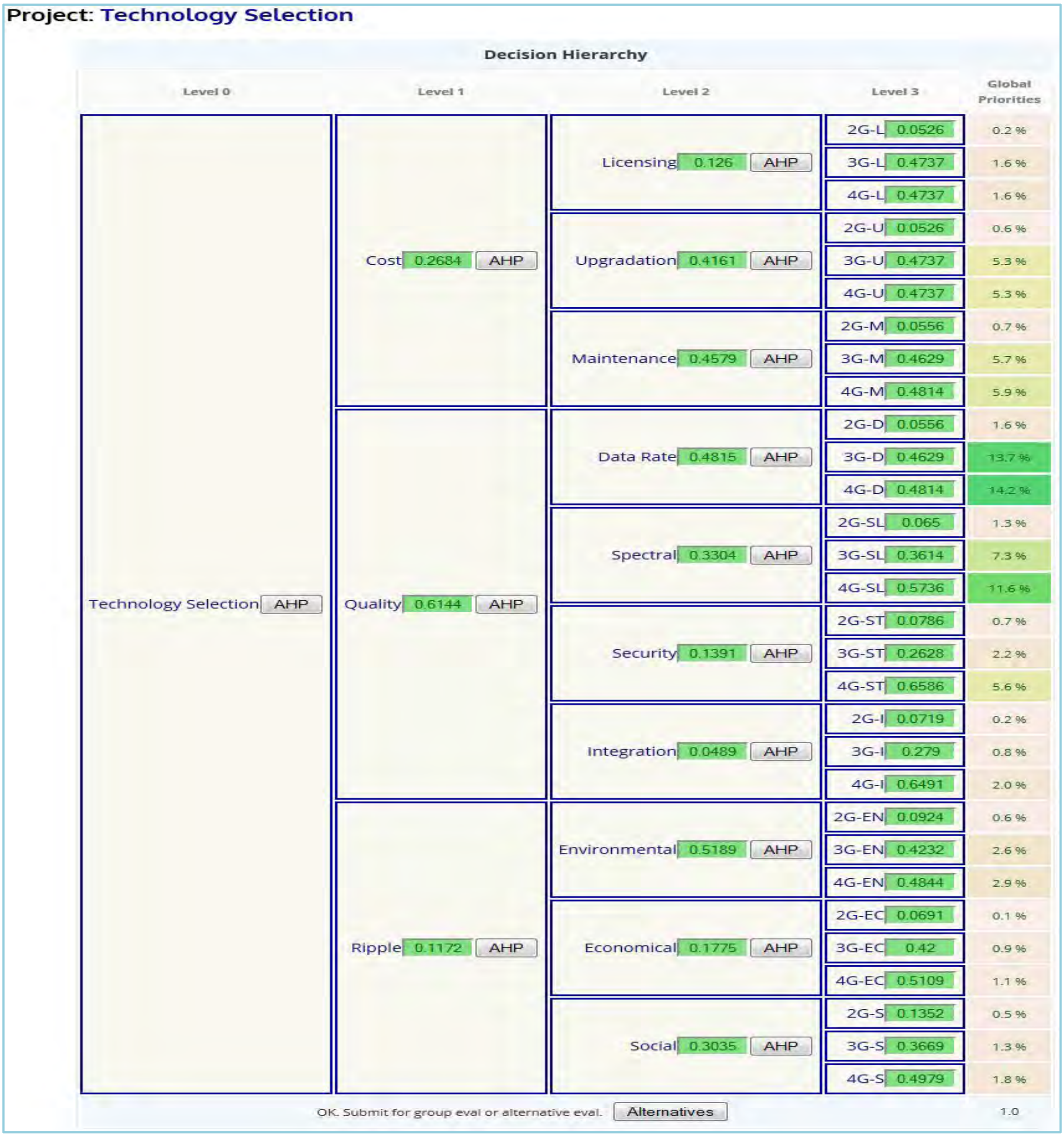

Figure 60: Priorities for Telecommunication Technology Selection Alternatives for general user-12 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-12 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 42 for the final score of telecommunication technology selection.

Table 42: Global weights of the Telecommunication technology alternatives and final ranking (General User-12)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.065	6.50%	3
3G (UMTS/HSDPA/HSPA)	0.414	41.40%	2
4G (LTE/WiMAX)	**0.521**	**52.10%**	**1**

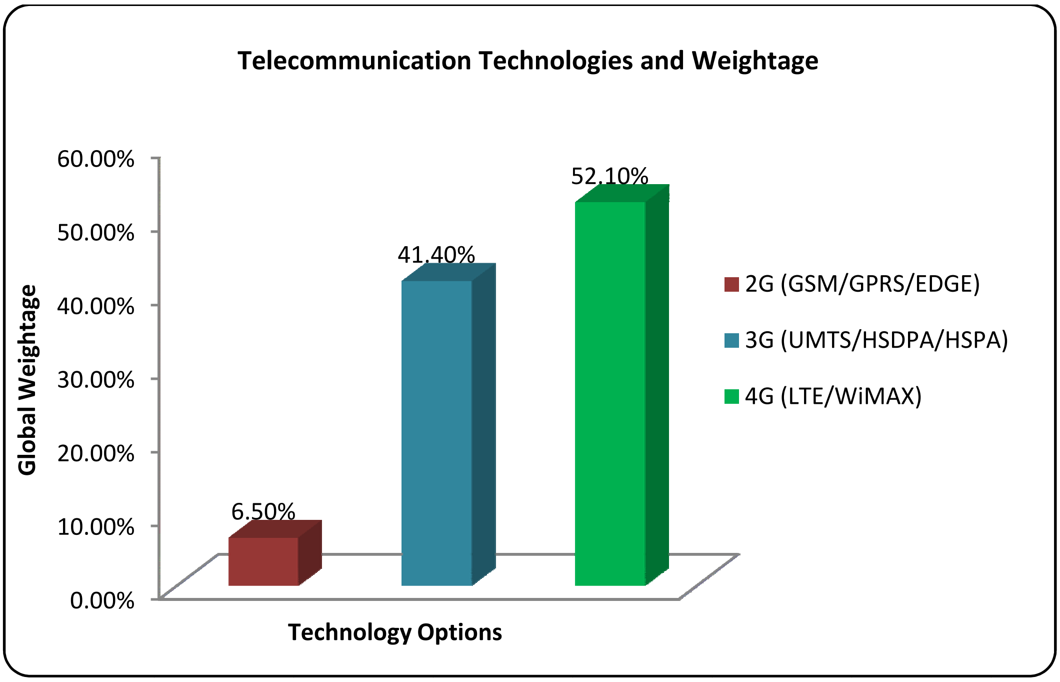

Figure 61: The result of telecommunication technology alternatives from general user-12 feedback

From Figure 60, the results of the empirical analysis show that the general user-12 preferred the Quality Features criterion as most important criterion and Data Rate as most important sub-criteria. Table 42 and Figure 61 show that general user-12 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 52.10% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 41.40% and 2G (GSM/GPRS/EDGE) technology with 6.50%.

4.2.13 AHP Calculation for General User-13

Similar data analysis has been conducted by AHP-OS tool for the general user-13 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

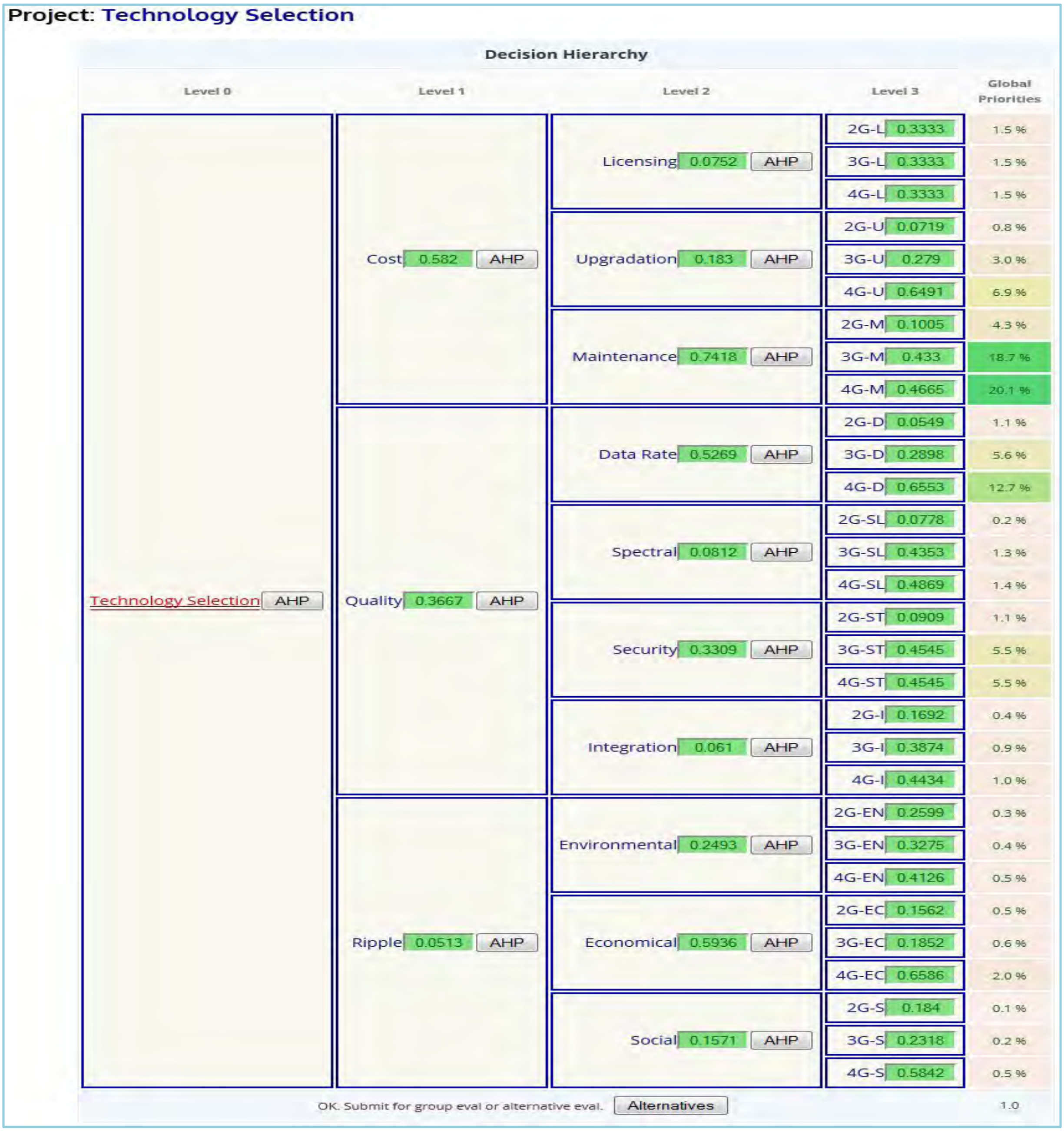

Figure 62: Priorities for Telecommunication Technology Selection Alternatives for general user-13 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-13 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 43 for the final score of telecommunication technology selection.

Table 43: Global weights of the Telecommunication technology alternatives and final ranking (General User-13)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.103	10.30%	3
3G (UMTS/HSDPA/HSPA)	0.377	37.70%	2
4G (LTE/WiMAX)	**0.520**	**52.00%**	**1**

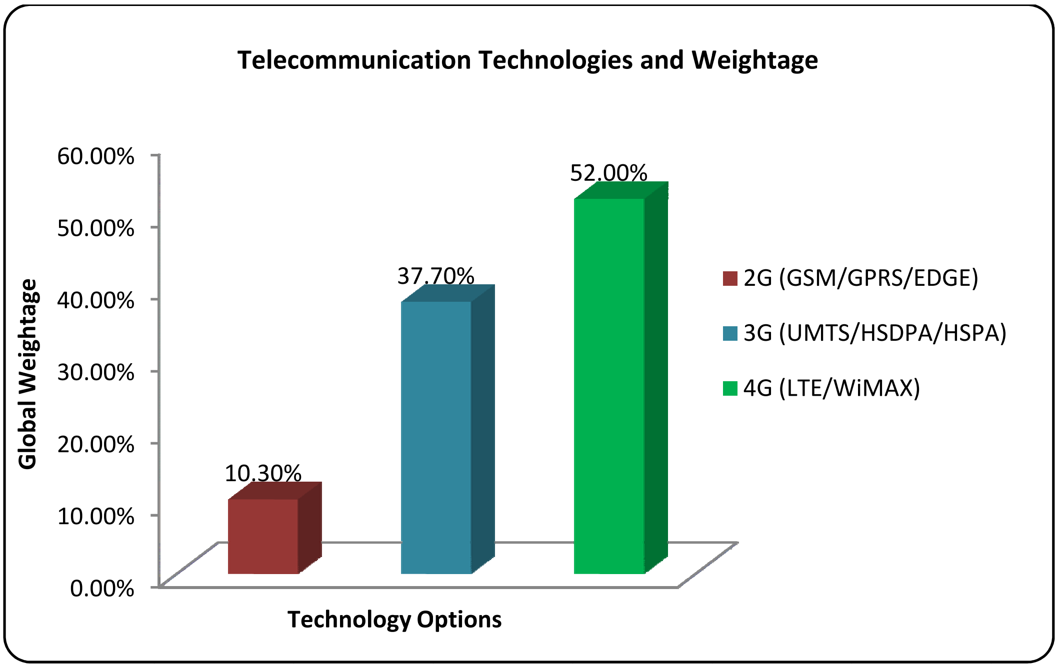

Figure 63: The result of telecommunication technology alternatives from general user-13 feedback

From Figure 62, the results of the empirical analysis show that the general user-13 preferred the Cost Components criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 43 and Figure 63 show that general user-13 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 52.00% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 37.70% and 2G (GSM/GPRS/EDGE) technology with 10.30%.

4.2.14 AHP Calculation for General User-14

Similar data analysis has been conducted by AHP-OS tool for the general user-14 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

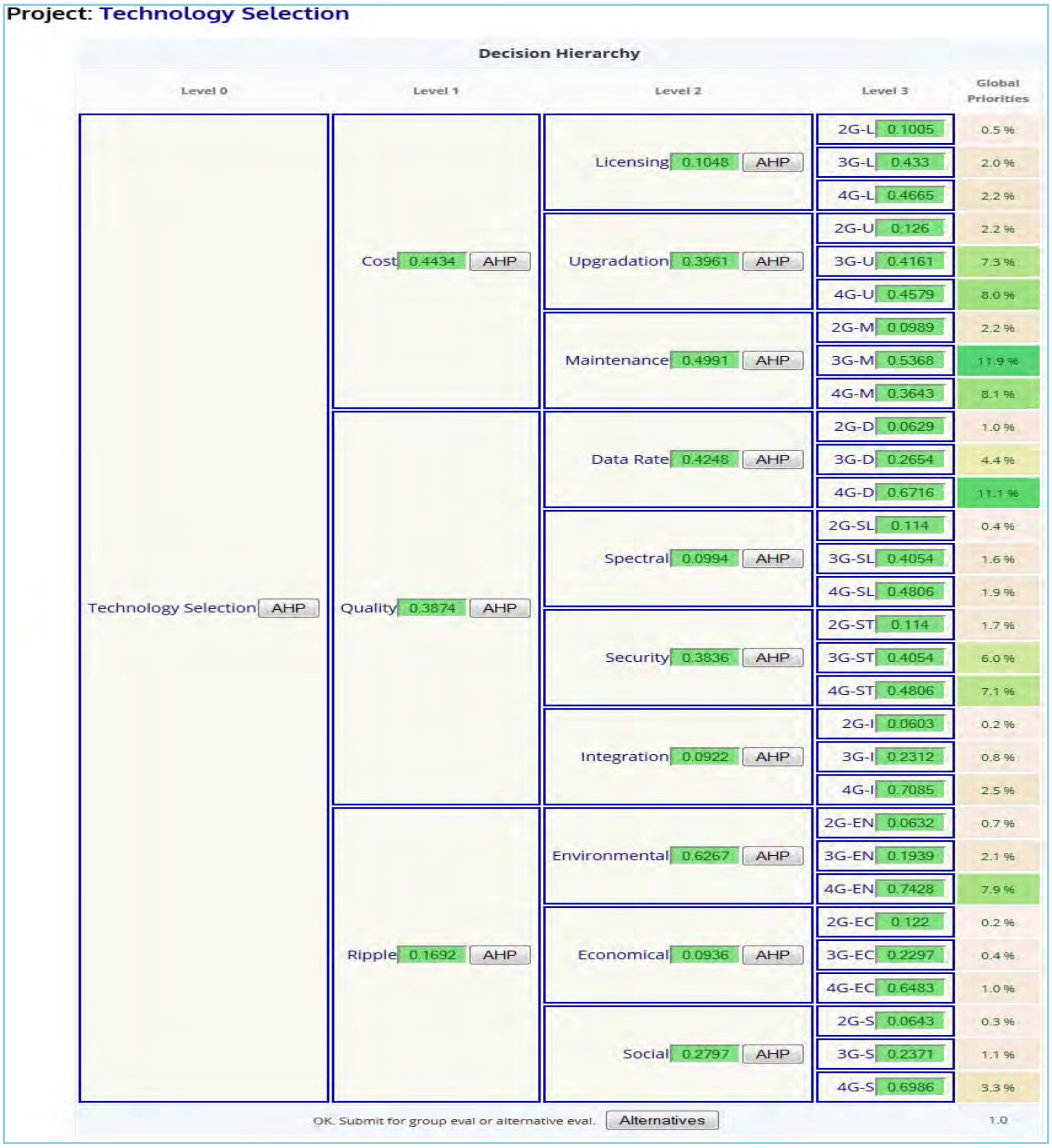

Figure 64: Priorities for Telecommunication Technology Selection Alternatives for general user-14 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-14 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 44 for the final score of telecommunication technology selection.

Table 44: Global weights of the Telecommunication technology alternatives and final ranking (General User-14)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.094	9.40%	3
3G (UMTS/HSDPA/HSPA)	0.375	37.50%	2
4G (LTE/WiMAX)	**0.531**	**53.10%**	**1**

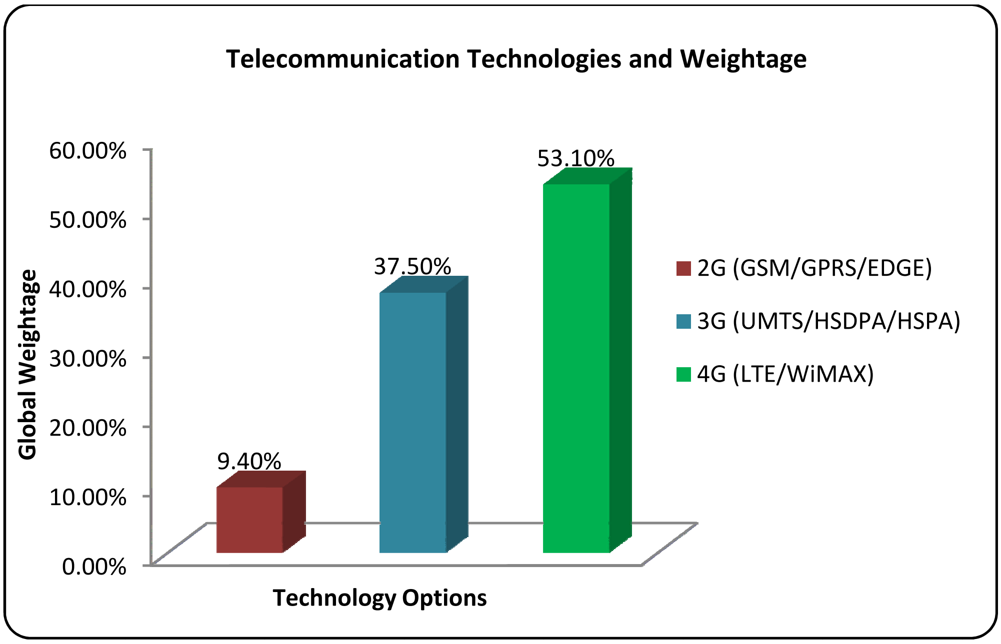

Figure 65: The result of telecommunication technology alternatives from general user-14 feedback

From Figure 64, the results of the empirical analysis show that the general user-14 preferred the Cost Components criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 44 and Figure 65 show that general user-14 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 53.10% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 37.50% and 2G (GSM/GPRS/EDGE) technology with 9.40%.

4.2.15 AHP Calculation for General User-15

Similar data analysis has been conducted by AHP-OS tool for the general user-15 feedback. Detail result presented below for the priorities of Criteria, Sub-Criteria and Alternatives for the appropriate Telecommunication Technology selection.

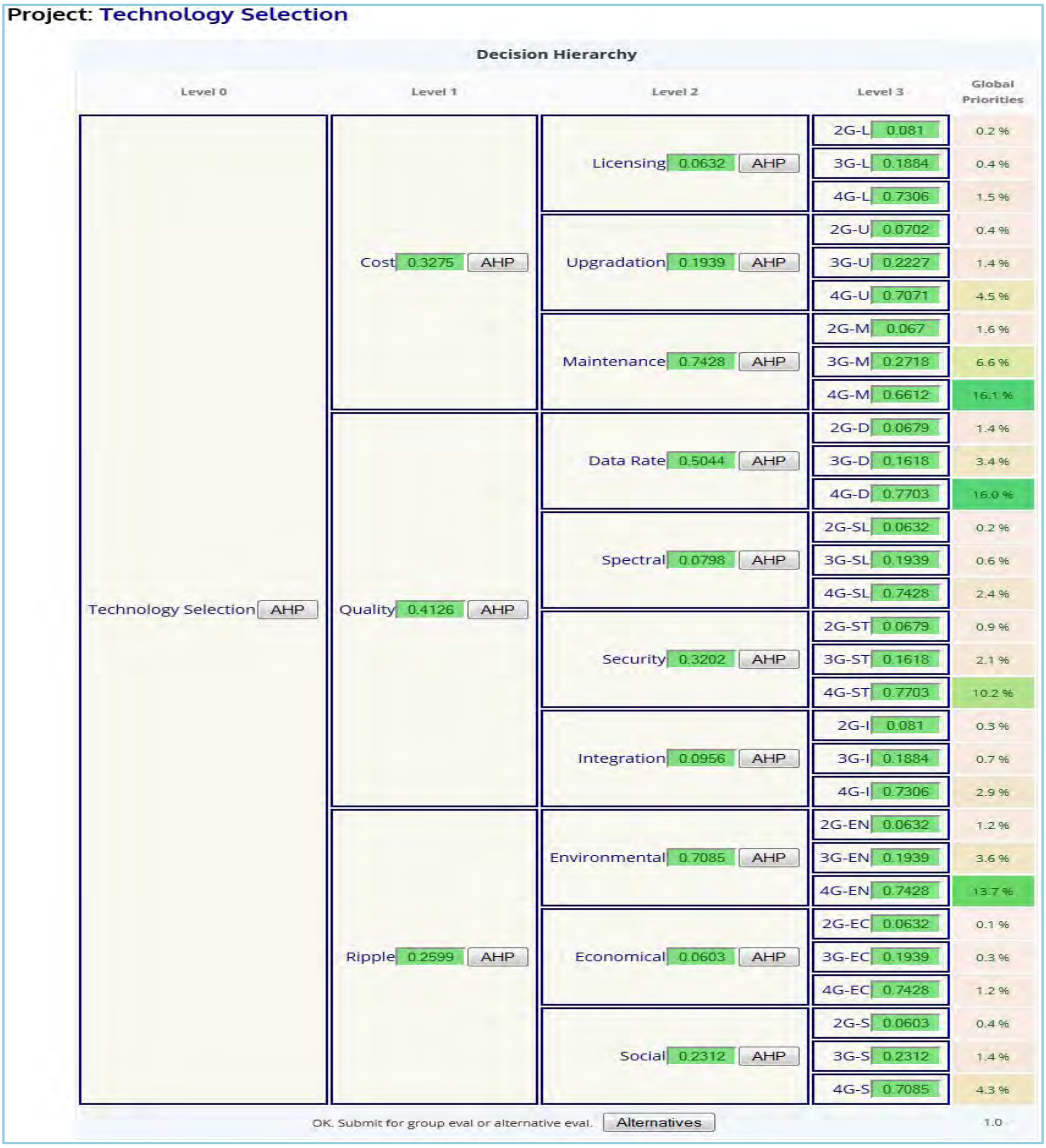

Figure 66: Priorities for Telecommunication Technology Selection Alternatives for general user-15 using AHP-OS

From above calculations by AHP-OS we calculated the final result for general user-15 feedback. After summing up all priorities for 2G, 3G and 4G global priorities and global weight achieved for 2G, 3G and 4G respectively. After calculating all priorities and weight, I have prepared the Table 45 for the final score of telecommunication technology selection.

Table 45: Global weights of the Telecommunication technology alternatives and final ranking (General User-15)

Telecommunication Technology selection			
Telecommunication Technologies	Global Priorities	Global Weight	Rank
2G (GSM/GPRS/EDGE)	0.067	6.70%	3
3G (UMTS/HSDPA/HSPA)	0.205	20.50%	2
4G (LTE/WiMAX)	**0.728**	**72.80%**	**1**

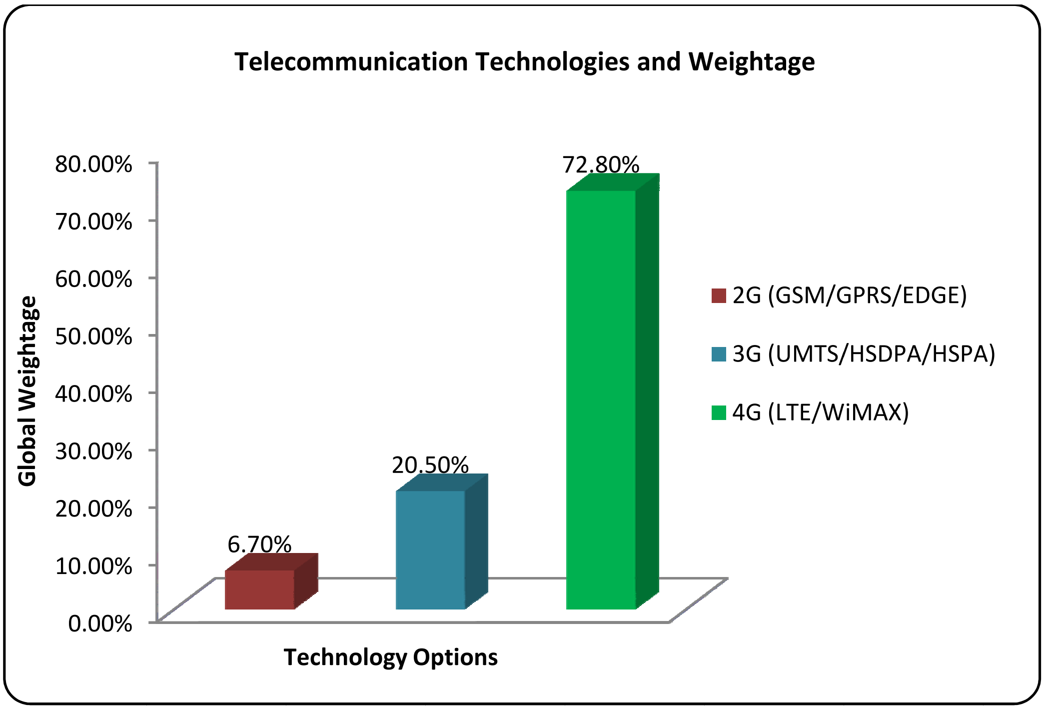

Figure 67: The result of telecommunication technology alternatives from general user-15 feedback

From Figure 66, the results of the empirical analysis show that the general user-15 preferred the Quality Features criterion as most important criterion and Maintenance Cost as most important sub-criteria. Table 45 and Figure 67 show that general user-15 preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 52.80% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 20.50% and 2G(GSM/GPRS/EDGE) technology with 6.70%.

4.2.16 Result Consolidation and Simulation (General User Feedback)

For result consolidation I have taken all the global weight of General User-1 to General User-15 feedback and have been plotted in Table 46. By averaging these values got final result in Table 46 as well. Final result has been presented by using MS Excel and plotted in Figure 68.

Table 46: Global weights of the Telecommunication technology alternatives and final ranking (General User Feedback)

Telecommunication Technology selection						
Telecommunication Technologies	Global Weight (GU-1)	Global Weight (GU-2)	Global Weight (GU-3)	Global Weight (GU-4)	Global Weight (GU-5)	Global Weight (GU-6)
2G (GSM/GPRS/EDGE)	6.90%	9.90%	7.00%	6.80%	6.80%	6.70%
3G (UMTS/HSDPA/HSPA)	34.30%	28.10%	37.60%	40.10%	21.60%	46.50%
4G (LTE/WiMAX)	**58.80%**	**62.00%**	**55.40%**	**53.10%**	**71.60%**	**46.80%**
Telecommunication Technology selection						
Telecommunication Technologies	Global Weight (GU-7)	Global Weight (GU-8)	Global Weight (GU-9)	Global Weight (GU-10)	Global Weight (GU-11)	Global Weight (GU-12)
2G (GSM/GPRS/EDGE)	6.70%	14.20%	10.80%	12.30%	11.10%	6.50%
3G (UMTS/HSDPA/HSPA)	38.00%	33.00%	27.50%	33.70%	39.10%	41.40%
4G (LTE/WiMAX)	**55.30%**	**52.80%**	**61.70%**	**54.00%**	**49.80%**	**52.10%**
Telecommunication Technology selection						
Telecommunication Technologies	Global Weight (GU-13)	Global Weight (GU-14)	Global Weight (GU-15)	**Average Weight**	**Final Ranking**	
2G (GSM/GPRS/EDGE)	10.30%	9.40%	6.70%	**8.81%**	**3**	
3G (UMTS/HSDPA/HSPA)	37.70%	37.50%	20.50%	**34.44%**	**2**	
4G (LTE/WiMAX)	**52.00%**	**53.10%**	**72.80%**	**56.75%**	**1**	

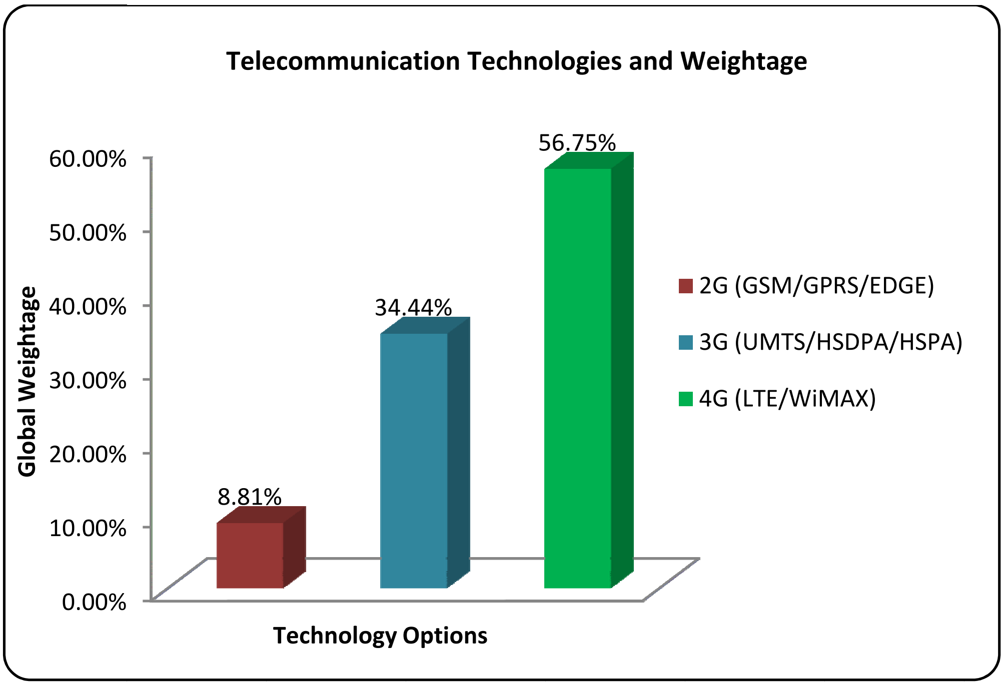

Figure 68: The result of telecommunication technology alternatives (General User Feedback)

The final results of the empirical analysis show that general user-1 and general user-3 preferred Ripple Effect criterion as most important criterion. General user-2, general user-10, general user-11, general user-12 and general user-15 preferred Quality Features. General user-4, general user-6, general user-7, general user-8, general user-9, general user-13 and general user-14 preferred Cost Components criterion as most important criterion. Only general user-5 preferred all three criterions equally as most important criteria. In terms of sub criteria general user-1, general user-2, general user-10, general user-11 and general user-12 preferred Data Rate as most important sub criterion. General user-4, general user-5, general user-8, general user-9, general user-13, general user-14 and general user-15 preferred Maintenance Cost as most important sub criterion. Another side general user-3, general user-6 and general user-7 preferred Environmental Issue, Licensing Cost and Upgradation Cost respectively as most important sub criterion. As for overall result, Table 46 and Figure 68 show that experts preferred the 4G (LTE/WiMAX) telecommunication technology most than all other telecommunication technologies with 56.75% global weight, followed by 3G (UMTS/HSDPA/HSPA) technology with 34.44% and 2G (GSM/GPRS/EDGE) technology with 8.81%.

4.3 Result Analysis

Result analysis shows that all the experts (Academy & Industry) and general users provided their feedback on 4G as appropriate telecommunication technology among other telecommunication technologies in Bangladesh. All experts selected Quality Feature as the main criteria among three criteria (Cost component, Quality Features and Ripple effect). For sub-criteria, expert-1, expert-3, expert-4 and expert-10selected data rate as the most important sub-criteria whereas expert-2, expert-5, expert-7 and expert-8 selected security features as the most important sub-criteria and expert-6 & expert-9 selected spectral efficiency and mobility as the most important sub-criteria among ten sub-criteria (Licensing Cost, Upgradation Cost, Maintenance Cost, Data Rate, Spectral Efficiency & Mobility, Security Features, Integration Scalability, Environmental Issue, Economic Impact and Social Impact). General users have divided their opinion for criteria as general user-1 and general user-3 preferred ripple effect criteria as most important criteria whereas general user-2,general user-10, general user-11, general user-12 and general user-15 preferred Quality Features and general user-4,general user-6, general user-7, general user-8, general user-9, general user-13 and general user-14 preferred Cost Components criterion as most important criterion and only general user-5 preferred all three criterions (Cost component, Quality Features and Ripple effect) equally as most important criteria. For sub-criteria general user-1, general user-2, general user-10, general user-11 and general user-12 preferred Data Rate as most important sub criterion. General user-4, general user-5, general user-8, general user-9, general user-13, general user-14 and general user-15 preferred Maintenance Cost as most important sub criterion. Another side general user-3, general user-6 and general user-7 preferred Environmental Issue, Licensing Cost and Upgradation Cost respectively as most important sub criterion among ten sub-criteria (Licensing Cost, Upgradation Cost, Maintenance Cost, Data Rate, Spectral Efficiency & Mobility, Security Features, Integration Scalability, Environmental Issue, Economic Impact and Social Impact).

It is also observed that, general user’s feedback scattered into different criteria and sub-criteria where expert’s opinion is focused and concrete as all experts preferred quality criteria and data rate, security and spectral efficiency sub-criteria.

Analyzing expert opinions (Academy & Industry) and general user feedbacks, it is observed from the empirical analysis that experts as well as general users recommending 4G technology as an appropriate wireless communication system for Bangladesh considering presented criteria and sub-criteria.

4.4 Discussion with Telecom Users

This chapter focuses on the discussion along with general user who have participated though questionnaire for the selection of appropriate telecommunication technology based on presented criterion and sub criterion. Two questions have been asked to telecom users, "why you have switched to 3G?" and "what is your expectation from 4G?" In response to above question I have captured their valuable feedback and these presented below.

"I'm having higher speed at same cost of 2G that's why I preferred 3G. My expectations to 4G is super speed and cheaper cost" **– user 6**

"Mainly I switched to 3G for video call and high internet speed and its price was also reasonable as I can avail GP 2GB data for a month worth of 265 taka. But I'm not happy with speed which I'm currently getting in 3G. Expectation is to real time video call as well as smooth internet speed from 4G" **– user 7**

"My family member lives in abroad. To communicate with them over internet video call, I mainly took 3G connectivity. Parallel, I can do online transactions. I'm using Airtel 3G 40 MB small internet pack for three days validity worth of 15 taka. It's cost not reasonable and validity time is insufficient. So my expectation from 4G is cheaper data plan and definitely higher internet speed for video calling." **– user 11**

"Me as telecom user I have been using Robi, GP and Banglalink 3G SIM for my day to day communication as well as social networking. Among those GP is most expensive and Banglalink is less expensive. My most of internet data being used on Facebook, YouTube, game download etc. In 2G these are unimaginable while in 3G these are real and I enjoy a lot. For me as I'm student these are still so costly e.g. for any game downloading it takes around 50-80 MB and costs thereby. I'm looking forward these will be cheaper in 4G and speed will be much higher than 3G." **– user 13**

"I use GP 3G internet package of 60 MB for five days price of 15 taka so it costs 4MB per taka. Its quite costly. My purpose of 3G usages are Facebook, Viber etc. I expect 4G will bring fast speed with lower cost" **– user 10**

“My office provides 3G facilities for faster mail communication and access in office tools remotely. It allows me to do home office when necessary. I would like to have faster data rate in 4G where real time communication is possible which is missing in 3G” **– user 14**

“I can send money to village through my Robi 3G SIM using mobile banking. It is faster and reliable. I expect high speed and these facilities from 4G.” **– user9**

“Most of my 3G data being used on Facebook, YouTube and study purpose. I use both GP 3G 75MB package and unlimited package as per my convenience. Unlimited packages offer unlimited data usage monthly period price of 350 taka. Other hand GP 3G 75 MB package has 512 Kbps speed, five days validity and price is 28 taka. it always not possible for me to avail unlimited package considering cost. I would be happy if I get more data at cheap price and higher speed in 4G. It’s my expectation from 4G.”**– user8**

“I see internet TV in my cell phone. This feature was not available in 2G. Still in 3G it takes much time for streaming and buffering. Hope in 4G there will be no delay and real time streaming will be available as well.” **– user15**

“3G is now part of my daily communication. I do many things by 3G, say mobile train ticket, online transaction, video call, job search etc. I can’t even think this in 2G where it took long time to be loaded a single page in 2G. Now it’s matter of a click. I honestly feel that price for 3G internet package is higher. Government regulations and Operators willingness could push down this price to a reasonable level that mass level can effort. As in neighbors country 4G already launched and they are having its benefit in large scale in each and every sector. So my expectation and hope that 4G will be launched in Bangladesh at earliest time keeping price level lower and maintaining highest band of 4G speed.” **– user12**

4.5 Cost Benefit Analysis of Telecommunication Technologies

The OPEX costs for operating a network are considered the main cost for network providers for any wireless communication technology. A comparison based on the total OPEX cost for operating a 4G network per sq-km is approximately 34% less than that of an equivalent 3G network. For a complete breakdown of OPEX costs for 4G & 3G please refer to appendix B & C respectively.

For cost benefit analysis here I have presented UK telecommunication scenario as relevant data not available for Bangladesh telecommunication sector. OPEX cost for network operators was calculated per sq-km based on dense-urban areas (cities). Dense-urban user density was chosen as 90.1% of the UK population lives in cities and hence the most profitable deployment area for network operators [55].

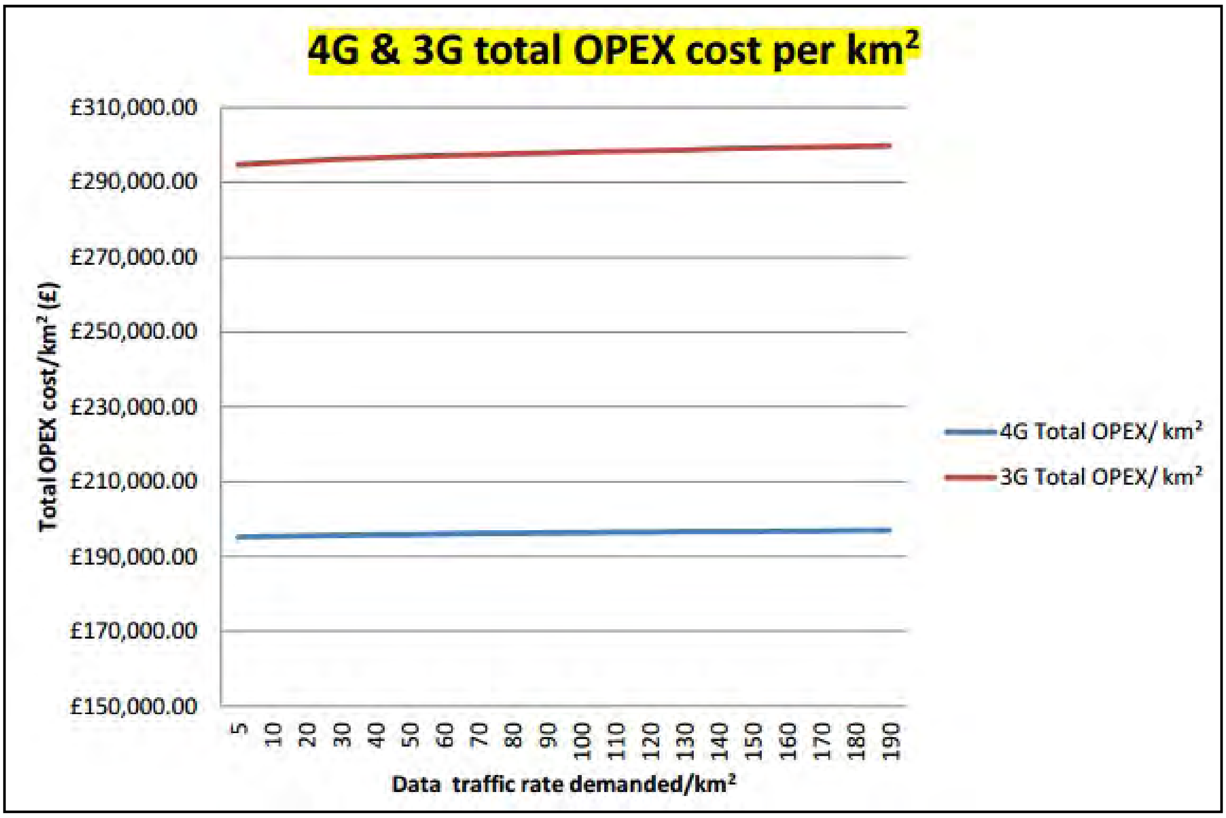

Figure 69: 4G & 3G OEPX costs per sq-km [56]

Analysis of the above OPEX costs shows the overall trend that OPEX costs increase for both 4G and 3G with respect to traffic demand. Furthermore, it can be noticed that the change in OPEX costs when operating at high traffic loads and low traffic loads is very small. In 4G the OPEX cost for a demanded traffic rate of 190 Mbps/sq-km and 5Mbps/sq-km is £196,956 and £195,152. This shows a change of £1,804 between the maximum and minimum offered data rate.

Similarly, applying the same analysis to 3G OPEX costs, the change in cost for the maximum and minimum demanded traffic rate is £4, 942. One can therefore view the OPEX cost per sq-km relatively static with increase in demanded traffic rate. However it should be noted that depending on the size of the entire network, the change in OPEX costs with increasing traffic could bare greater significance [56-57].

A more prominent observation shows a 34% reduction in the 4G OPEX costs in comparison to3G. From a network operator's perspective, it enables providing higher throughput speeds at lower costs. From the cost benefit analysis, it can be determined that with consumers wanting unlimited data and network operators wanting to maximize profits a trade-off must be made between user satisfaction and network operator profitability. Network operators should therefore offer 'unlimited' data packages as tariffs and consider the deployment of 4G as a technology that enhances the user experience rather than a technology that could enhance network operator profitability. The results show that the network operators will be profitable with the deployment of 4G with profits exceeding that of 3G.

4.6 Scenario Based Analysis

Rapid sustained growth of customer base and usage, together with the global evolution of mobile broadband technologies provides an attractive business environment. The continuing advance of mobile broadband technology offers new services and applications, as well as opportunity for new players in the marketplace. Unsurprisingly the key driver for service providers and network operators is profit. They are moving to 4G and beyond with the clear goals of increasing capacity, increasing revenues and decreasing costs, alongside remaining competitive in terms of their offerings. There is a trend away from custom network cores and intelligence at the edge, towards a generic core with heterogeneous access and centralized service level intelligence.

4G and beyond wireless communications bring challenges to consolidated use of electromagnetic spectrum, as well as design of spectral, cost and energy efficient high speed systems with downward compatibility and upgrade capability. Meanwhile, there are tremendous opportunities, such as seamless access to all IP-based services anywhere, anytime. Networks around the world entering the deployment phase of fourth generation (4G). The promise of 4G network, with broadband type speed and latency, opens a world of opportunity for the types of applications that developers can build. The following are some examples of the kinds of applications that could be enhanced by LTE.

Interactive Applications: Apps are considered the major driver of mobile data consumption. Video apps alone (e.g., Hulu, Netflix) consume 66% of all mobile data traffic. Apps on powerful, faster mobile networks and mobile devices bring opportunities to developers that understand both the device platforms and the mobile networks (2G, 3G and 4G) in which they operate. Developers will be able to build more efficient and powerful mobile apps when they understand how networks function. This efficiency in turn makes networks more valuable so customer adoption of apps accelerates [58].

There are over 135 million applications and gamers in the U.S. and with the rise of MMOs (Massively Multiplayer Online games), gamers and applications can now play latency sensitive and bandwidth hungry applications such as Bus Tracker that are streamed directly to their LTE devices. In addition, in 2012, game streamers such as OnLive and Gaikai already stream hardcore game titles such as Need for Speed directly to broadband devices such as laptops and smart TVs. This is being extended to LTE devices as well which, because of their reduced latency, provide a better gaming experience than prior generation mobile devices. Note that streaming apps, as explained in the challenges section, are battery and data hungry and should be tested and optimized with tools such as AT&T's Application Resource Optimizer (ARO) to minimize power consumption [59].

M2M: Mobile networks used to be only for voice communication. But now, the trend is to the internet of things or machine to machine (M2M) communication. Smart meters, traffic lights, cars, household appliances, and other devices are able to communicate with each other. M2M is used in 2G and 3G. The benefit that LTE brings to M2M is increased spectral efficiency. Spectral efficiency in 3G UMTS for example, is 3 bits per second (bps)/Hz. LTE, however, increases that five-fold to 15 (bps)/Hz. This increased efficiency becomes critical when forecasts show that the number of connected devices is forecasted to double to 12 billion by 2020. Thus, carriers are able to offload M2M data traffic from congested 3G to LTE.

One example of M2M is AT&T's Digital Life (digitallifeservices.att.com) that provides a remote monitoring and automation platform for connecting a user's device to devices in their home. This platform makes it possible to create apps for web-based home automation, security, energy management, and healthcare services [60].

Powerful Devices: Computing power is bringing desktop quality computing to mobile devices (smart phones and tablets). Declining price-points for increasingly more powerful devices are resulting in the increased usage of Internet enabled mobile devices. For example, over 56% of AT&T's customers are already using smart phones.

Power Consumption: UK Scenario, the comparison of 4G and 3G reveals that 4G power consumption per sq-km is almost 63% lower than 3G power consumption. This suggests 4G can deliver the same data throughput per sq-km as 3G consuming far less power. It can also be noted that the power increases exponentially, this is due to the power amplifier efficiency increasing with respective to data traffic, as a result with data demand expected to increase in the future and data traffic demand expected to rise far beyond 190 mbps/sq-km the power consumption will further improve. Achieving greater spectral efficiency per cell in 4G has meant fewer 4G cells are required to deliver the same throughput per sq-km compared to 3G. As a result consumers can now achieve higher throughput speeds using 4G compared to 3G and network operators can benefit from lower power consumption per km-sq [61].

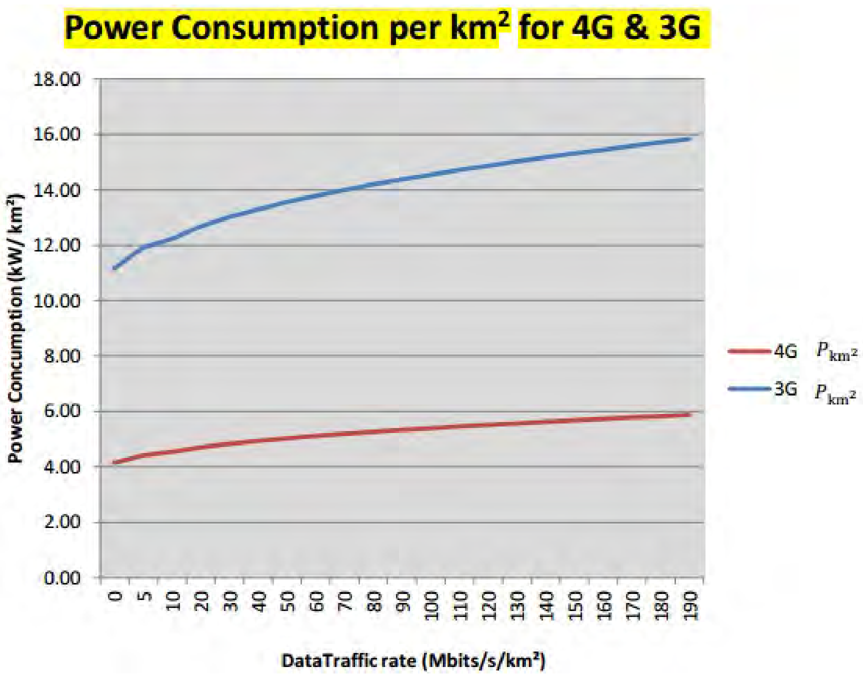

Figure 70: Power consumption comparison of 3G and 4G technology [61]

Annual power consumption of 3G and 4G network is respectively 51445 and 138677 KWh/sq-km. 3G network consumes around 2.7 times more energy compared to 4G network [61].

Table 47: Annual energy consumption of 3G and 4G technology [61]

Mobile Technology	Annual Energy Consumption per sq-km (KWh)
4G	51,445
3G	138,677

CO$_2$Emission: UK scenario, Energy consumption per BS for 4G LTE technology is less than that of 3G HSPA technology. Mobile operators committing to reducing their carbon footprint an estimation of the CO_2 emissions of 4G and 3G technologies was produced in order to determine the effect of each technology on the environment. Annual CO_2 emission per sq-km for 4G and 3G is 24.66 and 66.54 tones, respectively. This shows that the migration from 3G to 4Gcan produce a 63% reduction in CO_2 emissions with a potential 41.88 tons of CO_2 prevented from being released into the atmosphere. Given the deployment ratio of 3G BS to 4G BS per sq-km. Operators will benefit as the growing pressure from consumers for ‘green tariffs’ which either use more renewable energy sources, or produce less CO_2 can be introduced with a switch to 4G and will therefore be seen as a positive for consumers. Growing emphasis on corporate responsibility and sustainability being a key issue, lower levels of CO_2 emission will aid in increasing a network provider’s profile in ‘going green’, while certain experts also suggest it can form a competitive advantage. Operators can also take advantage of the global ‘carbon credit’ trading schemes. Carbon credits place a monitoring price on polluting activities; as a result the businesses can earn money for their reduction in carbon emissions [62].

LTE, the fourth generation mobile network, is currently being deployed worldwide. This 4G network has a significantly higher bandwidth, lower latency, better security, and more types of QoS than earlier generations. All these benefits offer the opportunity for developers to build enhanced applications not possible with 3G. Some possible applications are live, HD broadcasts from smart phones or the ability to play latency-sensitive, interactive games. However, this network is only one of three elements in an ecosystem that has the potential for new revenue opportunities for carriers and developers. Networks, devices, and apps have to work seamlessly together to drive consumer adoption and thus revenue.

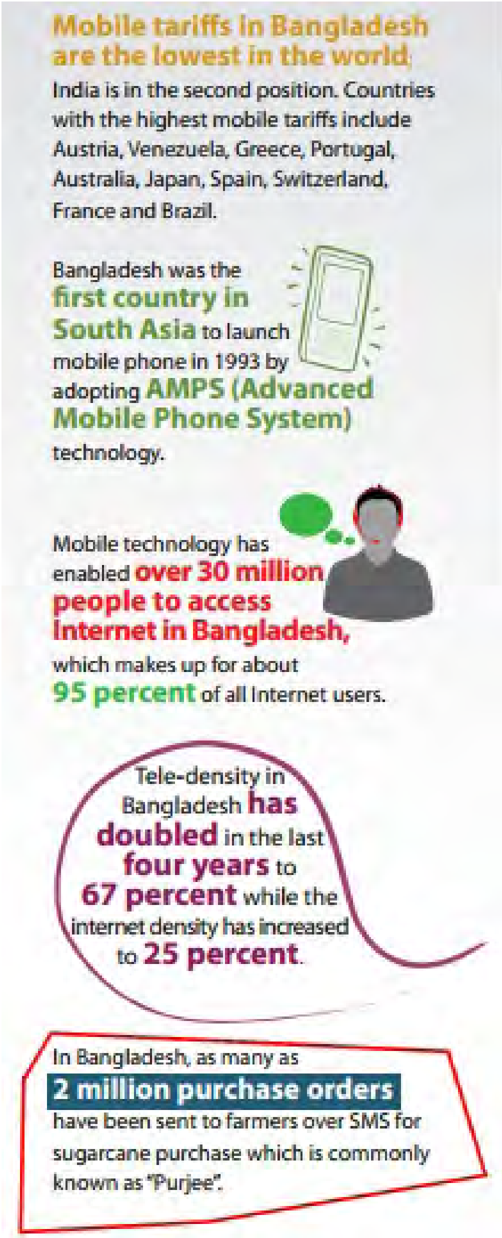

Figure 71: Dimension of Bangladesh Telecom Industry [63]

Bangladesh's mobile telecom industry is undergoing a mature phase amid the journey to implement a 'Digital Bangladesh' through embracing new technologies such as 'Third Generation' (3G) to spread the benefit of broadband Internet to the mass people. A major contributor to the national exchequer as well as Foreign Direct Investment, the telecom sector is playing a vital role in moving forward the economic progress of the country to the next level of accomplishment. Broadband needs to be widely available and adorable, as Bangladesh wants to achieve the full economic benefits of mobile broadband. Broader policies and investment framework should be in place to help achieving ‘Digital Bangladesh’. It will enable to deliver the telecom sector government services, health, education, industry, agriculture and so forth.

In fact we have already observed the impact of telecommunication on the GDP growth of Bangladesh. A study made by Deloitte & Touché in 2007 found that mobile communication has raised GDP growth in Bangladesh by 0.12 percent for 1 percent increase in mobile penetration [60].

According to a study by the Boston Consulting Group (BCG) in 2010 titled, “Towards a Connected Bangladesh: Socio-economic Impact of Internet in Bangladesh Economy”, in terms of overall GDP contribution in 2020 for Bangladesh, the report stated that Internet is expected to contribute 2.6 percent of total GDP and suggests that a 10 percentage in Internet penetration is correlated with a 1 percent increase in the annual rate of new business formation; calculating the creation of over 129,000 jobs in Bangladesh by 2020 [63]. The bulk of the GDP contribution coming from the increased productivity that Internet users enjoy in services, manufacturing, including agriculture, as well as increased diversification of sources of income.

For Bangladesh to achieve these economic benefits, broadband needs to be widely available and affordable. Aligning on globally harmonized spectrum enables consumers to benefits from economies of scale, through lower cost devices and operators can deliver high performing networks based on equipment and software used in many markets. Availability of sufficient spectrum enables operators to deploy networks most cost effectively. Mobile services have the greater potential to impact economic development with the high value 3G services delivering data services to business and consumers. Countries with higher level of mobile penetration tend to be countries with higher level of capital investment in the mobile sector. Mobile penetration is regarded as an input of the aggregate GDP production function since higher level of investment in the mobile sector generates more employment and more activity in the wider economy [63].

Wider access of mobile penetration reduces transaction costs, promotes efficiency and with the advent of 3G and coming 4G will allows faster information flow and dissemination. The increase in Total Factor Productivity leads to the increase in GDP through the maximum utilization of capital and labor inputs and as a result increasing the productivity of a nation like Bangladesh. As per AMTOB (Association of Mobile Phone Operators in Bangladesh) Bangladesh telecommunication evolution path could lead to 4G by 2015 [63].

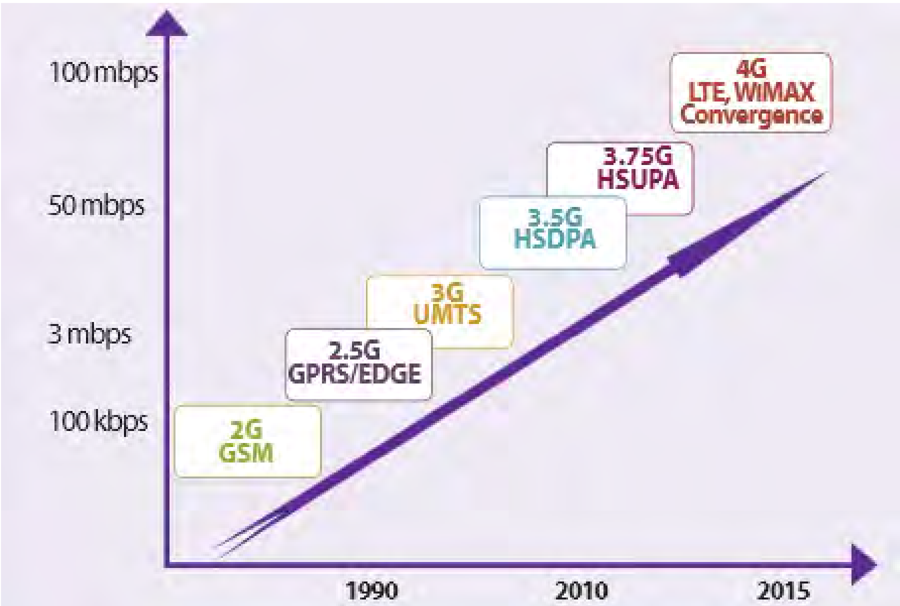

Figure 72: Mobile telecom technology evolution in Bangladesh [63]

4.7 SWOT Analysis of Telecommunication Technologies

Considering telecommunication technology alternatives context, a SWOT analysis presented below for 2G, 3G and 4G wireless communication system. Figure 34 shows SWOT analysis with its four elements. Considering this elements SWOT analysis presented below for 2G, 3G and 4G.

Figure 73: SWOT Analysis with its four elements

4.7.1 SWOT Analysis for 2G

<u>Strengths in 2G:</u>

- Digital wireless communication system over analog telephony.
- Flexibility

<u>Weakness in 2G:</u>

- Unable to fulfill higher data rate requirement.
- Multi-platform not supported.

<u>Opportunities in 2G:</u>

- No opportunities. 2G now it’s in decline phase.
- Many areas across the world it’s an obsolete technology

<u>Threats in 2G:</u>

- No threat as its decline phase as well as obsolete in many area.
- Major 2G market covered by latest telecommunication technologies.

4.7.2 SWOT Analysis for 3G

Strengths in 3G:

- Worldwide standard for accessing global telecommunication.
- Increased clarity
- Highly sophisticated form of communication.
- Data transmission up to 10+ Mbps.

Weakness in 3G:

- Higher cost as compared with predecessor.
- Need for continuously increasing data rate and bandwidth to meet the multimedia requirements.
- Limitations of spectrum and its allocation.
- Lack of seamless transport end to end mechanism.

Opportunities in 3G:

- Consumer replacing handset and accessories with this newer technology pushes new sector for Mobile accessories.
- Greater subscriber capacity
- Fast packet based data service like email, short message service (SMS) and internet access at broadband speeds.
- Faster communication helps for growth and development m-commerce, m-banking, m-agriculture.

Threats in 3G:

- Upcoming 4G technology
- Regulatory issue for approval and deployment.

4.7.3 SWOT Analysis for 4G

Considering 4G characteristics, expected scenarios and market trends, we can find out strengths, weaknesses, opportunities and threats of 4G with better understandings. The lists and findings follow.

Strengths in 4G:

- 4G visions take into account installed base and past investments.
- Strong position of telecommunications vendors expected in the marketplace.
- Real time data transmission and higher bit rate and bandwidth, allow more business applications and commercialization.
- Has advantage for personalized multimedia communication tools.

Weakness in 4G:

- No large user community for advanced mobile data applications yet.
- Growing divergence between telecommunications vendors and operators.
- Not possible to offer full internet experience due to limited speed and bandwidth.
- Higher cost involvement to use and deploy infrastructure.

Opportunities in 4G:

- Evolutionary approach may yield opportunities for the 4G.
- Emphasis on heterogeneous networks capitalizes on past investments.
- Strategic alliance and coalition opportunities with traditional non-telecommunication industries.
- Sophisticated and mature commercialization of 4G technology would encourage more applications of e-commerce and m-commerce.
- Worldwide economy recover stimulates consumption and consumer confidence; therefore bring in opportunities for telecommunication sectors.
- It is expected and predicted that consumers will continue to replace handsets with newer technology at a fast rate.
- Desirable higher data capacity rates, the growth opportunity for 4G is very bright and hopeful.

Threats in 4G:

- Faster rate of growth and developments in other region
- Since 3G mobile is still in the market, it squeezes the market competition in the mobile industry.

It is inevitable that 4G would completely replace 3G in a long run. Nevertheless, 4G and 3G trend to keep a co-competitive relationship in a short run. In order for 4G to grow in the future market, it is unavoidable to compete with 3G and acquire 3G's customers.

As it was also analyzed and investigated through the scenarios, the comparison was made here that among three candidates for the 4G presented. Every service providers and manufacturers strategize towards high mobility and high data rates whether it is 3GPP, WiMAX. However, the mainstream of service providers concern about regulation, uncertainty of market, and economic burden. There is also new spectrum allocation issue which should be resolved and determined, much as the technology feasibility. Anyhow, there are plenty of opportunities for 4G. Under these circumstances, to be flourished in the future telecommunication market, 4G technology should be on boarded soon and deployed systems to meet needs of consumer demands in near future.

4.8 Tabular Representation of 2G, 3G and 4G Technology

Table 48: Tabular representation of 2G, 3G and 4G technology

Parameters	**2G**	**3G**	**4G**
Standard Protocols	GSM, GPRS, EDGE	UMTS, HSDPA, HSPA	LTE, WiMAX
Key Features	Digital, secure, voice and data.	Digital, highly secure, multimedia, global roaming across single type of network, limited IP interoperability.	Digital, highly secure, multimedia, global roaming across multiple wireless networks, IP interoperability for seamless mobile internet.
Data Speed	Up to 100 Kbps	Up to 46 Mbps	100 Mbps +
Annual Energy Consumption	-	1,38,677 KWh/sq-km	51,455 KWh/sq-km
Annual CO_2 Emission	-	66.54 Tones/sq-km	24.66 Tones/sq-km
Opportunities	Existing user base and attractive price plan.	Faster data transmission and higher bit rate and bandwidth, allow more business applications and commercialization. Pushing new market for 3G handsets.	Real time communication will help for growth and development of m-commerce, m-banking, m-agriculture etc.

Parameters	2G	3G	4G
Upcoming Threats	It's in decline phase. Major market covered by latest telecommunication technologies.	Upcoming 4G technology and regulatory issue.	Since 3G technology still in the market, it squeezes the market competition.
Operators in Bangladesh	Grameenphone, Robi, Banglalink, Airtell, Citycell and Teletalk.	Grameenphone, Robi, Banglalink, Airtell, and Teletalk.	No operators providing 4G service currently.
Current Package with Cost	GP 2G 2GB Pack Price: 300 BDT+VAT Teletalk 2G 2GB Internet Pack Price: 220 BDT+VAT Robi 2G 2GB Internet Pack Price: 300 BDT+VAT	GP 3G 2GB (512 Kbps) Standard Pack Price: 400 BDT+VAT Teletalk 3G 2GB (512 Kbps) Internet Pack Price: 350 BDT+VAT Robi 3G 2GB (512 Kbps) Internet Pack Price: 300 BDT+VAT	Not available as 4G yet not launched in Bangladesh.

Conclusion

Chapter 5

5.1 General Discussion

Standards in the telecommunications industry are constantly changing as advances are made in new technologies and the public demand for a richer content, delivered at faster speeds and at all times is the main driving force behind these technological developments. Nowadays, many of the devices we own including mobile phones and laptops are capable of connecting to 3G or 3rdGeneration networks with speeds ranging from 2.4–7.2 Mbps, depending on the network operator, coverage area and the device platform. With demand for this high speed broadband services set to grow constantly, the ITU’s Radio communication sector (ITU-R) came up with recommendations for the design of anew air interface which would support this growing demand. Such systems would be considered as 4G.

This thesis began by looking at the technological evolution path adopted by the industry bodies. Telecommunication technology evolution time by time has been described with technical specifications of mobile system based on evolved GSM core networks and their supported technologies to maintaining and developing new evolved radio access technologies based on GSM including GPRS and EDGE. With the evolution of 4G the technical specification with evolution of mobile system based on advanced LTE and WiMAX presented. The latest standards from these industry bodies currently making their way into the market, LTE detail feature presented.

Finally, an empirical analysis has been conducted using Technology Assessment tool with Analytical Hierarchy Process, where all technological choices are analyzed in context of present Bangladesh telecommunication technology. Result and simulation showed 4G technology has high preference as most appropriate technology selection by academy and industry telecom expert. Another observation came out through Cost Benefit Analysis that4G will have market advantage and 4G will enjoy a significant growth in the coming year’s mainly in developing countries, and will also enjoy backing from the existing GSM-standard operators. This will consequently push down the price of LTE-supported devices and hence prepare the way for LTE and LTE-Advanced to make a grand entrance.

The history of mobile communications shows, attempts have been made to reduce a number of technologies to a single global standard. Projected 4G systems offer this promise of a standard that can be embraced worldwide through its key concept of integration. The fourth generation promises to fulfill the goal of PCC (personal computing and communication)—a vision that affordably provides high data rates everywhere over a wireless network. Therefore, there is wide scope for future demographic researches on this topic. Nevertheless, AHP model used in this study provides a fair analysis for assessing the 4G wireless communication technologies in Bangladesh context [64].

5.2 Scope for Future Work

In future, it will be interesting to know how all these developments in the mobile communications industry takes account of other related public issues like global warming. To evaluate impact of future telecommunication technologies, how technology management deal for assessment. In particular, it would be interesting to know how the design and implementation of the new 4G standards can reduce power consumption at the level of BS or mobile devices which will be carried and used by millions of people worldwide.

In the future, the wireless network's energy efficiency has got to rise drastically yet again from the previous generation. The energy efficiency jump for the same level of coverage was about 60-fold when going from the legacy 2G systems to LTE [65] and nothing less should be anticipated from the upcoming 5G. It can also be expected that the wireless network assessment is going to rise into an even more important role as a research topic in future.

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Appendix

A	AHP Questionnaire for selection of Wireless Communication Technology
B	3G detailed OPEX costs per sq-km
C	4G detailed OPEX costs per sq-km

Objective of this document is to collect and analyze data, based on expert opinion from Academy and Industry for the impact analysis of Fourth Generation (4G) wireless communication technology in Bangladesh.	
Expertise From	☐ **Academy** ☐ **Industry** ☒ **General User**
Name	
Designation	
Organization/Occupation	
Cell	
Email	
Signature	

Appendix A: AHP Questionnaire for selection of Wireless Communication Technology

Selection	Technology for Wireless Communication
Factor	Cost Component, Quality Features and Ripple Effect
Sub Factor	Licensing Cost, Upgradation Cost and Maintenance Cost Data Rate, Spectral Efficiency & Mobility, Security Features and Integration Scalability Environmental Issue, Economical Impact and Social Impact
Technology	**2G**(GSM/GPRS/EDGE), **3G**(UMTS/HSDPA/HSPA) and **4G**(LTE/WiMAX)

This research will assess the advantages and disadvantages of a full range of technology options of the 4G wireless telecommunication systems and enhancements of superior 4G technology to the existing 3G technology in terms of costparameters and reliable quality of services. Above the establishment of technical criteria that influence the technology choices, the system options will be reviewed and compared. Based on the results, an appropriate telecommunication technology strategies and recommendation will be formulated for appropriate selection of the wireless communication system in Bangladesh.

Appendix A: AHP Questionnaire for selection of Wireless Communication Technology

The questionnaire and scale considered for this research is from 1 (Equally Preferred) to 9 (Extremely Preferred). Standard Preference Table is givenin last page for the detail of scale 1-9. Questions are formulated in comparative term, as presented below:

1(a) Given the Technology selection, what do you think is more important: the factor of Cost Component (F1) or the factor of Quality Features (F2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

2(a) Given the Technology selection, what do you think is more important: the factor of Cost Component (F1)or the factor of Ripple Effect (F3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

3(a) Given the Technology selection, what do you think is more important: the factor of Quality Features (F2) or the factor of Ripple Effect (F3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

4(a) Given the Factor (F1), what do you think is more important: the sub factor of Licensing Cost (F1A1) or the sub factor of Upgradation Cost (F1A2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

5(a) Given the Factor (F1), what do you think is more important: the sub factor of Licensing Cost (F1A1) or the sub factor of Maintenance Cost (F1A3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

6(a) Given the Factor (F1), what do you think is more important: the sub factor of Upgradation Cost (F1A2) or the sub factor of Maintenance Cost (F1A3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

7(a) Given the Factor (F2), what do you think is more important: the sub factor of Data Rate (F2B1) or the sub factor of Spectral Efficiency & Mobility (F2B2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

8(a) Given the Factor (F2), what do you think is more important: the sub factor of Data Rate (F2B1) or the sub factor of Security Features (F2B3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

9(a) Given the Factor (F2), what do you think is more important: the sub factor of Data Rate (F2B1) or the sub factor of Integration Scalability (F2B4)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

10(a) Given the Factor (F2), what do you think is more important: the sub factor of Spectral Efficiency & Mobility (F2B2) or the sub factor of Security Features (F2B3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

11(a) Given the Factor (F2), what do you think is more important: the sub factor of Spectral Efficiency & Mobility (F2B2) or the sub factor of Integration Scalability (F2B4)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

12(a) Given the Factor (F2), what do you think is more important: the sub factor of Security Features (F2B3) or the sub factor of Integration Scalability (F2B4)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

13(a) Given the Factor (F3), what do you think is more important: the sub factor of Environmental Issue (F3C1) or the sub factor of Economic Impact (F3C2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

14(a) Given the Factor (F3), what do you think is more important: the sub factor of Environmental Issue (F3C1) or the sub factor of Social Impact (F3C3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

15(a) Given the Factor (F3), what do you think is more important: the sub factor of Economic Impact (F3C2) or the sub factor of Social Impact (F3C3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

16(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

17(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

18(a) Given the Sub Factor (F1A1), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

19(a) Given the Sub Factor (F1A2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

20(a) Given the Sub Factor (F1A2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

21(a) Given the Sub Factor (F1A2), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

22(a) Given the Sub Factor (F1A3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

23(a) Given the Sub Factor (F1A3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

24(a) Given the Sub Factor (F1A3), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

25(a) Given the Sub Factor (F2B1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

26(a) Given the Sub Factor (F2B1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

27(a) Given the Sub Factor (F2B1), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

28(a) Given the Sub Factor (F2B2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

29(a) Given the Sub Factor (F2B2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

30(a) Given the Sub Factor (F2B2), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

31(a) Given the Sub Factor (F2B3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

32(a) Given the Sub Factor (F2B3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

33(a) Given the Sub Factor (F2B3), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

34(a) Given the Sub Factor (F2B4), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

35(a) Given the Sub Factor (F2B4), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

36(a) Given the Sub Factor (F2B4), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

37(a) Given the Sub Factor (F3C1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

38(a) Given the Sub Factor (F3C1), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

39(a) Given the Sub Factor (F3C1), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

40(a) Given the Sub Factor (F3C2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

41(a) Given the Sub Factor (F3C2), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

42(a) Given the Sub Factor (F3C2), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

43(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 3G [UMTS/HSDPA/HSPA] (T2)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

44(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 2G[GSM/GPRS/EDGE](T1) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

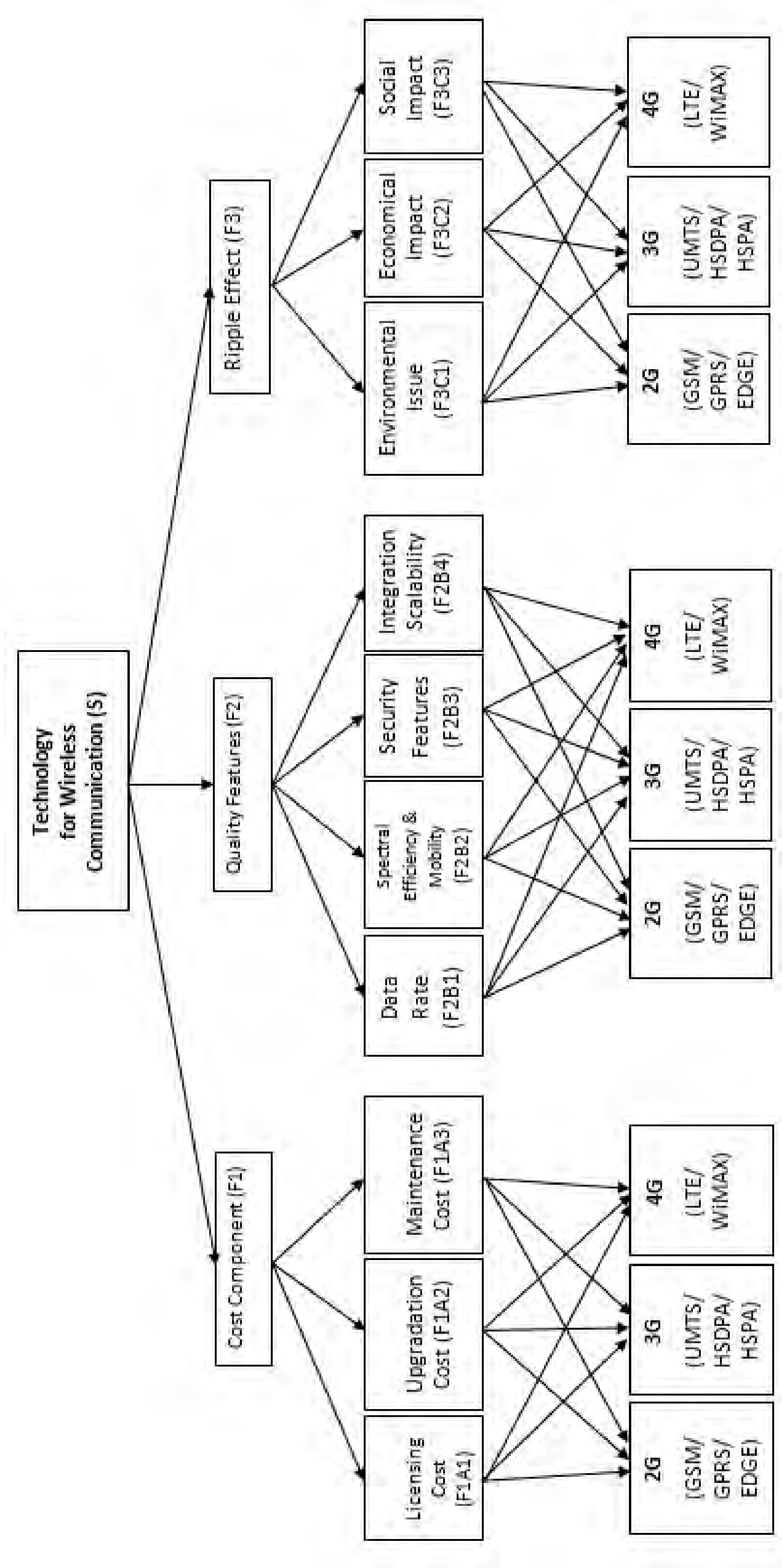
(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

45(a) Given the Sub Factor (F3C3), what do you think is more important: the technology of 3G [UMTS/HSDPA/HSPA] (T2) or the technology of 4G [LTE/WiMAX] (T3)? **Ans:**

(b) Please indicate, on a scale from 1 to 9 to what extent you consider your previous choice is more important than the other one. **Ans:**

AHP (Analytical Hierarchy Process) Standard Preference Table	
Judgments of preference	**Numerical Rating**
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

Appendix A: AHP Questionnaire for selection of Wireless Communication Technology



Appendix A: AHP Questionnaire for selection of Wireless Communication Technology

3G detailed OPEX costs per sq-km

3G OPEX per km²									
Cost elements/cell	Traffic rate demanded Mbits/km²								
	5	10	20	30	40	50	60	70	80
Electrcity Bill/km²	£14,814	£15,204	£15,756	£16,179	£16,536	£16,851	£17,135	£17,396	£17,640
Electrcity Bill	£1,195	£1,226	£1,271	£1,305	£1,334	£1,359	£1,382	£1,403	£1,423
Backhaul Rent	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500
Site Rental	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800
Maintance	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900
3G Total OPEX/ km²	£294,773.16	£295,169.58	£295,730.20	£296,160.38	£296,523.03	£296,842.54	£297,131.40	£297,397.03	£297,644.27

3G OPEX per km²										
Traffic rate demanded Mbits/km131										
90	100	110	120	130	140	150	160	170	180	190
£17,868	£18,084	£18,290	£18,486	£18,675	£18,856	£19,031	£19,200	£19,364	£19,523	£138,677
£1,441	£1,458	£1,475	£1,491	£1,506	£1,521	£1,535	£1,548	£1,562	£1,574	£1,587
£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500
£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800
£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900
£297,876.49	£298,096.13	£298,305.03	£298,504.63	£298,696.08	£298,880.29	£299,058.04	£299,229.95	£299,396.57	£299,558.35	£299,715.70

Appendix B: 3G detailed OPEX costs per sq-km

4G detailed OPEX costs per sq-km

	4G OPEX per km²										
Cost elements per cell	Traffic rate demanded Mbits/km²										
	5	10	20	30	40	50	60	70	80	90	100
Electrcity Bill/km²	£5,496	£5,640	£5,845	£6,002	£6,134	£6,251	£6,357	£6,454	£6,544	£6,629	£6,709
Electrcity Bill	£1,195	£1,226	£1,271	£1,305	£1,334	£1,359	£1,382	£1,403	£1,423	£1,441	£1,458
Backhaul Rent	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500
Site Rental	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800
Maintance	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900
Marketing Cost	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257
CAPEX per cell	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795
CAPEX repayment per cell over 12 years	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553
4G Total OPEX/ km²	£195,152.00	£195,296.72	£195,501.39	£195,658.44	£195,790.84	£195,907.48	£196,012.94	£196,109.92	£196,200.18	£196,284.96	£196,365.14

Cost elements per cell	110	120	130	140	150	160	170	180	190
Electrcity Bill/km²	£6,785	£6,858	£6,928	£6,995	£7,060	£7,123	£7,184	£7,243	£51,445
Electrcity Bill	£1,475	£1,491	£1,506	£1,521	£1,535	£1,548	£1,562	£1,574	£1,587
Backhaul Rent	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500	£7,500
Site Rental	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800	£10,800
Maintance	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900	£3,900
Marketing Cost	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257	£3,257
CAPEX per cell	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795	£139,795
CAPEX repayment per cell over 12 years	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553	£12,553
4G Total OPEX/ km²	£196,441.41	£196,514.28	£196,584.17	£196,651.42	£196,716.32	£196,779.08	£196,839.91	£196,898.97	£196,956.42

Appendix C: 4G detailed OPEX costs per sq-km