# EFFECTS OF LOGARITHMIC AND EXPONENTIAL FUNCTIONS ON VERTICAL HANDOVER USING MULTI-CRITERIA DECISION MAKING METHODS

**A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES**
**OF**
**NEAR EAST UNIVERSITY**

**By**
**ABDULHAKIM MEHEMED ZENTANI**

**In Partial Fulfilment of the Requirements for the Degree of Master of Science**
**in**
**Electrical and Electronic Engineering**

**NICOSIA, 2016**

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**Approval of Director of Graduate School of Applied Sciences**

**Prof. Dr. İlkay SALİHOĞLU**

**We certify this thesis is satisfactory for the award of the degree of Masters of Science in Electrical and Electronic Engineering**

**Examining Committee in Charge:**

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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**To my family......**

## ABSTRACT

In the end of 90s and beginning of the $20^{th}$ century, wireless networks have evolved from being just a promising technology to become a requirement for everyday activities in developed societies. The transportation means have also been developed and equipped with new communication technologies. These technologies were meant to offer more safety and better service. End-user requirements have become technology dependent, their connectivity needs have increased due to the different requirements for applications running on their portable devices such as tablets, smart-phones, laptops and other devices. To fulfil these connectivity requirements while considering different available wireless networks, vertical handover techniques are required in order to seamlessly and transparently switch between networks without requiring user intervention. The resulting algorithms present novelties concerning heterogeneous networks and the use of the IEEE 802.21 standard. Moreover, advanced geolocation is used to improve the VHDA. The algorithms introduce new concepts about QoS guarantees supported by the combination of geolocation, network, and context information, improving the decision-making process by considering multiple criteria in order to fairly evaluate the candidate networks to switch into networks seamlessly. The algorithms are evaluated on well thought out MATLAB simulation environments, obtaining results that offer useful insights concerning processes and VHDAs.

The major aim of this study is to analyze the effects of linear, logarithmic and exponential functions on the TOPSIS algorithm for vertical handover technology. The effect of each function on the weights of each parameter in the network is studied during the decision for the best network. Different experiments are applied under different conditions to evaluate the best network to be used with better throughput, low latency, minimum BER and low price per MB.



***Keywords*****:** Vertical Handover; Multi Criteria Decision Making; Technique for Order Preference by Similarity to Ideal Solution

# ÖZET

90'lı yılların sonunda ve yirminci yüzyılın başlarında, bilgisayar ağları gelişmiş toplumların günlük yaşamlarında bir gereksinim olarak ortaya çıkmıştır Bu arada geliştirilen ulaşım araçlarında da yeni iletişim teknolojisi kullanılmaya başlanmıştır. Bu tür teknoloji daha iyi ve güvenilir hızmet anlamı taşımaktadır. Buna paralel olarak, kullanıcıların ihtiyaçları onları teknoloji bağımlısı yapmış ve portabıl aletlerindeki (tablet, yeni telefonlar, dizüstü bilgisayar vs) değişik gereksinimler nedeniyle bağlantı ihtiyaçları daha da artmıştır. Mevcut kablosuz bağlantılar yanında, bu tür bağlantı ihtiyaçlarını karşılamak için, kullanıcının müdahalesi olmadan, bilgisayar ağları arasında sorunsuz şekilde dolaşabilmek için vertical handover) ihtiyaç vardır. IEEEE 802.21 in ve heterojen ağların kullanımıyla meydana gelen algoritmalar birçok yeniliklere sahne olmuştur. Dahası, VHDA nın geliştirilmesi için yeni alanlar kullanılmıştır. Algoritmalar, QoS garantileriyle ilgili yeni alanların - bilgisayar ağlarının, ve içerik bilgilerinin- destekleriyle yeni algılar yaratmışlardır. Bu da, kişinin ağlar arasında kesintisiz dolaşımı ve karar verme aşamasındaki çoklu kriterleri dikkate alması konusunda gelişme sağlamaktadır. Algoritmalar, çok iyi hazırlanmış MATLAB similasyon ortamlarında değerlendirilmiş ve elde edilen sonuçlar VHDA'larla ilgili faydalı algılar yaratmıştır.

Bu çalışmanın en büyük hedefi, linear, logaritmik, ve sürat fonksiyonlarının VHO teknolojisiyle ilgili TOPSIS algoritmaları üzerindeki etkisini incelemektir. Bilgisayar ağları göz önüne alındığında, her fonksiyonun her parameter ağırlığı üzerindeki etkisi en iyi bağlantıyı elde etmek için incelenmiştir. Bunu yaparken, daha iyi zamanlama, daha az belirsizlik, asgari BER ve MB başına daha az fiyat konularının değerlendirilmesiyle ilgili, dağişik ortamlarda farklı denemeler yapılmıştır.



**Anahtar Kelimeler:** Vertical Handover; Multi Criteria Decision Making; Technique for Order Preference by Similarity to Ideal Solution

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| | |
|---|---|
| **3GPP:** | 3rd Generation Partnership Project |
| **4G:** | fourth Generation |
| **$\gamma$:** | signal to noise ratio |
| **$\lambda_{in}$:** | arrival rate into queue |
| **$\lambda_{out}$:** | queue service rate |
| **AHP:** | Analysis Hierarchy Process |
| **AWGN:** | Additive White Gaussian Noise |
| **A:** | number of packet per second |
| **ANN:** | Artificial Neural Networks |
| **ACL:** | Access Control List |
| **BT:** | Bluetooth |
| **BIR:** | Bit Error Ratio |
| **B:** | Band withed |
| **BW:** | Band withed |
| **BS:** | Base Station |
| **BSC:** | BS Controllers |
| **CN:** | Candidate Network |
| **CSG:** | Closed Subscriber Group |
| **CPE:** | Consumer Premise Equipment |
| **CIR:** | Committed Information Rate |
| **CSI:** | Channel Side Information |
| **C:** | Capacity (throughput) |
| **DVB:** | Digital Video Broadcasting |
| **DM:** | Decision Matrix |
| **DSL:** | Digital Subscriber Line |
| **DL:** | Downlink |
| **E-UTRAN:** | Enhanced UMTS Radio Access Network Extensions |
| **Exp-TOPSIS:** | Exponential TOPSIS |
| **EAP:** | Extensible Authentication Protocol |
| **Eb:** | signal energy per bit |
| **Es:** | signal energy per symbol |
| **eNB:** | evolved Node B |
| **FTP:** | File Transfer Protocol |
| **GRA:** | Gray Relational Analysis |
| **GPS:** | Global Positioning System |
| **HetNets:** | Heterogeneous Networks |
| **HSPA:** | High Speed Packet Access |
| **HTTP:** | Hypertext Transfer Protocol |
| **IEFT:** | Internet Engineering Task Force |
| **IWLAN:** | interworking wireless Local Area Network |
| **LEO:** | Low Earth Orbit |

| | |
|---|---|
| **LTE:** | Long Term Evolution |
| **LTE-A:** | Long Term Evolution -Advanced |
| **L:** | Length of packet |
| **Log-TOPSIS:** | Logarithmic TOPSIS |
| **MCDM:** | Multi Criteria Decision Making |
| **MADM:** | Multi Attribute Decision Making |
| **MEW:** | Multiplicative Exponent Weighting |
| **MIHU:** | Media Independent Handover User |
| **MIHF:** | Media Independent Handover Function |
| **MIH:** | Media Independent Handover |
| **MIES:** | Media Independent Event Service |
| **MIIS:** | Media Independent Information Service |
| **MICS:** | Media Independent Command Service |
| **MISHAP:** | Mobility for IP Performance, Signaling and Handover Optimization |
| **MT:** | Mobile Terminal |
| **MDP:** | Markov Decision Process |
| **M-QAM:** | Multi-level Quadrature Amplitude Modulation |
| **MB:** | Mega per Bit |
| **M/M/1:** | Markovian input process/Markovian output process/1 |
| **MPWCA:** | Mobility Prediction of the based Weighted Clustering Algorithm |
| **MBMS:** | Multimedia Broadcast/Multicast Service |
| **MIMO:** | Multiple Input Multiple Output |
| **NGN:** | Next Generation Network |
| **NSR:** | Noise Signal Ratio |
| **N0:** | power spectral density |
| **n:** | average number of packets |
| **OFDMA:** | Orthogonal Frequency-Division Multiple Access |
| **OBUs:** | Onboard Units |
| **QoS:** | Quality of Service |
| **QoE:** | Quality of Experience |
| **PC:** | Personal Computer |
| **PoA:** | Point of Attachment |
| **Pb:** | bit error probability |
| **Ps:** | symbol error probability |
| **Pr:** | Received Signal Power |
| **PDA:** | Personal Digital Assistant |
| **RAN:** | Radio access network |
| **RFID:** | Radio Frequency Identification |
| **RSS:** | Received Signal Strength |
| **SAW:** | Simple Adaptive Weighting |
| **SBSs:** | Small Base Stations |
| **SON:** | Self-Organization Network |
| **SAPs:** | Service Access Points |

| | |
|---|---|
| **SLA:** | Service Level Agreement |
| **SLA:** | Service Level Agreement |
| **SIR:** | Signal to Interference Ratio |
| **SNR:** | Signal to Noise Ratio |
| **TOPSIS:** | Technique for Order Preference by Similarity to Ideal Solution |
| **Ts:** | symbol time |
| **Tb:** | bit time |
| **TDD:** | Time Division Duplex |
| **UMTS:** | Universal Mobile Telecommunications System |
| **UL:** | Uplink |
| **UE:** | User Equipment |
| **VNs:** | Vehicular Networks |
| **VoIP:** | Voice over Internet Protocol |
| **VHO:** | Vertical Handover |
| **VHDA:** | Vertical Handover Decision Algorithm |
| **Wi-Fi:** | Wireless Fidelity |
| **WLAN:** | Wireless Local Area Network |
| **WiMAX:** | Worldwide interoperability for Microwaves access |
| **WiBro:** | Wireless Broadband |
| **WMC:** | Weighted Markov Chain |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

In advanced nations the consumer interest for mobile services is expanding because of the need to get access to data whenever, anyplace. The growth in communication infrastructures offers connectivity via imploring various wired and unwired (remote) technologies in distinct environments. Wireless technologies usage is growing at a very fast rate which is fundamentally because of factors such as the shrinking of gadgets including portable PCs, PDA (Personal Digital Assistant), tablets, smartphones and netbooks. The numerous networking interfaces accessible mostly in all devices with various wireless technologies are Wi-Fi (Wireless Fidelity), WiMAX (worldwide interoperability for Microwaves access), UMTS (Universal Mobile Telecommunications System) and LTE (Long Term Evolution). Furthermore, it is well-known that most people spend less time in their cars or commercial transport on a daily basis under the always-on paradigm; consumers anticipate network availability always to meet their connectivity needs. Presently, the accessible structures do not offer full coverage, hence hindering consumers from getting the best connections. Nowadays, heterogonous wireless networks are constantly being upgraded to enhance safety and provide relaxed components. The industries are capitalizing on the latest developments of the various incorporated or attached systems and communication technologies. Since users can chose from different option of communication, the industries must face the issue between the users and the infrastructure on cosmopolitan area when diverse wireless innovations and technologies are implored in vibrant environments for the users. The various wireless network technologies and inventions is being incorporated into the system to deliver a “smooth” integration, interoperability and convergence amid these diverse technologies. Consequently, the usage of VHO (Vertical Handover) system is necessary. The transfer of a movable station from one channel or a single base station to the other is called a handover event. When a handover takes place inside one domain of a wireless entry technology, then the procedure is referred to as a horizontal handover. Similarly, vertical handover is a scenario where this handover occurs amidst of heterogeneous wireless access network technologies (Rappaport, 2002).

## 1.2 Literature Review

In this segment, we talk on previous work intending at efficient handover mechanisms which concentrate on various design issues such as network delays and ping pong effect, etc. In Jeong et al., (2011), a combination of mobility pattern and area forecast is given as the means in reducing the amount of needless handovers because of short-term small-cell guests. A recent handover choice system centered on RSS and velocity. A composite or hybrid access system and a small-cell started handover method with adjustable bearing capacity. While taking an appropriate handover choice, time of delay is basic. It is not an inactivity prompted by the system but a watch period to determine the consistency of a BS. In Choi et al., (2007), during an investigated concerning the consequence of inactivity in VoIP, which is sensitive to delay and actualized using a TDD (Time Division Duplex), is an OFDAMA technique to sustain necessary capability. Overall capacity and handling delay sensitive services are emphasized. For co-operative radio networks using of lingering expectation and decide a link to be appropriate for selecting, for spectrum control is introduced in (Lertsinsrubtavee et al., 2012). In Choi et al., (2009) a study on the operation and function of several administrations for the affirmation of call mechanism systems is exhibited to study the gap in queue up packets according to 3G/4G criteria for LTE structures. On the subject of control, call admission and entry control is discussed widely in (Choi et al., 2009). In a situation of the handover algorithm decision distance based is being proposed and this is well suited for most situations considering the fact that SNR, SINR are all derived from it (Itoh et al., 2002). Local neighbor cell list maintenance while looking for missing hidden nodes through a map is being presented (Han et al., 2010). One significant feature is the topology generation or knowing the entire map is for location based list updates benefits. Other inclusions are a management server which maintains a listed record of correspondent to a BS relative to its neighbors. MOBIKE method is realized as a requirement for small-cell networks which will support vertical handovers between legacy and flat mode to give uninterrupted, delay subtle services, for example, VoIP in (Chiba et al., 2009). A method involving small-cell access points and also its role on maintaining sessions through key exchange to secure data communicated between verticals is presented. For table assisted handovers in small-cell networks based on future prediction with metrics like availability of small-cell, RSS at the desired location of service are to be well-preserved or refreshed from time to time. Suggests maintaining lists and prioritizing nodes for prediction. The study is about MANETs which is about weight assignment to cluster heads in MPWCA (Mobility Prediction of the based Weighted Clustering Algorithm), and this can be related for similar assignments, decreased area under local cluster heads, solving of a minimizing problem thereby reducing the amount of hops been focused on (Nasser et al., 2006). As our focus is on providing stable handovers wherein one user is connected with a single femto-cell base station (FBS) for maximum possible time; the above contributions were noted. A map based analysis will be needed to keep a record of the user association and number of BS connection individually. Suggestions for synchronization over internet between small-cells and macro-cell are through GPS (Global Positioning System) among other methods. Choosing a factor for user assignment is important as a good chunk of these factors are interrelated and thereby causes redundancy and unnecessary computational complexity. End users gradually anticipate undisrupted connectivity at every point including when they are on the dynamic situations. With numerous available wireless access technologies, everyone anticipates to constantly stay connected on the most seemly technology that most suites their functional objectives and value needs. Meanwhile, superior, i.e. onboard units (OBUs), facilitate complex computation and also geolocation support the imploration of handover. This work presents a detailed outline of a vertical handover methods and recommend an algorithm authorized by the IEEE 802.21 quality, while vehicular networks (VNs) particularities where been considered, the context requirements for application, user's preference, and the diverse existing wireless networks, i.e. Wi-Fi, WiMAX and UMTS to advance consumers quality of experience (Marquez et al., 2015). From the results it was demonstrated that their approach, under the considered scenario, which should match up to the application of this needs and also making sure consumers choice are likewise achieved. Multiple Criteria Based Algorithms rely on a typical MADM problem where the selection of an access network is performed on the bases of multiple attributes measured from all available candidate networks. Many of the MADM techniques are explained next. Simple Adaptive Weighting (SAW) is the leading known and acceptable method of scoring utilized by (Tawil et al., 2008), to rank candidate networks. The aggregate of weighted networks attributes is used to ascertain the overall score for each candidate network. The candidate network score is acquired by including the contribution from each metric which is normalized, multiplied with the weight assigned to the metric. Multiplicative Exponent Weighting (MEW); in these techniques, a handoff decision matrix is designed in which a specific row and column tally to the candidate network and also the attribute of the network, respectively (Taniuchi et al., 2011). There is order of preference by comparison for the techniques in an Ideal Solution; the network being selected in the TOPSIS schemes is a bit closer to the perfect answer plus the utmost beginning from the most awful-instance reaction. This perfect solution is acquired by imploring the optimal value for every metric (Nguyen and Boukhatem, 2008).

### 1.3 Objectives

This thesis objective is mainly to study the Vertical Hand-Off (VHO) decision making within different algorithms. Moreover, the main aim is study some VHO techniques used in wireless networks to ensure the continuity of service using the best available wireless network. In an attempt to actualize the major goal of this thesis, we study VHO considering the TOPSIS methods in various ways, such as linear-TOPSIS, exponential-TOPSIS and logarithmic-TOPSIS. The work studies the TOPSIS algorithm and the effect of each one of these functions on its network choice. Comparison between these algorithms under different network and parameters are established and studied to build a better understanding of the TOPSIS and VHO technique.

### 1.4 Thesis Outlines

This thesis entails five chapters described as follows:

Chapter one: Introduction, literature review, the main objectives and thesis outline.

Chapter two: Presents the work related and also the literature review showing vertical handover and the procedure of making decision.

Chapter three: Showcases a general insight on the vertical handover.

Chapter four: Provides the results and discussions. Chapter five: This chapter gives a short and concise conclusion of the thesis and recommendation.

# CHAPTER 2

# BACKGROUND AND OVERVIEW

This chapter displays the outline of cellular network, heterogeneous networks (HetNets), small cells and finally summary of excellence service and multimedia traffic.

## 2.1 Cellular Networks

Figure 2.1 presents the basic cellular network. Cellular network or mobile network is a remote radio system, where the area coverage is shared into different regions covered geographically called cells. A base station (BS) is located in every cell site which can support more of this cells which depends upon the manufacturer's device. BSs provides the needed radio communication for UEs in between the cell (e.g., cell phones, smartphones) to communicate with one another and with the operator his network. Every UE uses a radio communication (e.g. LTE) to communicate with the BS by means of a pair of radio channels, one channel for Downlink (DL) transmitting from the cell site to UE and the other channel for Uplink (UL) transmitting from UEs to the cell site (Taha et al., 2012).

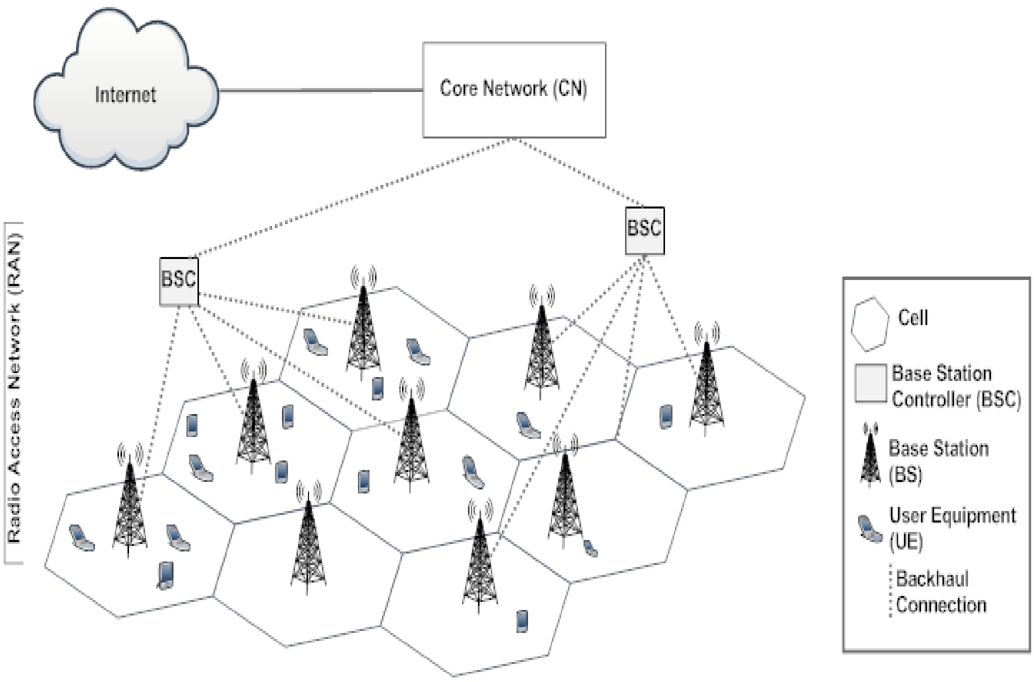


**Figure 2.1:** An outlook of the basic cellular network (Taha et al., 2012)

The coverage area cells are typically showed as possessing a hexagon shape but in real networks their shapes are irregular. The cell's range relies on various factor for example, BSs height and transmitting power. Every cells varies by the range or side covered. Macro-cells (radius range 1 to 10 km) have the broadest coverage and used in open, suburban and modern areas and also on highways. Microcells (radius range 200 m to 1 km) are utilized in parts of urban and high population area density. Pico-cells (radius range 100 to 200 m) coverage area is smaller than microcells and used in portion of malls, shopping centers or subways. Femtocells (radius range under 100 m) have the small area range and commonly applied indoors (workplaces or homes).

The BS Controllers (BSC), BSs and the radio communication channels all-together are called Radio access network (RAN). BSCs manage a number of BSs at an interval and connect cell sites to other entities in the operator his candidate network. The cellular network helps in collecting traffic from tons of cells and are passed to local or public network. The CN likewise offers further vital tasks like call handling, traffic control and call transmitting as UE moves within cells coverage area (Taha et al., 2012).

Long term evolution (LTE) is a 3GPP radio access innovation and is viewed as a notable step towards accomplishing fourth Generation (4G) cellular communication. LTE system is part of the Global System for Mobile (GSM) way for transforming of cellular networks. LTE is intended to offer high information rates (100Mbps for DL, 50Mbps for UL), latency reduction and optimized the using of existing spectrum in comparison with third generation (3G) HSPA+. LTE utilizes distinctive types of radio methods such as, OFDMA for DL and SC-FDMA (Single Carrier-Frequency Division Multiple Access) for UL (Wisely, 2009).

LTE system comprises three major parts; SAE (System Architecture Evolution), E-UTRAN (Evolved UMTS Terrestrial Radio Access Networks) and E- UTRAN represents RAN (Radio Access Network) in addition simply consists of enhanced BSs named (eNB). The SAE is the new CN fully simplified IP-based architecture.  LTE utilize an optimized reception antenna technology identified as Multiple Input Multiple Output (MIMO). The subsequent phase for LTE is LTE-A which is completely 4G network designed for meeting the desired International Mobile Telecommunications-Advanced (IMT- Advanced).

Handover administration remains a key function in which cellular systems backs mobility and keep up QoS for UEs. Handover facilitates the network to preserve UE his link (connected mode) while one user can move from the coverage region of one cell to the other (Giannattasio, 2009). Handover remains a procedure of exchanging a continuous data and voice call data session from a connected cell to another. Handover is grouped into two general classifications as strong and soft handovers. In a strong handover the present resources are been used up before making use of new ones. While in soft handover, new and old resources are being in use during the handover procedure. A different class is vertical and horizontal handovers. Horizontal handover happens in a case where a switch occurs in UE different coverage area cells in same radio access. Vertical handover occurs when a UE switches between two dissimilar radio access networks (i.e., LTE with WiFi).

### 2.2 Heterogeneous Networks

In a scenario where there is a specific end goal to take care of demand on both limit and scope of cellular networks, another configuration or design paradigm HetNet was showcased in LTE (ElSawy et al., 2013). The idea of HetNets is to deploy several small cells under macro cells coverage so as to boost capability and also extend coverage in high-demand areas. HetNets represent a key prototype shift in cellular network plan, offer extend coverage and optimize network capacity. HetNets refers to multi-access network when diverse radio access ethics are accessed with the same UE (LTE with WiFi) and can refer to hierarchical cell structures where numerous cell classes with similar radio admittance standard is utilized Macro-cells with Pico-cells (Nakamura et al., 2013).

### 2.3 Small Cells

This type of cells is cellular coverage area aided by a low power small base station (SBS). A SBS is a completely highlighted small BS that is normally intended to be client deployed for indoor deployment (residential homes, subways, and offices) and backhauled to the operators CN by means of Internet connection (DSL, cable, etc.). An illustration of a usual small cell (i.e. femtocell) deployment is presented in Figure 2.2 Small cell deployments include femtocells, pico-cells and metro-cells. SBSs is used in enhancing capacity and improved coverage, thereby facilitate offloading from macro-cells. In view of their potential advantage, small cell organizations have garnered critical enthusiasm for this industry and the academic/research communities. Actually, the total number of installed small-cells has surpassed that of macro-cells been installed (Andrews, 2013).

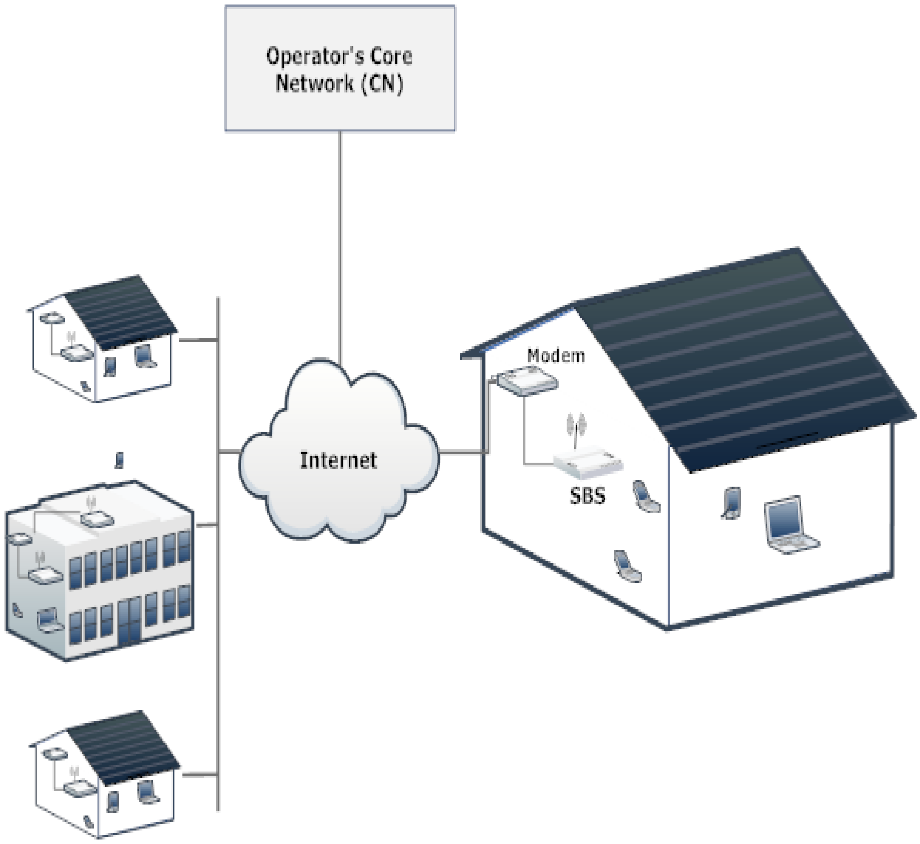


**Figure 2.2:** Overview of typical small cell (Elsawy et al., 2013)

## 2.4 Deployment Aspects

We have numerous possible circumstances of deployment arrangements in small cells. The deployment aspects are categorized relying on access mode, spectrum allocation, and owners.

### 2.4.1Access Modes

A significant characteristic for small cells is their ability in controlling access. There are three regular access mode controls:

- Closed Access Mode:  This is equally called Closed Subscriber Group (CSG). This mode is mainly for femtocells to serve as restricted amount of UEs which are defined before in Access Control List (ACL).

- Open Access Mode: otherwise referred to as Open Subscriber Group (OSG). In this mode, any UE can associate with the SBS devoid of limitations. This mode can be utilized by pico-cells in hot-spot areas, shopping centers and airports.

- Hybrid Access Mode: this mode is an adaptive access strategy in the middle of CSG as well as OSG. In this mode, a part of SBS assets are kept for private deployment of the CSG and the rest materials are assigned in an open way.

### 2.4.2 Sharing of Spectrum

Allocation of spectrum in HetNet organizations take after three procedures for sharing the frequency bands between macro-cells and small-cells:

- Dedicated approach: in this approach, different frequency bands are independently allocated to the macro-cells and small cells.
- Co-channel approach: small cells and macro-cells both share the entire accessible frequency bands in this approach.
- Co-channel Partial approach: small cells and macro-cells utilize a portion of the whole frequency bands and the rest is saved for macro-cells.

### 2.4.3 Owners

Small cells are either installed by users or operator deployed which hang on the deployment environments.

### 2.4.4 Challenges in Deployment

In spite of the merits and benefits of HetNets, they have its specific challenges and problems. These challenges and problem should be tackled for positive large scale organization of small cells. Some pertinent problems consist of:

- Auto configurations and Self-Organization Network (SON): SBS is equally a consumer Premise Equipment (CPE) which are installed as plug and play devices, which should incorporate itself in the cell system devoid of client intercession. Subsequently, diverse SON and auto configuration algorithms is needed (Quck et.al, 2013)
- Frequency interference: spontaneous arrangement of big number of SBSs (i.e.,

client deployed Femtocell BS) presents critical interference problems for cellular networks. Frequency interference is the highest critical problem that hurts small-cell arrangement. Frequency interference in HetNets comprises of co-layer and cross-layer. In co-layer interference, a SBS interferes with different neighboring SBS or SBSs client. In cross-layer interference, a SBS interferes with MBSs or vice versa.

- Handover and mobility management: as for the large number of deployed SBSs, it may or may not be accessible to every consumer (i.e., closed access). Managing mobility in small cells (for example looking for SBS, handover from/to MBS, access control) turn out to be sophisticated and challenging process.
- Backhaul: the backhaul is the joint connecting the RAN through the operator CN. In HetNet deployments, backhaul access design would be a huge concern for different cells requirements (Quck et.al, 2013).

## 2.5 Multimedia Traffic

Telecommunication systems are advancing toward multi service, multi domain and multi-vendor models suited to the provision of Quadruple-Play aid which includes data, voice and video (Triple-Play) are presented on similar IP network base by media application above wireless networks. In addition, sending of multi service from networks bring about fresh challenges such as Quality of service problems and network policy control. The traffic in network should be of priority, observing of specific features in the IP packets and recognizing what precise requirements should be guaranteed.

## 2.6 Quadruple-Play Applications

Next generation networks make use of QoS requirement for wireless condition that are multi-domain and multivendor designs aligned to the provide Quadruple-Play services. They provide video, audio and data on similar IP system base (Hughes and Jovanovic, 2012). The key parameters effecting the client services incudes:

- **Latency**: this factor got different implications such as the period required to fix a specific service from the underlying client demand and an ideal opportunity to get particular data after the service is established. Latency (delay) show an immediate effect on client fulfillment, slowdown in the terminal, network, and any cut off.

Looking at the client perspective, delay additionally produces an account that results in other network parameters for example, throughput which refers to how much data is transferred from one place to another in a specified period of time.

- **Data loss**: has an instant outcome on the excellent data offered to the client, be it audio, video or data. In this setting, data loss reduction is not restricted to the impacts of packet loss or bit errors during broadcast, additionally incorporates the impact of any break down presented by media programming for more effective broadcast (for example using small bit-rate speech codecs for voice). The delay behavior and applications is ordered into two primary classes elastic applications and real-time or streaming applications (Andrews et al., 2012).

## 2.7 Elastic Applications

Elastic applications are those normally presented in the Internet for example, web browsing, email, FTP etc. They constantly wait for data to arrive, it does not say that the applications are unresponsive to delay, expanding the packet delay will regularly damage the performance of the application. The main idea is that the application regularly utilizes the incoming information instantaneously, instead of buffering it for some period, it will continuously wait for the arriving data instead of advancing without it. Since incoming information is being utilized quickly, these applications do not need any priority classification for the application to work (Andrews et al., 2012). Elastic applications might be partitioned in the three subgroups with various delay expectations:

- Burst interaction: they are described by the bit-rate peaks that significantly differs with the mean value.
- Interactive bulk transfer: Here huge data is transferred without limitations on period of dispatch and are transmitted with continuous bit-rate for example applications for Hypertext Transfer Protocol (HTTP) or file transfer protocol (FTP) traffic.
- Asynchronous bulk transfer: used in electronic mail or FAX. It is a fewer delay-sensitive application.

## 2.8 Applications for Real-Time

In real time applications, the transferred data is of importance only if it arrives within a particular period. However, these classes of applications belong to the group of playback applications which comprises of a source that converts a signal into data packets and transmitted over to the network. At the receiving point, these packets arrives in chaotic manner and with flexible delays. At this point the recipient reforms the source data from the packets and tries to replay the signal as authentically with stable counterbalance delay from the leaving period. An application need discover an appropriate priori estimation of this counterbalance delay. However, it will be delivered by the network by observing the formerly established traffic (Andrews et al., 2012).

### 2.9 Different Applications Performance Consideration

Through these section several applications will be discussed, they are:

- Voice messaging: Requirements for data loss are mainly same with the conversational voice (i.e. reliant on the audio code), however an important distinction in this case is the additional tolerant for delay. The principle issue in this manner is how much delay can be accepted among the consumer giving a command to play back audio message from the real beginning.
- Streaming audio: Streaming of an audio is likely to give an improved quality than orthodox telephony and necessities for data loss according to packet loss will be consistently more tightly. Nevertheless, in voice messaging, there is no conversational component and delay requirement for voice stream.
- Videophone: as utilized in this context suggests a full-duplex framework conveying together sound and video planned to be used in conversational domain. Accordingly, on a basic level the same delay requirements concerning conversational voice will apply.
- One-way video: the primary recognizing highlight of restricted video shows no conversational component included, implying that the delay requirements might not be too severe and should be able to accompany those of streaming audio.
- Web-browsing: this group refers to recovering and reviewing HTML segment of Web page and different parts like pictures, video and sound clips are managed under their different classes. From the client perspective, the principle execution element is a means which a rapidly page shows up after being demanded. Delays of many seconds is tolerable, but it should not be above ten seconds.

## 2.10 Quality of Service

The service quality states an extensive gathering of network technology and procedures. The aim of Quality of service is to guarantee the potential network to provide probable outcomes. Components of network action in the range of QoS includes latency, throughput, bandwidth and bit error rate. QoS knows how to focus on a network interface concerning a particular server or routers performance of particular applications (ElSawy H et.al, 2013). The heterogeneous for next generation network (NGN) system has three fundamental stages of end-to-end QoS known as:

- Best-effort service (shortage of QoS): the greatest service is simple connectivity having no assurances. This is categorized by backlogs having no separation among streams.
- Discerned service (soft QoS): most traffic is handled well than others. Such as bit error rate and regular bandwidth.
- Guaranteed service (hard QoS**:** here there is a complete reserved network resources used for particular traffic.

## 2.11 Vertical Handover Criteria

Figure 2.3 is a block diagram of the vertical handover decision algorithm technique that processes certain criteria to find the best candidate network. The application necessities are a set of parameters that the vertical handover decision algorithm (VHDA), in conjunction with the user preferences, takes into account for evaluating the best candidate network. These parameters are evaluated by MCDM algorithm. We now proceed to explain signal to noise ratio (SNR) then describe each parameter as well.

### 2.11.1 Signal-to-noise power ratio

Signal to noise ratio (SNR) is the ratio between the power of the received signal Pr and the noise power in the given bandwidth of the signal. The power of the received signal Pr is a function of the transmitted power, the losses of the path, shadowing effects, and fading. The power of the noise is determined from the transmitted signal bandwidth and the spectral features of n(t). n(t) is a white Gaussian random noise with zero mean and power density N0/2. The total noise power in the bandwidth 2B is $\mathrm{N} = \frac{\mathrm{N_0} \times 2\mathrm{B}}{2} = \mathrm{N_0}\mathrm{B}$, where B is the bandwidth, $N_0$ is the power of the noise. From these relations we can find the SNR of the received signal. It can be given by: $SNR = \frac{P_r}{(N_0 B)}$, where $P_r$ is received power. SNR is usually defined in function of the signal energy per bit $E_b$ or per symbol $E_s$ such that $SNR = \frac{P_r}{(N_0 B)} = \frac{E_s}{(N_0 BT_S)} = \frac{E_b}{(N_0 BT_b)}$, Ts here is the symbol time while $T_b$ is the bit time.

In order to quantify the performance of the process, we are more concerned by the bit error probability $P_b$. However, for multiple array signals, the bit error probability is function of the symbol error and the mapping of bits to symbols. Typically, the symbol error probability $P_S$ is found as a function of γs, and $P_b$, is found as a function of γb by means of an exact or approximate methods. The approximate method generally considers that the energy of symbol is divided equally between all bits (Andrea, 2004).

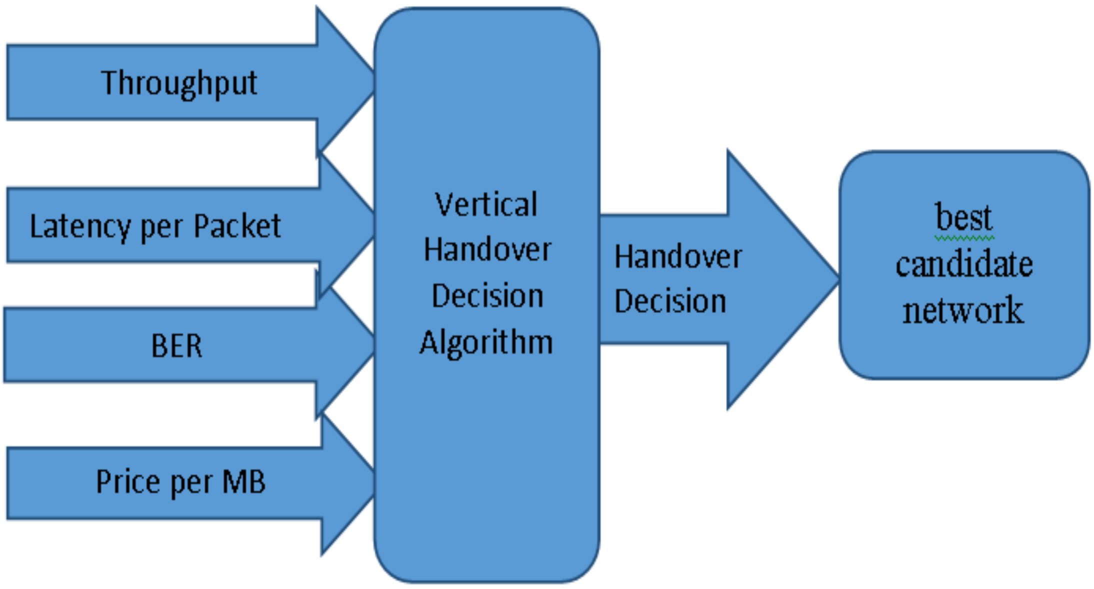


**Figure 2.3:** Vertical handover decision algorithm technique process

### 2.11.2 Throughput

Shannon capacity of a fading channel with receiver at channel side information (CSI) for an average power *S* constraint can be obtained as in Equation 2.1:

$$\gamma = \frac{S}{(N_0 B)} \tag{2.1}$$

$$C = \int_0^{\infty} B \log_2(1+\gamma) p(\gamma) d\gamma \tag{2.2}$$

Equation 2.2 is a probability mean; Shannon capacity is equal to Shannon capacity of an additive white Gaussian noise with $\gamma$, given by B $\log_2(1 + \gamma)$, and averaged over the $\gamma$. For this reason, Shannon capacity is also known as Ergodic capacity. However, care must be taken in interpreting an average as in Equation 2.2. In particular, it is incorrect to interpret Equation 2.3 to mean that this average capacity is achieved by maintaining a capacity B $\log_2(1 + \gamma)$ when the instantaneous is $\gamma$ (SNR), because just the receiver has an idea about $\gamma(i)$, and the data broadcast over the channel is fixed whatever the value of $\gamma$. That is fading decreases Shannon capacity just if the receiver has CSI. In addition, capacity can be totally decreased if the receiver CSI is not perfect.

Considering a discrete time AWGN channel having the relationship $y(i) = x(i) + n(i)$ with a bandwidth B and power S. The channel SNR is equal to the power in $x(i)$ divided by the power $n(i)$. This SNR is constant and defined by $\gamma = S/(N_0B)$, where $N_0$ is the noise power density. The capacity of such a channel is expressed by Shannon his Equation:

$$C = B \log_2(1 + \gamma) \tag{2.3}$$

Capacity with outage is applied to slowly varying channels. In such channels, the SNR can be considered fixed over a large number of transmissions or a burst. After the burst it changes to a new value according to the fading parameters. In this model, if the channel has received a given SNR during a burst, data can be sent through the channel at rate B $\log_2(1 + \gamma)$. The transmitter should keep the transmission rate constant as it has no idea about the SNR. Capacity with outage permits the sent bits over a burst to be decoded at the end of the burst. These bits have some probability of being incorrectly decoded.

$$C = B \log_2(1 + \gamma_{min}) \tag{2.4}$$

The data is received correctly if the SNR is more than or equal to $\gamma_{min}$. If the received SNR is less than $\gamma_{min}$, the decoder cannot decode the bits correctly. The probability of outage declared by the transmitter is then given by:

$$P_{out} = P(\gamma < \gamma_{min}) \tag{2.5}$$

The rate of the correctly received bits out of many transmission bursts can be given by:

$$C_o = (1 - p_{out})B \log_2(1 + \gamma_{min}) \quad (2.6)$$

The value of $\gamma_{min}$ is normally a constraint of the design that is based on the probability of the outage. Capacity is generally configured by a curve of SNR to the capacity as demonstrated by Figure 2.4 The figure shows the normalized capacity $C = \log_2(1+\gamma)$ then the capacity approaches small value when the signal to noise ratio is decrease and capacity is increase when the value of signal to noise ratio is increases (Andrea, 2004).

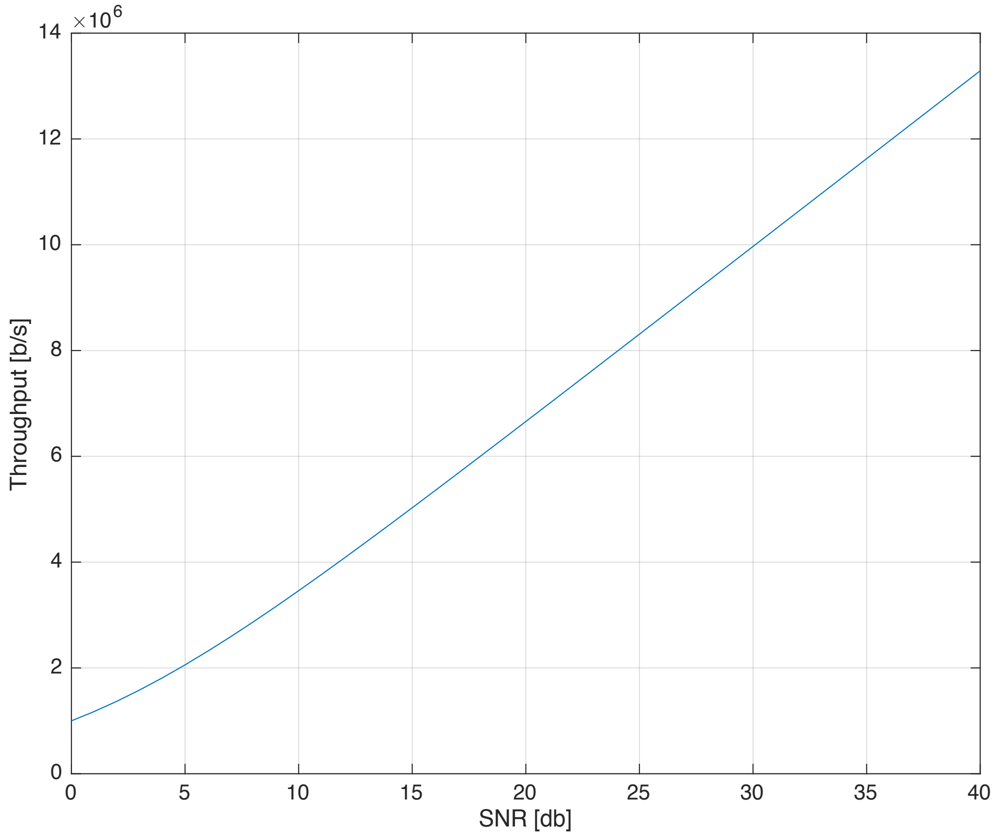


**Figure 2.4:** Throughput configured by a curve of SNR

### 2.11.3 Latency per packet

The behavior of a Markovian input/Markovian output process /1 server (M/M/1) queuing system is shown in Figure 2.5 In the M/M/1 model, the packet is assumed to arrive into the queue and leave out of it randomly. They are also assumed to happen with exponentially distributed periods of time. The packets are also assumed to be serviced on a first come first serve base in a steady state system (Barberis, 1980).

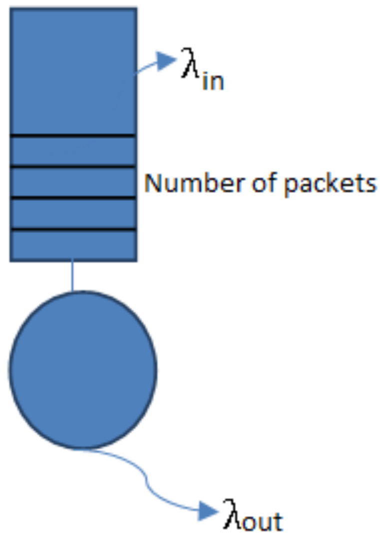


**Figure 2.5:** Queuing system with packets in queue

For queuing systems, by using the Equation 2.7 we can get

$$\text{latency per packet} = \frac{\text{L}\times\text{A}}{\text{C}} = \frac{\text{Lenght of packet} \times \text{Number of packet per second}}{\text{Throughput}} \quad (2.7)$$

where L is the packet size, C is the link speed and A is the offered load in packets/second. Noting that latency per packet is clear to be between 0 and 1. To find the values of A suitable for a known queuing system, packet size L and the link speed C need to be defined. With the supposition of a definite arrival and service process, the only applicable restrictions to describe the performance of a queuing system are the arrival to service package rate. The speed of link C and the packet size L are simply scalar values that influence the form of the curve of delay. In the next step, we can simplify the description by expressing $\lambda_{\text{in}}$ in terms of $\lambda_{\text{out}}$ like in Equations 2.8 and 2.9.

$$\lambda_{\text{in}} = \frac{0}{\lambda_{\text{out}}} = 0 \quad (2.8)$$

$$\lambda_{\text{in}} = \frac{\lambda_{\text{out}}}{\lambda_{\text{out}}} = 1 \quad (2.9)$$

Whenever the traffic is expressed with arrival times distributed exponentially, latency per packet is used to evaluate the performance of systems and access techniques. Based on the derivation of the M/M/1 queue, the average packet number n in the queue is given based on the geometric distribution. It can be expressed simply in terms of $\lambda_{in}$ as follow:

$$n = \frac{\lambda_{in}}{1-\lambda_{in}} = \frac{\text{latency per packet}}{1-\text{latency per packet}} = \frac{L\times A}{C} / 1 - \frac{L\times A}{C} \tag{2.10}$$

The following remarks are built out of the last equation: the mean packets number n is always positive and increasing to infinity when $\lambda_{in}$ increases to 1. Figure 2.6 presents the latency per packet curve versus SNR. The latency decreases with the increase of SNR.

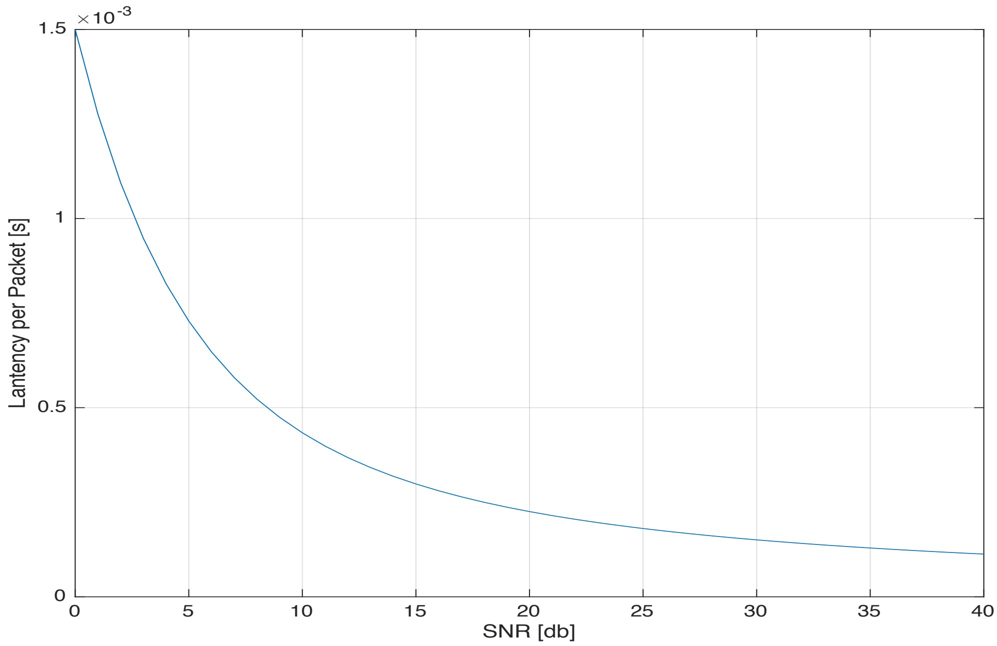


**Figure 2.6:** Latency per packet configured by a curve of SNR

### 2.11.4 Bit Error Rate

Bit Error Rate (BER) is a significant measure of the systems performance in communication systems. In simple systems where the channel is simplified by an AWGN noise, the BER is found easily. However, for mobile communications, the BER of additive white Gaussian noise channels is not valid because of multipath fading. To find the Bit Error Rate of a modulation scheme, the BER of the modulation for an AWGN noise is averaged with fading statistics (Haci, 2015). The required power to keep a probability of error ($P_b$) small in fading channels is higher than in AWGN channels. As an example, in Figure 2.7 the error probability of M-QAM is presented. It is clear that 24dB SNR are required to maintain a $10^{-3}$ BER in the fading channel. In order to find the accurate average probability of bit error for fading channel given in Equation 2.11, the digital modulation M-QAM can be used (Sanjay Singh et al., 2012).

$$P_{b,M-QAM}^{Fading} = K_1 + K_2\sqrt{\frac{\beta_1\gamma}{\beta_1\gamma+2}} \tag{2.11}$$

where $K_1 = \frac{2\alpha_1-\alpha_1^2}{\log_2 M}$, $K_2 = \frac{4\alpha_1^2 \arctan\left(\sqrt{\frac{\beta_1+2}{\pi\log_2 M}}\right)-2\pi\alpha_1}{\pi\log_2 M}$, $\alpha_1 = \frac{\sqrt{M}}{\sqrt{M}} - 1$, $\beta_1 = \frac{3}{M-1}$

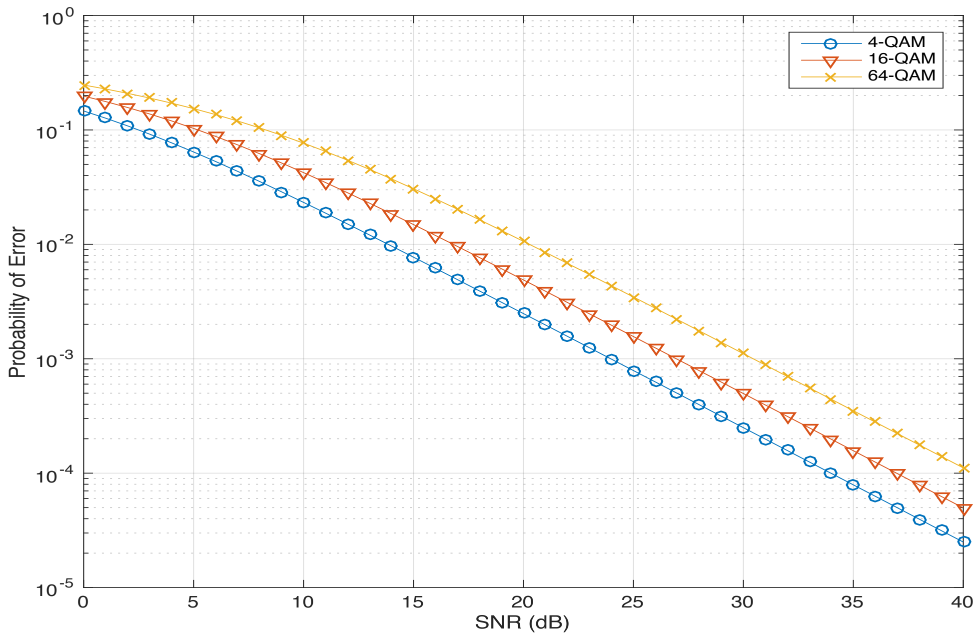


**Figure 2.7:** Probability of error configured by a curve of SNR

### 2.11.5 Price per MB

The user is too much affected by the costs of network usage. The network services providers provide different price plans or choices. This generally can affect the choices of their customers and the handoff process (Kibria and Jamalipour, 2009). In Figure 2.8 the price per MB versus throughput is presented. The price per 1MB is equal to 0.05$, so the price increases when the throughput increases. We can get price per MB as in Equation 2.12.

$$Price\ per\ MB = \frac{price}{1\times10^6}\ \times Throughput \tag{2.12}$$

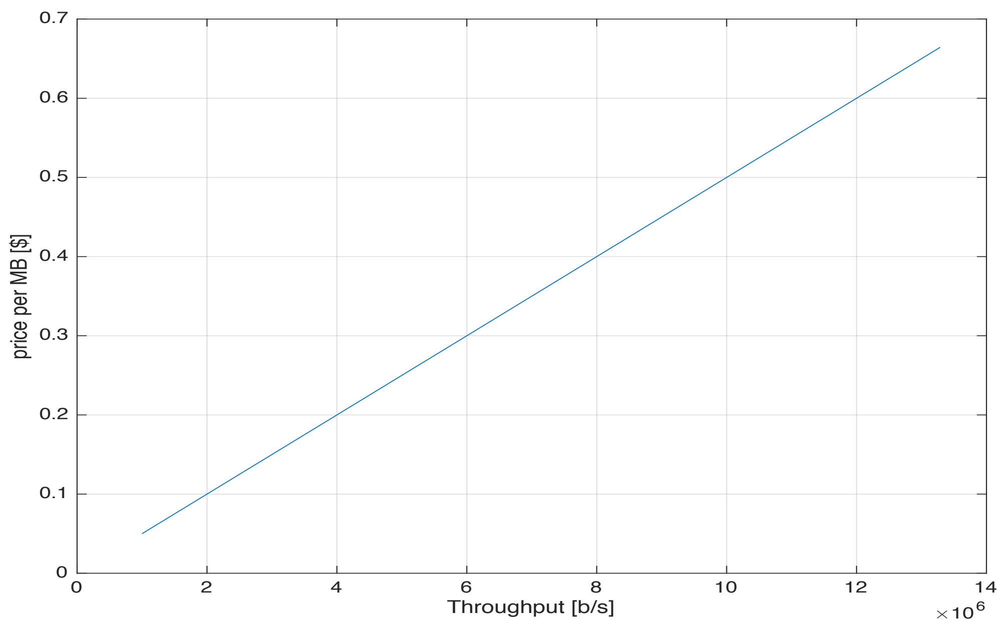


**Figure 2.8:** Price per MB configured by a curve of throughput

## 2.12 Technique for Order Preference by Similarity to Ideal Solution

Methods and material required for this research work are described in this chapter. VHD schemes for network selection using MCDM algorithms are used in a distributed manner also some of type of MCDM algorithms and VHD technology are discussed in chapter 3, the handover decision schemes are mainly focused, assuming the calculation of the handover decision criteria is performed on the MT and the candidate network. The chosen network must be the network that is closer to the ideal solution and far from the worst solution. Such networks are known as the networks of the best and worst values for each one of the metrics. Concerning the performance metric, the largest the value the better the metric is. However, for the cost metric, the lower the cost the better the metric is. The TOPSIS algorithm is used to find the best solution for the system under different conditions for each metric. The steps of TOPSIS are:

- Construct the decision matrix (DM) as shown in Equation 2.13, where network1 and network 2 are possible alternatives among which decision makers have to chose $C_1, C_2, C_3$ $and$ $C_4$. $x_{ij}$ is the rating of alternative network$_i$ with respect to criterion $C_j$.

$$DM = \begin{bmatrix} C_1 & C_2 & C_3 & C_4 \\ x_{11} & x_{12} & x_{13} & x_{14} \\ x_{21} & x_{22} & x_{23} & x_{24} \end{bmatrix} \tag{2.13}$$

- Construction of the Normalized Decision Matrix, as shown in Equation 2.14, where $r_{ij}$ the normalized value, i=1,2,...m, and j=1,2...,n to convert the dimensional attributes into non-dimensional ones to compare between different attributes. different attributes. Creating the weighted standard (normalized) decision matrix $r_{ij}$. In other words, process in this step, converting values to different criteria in interval, in the unit (normalized) is intended to provide opportunities for comparisons between the recognition criteria. After the decision matrix is created, using the vector normalization formula so decided each row vector in the matrix, it is achieved by dividing the value of the normalize of the vector $r_{ij}$. So normalized decision matrix can be represented as shown in Equation 2.14.

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, \text{ where } r_{ij} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} \\ r_{21} & r_{22} & r_{23} & r_{24} \end{bmatrix} \quad (2.14)$$

Construct the Weighted Normalized Decision Matrix as shown in Equation 2.15, where $w_i$ is the weight of criterion $r_{ij}$.

$$v_{ij} = r_{ij} \times w_{ij} \text{ then } v_{ij} = \begin{bmatrix} r_{11}\times w_1 & r_{12}\times w_2 & r_{13}\times w_3 & r_{14}\times w_4 \\ r_{21}\times w_1 & r_{22}\times w_2 & r_{23}\times w_3 & r_{24}\times w_4 \end{bmatrix} \quad (2.15)$$

- Determine Ideal and Negative-Ideal Solutions.

$A^+ = \{v_1^+, v_2^+ \ldots\ldots\}, v_j^+ = max_i(v_{ij})$, associated with benefit or best criteria.

$A^- = \{v_1^-, v_2^- \ldots\ldots\}, v_j^- = min_i(v_{ij})$, associated with cost or worse criteria.

- Calculate the Separation Measure as shown in Equations 2.16 and 2.17.

$$S_i^+ = \sqrt{\sum_{j=1}^{m} |v_{ij} - v_i^+|}, \text{ i=1, 2,..., m (Positive-Ideal Separation)} \quad (2.16)$$

$$S_i^- = \sqrt{\sum_{j=1}^{m} |v_{ij} - v_i^-|}, \text{ i=1, 2,…,m (Negative-Ideal Separation)} \quad (2.17)$$

- Calculate the Relative Closeness to the Ideal Solution $C_i$, as shown in Equation 2.18.

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-}, 0 < C_i < 1, \{ i = 1,2 \ldots\ldots\ldots. m\} \quad (2.18)$$

where $C_i = 1$ if $S_i = S^+$ also $C_i = 0$ if $S_i = S^-$

### 2.13 Exponential and Logarithmic Functions

Since we will be using linear, exponential and logarithmic functions, let us start with a quick review of their behaviors. In Figure 2.9, a linear function is presented. It is linearly increasing with a fixed rate. In Figure 2.10, an exponential function is presented and is rapidly increasing with a small rate. In Figure 2.11, the logarithmic function is depicted; it is monotonously increasing.

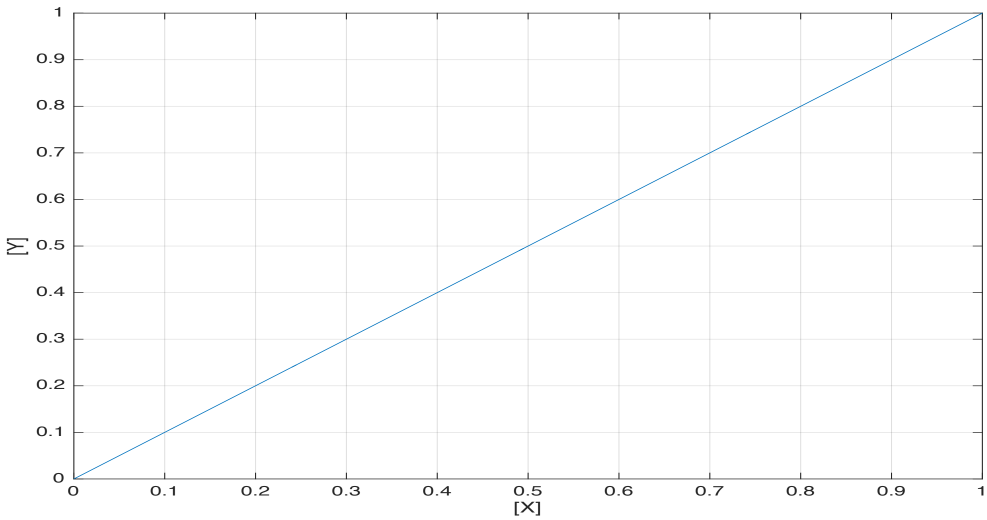


**Figure 2.9:** Linear function behavior

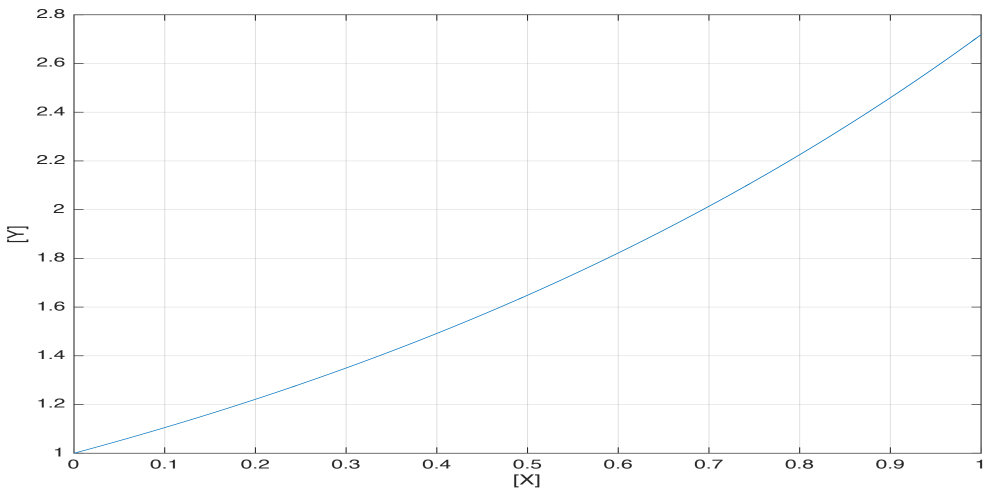


**Figure 2.10:** Exponential function behavior

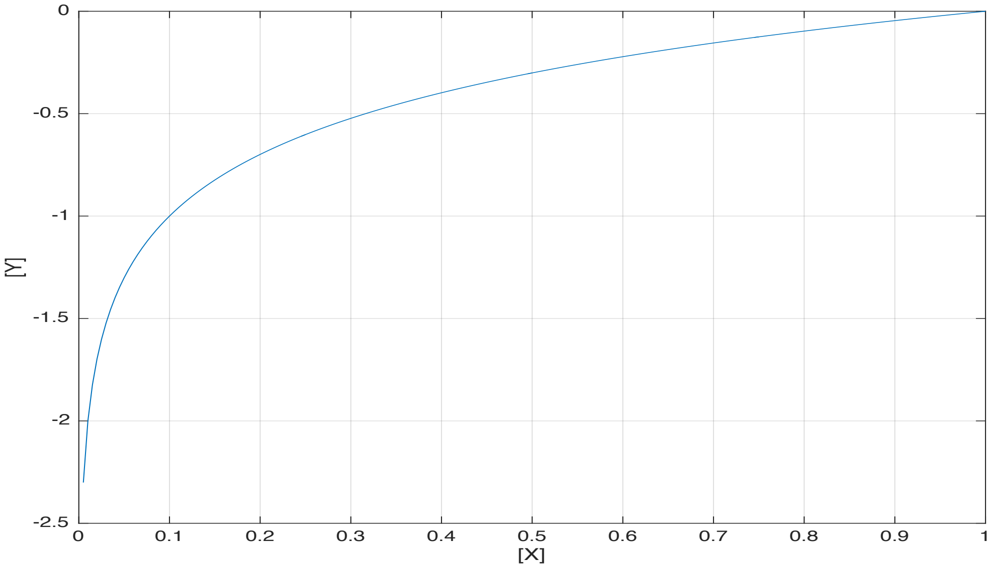


**Figure 2.11:** Logarithmic function behavior

# CHAPTER 3

# VERTICAL HANDOVER OVERVIEW

## 3.1 Introduction

The combining of several wireless networks is advancing in other to give a seamless interoperability in heterogeneous technologies that needs the use of VHO strategies for the end user. Figure 3.1 indicates vertical and horizontal handover technologies, which signifies the horizontal handover and vertical handover events (Akyildiz and Mohanty, 2004). In the area of cellular communications, handover plans have been analyzed in the cell area and the acclaim is extending among remote based IP frameworks. Handover is deemed whole if it is capable of preserving the connectivity of all services which are consecutively on the mobile equipment, offering short latency and least packet loss.

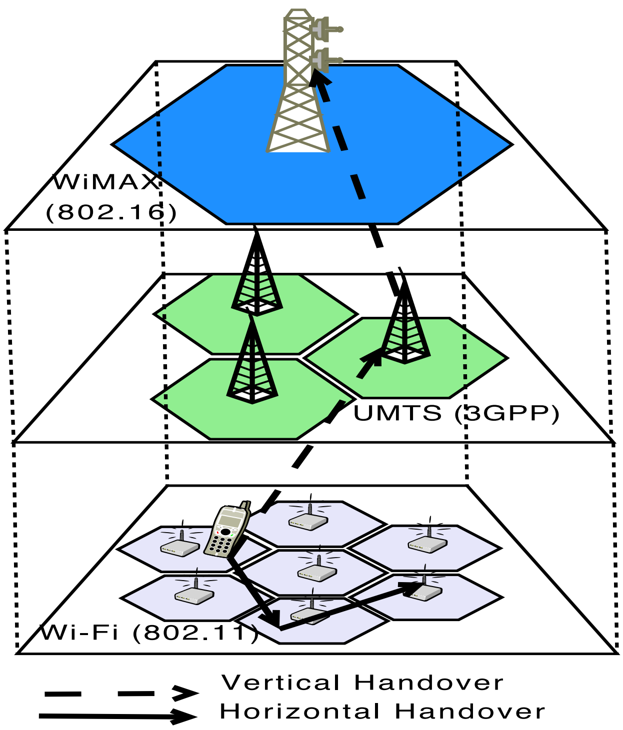


**Figure 3.1:** Vertical and horizontal handover procedures (Yan, 2010)

## 3.2 Media Independent Handover Function (MIHF)

MIHF procedure considered in standard (IEEE 802.21) fix messages traded among associate MIH users for handover and presenting a typical message payload crosswise over various 802.3, 802.11, 802.16 and Cell media. The bottom layers retrieves various data, identify and implement the VHO, whereas the higher ones request that data and are referred to as MIHU. Service access point is presented by Media Independent Handover Function to both bottom/ higher layers with a specific end goal of trading the service messages. Overall standard plan depends on MIHF as an intelligent system that encourages handover basic decision making. Figure 3.2 displays the simple architecture of IEEE 802.21.

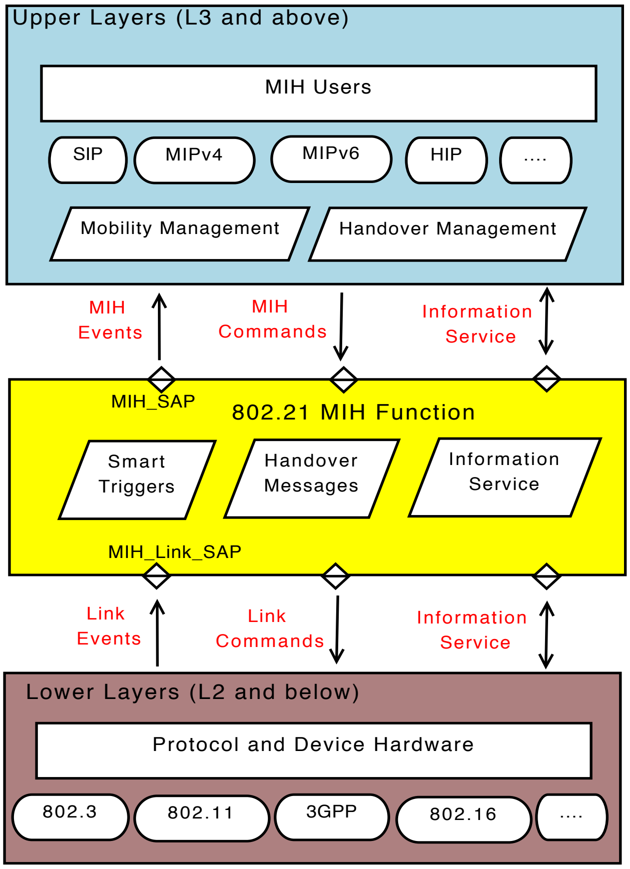


**Figure 3.2:** IEEE 802.21 architecture (Ieee, 2009)

The upper layer flexibility management rules are defined by signals mechanism for vertical handover. Also, certain developments have characterized the network signal of handover devices to enable horizontal handoff. The MIH technology is to act as handoff encouraging aid, as well as to amplify the impact of such deliveries by providing appropriate connection layer and system data. Figure 3.4 presents the cooperation and relationship among the diverse connection layers. The Standard offers support for remote events (Ieee, 2009).

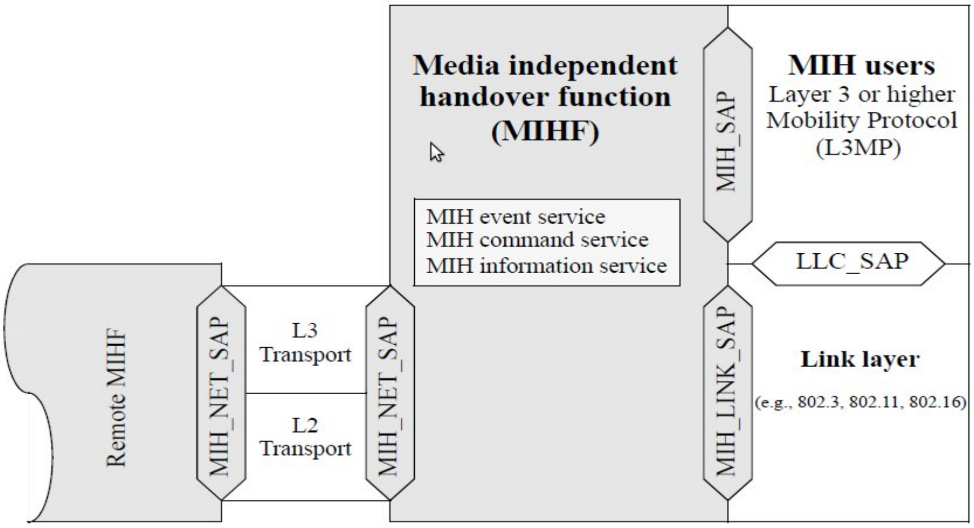


**Figure 3.3:** MIHF model orientation (Ieee, 2009)

### 3.3 Media Independent Event Service (MIES)

This service recognizes adjustments in lower layers. The MIH function send words on what is happening in this layer (lower) to MIHU as demanded. The MIES addresses outcomes like:

- State change scenarios such as the up and down connection parameter.
- Prognostic scenarios like connection going down.
- Network started scenarios like load adjusting, user preference.

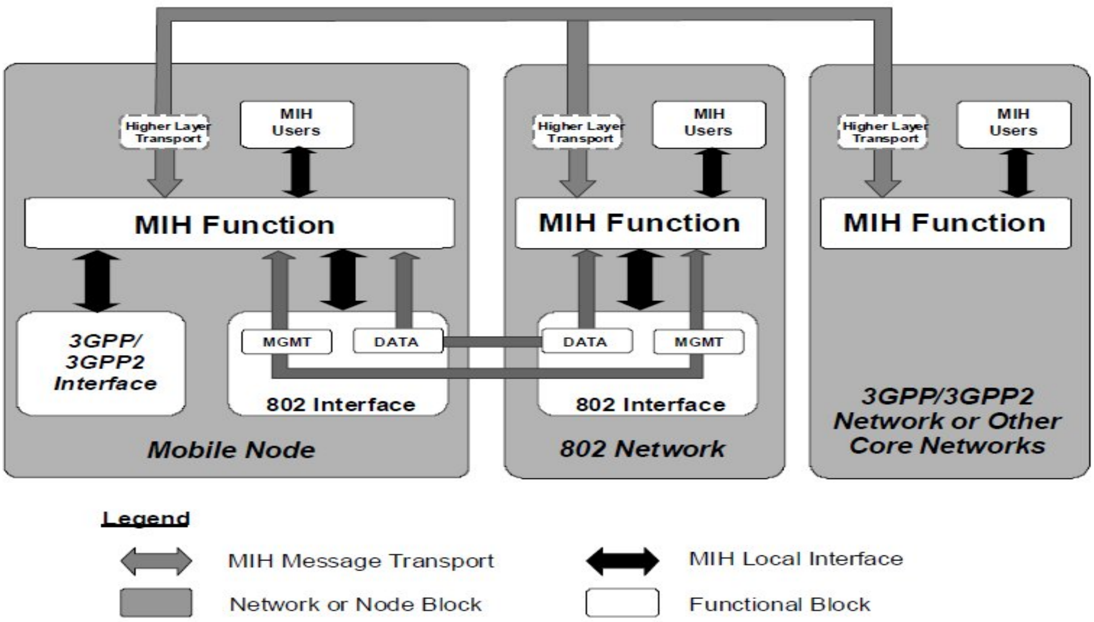


**Figure 3.4:** MIHF relationship (Ieee, 2009)

### 3.4 Media Independent Information Service (MIIS)

MIH function is permitted by MIIS to determine or find the system surroundings by means of collecting data the layers (upper) uses in making judgments. The data components denote the available network, point of attach (PoA), operator identity, roaming associates, price, safety, QoS, PoA abilities, and Seller particular data.

### 3.5 Media Independent Command Service (MICS)

The MICS permits the MIHU takes charge of layers (lower) over an arrangement of instructions which was granted by media independent command service. Through the data accumulated by both MIIS and MIES, the MIHU choose to start with one PoA then onto the next. The changes are to effect handover, towards fixing distinctive factors in lower layer components. The instructions which are normally utilized by media independent command service are:

- Initiation of MIH Handover.
- Preparation of MIH Handover.
- Commit and Completion of MIH Handover.

### 3.6 Amendments

For handover services to completely take place, the 802.21 is needed for implementation into network and mobile devices. The devices needed by MIHF for adjustment are characterized as:

- 802.11u is outlined in MIH messages 802.11 Container.
- 802.16g is outlined in MIH messages 802.16 Container.
- 3GPP is used to operate 3GPP-SAE.
- The required improvements or determinations for IP-based support of MIH Protocol are created by IEFT-MISHAP.
- 802.3 protocol is preferred.
- 802.21a-2012 gives security to ensure independent handover service, in sight of proactive validation (Extensible Authentication Protocol (EAP)).
- 802.21b-2012 is an expansion for supporting handovers with downlink technologies.

### 3.7 MIHF Network Model

A reference network model is presented in Figure 3.5 which incorporates MIH services. As illustrated, the model incorporates mobile nodes capable of operating with MIH primitives. Mobile nodes are supplied by multiple wireless and wired interface which helps in dealing with different technologies. The serving network system allows users to roam into various network technologies when close to the Service Level Agreement (SLA) and also allow suppliers offering MIH services in their entrance systems to seamless heterogeneous handovers.

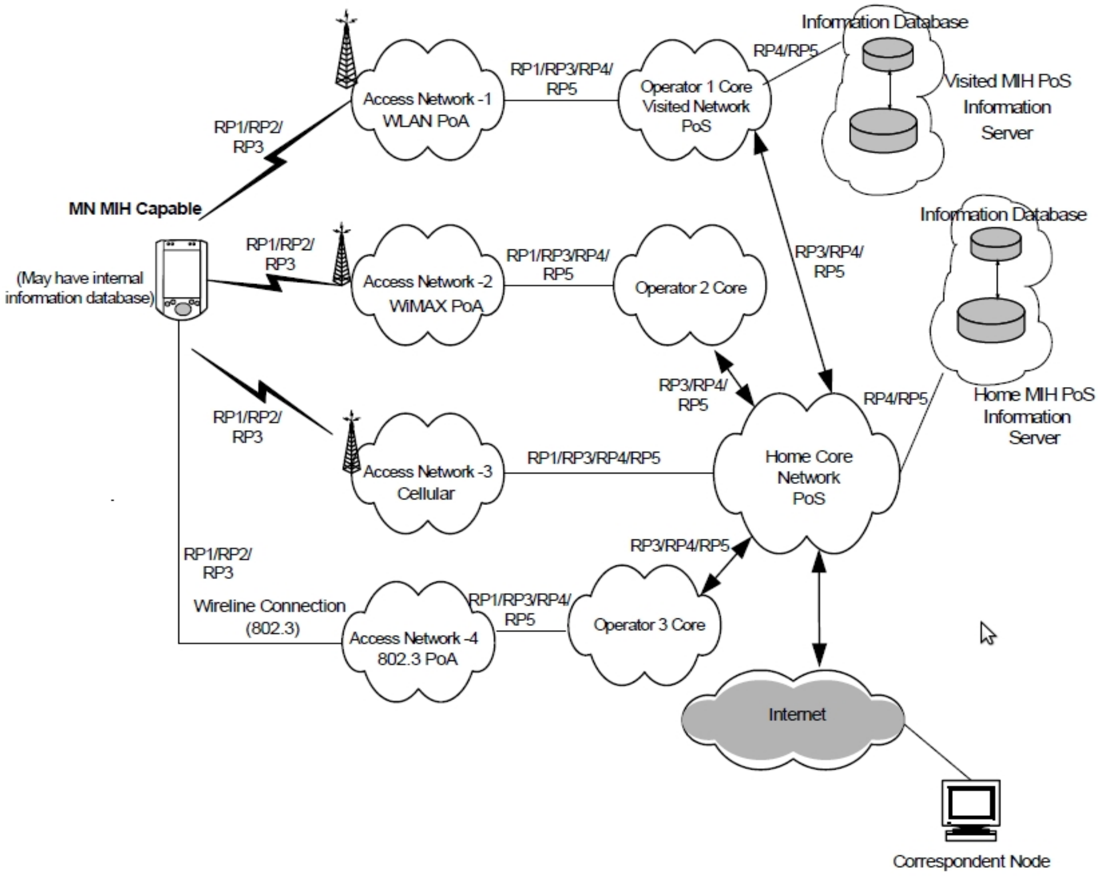


**Figure 3.5:** Example of IEEE 802.21 network (Ieee, 2009)

### 3.8 Vertical Handover

An accurate VHO procedure ought to consider and think about network detection, network selection, security, device management and QoS concerns (Yu et al., 2009). Concentrating on the last part been mentioned, few applications split VHO procedure into three sections as seen in Figure 3.6, the connections between the three stages is needed to execute handover in mixed systems such as:

- Handover discovery (gathering stage).
- Handover decision stage.
- Handover execution stage.

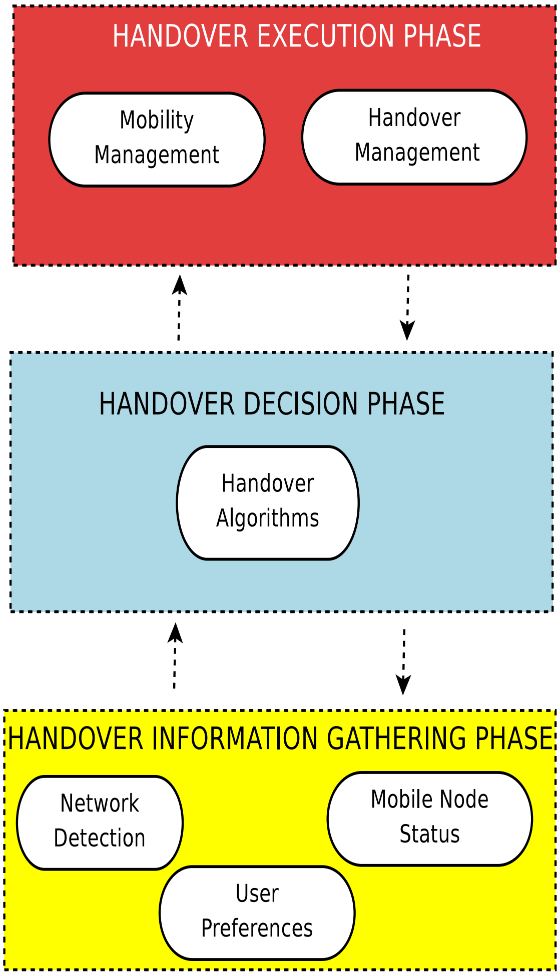


**Figure 3.6:** Handover management procedure (Ieee, 2009)

### 3.8.1 Information Gathering

The information gathering stage transmits system information as well as gives information on whatever is left of the sections framework, for instance, system properties, mobile equipment, customer preference and access. This level takes different names like handover information gathering, disclosure and recognition (Li and Zeng, 2010). At this stage, the data assembled will be utilized and treated for settling decision when handover stage happens. The data will be utilized by adjoining system by presenting information for instance, yield, cost, ratio of packet loss, level of handoff, RSS, NSR, CIR, SIR, BIR, area, separation and parameters of QoS which incorporates:

- The mobile equipment state collects information about service class, status of battery, speed and resources.
- User inclinations information, for example, budget and service are desired.

### 3.8.2 Gathering Phase of Handover Information

Gathering data is reliably basic for VHO procedure, consequent to the basic handling of decision and information data. Table 3.1 offers the information that are to be considered with exact end goal to increase the merits of basic handling of decision. It obviously shows that data must be met at all the level in the given protocol stack with the objective to cover all the conceivable information sources (Gustafsson and Jonsson, 2003).

**Table 3.1:** VHO Information process parameters

| Layers | Parameters |
|---|---|
| Application | Client preference, like (cost, supplier)<br>Context data information (speed)<br>Area data information (geo-location)<br>QoS parameters, like (band withed (B) presented, delay and motion)<br>Network load and obtainable foreign agents |
| Transport<br>Network | System load (B), reachable specialists<br>System pre-confirmation, Network setup<br>System topology and Routing data |
| Data-link | Radio access network situations |
| Physical | Access media available |

### 3.8.3 Decision of Handover

The decision stage is noticeable in the midst of basic procedure of handover. This can also be named a System selection. In respect to the gathered information, this stage as an obligation of making decision on When and Where to trigger the handover. In a homogeneous framework environment, choosing When to handover normally relies on RSS values, while the Where is not an issue since it uses the same frameworks advancement (horizontal handover). In heterogeneous frameworks the reactions of these request is exceptionally. To settle on the ideal choice, the information data collected is assessed considering various parameters gotten from the different data sources, system, mobile devices, and client inclinations. Vertical Handover Decision Algorithms (VHDAs) are used to weigh up and survey the parameters included under each specific rule.

#### 3.8.3.1 Decision Phase of Handover

This phase can be viewed as the key stage of the VHO since it is accountable for surveying and choosing the best proper network choices which will fulfil both framework, customer prerequisites and gives a seamless network connection. To settle on a precise choice this stage uses the benefit of the algorithm considering the data that is available and getting the finest decision for handoff implementation. These computations are regularly called VHO Algorithms.

### 3.8.4 Handover Execution

This stage performs the handoff itself by mobility and handover management, it ought to guarantee ensure a smooth session process (VHO implementation).

## 3.9 Selection of Algorithms Parameters

This sort of algorithms uses the benefit of the context data, creating knowledge to accomplish a precise decision. Any variation in the network triggers selections and procedures that are advised to VHO decision step via Information gathering stage. Relying on the amount of parameters chose for processing, these algorithms are considered as essential. When the information data is accumulated, a QoS indicator plays out a path conjecture to ensure the end to end Quality of Service (Chen et.al, 2010).

## 3.10 Processing of Algorithms Parameters

The processing of algorithm parameters is in charge of handling the picked parameters and giving the data to the parameter collection algorithm. The surveyed work utilizes different roles to set up the information depending upon its inclination. The roles used could change from computational to numerical algorithms.

### 3.11 Algorithms Based on Mathematical Approach

Most algorithms based on mathematical approach are algorithms designed by self. Few writers proposed their own specific self-outline decision algorithms to content their VHO needs in perspective of the data existing in their framework. Markov decision approach relying on rank aggregate, where the top weighted framework is picked. This method resembles the MCDM Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) yet deters the perfect system correlation. A score capacity is used in seamless decision keeping the end goal to select the best network and time to make handoff (Steven et.al, 2008).

### 3.12 Algorithms Based on Computational Approach

Algorithms based on computational approach use Neural Networks and Fuzzy Logic strategies to translate uncertain data, regardless of the way that authors make utilization of their own specific self-composed calculations to accomplish the issue. The previously stated algorithms need definite data to measure attributes and to play out an exact choice. Nonetheless, the collected information is frequently free to handle the issue of fuzzy control logic and neural network strategies. Usually, these algorithms are associated first with a particular end goal to adjust unverifiable data into exact data. Subsequently, a MCDM algorithm is maintained with this data to choose the best decision. Combine fuzzy logic process with MCDM methodology, combining fuzzyfication procedure with Gray Relational Analysis techniques and cost based technique with fuzzy logic algorithm with a particular end goal to settle on the best decision. This technique is useful at merging the distinctive information data sources to evacuate significant information, since in mobile situations like Vehicular networks (VNs) and high speed makes the gained information not to be reliable. Nevertheless, the significance of this sort of algorithms could be diminished if computational times included turns out to be too high (Rodrigo and Victor, 2010).

### 3.13 Algorithms Based on Aggregation of Parameters

Vertical handover decision frameworks consider different measurements and parameters in surveying the best candidate network, the prerequisite for algorithms that can deal with various parameters and measurements is given in Table 3.1 Subsequently, MCDM algorithms are gotten to fulfil this essential by gathering all prepared parameters. MCDM algorithms incorporate algorithms relying upon the numerous characteristics or different decisions. Different Attribute Decision-Making algorithms measure the various decisions depending on their characteristics, while the Multiple Objective Decision-Making algorithms focus on arranged targets that cannot happen at same time. Both sorts of algorithms are called MCDM. We now continue to quickly depict the most widely recognized MCDM algorithms.

### 3.13.1 Hierarchy Process of Analysis

This sort of calculations depends on the divide and-win paradigm. The principle choice issue is sorted into sub-issues, where each sub-issue is assessed as a choice element. From the set of options, the best ideal solution is gotten from this method (Thanachai and Anjum, 2010).

### 3.13.2 Analysis Based on Grey Relation

This numerical algorithm builds a gray relationship between components (network), one of them with the ideal qualities. Thus, whatever is left of the essentials are broken down and evaluated against the ideal arrangement. The alternative that comes closer to this perfect arrangement gets the top score (Atiq et al., 2010).

### 3.13.3 Order Preference by Similarity to Ideal Solution Technique

Likewise, to analysis based on grey relational algorithms, order preference by similarity to ideal solution algorithms consider and perfect answer for execution examination and considering the best option as the one closest to the perfect arrangement, as worst the one furthest from such solution (Shusmita and Manzur, 2010).

### 3.13.4 Weighting of Simple Additive

Weighting of Simple Additive algorithms are most of the time used when MCDM is associated. This strategy involves in scoring elective by including attributes and then multiplied by the unit weight to get a high score, being the most elevated score (Shusmita and Manzur, 2010).

### 3.14 Management of Handover

In the handover procedure there ought to be a substance responsible for controlling the VHO procedure. In most part, the handover can either be Network controlled or Mobile controlled. In the past cases it began and organized by the network, an answer that is normally adopted by services to perform load adjusting obligations and traffic service among others. The last case VHO is begun and organized by the mobile terminal. This sort of organize is a usual case, typically in perspective of customer preference. Also, the VHO could be Network aided, mobile aided when it is started by the system and using data service. In the midst of the handover procedure, a mobile device accomplishes another Point of Attachment; the network may execute techniques to select network (Kam et.al, 2010).

### 3.15 VHD Criteria

A criteria shown in Figure 3.8 were proposed as a common used in VHDAs (Yan, 2010).

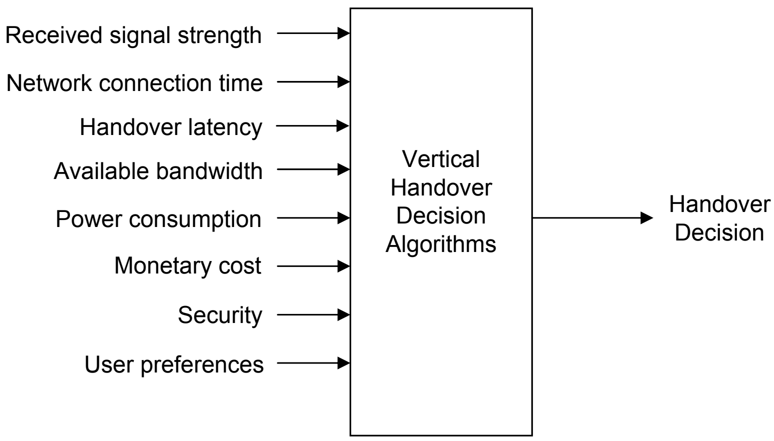


**Figure 3.7:** VHD decisions parameters (Yan, 2010)

We briefly clarify each of them:

- RSS is a frequently utilized standard since it is easy to size and is clearly significant to the service quality. There is relationship between the readings of RSS and the separating space amid the mobile device and point of access. The part of present algorithm of handover uses the main requirement (RSS) as the primary choice model for VHD algorithms.

- Network connection time denotes the length in which a mobile station stays connected with a specific system access. Deciding the framework affiliation time is basic for selecting the right minute in triggering handover so that the service quality could be kept up at a satisfactory level. The network association is identified with a mobile stations velocity and range. The velocity coming from the point of attachment of the mobile station as an influence on the RSS at that point.
- Latency of handover characterized for mobile terminal is the passing time amongst the latter packet accepted through transmitting access and the coming of new packet in new transmitting access after handover.
- Available bandwidth is the sizing of accessible information communication assets conveyed in bits. It is a decent indication of movement conditions in network access.
- Power consumption is a big concern especially if the battery of the mobile station is low. In this kind of circumstances; it is desirable to switch to a suitable connection that will help in expanding the battery life significantly.
- Monetary cost of various systems has different charging strategies, hence, in a few circumstances the expense of system services needed to be thought about before any handover decisions.
- Security and integrity of conveyed information could be basic. Thus, a system with very high level security might be picked instead of one with lower level security of data.
- User preferences to ward system access might prompt the choice of a type of network over other network candidate.

# CHAPTER 4

# ANALYSES AND DISCUSSIONS

Rapid increase in the development of wireless communication technologies in addition to the high demand of mobile users imply that wireless communication be a collaborative working of different networks. Progress of mobile terminals with diverse access edges and techniques through different networks is inevitable. It depends on the increasing user needs. Anywhere, at any time, any connectivity is a requirement for users either for real time or non-real time services. Literature has proposed many vertical handoff protocols to connect to the best network. In this chapter, we have established a synthesis of different vertical handoff decision algorithms, such as linear-TOPSIS, exponential-TOPSIS and logarithmic-TOPSIS as function schemes depending on the need for high capacity (throughput) and low latency per packet, bit error rate (BER) and cost per MB. In this work, nine different scenarios with different configurations will be evaluated. The evaluation will show the effect of the different parameters on network and user decision as in dynamic environments obtained by MATLAB simulations. Moreover, The VHO technology provides information about the available networks and their respective PoAs within the area. To get the most out of these achievements, Table 4.1 summarizes the main configuration set for the experiments parameters (SNR, band withed) for both networks to all scenarios. As observed, there are two networks covering areas with offered data rates. Nine scenarios with different parameters were examined and illustrated with different configurations of network parameters to cover different network technologies. These scenarios considered the network limitations for both networks. Moreover, we have configured each network in the scenario with different performance parameters. The parameter set for each network and the requirements for the video traffic that must be fulfilled by the chosen network during the theoretical simulation. We have considered video streaming traffic since video is expected to be a major component of the mobile services in the near future. To achieve the best QoS for the user during a service request and also to examine how linear, exponential and logarithmic functions affect the TOPSIS algorithms while choosing the best decision for both networks.

### 4.4 Result Scenarios

In this section, scenarios are intended to demonstrate how the scoring values and efficiency functions of linear, exponential and logarithmic algorithms are being effected when weights and attributes are changing. In other words, the change of criteria and attributes based on TOPSIS algorithm will be examined with linear, logarithmic, and exponential functions. Nine scenarios with different parameters are going to be examined and illustrated in the next part of the thesis. All the figures are drawn by using Equation (4.18). During the first scenario, the values of SNR of 20 and 16 dB were used for network 1 and network 2 respectively. The bandwidth values of 10 and 20 MHz were also used, also in scenario four we but all the weights equal. Table 4.1 presents the values of SNR and bandwidth used for each one of the nine scenarios. The relative importance of different attributes is determined to the weights using a pair-wise comparison by a scale of relative importance. The distributions of the weights depend upon type of service. We selected four criteria, for each having values out of 1. We consider throughput as extremely important (0.65), latency as very important (0.30), BER (0.025) and price per MB (0.025) equal important for all scenarios except scenario four, to be suitable for video streaming services. To evaluate the performance of the VHO scheme we used the following metrics throughput, latency, packet loss (BER) and price per MB, in order to obtain reliable results.

**Table 4.1:** Parameters used in the nine different scenarios

| | **NETWORK 1** | | **NETWORK 2** | |
|---|---|---|---|---|
| **Scenario** | **BW (MHz)** | **SNR (dB)** | **BW (MHz)** | **SNR (dB)** |
| **1** | 10 | 20 | 20 | 20 |
| **2** | 10 | 20 | 10 | 10 |
| **3** | 10 | 20 | 20 | 10 |
| **4** | 10 | 20 | 20 | 10 |
| **5** | 1.5 | 40 | 50 | 10 |
| **6** | 15 | 30 | 40 | 15 |
| **7** | 25 | 25 | 30 | 20 |
| **8** | 30 | 15 | 20 | 25 |
| **9** | 40 | 10 | 15 | 20 |

### 4.4.1 Scenario One Network Decisions

Table 4.3 shows the specifications and network parameters for scenario one. Table 4.4 shows the attribute values of the networks while Table 4.3 shows the decision networks for this scenario.

**Table 4.2:** Specifications and networks parameters for scenario one

| Parameters | Network 1 | Network 2 |
|---|---|---|
| Signal to noise ratio [dB] | 20 | 16 |
| Bandwidth [MHz] | 10 | 20 |
| Price per Mb [$] | 0.05 | |
| Length of packet [bit] | 1500 | |
| Channel/modulation | 16-QAM with Rayleigh fading channel | |
| Throughput weight | 0.65 | |
| Latency per packet weight | 0.30 | |
| Bit error rate weight | 0.025 | |
| Price per Mb weight | 0.025 | |

**Table 4.3:** Network attributes for scenario one

| Network1 | | | | | Network2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** |
| 20 | 63.29 | 0.000023 | 0.006 | 3.16 | 2 | 23.51 | 0.00006 | 0.177 | 1.17 |
| 18 | 56.75 | 0.000026 | 0.009 | 2.83 | 4 | 31.65 | 0.00004 | 0.137 | 1.58 |
| 16 | 50.27 | 0.000029 | 0.014 | 2.51 | 6 | 41.14 | 0.00003 | 0.103 | 2.05 |
| 14 | 43.89 | 0.000034 | 0.022 | 2.19 | 8 | 51.75 | 0.000028 | 0.074 | 2.58 |
| 12 | 37.64 | 0.000039 | 0.034 | 1.88 | 10 | 63.21 | 0.000023 | 0.051 | 3.16 |
| 10 | 31.60 | 0.000047 | 0.051 | 1.58 | 12 | 75.28 | 0.000019 | 0.034 | 3.76 |
| 8 | 25.87 | 0.000057 | 0.074 | 1.29 | 14 | 87.78 | 0.000017 | 0.022 | 4.38 |
| 6 | 20.57 | 0.000072 | 0.103 | 1.02 | 16 | 100 | 0.000014 | 0.014 | 5.02 |

**Table 4.4:** Network decisions for scenario one

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 2 |
| DM{4} | 2 | 1 | 2 |
| DM{5} | 2 | 2 | 2 |
| DM{6} | 2 | 2 | 2 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figure 4.1 shows the results of TOPSIS using the two networks. Although network one is closer to a positive ideal solution than network two, the approach may prefer the greater distance to the negative ideal solution compared to network one.

Linear-TOPSIS algorithm defines an index called similarity to the ideal solution by combining the proximity to the positive ideal solution and the distance from the negative ideal solution. Then the method chooses an alternative with the maximum similarity to the positive ideal solution. TOPSIS assumes that each attribute takes either monotonously increasing or decreasing network.

Figure 4.2 illustrates the results of each network with Exp-TOPSIS algorithm, changing the weights produced different results when compared with the linear-TOPSIS especially when the values of attributes are similar for both networks.

In other words, the behavior of exponential function makes resulted in the score network decisions as that of Linear-TOPSIS, excepted one decision, as shown in Table 4.4.

Figure 4.3 presents the results of each network with Log-TOPSIS algorithm. The change of weight produced negative values before normalization step, however, after normalizing step in the TOPSIS method, gives the values have changed sign.

In other words, the behavior of logarithmic function resulted different network decision than both Linear-TOPSIS and Exp-TOPSIS as shown in Table 4.4.

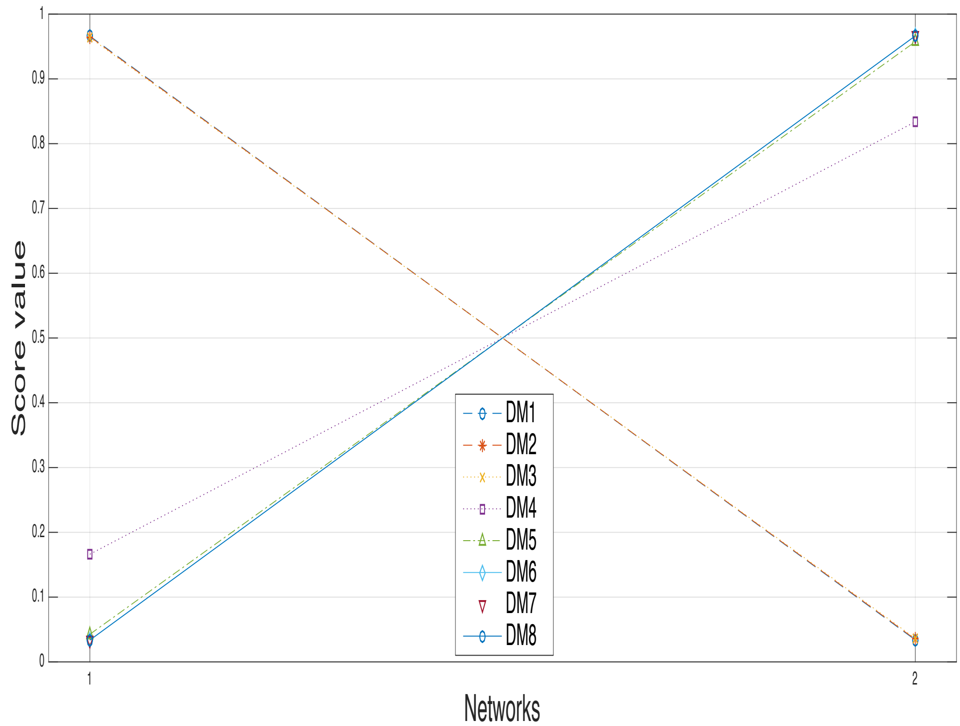


**Figure 4.1:** Score values of each network with Linear-TOPSIS algorithm for scenario one

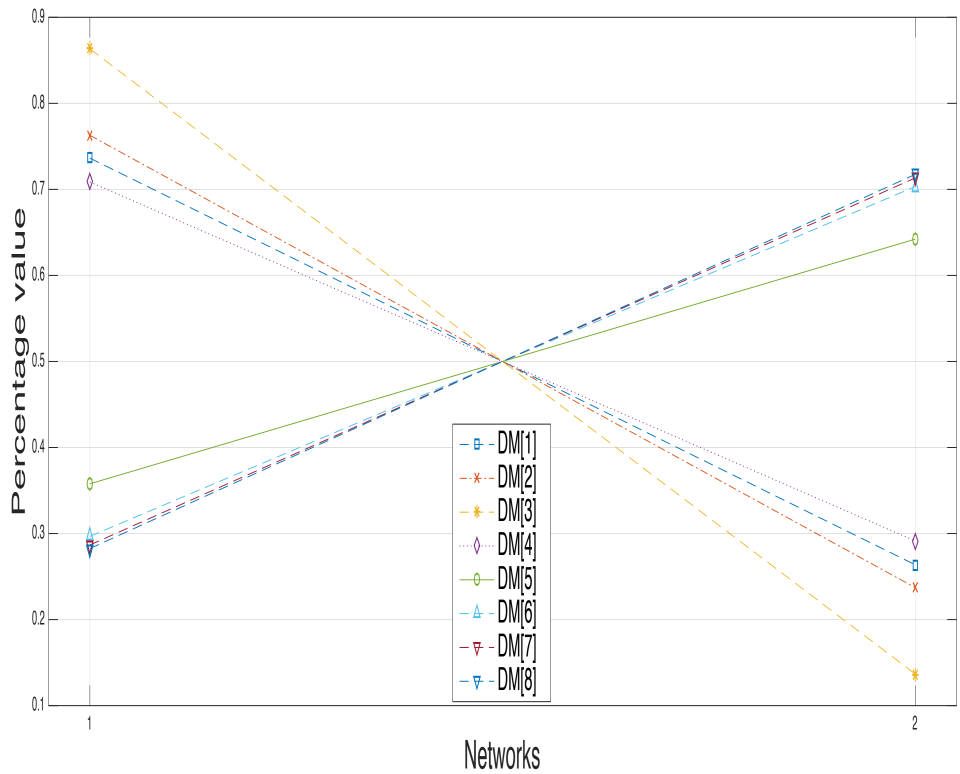


**Figure 4.2:** Score values of each network with Exp-TOPSIS algorithm for scenario one

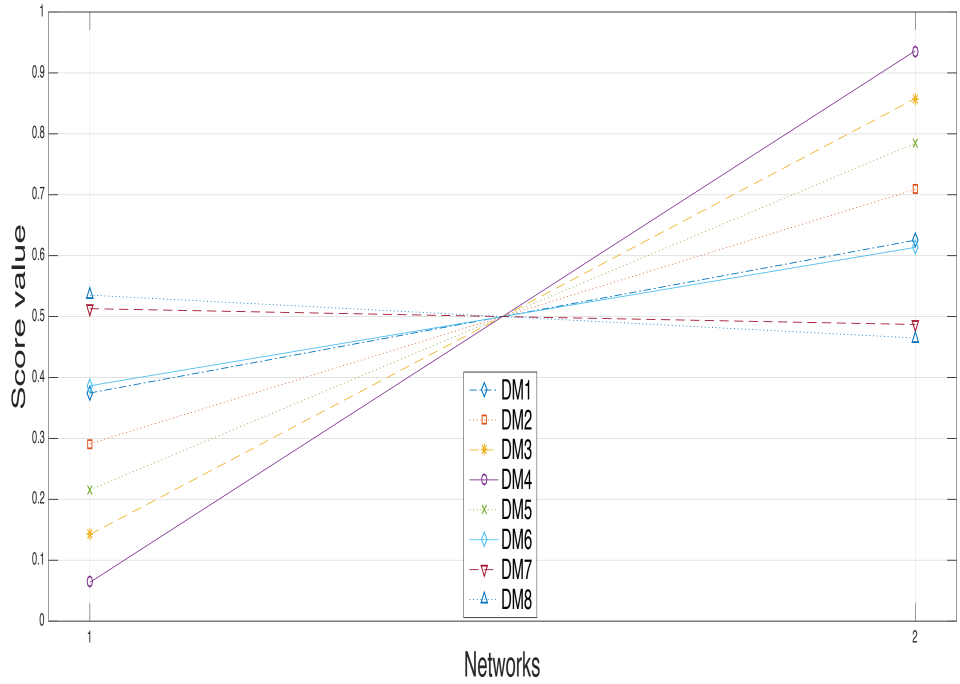


**Figure 4.3:** Score values of each network with Log-TOPSIS algorithm for scenario one

#### 4.4.1.1 Mathematical Description for functions on Algorithms

Construct the Normalized Decision Matrix to transform the various attribute dimensions into non-dimensional attributes, which allows comparison across the attributes. All algorithms are using the same parameters in the first two steps.

In linear-TOPSIS, attribute matrix $\text{TDM}\{4\} = \begin{bmatrix} 0.420 & 0.231 & 0.007 & 0.0161 \\ 0.495 & 0.190 & 0.023 & 0.0190 \end{bmatrix}$

At the end, the score of linear-TOPSIS is $\text{ScoreC}\{4\} = \begin{bmatrix} 0.166 \\ 0.833 \end{bmatrix}$. The result shows that the network 2 is the best selection.

In Exp-TOPSIS they become, $\text{TDM}\{4\} = \begin{bmatrix} 1.23 & 1.04 & 0.292 & 0.663 \\ 1.46 & 0.858 & 0.982 & 0.781 \end{bmatrix}$

score matrix $\text{ScorDM}\{4\} = \begin{bmatrix} 0.831 \\ 0.166 \end{bmatrix}$. This means that the second network 1 is the best selection for the user.

In Log-TOPSIS the result is $\text{TDM}\{4\} = \begin{bmatrix} -0.27 & -0.929 & -1.05 & -2.38 \\ -0.32 & -0.765 & -3.53 & -2.81 \end{bmatrix}$. This gives the score matrix $\text{ScorDM}\{4\} = \begin{bmatrix} 0.0636 \\ 0.936 \end{bmatrix}$. This means that the second network 2 is the best selection for the user.

#### 4.4.1.2 Scenario One User Decisions

Received SNR values and user dynamic are varied to investigate the performance of the decision method. Different combinations of average received SNR and bandwidth of user resulted in different values of parameters (throughput, latency per packet, BER and cost per MB). This is shown in Tables 4.5 and 4.6, obtained from the decision networks by TOPSIS algorithms under different conditions.

Table 4.5 shows that performance of throughput decreases as signal to noise ratio and bandwidth decreases. Linear-TOPSIS and Exp-TOPSIS for dynamic user achieve better throughput and latency when compared to Log-TOPSIS. The average throughput value of linear-TOPSIS is 68.5412, Exp-TOPSIS is 67.5587 and Log-TOPSIS is 41.6225. The throughput affects the latency per packet; if the throughput increases then latency per packet decreases.

**Table 4.5:** Averages for throughput and latency per packet for scenario one

| **Throughput (Mb/s)** | | | **Latency per packet** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 63.29 | 63.29 | 23.51 | 0.000023 | 0.000023 | 0.00006 |
| 56.75 | 56.75 | 31.65 | 0.000026 | 0.000026 | 0.00004 |
| 50.27 | 50.27 | 41.14 | 0.000029 | 0.000029 | 0.00003 |
| 51.75 | 43.89 | 51.75 | 0.000028 | 0.000034 | 0.000028 |
| 63.21 | 63.21 | 63.21 | 0.000023 | 0.000023 | 0.000023 |
| 75.28 | 75.28 | 75.28 | 0.000019 | 0.000019 | 0.000019 |
| 87.78 | 87.78 | 25.87 | 0.000017 | 0.000017 | 0.000057 |
| 100 | 100 | 20.57 | 0.000014 | 0.000014 | 0.000072 |
| **Average** | | | **Average** | | |
| 68.5412 | 67.5587 | 41.6225 | 2.2375e-05 | 2.3125e-05 | 4.1125e-05 |

Table 4.6 presents the results of BER and cost per MB. It also shows the average of BER; it is obvious that an increase in SNR causes a decrease in BER. The average BER for

Linear-TOPSIS is 0.0280, Exp-TOPSIS is 0.0215 and Log-TOPSIS is 0.0941. The cost per MB increases if throughput is increased. The average cost per MB for Linear-TOPSIS is 3.4250, Exp-TOPSIS is 3.3762 and Log-TOPSIS is 2.0762

**Table 4.6:** Averages for BER and cost per MB for scenario one

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 0.006 | 0.006 | 0.177 | 3.16 | 3.16 | 1.17 |
| 0.009 | 0.009 | 0.137 | 2.83 | 2.83 | 1.58 |
| 0.014 | 0.014 | 0.103 | 2.51 | 2.51 | 2.05 |
| 0.074 | 0.022 | 0.074 | 2.58 | 2.19 | 2.58 |
| 0.051 | 0.051 | 0.051 | 3.16 | 3.16 | 3.16 |
| 0.034 | 0.034 | 0.034 | 3.76 | 3.76 | 3.76 |
| 0.022 | 0.022 | 0.074 | 4.38 | 4.38 | 1.29 |
| 0.014 | 0.014 | 0.103 | 5.02 | 5.02 | 1.02 |
| **Average** | | | **Average** | | |
| 0.0280 | 0.0215 | 0.0941 | 3.4250 | 3.3762 | 2.0762 |

### 4.4.2 Scenario Two Network Decisions

In scenario two, The SNR in this scenario is chosen to be 20 dB for network1 and 10 dB for network 2. The bandwidth of network1 is 10MHz, while network 2 has a bandwidth of 10MHz. produced different results for the two networks are evaluated. Table (4.7) shows the attribute values for both networks under different SNR values, while Table (4.8) shows the network decisions for all values of SNR.

**Table 4.7:** Network attributes for scenario two

| Network1 | | | | | Network2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** |
| 20 | 63.29 | 0.000023 | 0.006 | 0.63 | 1 | 10.00 | 0.00015 | 0.177 | 0.10 |
| 18 | 56.57 | 0.000026 | 0.009 | 0.56 | 2 | 11.75 | 0.00012 | 0.137 | 0.11 |
| 16 | 50.27 | 0.000029 | 0.014 | 0.50 | 3 | 13.70 | 0.00010 | 0.103 | 0.13 |
| 14 | 43.89 | 0.000034 | 0.022 | 0.43 | 4 | 15.82 | 0.000094 | 0.074 | 0.15 |
| 12 | 37.64 | 0.000039 | 0.034 | 0.37 | 5 | 18.12 | 0.000082 | 0.051 | 0.18 |
| 10 | 31.60 | 0.000047 | 0.051 | 0.31 | 6 | 20.57 | 0.000072 | 0.034 | 0.20 |
| 8 | 25.87 | 0.000057 | 0.074 | 0.25 | 7 | 23.16 | 0.000064 | 0.022 | 0.23 |
| 6 | 20.57 | 0.000072 | 0.103 | 0.20 | 8 | 25.87 | 0.000057 | 0.014 | 0.25 |

**Table 4.8:** Network decisions for scenario two

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 1 |
| DM{4} | 1 | 1 | 1 |
| DM{5} | 1 | 1 | 1 |
| DM{6} | 1 | 2 | 1 |
| DM{7} | 1 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figures 4.4, 4.5 and 4.6 present the score values of each network obtained for scenario 2. As shown in these figures, the behaviors of logarithmic and exponential functions resulted in different score values for both networks, especially when the values of attributes are close to each other.

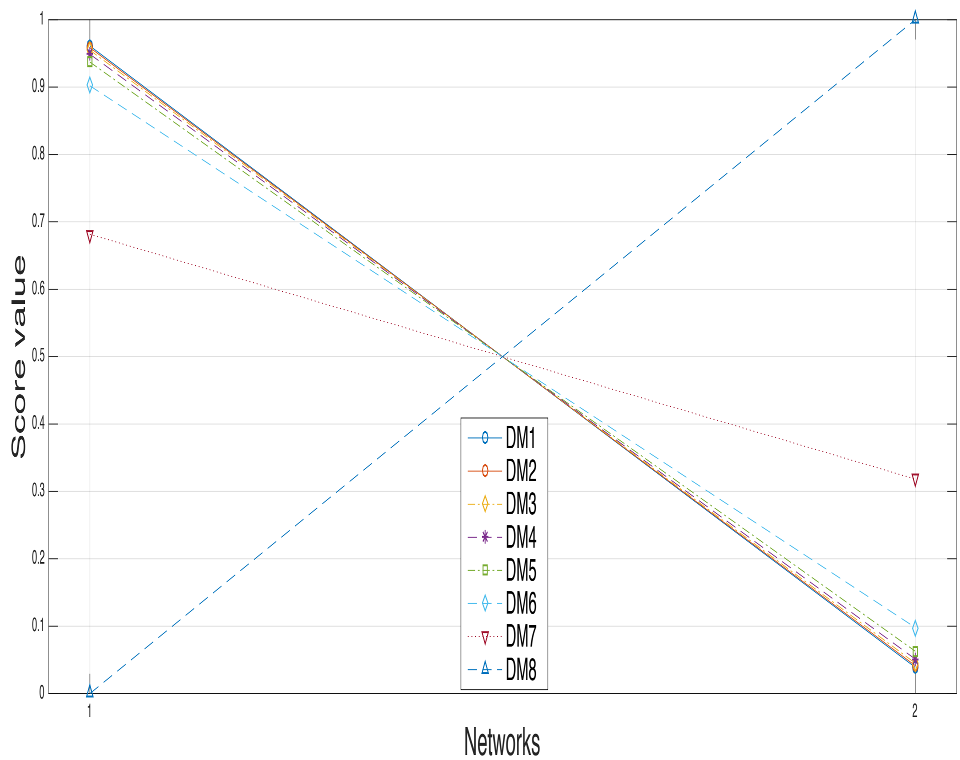


**Figure 4.4:** Score values of each network with Linear-TOPSIS algorithm for scenario two

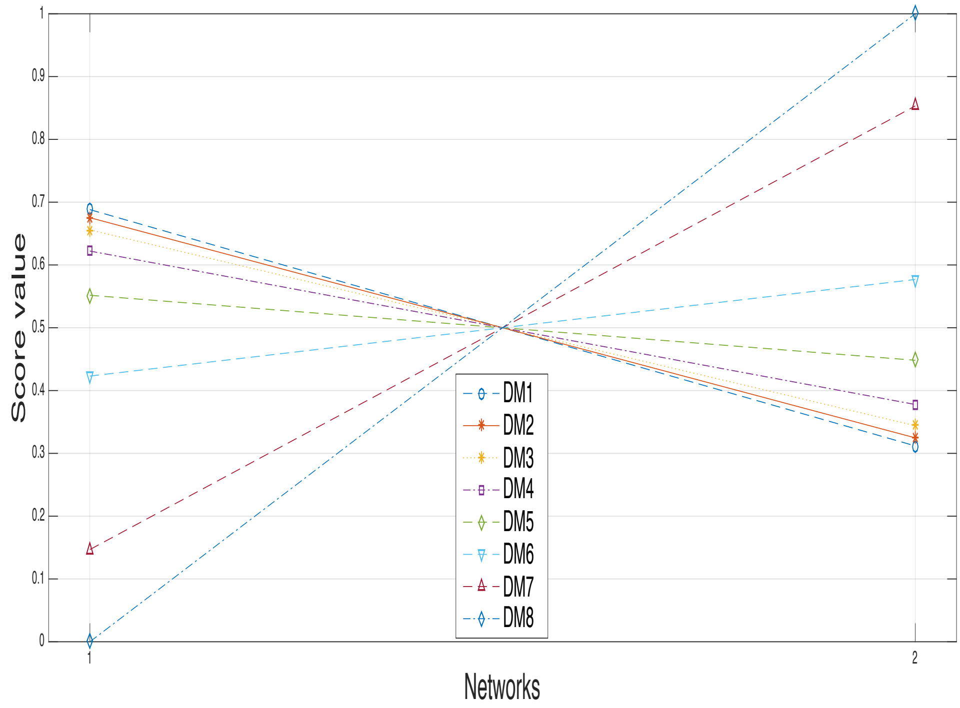


**Figure 4.5:** Score values of each network with Exp-TOPSIS algorithm for scenario two

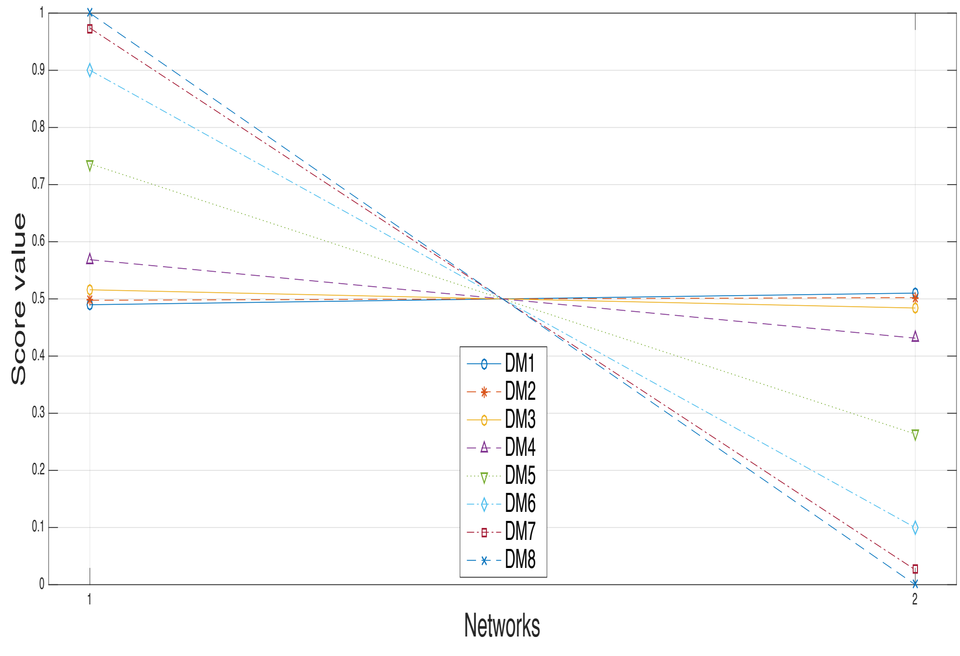


Figure 4.6: Score values of each network with Log-TOPSIS algorithm for scenario two

#### 4.4.2.1 Scenario Two User Decisions

Table 4.9 shows the average of throughput values for Linear-TOPSIS, Exp-TOPSIS, and Log-TOPSIS. It also presents the average latency per packet for the three functions. Table

4.10 shows that the average BER values of Linear-TOPSIS is 0.0280, Exp-TOPSIS is 0.0194 and Log-TOPSIS is 0.0765. In addition, the average cost per MB of Linear-TOPSIS is 0.4125, Exp-TOPSIS is 0.3963 and Log-TOPSIS is 0.2838. The results obtained show that the linear TOPSIS algorithm has given better results in terms of Throughput compared to the logarithmic TOPSIS, however, the exponential TOPSIS's results were near to those of linear TOPSIS. In terms of latency, linear TOPSIS has also shown the best performance with considerable difference from the other two algorithms. Again, the logarithmic TOPSIS has given the worst decision results. BER results show that the exponential TOPSIS has given the minimum BER value, whereas linear TOPSIS has come the next in terms of BER. Again, logarithmic TOPSIS has fallen in the last position with the worst BER values. Looking at the cost of each algorithm, results show that the logarithmic TOPSIS has the lowest cost compared to the linear TOPSIS that came the last with the highest cost average.

**Table 4.9:** Averages for throughput and latency per packet for scenario two

| **Throughput (Mb/s)** | | | **Latency per packet** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 63.29 | 63.29 | 10.00 | 0.000023 | 0.000023 | 0.00015 |
| 56.57 | 56.57 | 11.75 | 0.000026 | 0.000026 | 0.00012 |
| 50.27 | 50.27 | 50.27 | 0.000029 | 0.000029 | 0.000029 |
| 43.89 | 43.89 | 43.89 | 0.000034 | 0.000034 | 0.000034 |
| 37.64 | 37.64 | 37.64 | 0.000039 | 0.000039 | 0.000039 |
| 31.60 | 20.57 | 31.60 | 0.000047 | 0.000072 | 0.000047 |
| 25.87 | 23.16 | 25.87 | 0.000057 | 0.000064 | 0.000057 |
| 25.87 | 25.87 | 20.57 | 0.000057 | 0.000057 | 0.000072 |
| **Average** | | | **Average** | | |
| 41.8750 | 40.1575 | 28.9488 | 3.9000e-05 | 4.3000e-05 | 6.8500e-05 |

**Table 4.10:** Averages for BER and cost per MB for scenario two

| **BER** | | | **Cost per MB** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 0.006 | 0.006 | 0.177 | 0.63 | 0.63 | 0.10 |
| 0.009 | 0.009 | 0.137 | 0.56 | 0.56 | 0.11 |
| 0.014 | 0.014 | 0.014 | 0.50 | 0.50 | 0.50 |
| 0.022 | 0.022 | 0.022 | 0.43 | 0.43 | 0.43 |
| 0.034 | 0.034 | 0.034 | 0.37 | 0.37 | 0.37 |

| | | | | | |
|---|---|---|---|---|---|
| 0.051 | 0.034 | 0.051 | 0.31 | 0.20 | 0.31 |
| 0.074 | 0.022 | 0.074 | 0.25 | 0.23 | 0.25 |
| 0.014 | 0.014 | 0.103 | 0.25 | 0.25 | 0.20 |
| **Average** | | | **Average** | | |
| 0.0280 | 0.0194 | 0.0765 | 0.4125 | 0.3963 | 0.2838 |

### 4.4.3 Scenario Three Network Decisions

In scenario three, The SNR in this scenario is chosen to be 20 dB for network1 and 10 dB for network 2. The bandwidth of network 1 is 10MHz, while network 2 has a bandwidth of 20MHz.Table 4.11 shows the attribute values for both networks while Table 4.12 shows the decisions of the networks for all examined cases.

**Table 4.11:** Network parameters for scenario three

| **Network1** | | | | | **Network2** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** |
| 20 | 63.29 | 0.000023 | 0.006 | 0.63 | 1 | 20.00 | 0.000075 | 0.177 | 0.20 |
| 18 | 56.57 | 0.000026 | 0.009 | 0.56 | 2 | 23.51 | 0.000063 | 0.137 | 0.23 |
| 16 | 50.27 | 0.000029 | 0.014 | 0.50 | 3 | 27.40 | 0.000054 | 0.103 | 0.27 |
| 14 | 43.89 | 0.000034 | 0.022 | 0.43 | 4 | 31.65 | 0.000047 | 0.074 | 0.31 |
| 12 | 37.64 | 0.000039 | 0.034 | 0.37 | 5 | 36.24 | 0.000041 | 0.051 | 0.36 |
| 10 | 31.60 | 0.000047 | 0.051 | 0.31 | 6 | 41.14 | 0.000036 | 0.034 | 0.41 |
| 8 | 25.87 | 0.000057 | 0.074 | 0.25 | 7 | 46.32 | 0.000032 | 0.022 | 0.46 |
| 6 | 20.57 | 0.000072 | 0.103 | 0.20 | 8 | 51.57 | 0.000028 | 0.014 | 0.51 |

**Table 4.12:** Network decisions for scenario three

| **Matrix** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log-TOPSIS** |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 1 |
| DM{4} | 1 | 2 | 1 |
| DM{5} | 1 | 2 | 1 |
| DM{6} | 2 | 2 | 1 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figures 4.7, 4.8 and 4.9 show the behaviors of linear, logarithmic, and exponential TOPSIS algorithms. We can notice that linear TOPSIS has given better results compared to the other two functions. The efficiencies of Log-TOPSIS and Exp-TOPSIS are affected by the weight values and the network decision depends more on the price and BER.

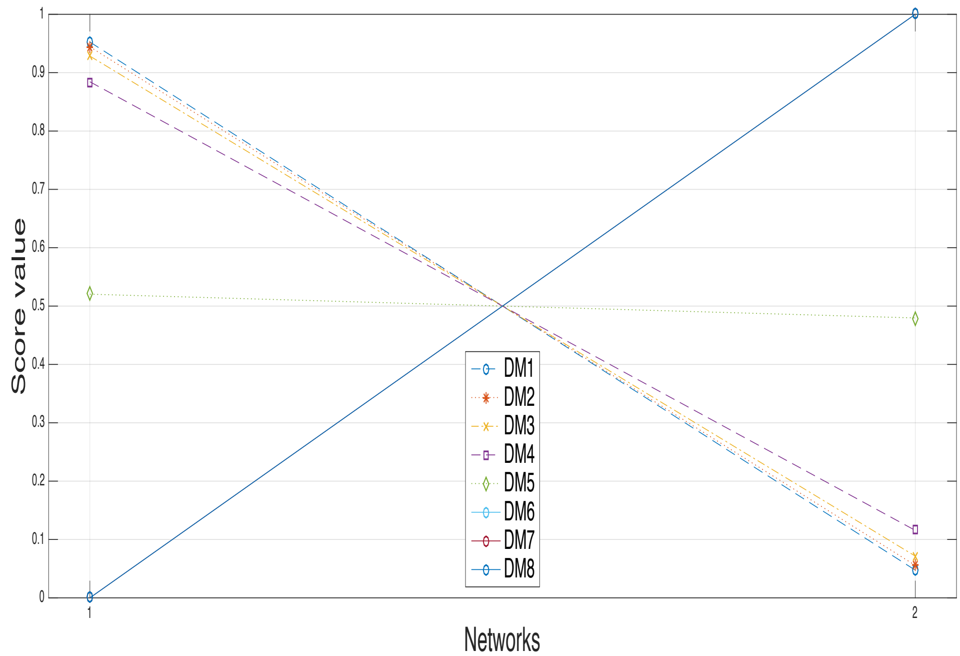


**Figure 4.7:** Score values of each network with Linear-TOPSIS for scenario three

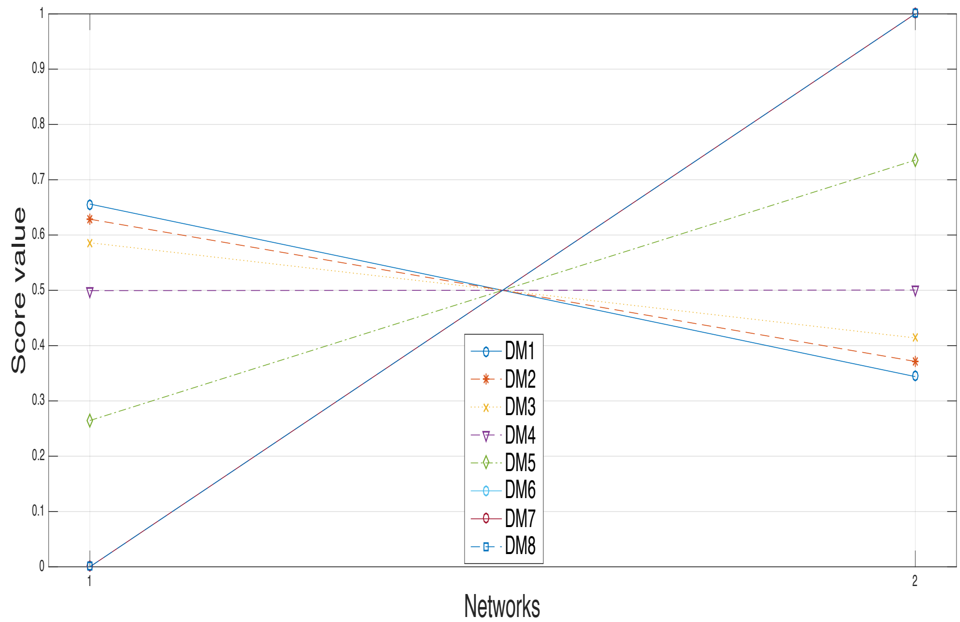


**Figure 4.8:** Score values of each network with Exp-TOPSIS algorithm for scenario three

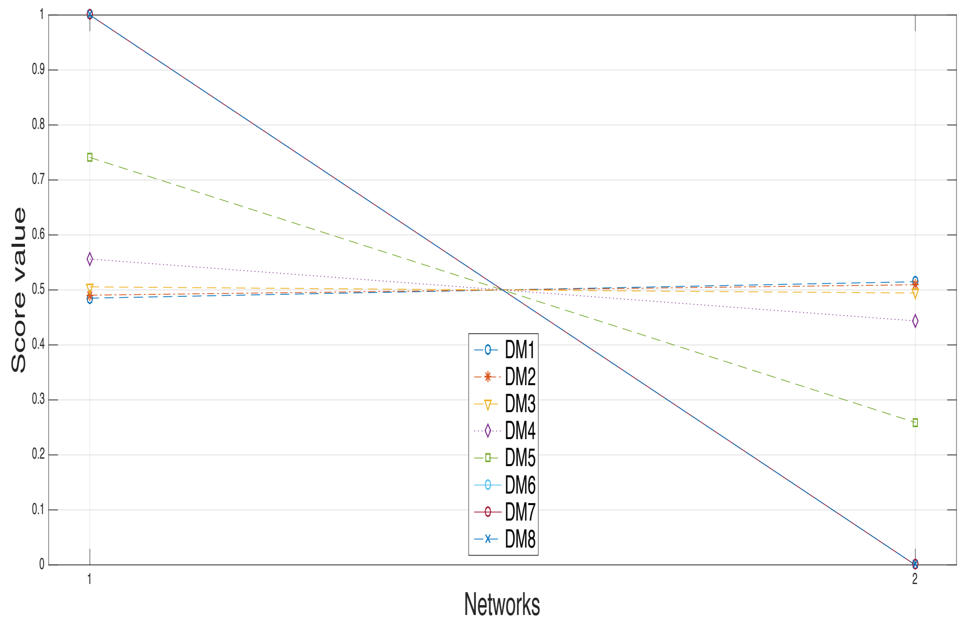


**Figure 4.9:** Score values of each network with Log-TOPSIS algorithm for scenario three

### 4.4.3.1 Scenario Three User Decisions

Table 4.13 shows the average throughput values for Linear-TOPSIS, Exp-TOPSIS and Log-TOPSIS. It also presents the average latency per packet corresponding to the three functions. Average BER and average cost per MB for the three functions with TOPSIS algorithms are also presented in Table 4.14.

**Table 4.13:** Averages for throughput and latency per packet for scenario three

| Throughput (Mb/s) | | | Latency per packet | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 63.29 | 63.29 | 20.00 | 0.000023 | 0.000023 | 0.000075 |
| 56.57 | 56.57 | 23.51 | 0.000026 | 0.000026 | 0.000063 |
| 50.27 | 50.27 | 50.27 | 0.000029 | 0.000029 | 0.000029 |
| 43.89 | 31.65 | 43.89 | 0.000034 | 0.000047 | 0.000034 |
| 37.64 | 36.24 | 37.64 | 0.000039 | 0.000041 | 0.000039 |
| 41.14 | 41.14 | 31.60 | 0.000036 | 0.000036 | 0.000047 |
| 46.32 | 46.32 | 25.87 | 0.000032 | 0.000032 | 0.000057 |
| 51.57 | 51.57 | 20.57 | 0.000028 | 0.000028 | 0.000072 |
| **Average** | | | **Average** | | |
| 48.8362 | 47.1313 | 31.6687 | 3.0875e-05 | 3.2750e-05 | 5.2000e-05 |

**Table 4.14:** Averages for BER and cost per MB for scenario three

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| Linear-TOPSIS | Exp-TOPSIS | Log- TOPSIS | Linear-TOPSIS | Exp-TOPSIS | Log- TOPSIS |
| 0.006 | 0.006 | 0.177 | 0.63 | 0.63 | 0.20 |
| 0.009 | 0.009 | 0.137 | 0.56 | 0.56 | 0.23 |
| 0.014 | 0.014 | 0.014 | 0.50 | 0.50 | 0.50 |
| 0.022 | 0.074 | 0.022 | 0.43 | 0.31 | 0.43 |
| 0.034 | 0.051 | 0.034 | 0.37 | 0.36 | 0.37 |
| 0.034 | 0.034 | 0.051 | 0.41 | 0.41 | 0.31 |
| 0.022 | 0.022 | 0.074 | 0.46 | 0.46 | 0.25 |
| 0.014 | 0.014 | 0.103 | 0.51 | 0.51 | 0.20 |
| **Average** | | | **Average** | | |
| 0.0194 | 0.0280 | 0.0765 | 0.4838 | 0.4675 | 0.3113 |

It is observed here as well that the results of linear and exponential functions are almost the same for all the cases so far while logarithmic function gives different results.

### 4.4.4 Scenario Four Network Decisions

The same parameters as in previous scenario are used for this scenario; the weight of each criterion has the same percentage values of 0.25 out of 1. Table 4.15 shows the attribute values for the two networks while Table 4.16 shows the network decisions for scenario four. In the three cases for linear, logarithmic, and exponential functions. The decisions of the first two algorithms were the same of all cases, while the logarithmic algorithm decision was different. It is important to notice the effect of the weight of each attribute on the decision of the algorithm. This will be clearer for the results of the scenarios considered next.

**Table 4.15:** Network parameters for scenario four

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SNR | Thro.(Mb/s) | Latency | BER | Price | SNR | Thro.(Mb/s) | Latency | BER | Price |
| 20 | 63.29 | 0.000023 | 0.006 | 0.63 | 1 | 20.00 | 0.000075 | 0.177 | 0.20 |
| 18 | 56.57 | 0.000026 | 0.009 | 0.56 | 2 | 23.51 | 0.000063 | 0.137 | 0.23 |
| 16 | 50.27 | 0.000029 | 0.014 | 0.50 | 3 | 27.40 | 0.000054 | 0.103 | 0.27 |
| 14 | 43.89 | 0.000034 | 0.022 | 0.43 | 4 | 31.65 | 0.000047 | 0.074 | 0.31 |
| 12 | 37.64 | 0.000039 | 0.034 | 0.37 | 5 | 36.24 | 0.000041 | 0.051 | 0.36 |
| 10 | 31.60 | 0.000047 | 0.051 | 0.31 | 6 | 41.14 | 0.000036 | 0.034 | 0.41 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 25.87 | 0.000057 | 0.074 | 0.25 | 7 | 46.32 | 0.000032 | 0.022 | 0.46 |
| 6 | 20.57 | 0.000072 | 0.103 | 0.20 | 8 | 51.57 | 0.000028 | 0.014 | 0.51 |

**Table 4.16:** Network decisions for scenario four

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 2 |
| DM{4} | 2 | 2 | 1 |
| DM{5} | 2 | 2 | 1 |
| DM{6} | 2 | 2 | 1 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figures 4.10, 4.11, and 4.12 show the score values distribution of linear, exponential, and logarithmic functions, respectively. Linear and exponential functions produce different score values based on the inputs, especially with similar attributes.

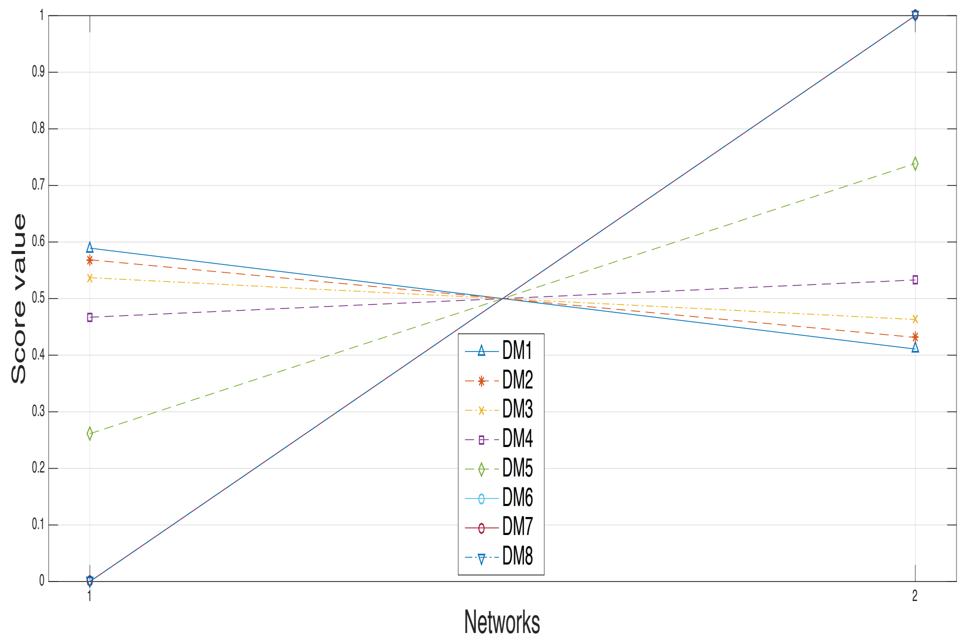


**Figure 4.10:** Score values of each network with Linear-TOPSIS for scenario four

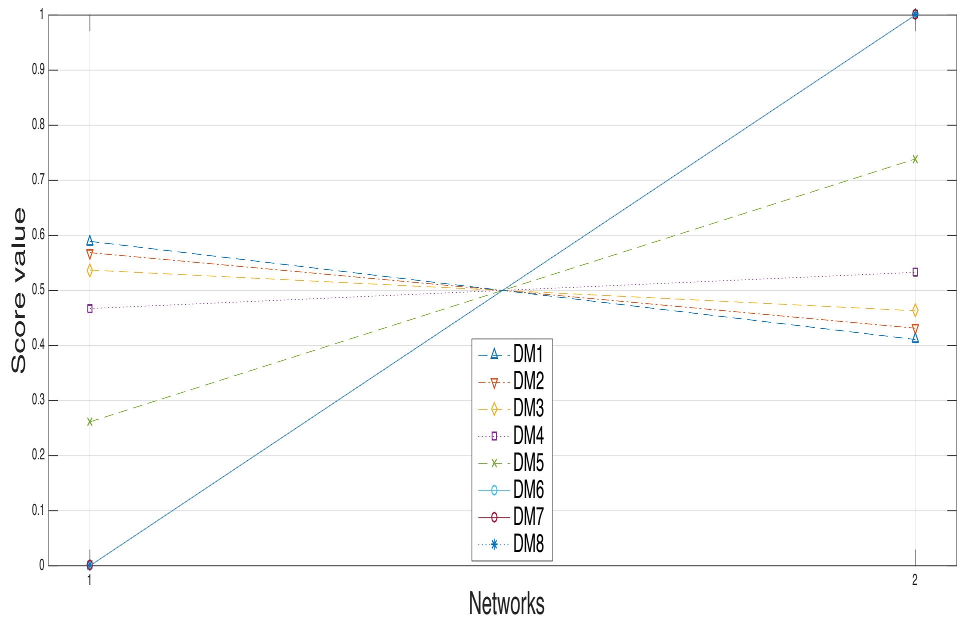


**Figure 4.11:** Score values of each network with Exp-TOPSIS algorithm for scenario four

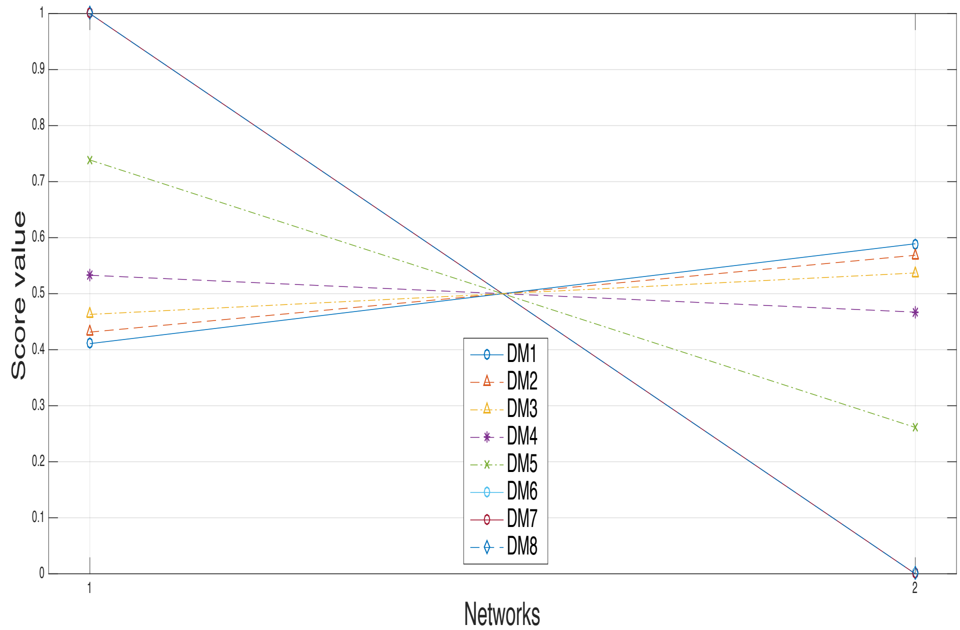


Figure 4.12: Score values of each network for Log-TOPSIS algorithm for scenario four

**4.4.4.1 Scenario Four User Decisions**

Table 4.17 shows the average throughput for Linear-TOPSIS (47.1313), Exp-TOPSIS (47.1313) and Log-TOPSIS (28.8100). It also presents the average latency per packet of Linear-TOPSIS (3.2750e-05), Exp-TOPSIS (3.2750e-05) and Log-TOPSIS (5.5125e-05).

Table 4.18 presents the average BER of Linear-TOPSIS, Exp-TOPSIS, and Log-TOPSIS, in addition to the average cost per MB for the three functions.

**Table 4.17:** Averages for throughput and latency per packet for scenario four

| **Throughput (Mb/s)** | | | **Latency per packet** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 63.29 | 63.29 | 20.00 | 0.000023 | 0.000023 | 0.000075 |
| 56.57 | 56.57 | 23.51 | 0.000026 | 0.000026 | 0.000063 |
| 50.27 | 50.27 | 27.40 | 0.000029 | 0.000029 | 0.000054 |
| 31.65 | 31.65 | 43.89 | 0.000047 | 0.000047 | 0.000034 |
| 36.24 | 36.24 | 37.64 | 0.000041 | 0.000041 | 0.000039 |
| 41.14 | 41.14 | 31.60 | 0.000036 | 0.000036 | 0.000047 |
| 46.32 | 46.32 | 25.87 | 0.000032 | 0.000032 | 0.000057 |
| 51.57 | 51.57 | 20.57 | 0.000028 | 0.000028 | 0.000072 |
| **Average** | | | **Average** | | |
| 47.1313 | 47.1313 | 28.8100 | 3.2750e-05 | 3.2750e-05 | 5.5125e-05 |

**Table 4.18:** Average for BER and cost per MB for scenario four

| **BER** | | | **Cost per MB** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 0.006 | 0.006 | 0.177 | 0.63 | 0.63 | 0.20 |
| 0.009 | 0.009 | 0.137 | 0.56 | 0.56 | 0.23 |
| 0.014 | 0.014 | 0.103 | 0.50 | 0.50 | 0.27 |
| 0.074 | 0.074 | 0.022 | 0.31 | 0.31 | 0.43 |
| 0.051 | 0.051 | 0.034 | 0.36 | 0.36 | 0.37 |
| 0.034 | 0.034 | 0.051 | 0.41 | 0.41 | 0.31 |
| 0.022 | 0.022 | 0.074 | 0.46 | 0.46 | 0.25 |
| 0.014 | 0.014 | 0.103 | 0.51 | 0.51 | 0.20 |
| **Average** | | | **Average** | | |
| 0.0280 | 0.0280 | 0.0876 | 0.4675 | 0.4675 | 0.2825 |

Results obtained for this scenario show that the network decision results of linear and exponential TOPSIS were similar. As shown in Table 4.16, the linear and exponential functions have chosen first network as the preferred network during the first three cases; while both function have chosen the second network for the rest of the cases. Logarithmic function has chosen the second network in the first three cases and the first network for the rest of cases, albeit a bad choice for the user.

### 4.4.5 Scenario Five Network Decisions

In scenario five, The SNR in this scenario is chosen to be 40 dB for network1 and 10 dB for network2. The bandwidth of network1 is 1.5MHz, while network2 has a bandwidth of 50MHz. Table 4.19 shows the network attribute values and Table 4.20 shows the network decisions.

**Table 4.19:** Network parameters for scenario five

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro (Mb/s)** | **Latency** | **BER** | **Price** |
| 40 | 19.43 | 0.000077 | 0.00006 | 0.97 | 3 | 68 | 0.000021 | 0.157 | 3.42 |
| 35 | 16.94 | 0.000088 | 0.00019 | 0.84 | 4 | 79 | 0.000018 | 0.137 | 3.95 |
| 30 | 14.45 | 0.00010 | 0.00062 | 0.72 | 5 | 90 | 0.000016 | 0.157 | 4.53 |
| 25 | 11.96 | 0.00012 | 0.0019 | 0.59 | 6 | 102 | 0.000014 | 0.103 | 5.14 |
| 20 | 9.49 | 0.00015 | 0.0061 | 0.47 | 7 | 115 | 0.000012 | 0.087 | 5.79 |
| 15 | 7.06 | 0.00021 | 0.018 | 0.35 | 8 | 129 | 0.000011 | 0.074 | 6.46 |
| 10 | 4.74 | 0.00031 | 0.051 | 0.23 | 9 | 143 | 0.000010 | 0.061 | 7.17 |
| 5 | 2.71 | 0.00055 | 0.11 | 0.13 | 10 | 158 | 0.000009 | 0.051 | 7.90 |

**Table 4.20:** Network decisions for scenario five

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 2 | 2 | 2 |
| DM{2} | 2 | 2 | 2 |
| DM{3} | 2 | 2 | 2 |
| DM{4} | 2 | 2 | 2 |
| DM{5} | 2 | 2 | 2 |
| DM{6} | 2 | 2 | 2 |
| DM{7} | 2 | 2 | 2 |
| DM{8} | 2 | 2 | 2 |

Figures 4.13, 4.14 and 4.15 present the TOPSIS results of scenario 5.  As shown in figures, all three functions are making the same network decision. Moreover, this scenario shows that if the bandwidth is worse as in network 1, all algorithms select the other network. This means that attributes like bandwidth has have effect on the decision of the algorithm.

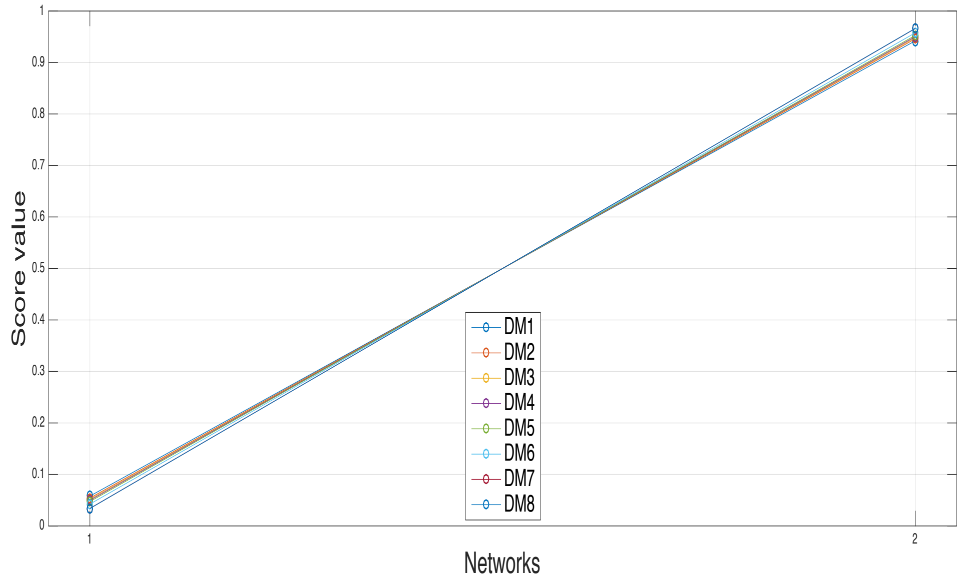


**Figure 4.13:** Score values of each network with Linear-TOPSIS for scenario five

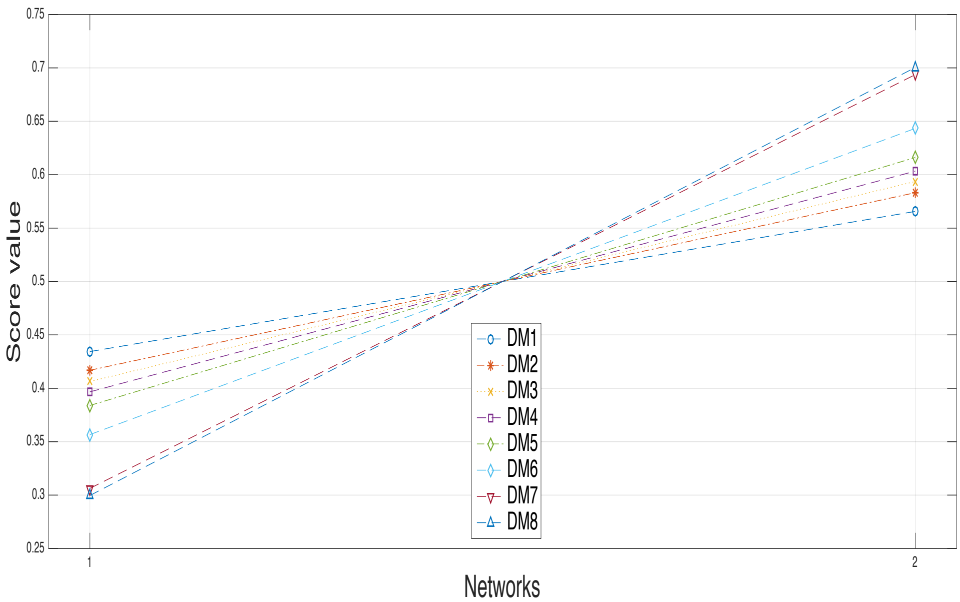


**Figure 4.14:** Score values of each network with Exp-TOPSIS algorithm for scenario five

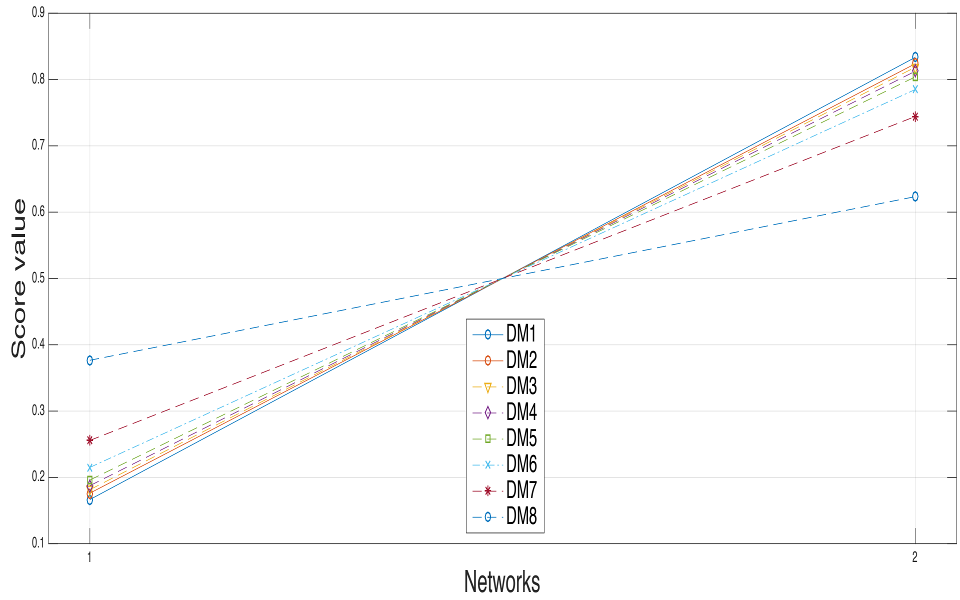


**Figure 4.15:** Score values of each network with Log-TOPSIS algorithm for scenario five

#### 4.4.5.1 Scenario five user decisions

As shown in Table 4.21, the average throughput of Linear-TOPSIS is 110.5, while the throughput of Exp-TOPSIS is 110.5 and that of Log-TOPSIS is 110.5. The average latency per packet in Linear-TOPSIS is 1.3875e-05, Exp-TOPSIS is 1.3875e-05 and Log-TOPSIS is 1.3875e-05. Table 4.22 presents the average BER values of Linear-TOPSIS, Exp-TOPSIS, and Log-TOPSIS algorithms. It also presents the average cost per MB of Linear-TOPSIS (5.5450), Exp-TOPSIS (5.5450) and Log-TOPSIS (5.5450) algorithms. These tables show that the three algorithms have resulted in the same results in terms of network selection and average values of the attributes. This is due to the fact that this scenario is using equal weights for all attributes.

**Table 4.21:** Averages for throughput and latency per packet for scenario five

| Throughput (Mb/s) | | | Latency per packet | | |
|---|---|---|---|---|---|
| **Lin-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Lin-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 68 | 68 | 68 | 0.000021 | 0.000021 | 0.000021 |
| 79 | 79 | 79 | 0.000018 | 0.000018 | 0.000018 |
| 90 | 90 | 90 | 0.000016 | 0.000016 | 0.000016 |
| 102 | 102 | 102 | 0.000014 | 0.000014 | 0.000014 |
| 115 | 115 | 115 | 0.000012 | 0.000012 | 0.000012 |
| 129 | 129 | 129 | 0.000011 | 0.000011 | 0.000011 |
| 143 | 143 | 143 | 0.000010 | 0.000010 | 0.000010 |

| | | | | | |
|---|---|---|---|---|---|
| 158 | 158 | 158 | 0.000009 | 0.000009 | 0.000009 |
| Average | | | Average | | |
| 110.5 | 110.5 | 110.5 | 1.3875e-05 | 1.3875e-05 | 1.3875e-05 |

**Table 4.22:** Averages for BER and cost per MB for scenario five

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| Lin-TOPSIS | Exp-TOPSIS | Log- TOPSIS | Lin-TOPSIS | Exp-TOPSIS | Log- TOPSIS |
| 0.157 | 0.157 | 0.157 | 3.42 | 3.42 | 3.42 |
| 0.137 | 0.137 | 0.137 | 3.95 | 3.95 | 3.95 |
| 0.157 | 0.157 | 0.157 | 4.53 | 4.53 | 4.53 |
| 0.103 | 0.103 | 0.103 | 5.14 | 5.14 | 5.14 |
| 0.087 | 0.087 | 0.087 | 5.79 | 5.79 | 5.79 |
| 0.074 | 0.074 | 0.074 | 6.46 | 6.46 | 6.46 |
| 0.061 | 0.061 | 0.061 | 7.17 | 7.17 | 7.17 |
| 0.051 | 0.051 | 0.051 | 7.90 | 7.90 | 7.90 |
| Average | | | Average | | |
| 0.1034 | 0.1034 | 0.1034 | 5.5450 | 5.5450 | 5.5450 |

### 4.4.6 Scenario Six Network Decisions

The SNR in this scenario is chosen to be 30 dB for network1 and 15 dB for network2. The bandwidth of network1 is 15MHz, while network2 has a bandwidth of 40MHz. Table 4.23 shows the attributes values for this scenario and Table 4.24 presents the network decisions.

**Table 4.23:** Network parameters for scenario six

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SNR | Thro.(Mb/s) | Latency | BER | Price | SNR | Thro.(Mb/s) | Latency | BER | Price |
| 30 | 144 | 0.000010 | 0.0006 | 7.22 | 8 | 103 | 0.000014 | 0.074 | 5.17 |
| 27 | 129 | 0.000011 | 0.0012 | 6.48 | 9 | 114 | 0.000013 | 0.061 | 5.73 |
| 24 | 114 | 0.000013 | 0.0024 | 5.73 | 10 | 126 | 0.000011 | 0.051 | 6.32 |
| 21 | 99 | 0.000015 | 0.0048 | 4.99 | 11 | 138 | 0.000010 | 0.042 | 6.91 |
| 19 | 90 | 0.000016 | 0.0076 | 4.50 | 12 | 150 | 0.0000099 | 0.034 | 7.52 |
| 16 | 75 | 0.000019 | 0.0148 | 3.77 | 13 | 162 | 0.0000092 | 0.028 | 8.14 |
| 13 | 61 | 0.000024 | 0.0282 | 3.05 | 14 | 175 | 0.0000085 | 0.022 | 8.77 |
| 10 | 47 | 0.000031 | 0.0514 | 2.37 | 15 | 188 | 0.0000079 | 0.018 | 9.41 |

**Table 4.24:** Network decisions for scenario six

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 2 | 1 | 2 |
| DM{4} | 2 | 1 | 2 |
| DM{5} | 2 | 1 | 2 |
| DM{6} | 2 | 2 | 2 |
| DM{7} | 2 | 2 | 2 |
| DM{8} | 2 | 2 | 2 |

Figures 4.16, 4.17 and 4.18 present the values of the networks for linear, exponential, and logarithmic TOPSIS, respectively. In some of cases linear and exponential algorithms behave differently in network selection; especially with close attribute values. The efficiencies of logarithmic and exponential algorithms are more affected by weight and attribute values when compared to linear algorithm based TOPSIS algorithm.

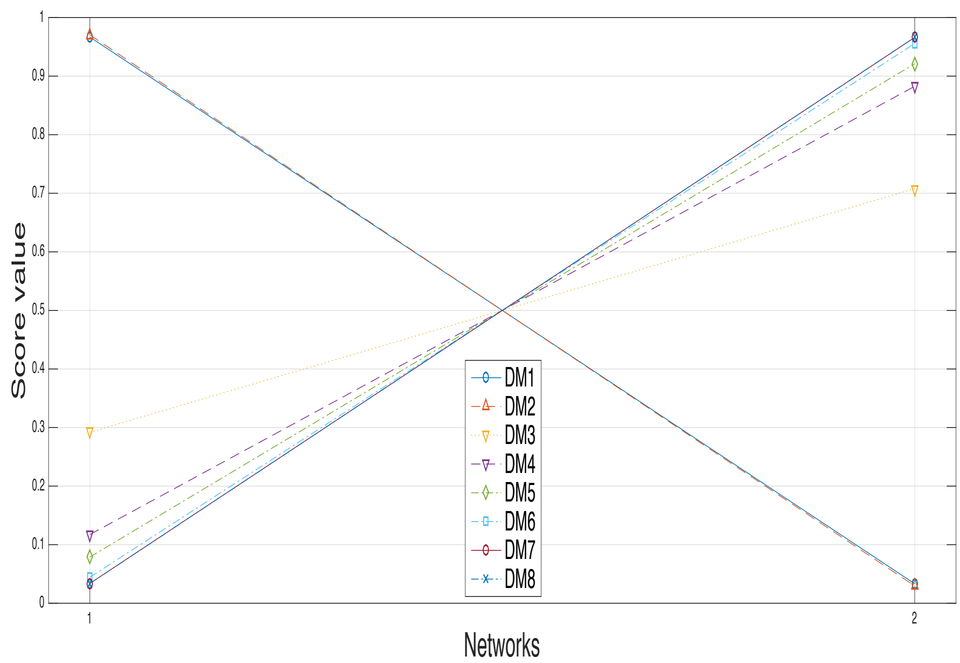


**Figure 4.16:** Score values s of each network with Linear-TOPSIS for scenario six

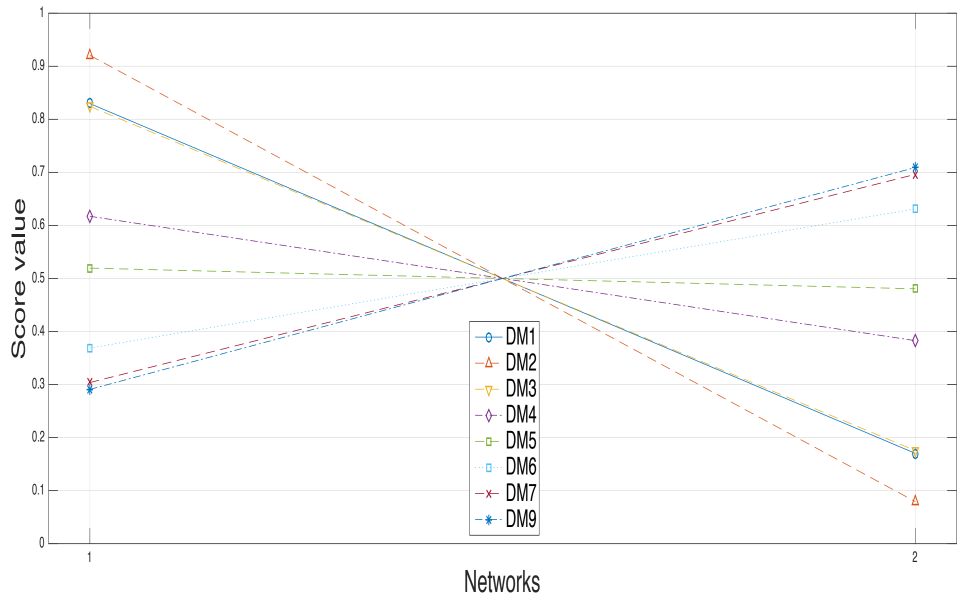


**Figure 4.17:** Score values of each network with Exp-TOPSIS algorithm for scenario six

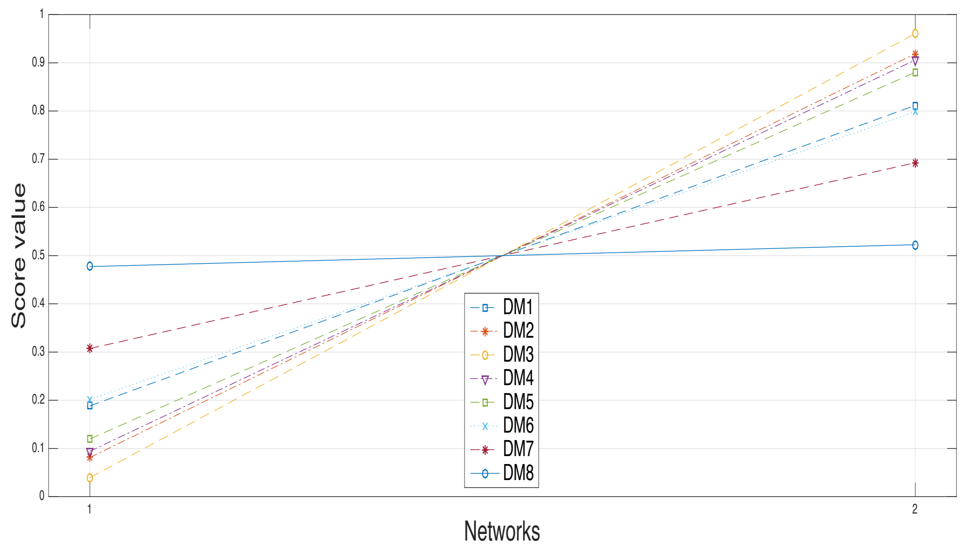


**Figure 4.18:** Score values of each network with Log-TOPSIS algorithm for scenario six

### 4.4.6.1 Scenario Six User Decisions

Table 4.24 presents the values of throughput and latency per packet for the three functions used. The table shows that the average throughput is maximal in the case of Linear-TOPSIS with a value of 151.5Mb/s. The worst average throughput is given by the Log-TOPSIS, which is 103Mb/s. The minimum latency per packet is also achieved using the Linear-TOPSIS function that has given an average latency of 0.968e-5s. The Log-TOPSIS has also given the worst result, which is an average latency of 1.4e-5s. Exp-TOPSIS has resulted in an average latency of 1.13e-5s. Table 4.26 shows the BER and the cost values for the three functions used in this scenario. It shows that the best BER values are achieved by Exp-TOPSIS with an average of 0.01, while Log-TOPSIS has resulted in a BER of 0.074 and Linear-TOPSIS a BER of 0.0246, which is the worst of the three. The minimum cost is achieved by Log-TOPSIS, while the maximum cost is obtained in the case of Linear-TOPSIS algorithm.

**Table 4.25:** Averages for throughput and latency per packet for scenario six

| Throughput (Mb/s) | | | Latency per packet | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 144 | 144 | 103 | 0.000010 | 0.000010 | 0.000014 |
| 129 | 129 | 114 | 0.000011 | 0.000011 | 0.000013 |
| 126 | 114 | 126 | 0.000011 | 0.000013 | 0.000011 |
| 138 | 99 | 138 | 0.000010 | 0.000015 | 0.000010 |
| 150 | 90 | 150 | 0.0000099 | 0.000016 | 0.0000099 |
| 162 | 162 | 162 | 0.0000092 | 0.0000092 | 0.0000092 |
| 175 | 175 | 175 | 0.0000085 | 0.0000085 | 0.0000085 |
| 188 | 188 | 188 | 0.0000079 | 0.0000079 | 0.0000079 |
| **Average** | | | **Average** | | |
| 151.5000 | 137.6250 | 103.000 | 9.6875e-06 | 1.1325e-05 | 1.4e-5 |

**Table 4.26:** Averages for BER and cost per MB for scenario six

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 0.0006 | 0.0006 | 0.074 | 7.22 | 7.22 | 5.17 |
| 0.0012 | 0.0012 | 0.061 | 6.48 | 6.48 | 5.73 |
| 0.051 | 0.0024 | 0.051 | 6.32 | 5.73 | 6.32 |
| 0.042 | 0.0048 | 0.042 | 6.91 | 4.99 | 6.91 |
| 0.034 | 0.0076 | 0.034 | 7.52 | 4.50 | 7.52 |
| 0.028 | 0.028 | 0.028 | 8.14 | 8.14 | 8.14 |
| 0.022 | 0.022 | 0.022 | 8.77 | 8.77 | 8.77 |
| 0.018 | 0.018 | 0.018 | 9.41 | 9.41 | 9.41 |
| **Average** | | | **Average** | | |
| 0.0246 | 0.0106 | 0.074 | 7.5962 | 6.9050 | 5.17 |

### 4.4.7 Scenario Seven Network Decisions

In scenario 7, the SNR in network1 is changed to 25dB, while in network2 it is changed to 20dB. The bandwidths of network1 and network2 are chosen to be 25MHz and 30MHz, respectively. Table 4.27 shows the attribute values for both networks and Table 4.28 shows the network decisions.

**Table 4.26:** Network parameters for scenario seven

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** |
| 25 | 199 | 0.0000075 | 0.0019 | 9.97 | 1 | 30 | 0.0000500 | 0.197 | 1.50 |
| 22 | 174 | 0.0000085 | 0.0038 | 8.73 | 3 | 41 | 0.0000364 | 0.157 | 2.05 |
| 19 | 150 | 0.0000099 | 0.0076 | 7.50 | 6 | 61 | 0.0000243 | 0.103 | 3.08 |
| 16 | 125 | 0.0000119 | 0.0148 | 6.28 | 9 | 86 | 0.0000174 | 0.061 | 4.30 |
| 13 | 101 | 0.0000147 | 0.0282 | 5.09 | 11 | 103 | 0.0000144 | 0.042 | 5.18 |
| 10 | 79 | 0.0000189 | 0.0514 | 3.95 | 14 | 131 | 0.0000113 | 0.022 | 6.58 |
| 7 | 57 | 0.0000259 | 0.0878 | 2.89 | 17 | 160 | 0.0000093 | 0.011 | 8.02 |
| 4 | 39 | 0.0000379 | 0.1379 | 1.97 | 20 | 189 | 0.0000078 | 0.006 | 9.49 |

**Table 4.27:** Network decisions for scenario seven

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 2 |
| DM{4} | 1 | 1 | 2 |
| DM{5} | 2 | 1 | 2 |
| DM{6} | 2 | 2 | 1 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figures 4.19, 4.20 and 4.21 show the score values of the networks for the three functions. Different decisions are made by Exp-TOPSIS and Log-TOPSIS functions, especially for similar attributes. Log-TOPSIS network decisions are mostly different than the decisions of linear-TOPSIS and Exp-TOPSIS.

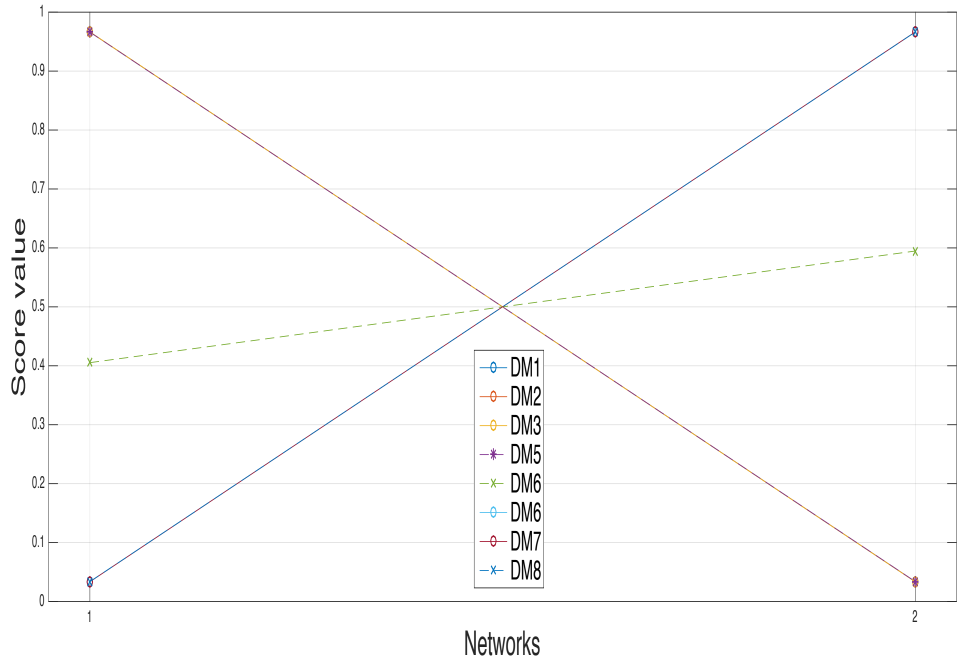


**Figure 4.19:** Score values of each network with Linear-TOPSIS for scenario seven

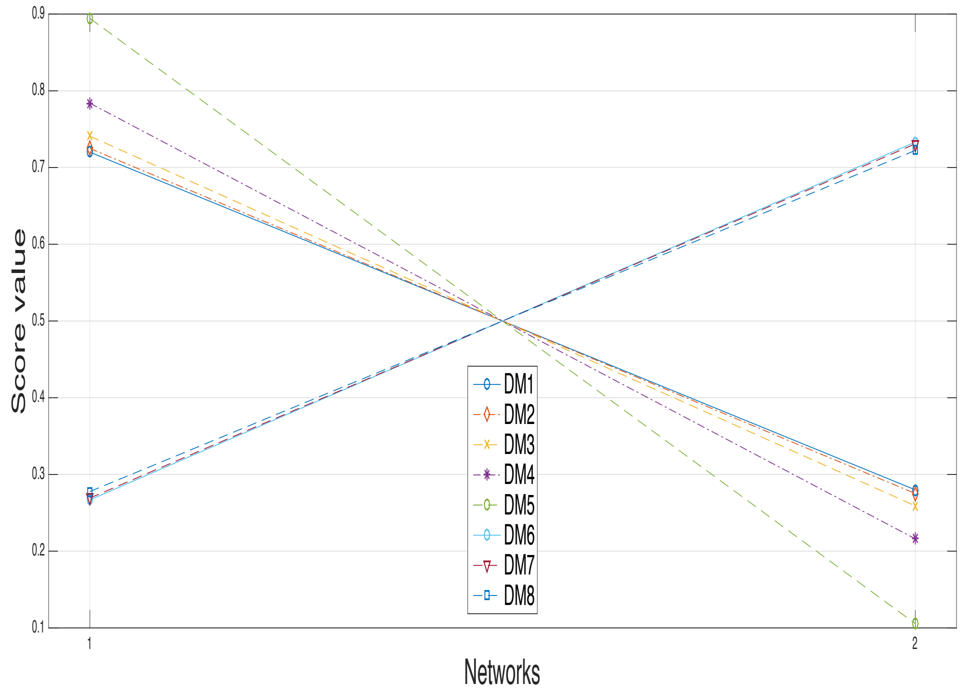


**Figure 4.20:** Score values of each network with Exp-TOPSIS algorithm for scenario seven

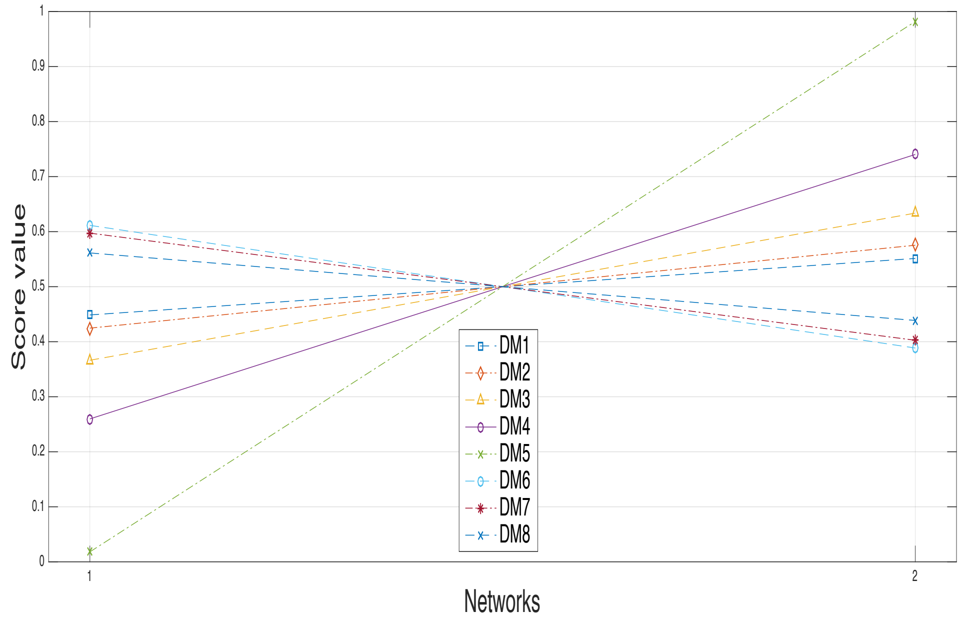


**Figure 4.21:** Score values of each network with Log-TOPSIS algorithm for scenario seven

### 4.4.7.1 Scenario Seven User Decisions

Tables 4.29 and 4.30 present the results of the TOPSIS algorithm using the three functions. They show the throughput, latency per packet, BER, and cost per MB of data. The results of Linear-TOPSIS and Exp-TOPSIS are very similar in this scenario.

**Table 4.29:** Averages for throughput and latency per packet for scenario seven

| Throughput (Mb/s) | | | Latency per packet | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 199 | 199 | 30 | 0.0000075 | 0.0000075 | 0.0000500 |
| 174 | 174 | 41 | 0.0000085 | 0.0000085 | 0.0000364 |
| 150 | 150 | 61 | 0.0000099 | 0.0000099 | 0.0000243 |
| 125 | 125 | 86 | 0.0000119 | 0.0000119 | 0.0000174 |
| 103 | 101 | 103 | 0.0000144 | 0.0000147 | 0.0000144 |
| 131 | 131 | 79 | 0.0000113 | 0.0000113 | 0.0000189 |
| 160 | 160 | 57 | 0.0000093 | 0.0000093 | 0.0000259 |
| 189 | 189 | 39 | 0.0000078 | 0.0000078 | 0.0000379 |
| **Average** | | | **Average** | | |
| 153.8750 | 153.6250 | 62.000 | 1.0075e-05 | 1.0112e-05 | 2.8150e-05 |

**Table 4.30:** Averages for BER and cost per MB for scenario seven

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| Linear-TOPSIS | Exp-TOPSIS | Log- TOPSIS | Linear-TOPSIS | Exp-TOPSIS | Log- TOPSIS |
| 0.0019 | 0.0019 | 0.197 | 9.97 | 9.97 | 1.50 |
| 0.0038 | 0.0038 | 0.157 | 8.73 | 8.73 | 2.05 |
| 0.0076 | 0.0076 | 0.103 | 7.50 | 7.50 | 3.08 |
| 0.0148 | 0.0148 | 0.061 | 6.28 | 6.28 | 4.30 |
| 0.042 | 0.0282 | 0.042 | 5.18 | 5.09 | 5.18 |
| 0.022 | 0.022 | 0.0514 | 6.58 | 6.58 | 3.95 |
| 0.011 | 0.011 | 0.0878 | 8.02 | 8.02 | 2.89 |
| 0.006 | 0.006 | 0.1379 | 9.49 | 9.49 | 1.97 |
| Average | | | Average | | |
| 0.0136 | 0.0119 | 0.1046 | 7.7188 | 7.7075 | 3.1150 |

From Table 4.28, it is seen that the Linear-TOPSIS and Exp-TOPSIS algorithms have selected the best network for all cases. Hence, Linear and Exp-TOPSIS algorithms result in the best average values.

### 4.4.8 Scenario Eight Network Decisions

In this scenario, the same parameters of the previous scenarios are applied, except for the SNR and bandwidth values. The SNR in this scenario is chosen to be 15dB and 25 dB for network1 and network 2, respectively. The bandwidth of network1 is chosen to be 30MHz, whereas network2 has a bandwidth of 20MHz. Attribute values of the scenario are presented in Table 4.31; Table 4.32 presents the network decisions.

**Table 4.31:** Network parameters for scenario eight

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SNR | Thro.(Mb/s) | Latency | BER | Price | SNR | Thro.(Mb/s) | Latency | BER | Price |
| 15 | 140 | 0.000010 | 0.018 | 7.06 | 4 | 31 | 0.000047 | 0.137 | 1.5 |
| 13 | 122 | 0.000012 | 0.028 | 6.11 | 7 | 46 | 0.000032 | 0.087 | 2.3 |
| 11 | 103 | 0.000014 | 0.042 | 5.18 | 10 | 63 | 0.000023 | 0.051 | 3.1 |
| 9 | 86 | 0.000017 | 0.061 | 4.30 | 13 | 81 | 0.000018 | 0.028 | 4.0 |
| 7 | 69 | 0.000021 | 0.087 | 3.47 | 16 | 100 | 0.000014 | 0.014 | 5.0 |
| 5 | 54 | 0.000027 | 0.119 | 2.71 | 19 | 120 | 0.000012 | 0.007 | 6.0 |
| 3 | 41 | 0.000036 | 0.157 | 2.05 | 22 | 139 | 0.000010 | 0.003 | 6.9 |
| 1 | 30 | 0.000050 | 0.197 | 1.50 | 25 | 159 | 0.000009 | 0.001 | 7.9 |

**Table 4.32:** Network decisions for scenario eight

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 2 |
| DM{2} | 1 | 1 | 2 |
| DM{3} | 1 | 1 | 1 |
| DM{4} | 1 | 2 | 1 |
| DM{5} | 2 | 2 | 1 |
| DM{6} | 2 | 2 | 1 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

The score values for each function are shown in Figures 4.22, 4.23 and 4.24. Figure 4.22 presents the results obtained using linear TOPSIS algorithm. From the figure, it is noticed that the results were identical in many cases. Figure 4.32 presents the results for the same networks under same conditions and exponential TOPSIS. However, it is noticed that the scores were more distributed and the maximum scores were less than those of linear TOPSIS. Figure 4.24 shows the scores of the logarithmic TOPSIS algorithm. As explained earlier in the tables, it is noticed that the scores are the inverse of the other two methods scores. Logarithmic TOPSIS is selecting the worst network in most of cases.

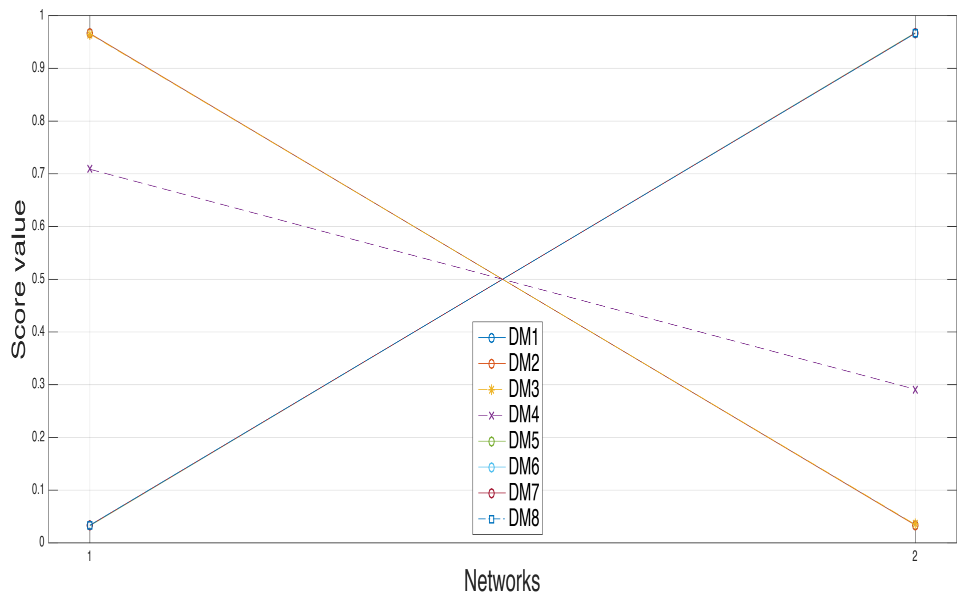


**Figure 4.22:** Score values of each network with Linear-TOPSIS for scenario eight

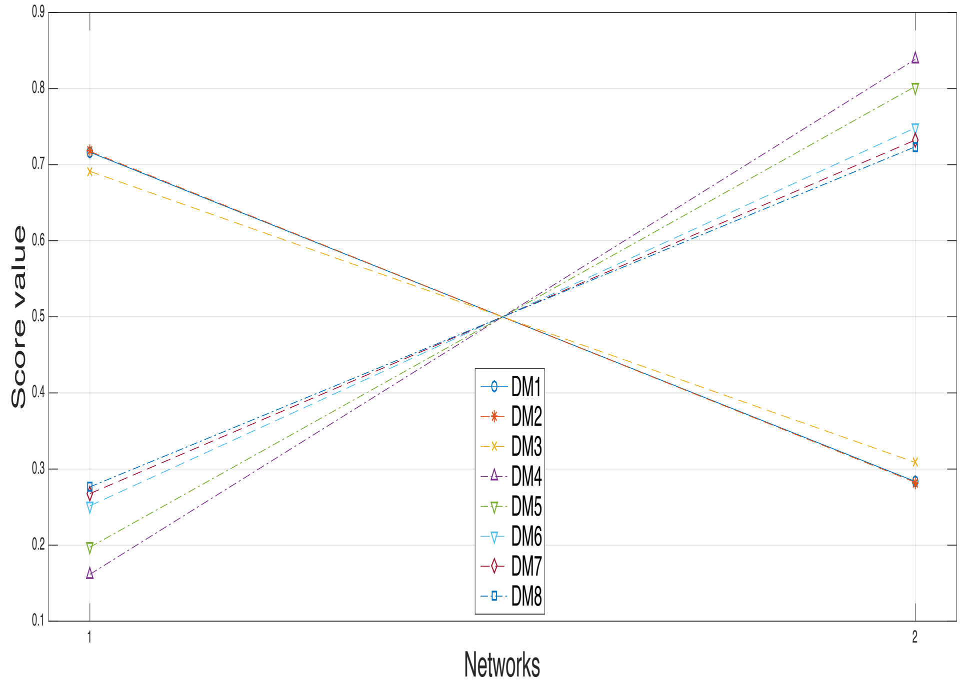


**Figure 4.23:** Score values of each network with Exp-TOPSIS algorithm for scenario eight

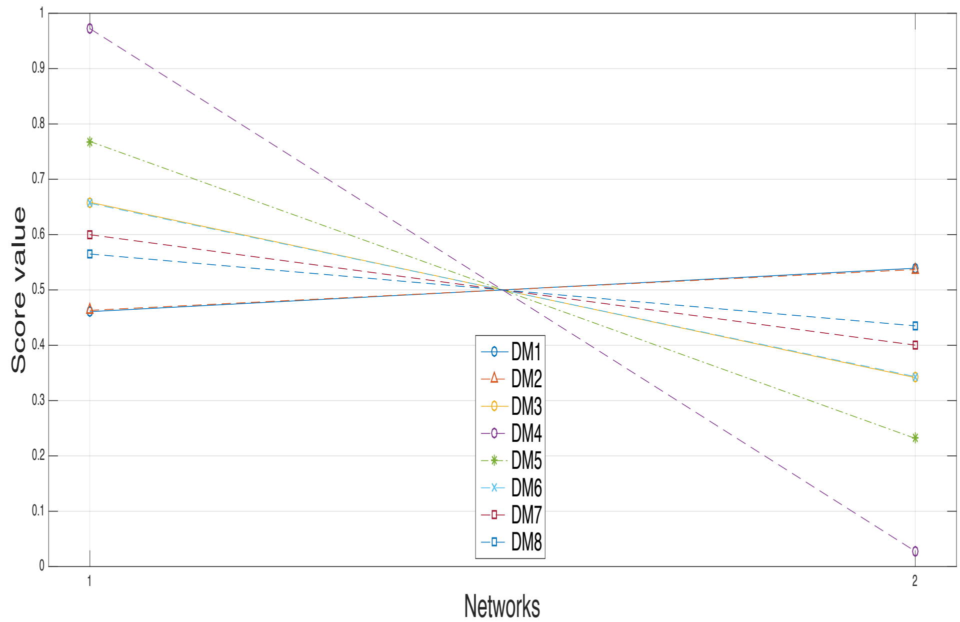


Figure 4.24: Score values of each network with Log-TOPSIS algorithm for scenario eight

**4.4.8.1 Scenario Eight User Decisions**

Tables 4.33 and 4.34 present the attributes of the networks for the different functions. The best results were obtained by using linear and exponential functions. Logarithmic function has the worst results in terms of throughput, latency, and BER. However, the price is the least in the case of Log-TOPSIS. Linear and Exp-TOPSIS have the same throughput average value of 120.5Mb/s. The latency of Linear-TOPSIS is the minimum with 1.22e-5s, followed by Exp-TOPSIS with latency of 1.23e-5s, and the maximum latency is obtained in the case of Log-TOPSIS with an average value of 3.05e-5s. The best BER average is obtained using Exp-TOPSIS algorithm, Linear-TOPSIS algorithm is next, while Log-TOPSIS has resulted in the maximum BER.

**Table 4.33:** Averages for throughput and latency per packet parameters

| **Throughput (Mb/s)** | | | **Latency per packet** | | |
|---|---|---|---|---|---|
| **Lin-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 140 | 140 | 31 | 0.000010 | 0.000010 | 0.000047 |
| 122 | 122 | 46 | 0.000012 | 0.000012 | 0.000032 |
| 103 | 103 | 103 | 0.000014 | 0.000014 | 0.000014 |
| 86 | 81 | 86 | 0.000017 | 0.000018 | 0.000017 |
| 100 | 100 | 69 | 0.000014 | 0.000014 | 0.000021 |
| 120 | 120 | 54 | 0.000012 | 0.000012 | 0.000027 |
| 139 | 139 | 41 | 0.000010 | 0.000010 | 0.000036 |
| 159 | 159 | 30 | 0.000009 | 0.000009 | 0.000050 |
| **Average** | | | **Average** | | |
| 120.5000 | 120.5000 | 57.5000 | 1.2250e-05 | 1.2375e-05 | 3.0500e-05 |

**Table 4.34:** Averages for BER and cost per MB for scenario eight

| **BER** | | | **Cost per MB** | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 0.018 | 0.018 | 0.137 | 7.06 | 7.06 | 1.5 |
| 0.028 | 0.028 | 0.087 | 6.11 | 6.11 | 2.3 |
| 0.042 | 0.042 | 0.042 | 5.18 | 5.18 | 5.18 |
| 0.061 | 0.028 | 0.061 | 4.30 | 4.0 | 4.30 |
| 0.014 | 0.014 | 0.087 | 5.0 | 5.0 | 3.47 |
| 0.007 | 0.007 | 0.119 | 6.0 | 6.0 | 2.71 |
| 0.003 | 0.003 | 0.157 | 6.9 | 6.9 | 2.05 |
| 0.001 | 0.001 | 0.197 | 7.9 | 7.9 | 1.50 |
| **Average** | | | **Average** | | |
| 0.0218 | 0.0176 | 0.1109 | 6.0563 | 6.0187 | 2.8763 |

### 4.4.9 Scenario Nine Network Decisions

Like other scenarios, scenario 9 has the same parameters like the first scenario, with different SNR and bandwidth values. The SNRs of network 1 and network 2 are 10dB and 20dB, respectively. A bandwidth of 40MHz for network1 and bandwidth of 15MHz for network2 are chosen. Table 4.35 shows the network attribute values and Table 4.36 shows the network decisions for this scenario. The results show that the linear network has given the best selection based on the throughput values where the speed of connection is given the most weight to obtain high speed communication. Exponential TOPSIS has come in the second order after the linear algorithm whereas logarithmic TOPSIS has given the worst results as shown from Table 4.36.

**Table 4.35:** Network parameters for scenario nine

| Network-1 | | | | | Network-2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** | **SNR** | **Thro.(Mb/s)** | **Latency** | **BER** | **Price** |
| 10 | 126 | 0.000011 | 0.051 | 6.32 | 1 | 15 | 0.000010 | 0.197 | 0.75 |
| 9 | 114 | 0.000013 | 0.061 | 5.73 | 3 | 20 | 0.000072 | 0.157 | 1.02 |
| 8 | 103 | 0.000014 | 0.074 | 5.17 | 6 | 30 | 0.000048 | 0.103 | 1.54 |
| 7 | 92 | 0.000016 | 0.087 | 4.63 | 9 | 43 | 0.000034 | 0.061 | 2.15 |
| 6 | 82 | 0.000018 | 0.103 | 4.11 | 11 | 51 | 0.000028 | 0.042 | 2.59 |
| 5 | 72 | 0.000020 | 0.119 | 3.62 | 14 | 65 | 0.000022 | 0.022 | 3.29 |
| 4 | 63 | 0.000023 | 0.137 | 3.16 | 17 | 80 | 0.000018 | 0.011 | 4.01 |
| 3 | 54 | 0.000027 | 0.157 | 2.74 | 20 | 94 | 0.000015 | 0.006 | 4.99 |

**Table 4.36:** Network decisions for scenario nine

| Matrix | Linear-TOPSIS | Exp-TOPSIS | Log-TOPSIS |
|---|---|---|---|
| DM{1} | 1 | 1 | 1 |
| DM{2} | 1 | 1 | 1 |
| DM{3} | 1 | 1 | 1 |
| DM{4} | 1 | 1 | 1 |
| DM{5} | 1 | 1 | 1 |
| DM{6} | 1 | 2 | 1 |
| DM{7} | 2 | 2 | 1 |
| DM{8} | 2 | 2 | 1 |

Figures 4.25, 4.26 and 4.27 present the score values of each function for both networks, Logarithmic TOPSIS is selecting the worst network in most of cases and the linear-TOPSIS have a best selection.

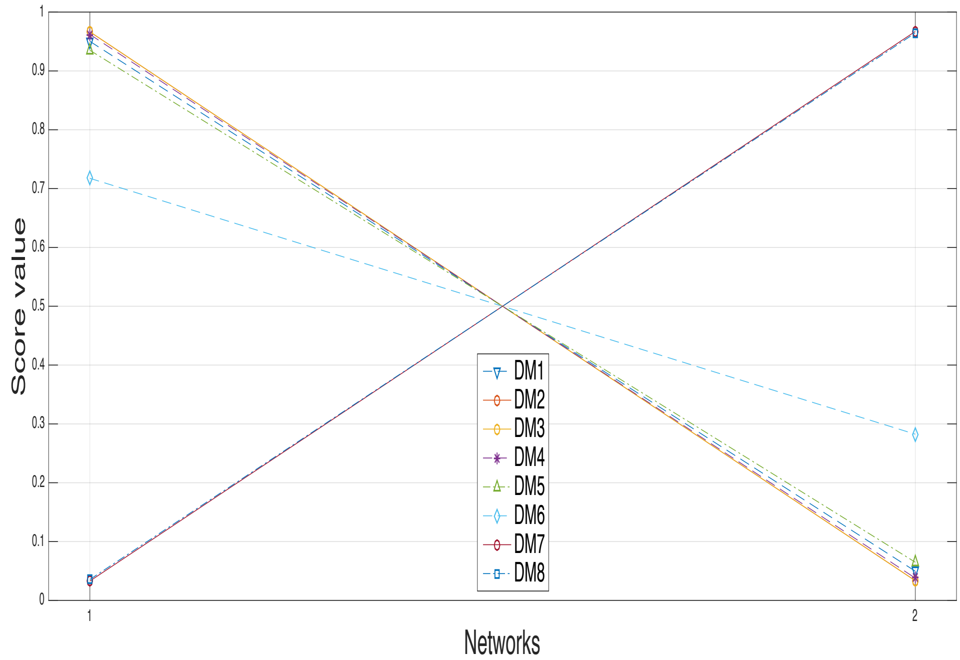


**Figure 4.25:** Score values of each network with Linear-TOPSIS for scenario nine

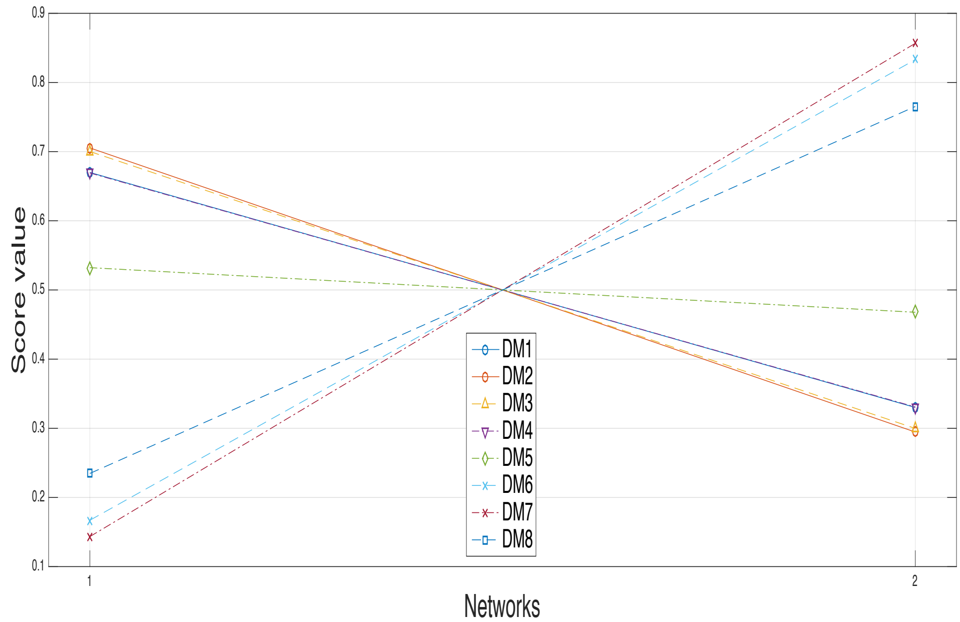


**Figure 4.26:** Score values of each network with Exp-TOPSIS algorithm for scenario nine

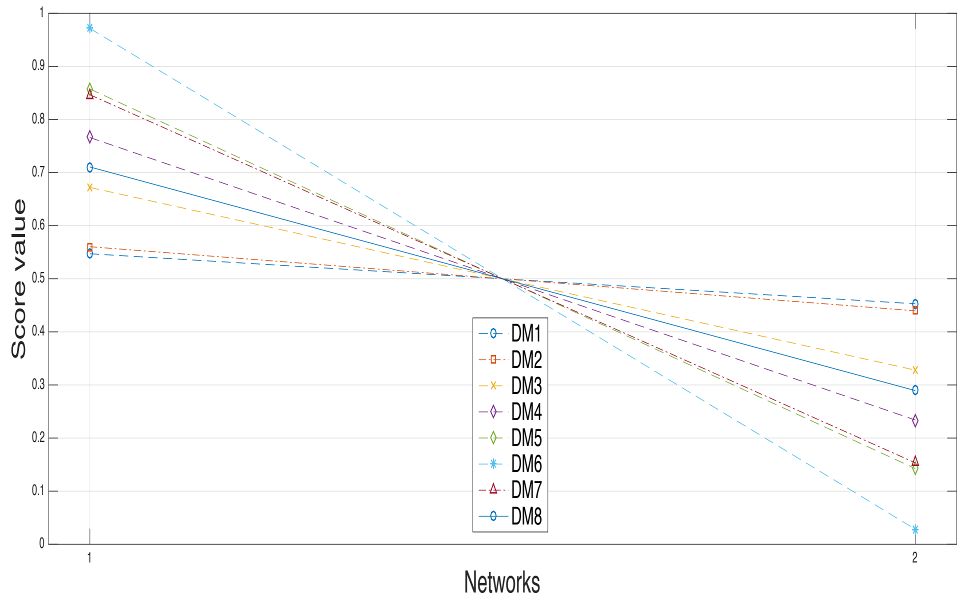


**Figure 4.27:** Score values of each network with Log-TOPSIS algorithm for scenario nine

### 4.4.9.1 Scenario Nine User Decisions

Table 4.37 presents the results obtained in this scenario. The average throughput of Linear-TOPSIS algorithm is 95.3750, for Exp-TOPSIS the average is 94.5, while Log-TOPSIS has an average throughput of 88.25. The best average latency per packet is obtained using the Linear-TOPSIS, which is 1.56e-5s. Exp-TOPSIS has an average latency of 1.58e-5s, while Log-TOPSIS has a latency of 1.77e-5s. The average BER and cost values are presented in Table 4.38.

**Table 4.37:** Averages for throughput and latency per packet for scenario nine

| Throughput (Mb/s) | | | Latency per packet | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log- TOPSIS** |
| 126 | 126 | 126 | 0.000011 | 0.000011 | 0.000011 |
| 114 | 114 | 114 | 0.000013 | 0.000013 | 0.000013 |
| 103 | 103 | 103 | 0.000014 | 0.000014 | 0.000014 |
| 92 | 92 | 92 | 0.000016 | 0.000016 | 0.000016 |
| 82 | 82 | 82 | 0.000018 | 0.000018 | 0.000018 |
| 72 | 65 | 72 | 0.000020 | 0.000022 | 0.000020 |
| 80 | 80 | 63 | 0.000018 | 0.000018 | 0.000023 |
| 94 | 94 | 54 | 0.000015 | 0.000015 | 0.000027 |
| **Average** | | | **Average** | | |
| 95.3750 | 94.5000 | 88.2500 | 1.5625e-05 | 1.5875e-05 | 1.77e-05 |

**Table 4.38:** Averages for BER and cost per MB for scenario nine

| BER | | | Cost per MB | | |
|---|---|---|---|---|---|
| **Linear-TOPSIS** | **Exp-TOPSIS** | **Log-TOPSIS** | **Linear-TOPSIS** | **Exp-TOPSIS** | **Log-TOPSIS** |
| 0.051 | 0.051 | 0.051 | 6.32 | 6.32 | 6.32 |
| 0.061 | 0.061 | 0.061 | 5.73 | 5.73 | 5.73 |
| 0.074 | 0.074 | 0.074 | 5.17 | 5.17 | 5.17 |
| 0.087 | 0.087 | 0.087 | 4.63 | 4.63 | 4.63 |
| 0.103 | 0.103 | 0.103 | 4.11 | 4.11 | 4.11 |
| 0.119 | 0.022 | 0.119 | 3.62 | 3.29 | 3.62 |
| 0.011 | 0.011 | 0.137 | 4.01 | 4.01 | 3.16 |
| 0.006 | 0.006 | 0.157 | 4.99 | 4.99 | 2.74 |
| **Average** | | | **Average** | | |
| 0.0640 | 0.0519 | 0.0986 | 4.8225 | 4.7812 | 4.4350 |

From the results presented in these two tables we can conclude that Linear-TOPSIS has produced the best results in terms of throughput and latency. However BER and cost per MB values are slightly higher in Linear-TOPSIS than the other two functions.

# CHAPTER 5

# CONCLUSIONS AND FUTURE WORK

## 5.1 Conclusions

In heterogeneous wireless networks, a continuous connection is very important for avoidance of connection drop of the users at dynamic situations; the IEEE 802.21 protocol was adopted to boost the VHO process among heterogeneous networks. This thesis has focused on the implementation of TOPSIS algorithm for the selection of best network to be used by network client. The TOPSIS algorithm is implemented in MATLAB environment and is examined under different parameter values. The use of different functions affects the weights given for each attribute in the TOPSIS algorithm. The value of each weight is diverse to show the effect of each function on the decision. Different parameters were used in the selection criteria of the network such as throughput, latency of data per packet, the error bit rate during transmission, and the cost per MB of received data. Different functions have made different choices for each one of the networks under same parameters. The simulation results showed that the use of logarithmic or exponential functions affect largely the network selection of TOPSIS algorithm. This was demonstrated through the simulation of nine different scenarios with different weight parameters. The comparison of the logarithmic and exponential functions with the linear TOPSIS function has shown that exponential function has produced approximately similar results to that of linear TOPSIS algorithm. However, the use of logarithmic TOPSIS has produced totally different results and worse case of selection. Linear TOPSIS has given the best results for all nine scenarios while logarithmic TOPSIS has produced the worst results for the nine scenarios.

## 5.2 Future Works

Vertical handover is an important subject especially with the increasing demand on the communication technologies. The work opens the doors widely to investigating modern intelligent algorithms like neural networks, fuzzy logic and other MCDM techniques such as GRE, SAW and MEW to study the effects of logarithmic and exponential functions by using services such as video streaming, VoIP, data browsing. This research is also suitable to have a scope for being proposed for 5G wireless communication technology to increase the efficiency of networks as the handoff is really an ever challenging process with the evolution of wireless communication standards.

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# APPENDIX

## TOPSIS ALGORITHMS SCENARIOS

```
clc;
clear all;
close all;
format long;
NM =8;
DM{1}= [63.29 0.000023 0.006 3.16; 23.51 0.000060 0.177 1.17];
DM{2}= [56.75 0.000026 0.009 2.83; 31.65 0.000040 0.137 1.58];
DM{3}= [50.27 0.000029 0.014 2.51; 41.14 0.000030 0.103 2.05];
DM{4}= [43.89 0.000034 0.022 2.19; 51.75 0.000028 0.074 2.58];
DM{5}= [37.64 0.000039 0.034 1.88; 63.21 0.000023 0.051 3.16];
DM{6}= [31.60 0.000047 0.051 1.58; 75.28 0.000019 0.034 3.76];
DM{7}= [25.87 0.000057 0.074 1.29; 87.78 0.000017 0.022 4.38];
DM{8}= [20.57 0.000072 0.103 1.02; 100.0 0.000014 0.014 5.02];
W=[0.65 0.3 0.025 0.025];
for k=1:NM
    [na,nc]=size(DM{k});
 %% step 1 calculate ((xij)^2 )^1/2 for each column
     SumDM=sum(DM{k}.^2);
     SqrtSumDM=sqrt(SumDM);

 %% step 2 Divide each column by ((xij)^2)^1/2 to get rij
 for i=1:nc
     RDM{k}(:,i)=((DM{k}(:,i)./SqrtSumDM(i)));
 end
 %% step 3 Multiply each column by wj to get vij
   for i=1:nc
       TDM{k}(:,i)=((RDM{k}(:,i)))*(W(i));
   end
 %% step 4 Determine ideal solution and negative ideal solution.
      APDM{k}=zeros(1,nc);
      ANDM{k}=zeros(1,nc);

 %% Ditermine the best and worst alternatives
 for i=1:nc
    if (i==1)
        APDM{k}(i)=max(TDM{k}(:,i));
        ANDM{k}(i)=min(TDM{k}(:,i));
    elseif(i>1)
        APDM{k}(i)=min(TDM{k}(:,i));
        ANDM{k}(i)=max(TDM{k}(:,i));
    end
 end
%% calculate the distance between targets and worst, target and best
%% alternative fro DM
  for i = 1:na
        PSDM{k}(i,1)= sqrt(sum(((TDM{k}(i,:)-APDM{1,k}(1,:))).^2));
        NSDM{k}(i,1)=sqrt(sum(((TDM{k}(i,:)-ANDM{1,k}(1,:))).^2));
  end
%% step 5 negative ideal sulotion
       ScorDM{k} =NSDM{k}./( PSDM{k} + NSDM{k});
      [valueDM{k},indexDM{k}]=max(ScorDM{k});

end
for k=1:NM
```

```
    plot(ScorDM{k},'-o');
    Network_Decision=indexDM{k}
    %scor=valueDM{k}
    hold on
    grid on
    set(gca,'XTick',[1 2])
    xlabel('Networks')
    ylabel('Percentage value')
    xlim([0.95,2.05])
end
```

## Networks parameters

```
clc;
close all;
format long;
price=0.05./1e6;
L=1500;
A=1;
B=1e6;
M=16;
SNRdb=0:40;
SNR=db2pow(SNRdb);
C=B*log2(1+SNR)
plot(SNRdb,C);
xlabel('SNRdb')
ylabel('Throughput [b/s]')
grid on
figure
latency=((L*A)./C)
plot(SNRdb,latency)
xlabel('SNRdb')
ylabel('Lantency per Packet [s]')
grid on
figure
price_per_MB=(price*C)
plot(C,price_per_MB)
xlabel('Throughput [b/s]')
ylabel('price per MB [$]')
grid on
figure

% Theoretical BER of 16-QAM in Rayleigh Fading
ber =3/8 * ( 1 -
sqrt(2/5*SNR*log2(M)/log2(M)./(1+2/5*SNR*log2(M)/log2(M))) ) ...
    + 1/4 * ( 1 -
sqrt(18/5*SNR*log2(M)/log2(M)./(1+18/5*SNR*log2(M)/log2(M))) ) ...
    - 1/8 * ( 1 -
sqrt(10*SNR*log2(M)/log2(M)./(1+10*SNR*log2(M)/log2(M))) )
semilogy(SNRdb,ber)
xlabel('SNR (dB)')
ylabel('Probability of Error')

xlim([0, 40]);
grid on;
```

## Functions behavior (logarithmic, exponential and linear)

```
clc;
close all;
clear all;
X =0:0.005:1;
Y =exp(X);
Z=log10(X);
plot(X,Y)
xlabel('[x]')
ylabel('[y]')
grid on
figure
plot(X,Z)
xlabel('[x]')
ylabel('[y]')
grid on
figure
plot(X,X)
xlabel('[x]')
ylabel('[y]')
grid on
```