A Fuzzy Decision Maker For Wireless Sensor Network In Ubiquitous Network Environment

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Dedication

Dedicated to my family and friends who always supported me and prayed for my success.

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Abstract

Large range of tiny embedded sensor devices capable of sensing, communicating and routing data is available now days. Due to higher failure rate of sensor nodes or their mobility, the sink node might not exist in their transmission range. We propose an approach which uses fuzzy logic to deal with diverse QoS requirements of sensor applications. We have designed, an Intelligent Intermediate Robust Gateway (IIRG) module, which provides an efficient and consistent QoS based connectivity to sensor applications to outside world. This Gateway defines a decision structure needed by sensor network applications to switch over to any wireless network, in order to make communication with the remote sink fulfilling application QoS requirement. The result of our approach shows that it is capable of selecting appropriate network for range of sensor network applications. So far many different approaches have been adopted, for making these switching decisions and among all of these approaches, MADM (Multiple Attribute Decision Making) is considered as one of the approach for solving such types of vertical handover problems. The types of few MADM algorithms are AHP, TOPSIS, MEW and SAW. A comparison between these MADM algorithms has been done. Results of each algorithm and their response against the decision ranking have been analyzed. It is observed that TOPSIS is suffering from non stability in behavior; MEW shows penalizing behavior towards poor attributes, where as AHP and SAW shows less risk in decision ranking with minimum standard error mean and statistical variance.

Chapter One: Introduction

In today's advanced world, the appearance of Wireless Sensor Networks (WSN) has created a significant and dramatic impact in our daily life applications. A WSN, consists of huge number of tiny low cost interconnected sensors nodes, which communicate with each other by Radio Frequency (RF) channel. The function of these sensor nodes is to process, route or communicate with other sensors or with the controlling authorities of the network The evolution of micro-electro-mechanical systems has enhance the vision of this network and are expected to be widely used in variety of applications. Their ubiquitous, on demand sensing capabilities have enabled numerous new applications, from vibration monitoring throughout buildings in active earthquake zones to air pollution tracking to microclimate investigations in tropical rain forests [1].

Basic features supported by these WSNs, are self –organizing capabilities, short range broadcasting communication and multihop routing, frequently changing of topology due to node failure, limiation in memory, power, computation and energy [2]. These features make sensor networks different from other wireless adhoc or mesh neworks.

1.1 Sensor Based Applications

Typical applications of WSNs include monitoring, tracking, and controlling. Examples followed by sensor neworks are.

- Immersive Gaming
- Traffic Monitoring Intrusion
- Intelligent Battlefields
- Hazard Response Systems

- Home Automation and Security
- Traffic Monitoring
- Industrial Control System
- Asset Track
- Habitat Monitoring

Immersive Gaming: It is an alternate for Reality Gaming, sometimes also called Immersive Gaming, or Interactive Fiction, is a rapidly up-and-coming type of online gaming and is one of the first true art and entertainment forms that was developed from and exclusively for the Internet.

The definition of immersion is wide and variable, but here it is assumed to mean simply that the user feels like they are part of the simulated "universe". The success of these games lies in 3D graphics, surround sound, interactive user-input and other factors such as simplicity, functionality and potential for enjoyment.

Intelligent Battlefields: By making use of vibration and magnetic sensors to detect any change in environment or motion of troops, vehicles and permitting close surveillance of opposing forces.

Hazard Response Systems: Shows responsible attitude towards any type hazards or critical situation such like earthquake, accidents etc.

Home Automation and Security: Home automation (also called domotics) is a field within building automation, specializing in the specific automation requirements of private homes and in the application of automation techniques for the comfort and security of its residents. Although many techniques used in building automation (such as light and climate control, control of doors and window shutters, security and surveillance systems, etc.) are also used in home automation, additional functions in home automation can include the control of multi-media home entertainment systems, automatic plant watering and pet feeding, automatic scenes for dinners and parties, and a more user-friendly control interface.

Traffic Monitoring : Study different rules of the traffic like speed limit, rush hour policies, pedestrian crossing, traffic signals through the help of sensor and help out in avoiding accidents

Industrial Control System ***:*** Industrial Control System (ICS) is a general term that encompasses several types of control systems, including Supervisory Control And Data Acquisition Systems(SCADAS), Distributed Control Systems (DCS). ICSs are typically used in industries such as electrical, water, oil and gas, data. Based on information received from remote stations, automated or operator-driven supervisory commands can be pushed to remote station control devices, which are often referred to as field devices. Field devices control local operations such as opening and closing valves and breakers, collecting data from sensor systems, and monitoring the local environment for alarm conditions.

Asset Track: If we are taking car as an asset then we can take Automatic Vehicle Location (AVL) as an example for it. AVL is a way for determining the geographic location of a vehicle and transmitting this information to a point where it can be used.

Habitat Monitoring : The place or environment where a plant or animal naturally or normally lives and grows Or the place where something is commonly found. Study and monitoring these application and take step after sensing this environment.

1.2 Challenges in The Field of WSNs

Although Sensor Network belongs to class of ad hoc networks, but there are some specific characteristics which are not present in the general ad hoc networks. Many challenges are faced by ad hoc and sensor networks such as energy constraints and routing. However, the traffic pattern induce by the general Ad hoc network, which are considered as mobile nodes, is quite different from the sensor networks[2].

The ***primary challenge*** of these networks is the finite amount of energy which is supplied to them in the form of battery. Any degradation in their battery life time drops them out from the communications network. This means that participation of that particular upstream sensor node towards the data collector may ends up. Thus the maximum useful lifetime of the network, a worst case, is the minimum lifetime of any sensor [3]. ***Secondly***, it is observed that most of the applications of sensor networks required delay –guaranteed services. This shows need of designing the protocols, which ensures the delivery of sensed data to the user in predefined amount of delay time. ***Third challenge***, the sensor network has to face is Fault Tolerance. This challenge states the need of redundancy and collaborative processing and communication. Considering scalability as a ***fourth issue***, it is required that there must be some methodology, which grantees that by increasing the amount of nodes in the network do not degrades the performance of the network.

All these challenges are interrelated with one and other, so that instead of using traditional layer-by-layer protocol design, the designer uses cross layer protocols in WSNs.

1.3 Quality of Service

Quality of Service (QoS) means the reliable and timely delivery of data in a network. It is an ability to provide better performance as compared to best effort service. An important issue in many WSNs is that of QoS guarantees. Comparing performance parameters of Ad hoc networks in multimedia communication with sensor networks, many factors, in addition to, Latency, Jitter, Packet delivery ratio, are to be considered. Talking about sensor networks the factors involve here are data gathering, signal to-noise ratio, coverage area and missed detection / false alarm probabilities.

1.4 Complexity of Problem in Remote Sensor Application

Although a rich body of research work is associated with sensor networks. But in most of the situations the main backbone, called data delivery problem is not typically considered in these scenarios. Mostly, it is often assumed that "data sink node "is locally available, with the facilities of well connected backbone, sufficient bandwidth with error free high data delivery rates. But departing from this scenario, if the availability of sink node is not local then question arise that how to make a reliable delivery of data to a remote sink. Many issues related to data delivery arises in such type of situation such as guaranteed QoS factors, security mechanisms, robustness and fault tolerance.

A typical example of remote sensor application in medical field is wearable physiological monitory system [9], which is composed of array of sensors covered in a wearable fabric and continually sensing, acquiring and transmitting the data to remote monitoring stations. Where the remote stations take action against the abnormal reading of vital signs sensed by the wearable and generates automatic alarms against it.

The problem to establish interconnectivity between remote sink node and sensor node can be solved by making use of radio, light, laser, Infra Red (IR), sound, inductive or capacity coupled [9]. Mostly we make use of radio waves for interconnectivity due to its unique feature of penetration of waves even when the source and sink are not in the line of sight. Further they have the feature of shorter range communication using low power and small antennas. Two basic types of radio based technologies network are infrastructure based network and second one is adhoc network. When we talk about remote applications adhoc network are considered to be most suitable for establishing such type of interconnectivity.

1.5 Challenges related to Remote Application

Making WSN, feasible for all types of local/remote applications, the designers have to keep in mind, that there should be simplicity in the designing of Topology, security and medium of access [9],so that less power will be consumed in WSN. Topology is used to describe the architectural design of communication between sources and sink nodes. It plays a vital role in describing the characteristics of network. For example if star topology is used between sink and source node, the data delivery takes place in single hop, where as failure of sink results in the collapse of whole network. Considering the case of multi hop network delay factors are involved. The appearance of delay factors requires a complex algorithms, latency and data handling capabilities for particular node [9]. While talking about coverage factor, one has to consider the range of wireless technology, which can give support to coverage area according to the requirement of application. Provision of this range gives facility to the remote sink/source to effectively collects, process and transmits the data. Any chance of the network that it may drops the data, lead to the loss of valuable information.

1.6 Data Model of sensor Applications

The sensor devices support many types of applications, with diverse requirement of QoS. The authors in [10] have classified the sensor applications on the bases of data delivery model due to the obvious importance of data delivery mechanism in every sensor applications.

- **Event Driven Applications:** give response to sink only in the situation of triggers. Parameters of QoS associated with Event driven applications are Security, Priority, latency and Reliability.

- **Query Driven Applications:** respond to query which is initiated by the sink. QoS factors which involved in this case are again low latency and reliability. The only difference between event and query driven application lies on the initiator. In event driven, initiator is source, where as in query driven the initiator is sink.

- **Continous Applications:** respond to sink continually by sending data from source at pre fixed data rate. Examples include real-time applications such voice, video or non real time such as file transfer. QoS parameters needed here are maximum bandwidth and low latency some reasonable extent.

- **Hybrid Application:** is basically the combination of all the above classes. For physiological monitoring application a hybrid model of data delivery will be suitable, where in, some of the parameters like ECG, EEG, GSR, body temperature, SaO2 and heart rate will be monitored continuously and parameter like blood pressure will be monitor periodically [9].

1.7 A big Question?

After studying the details of different sensor based data models and challenges to send sensor data to remote sink node, the question arises here is that "what type of wireless technology should be used which can help in timely, accurate and reliable delivery of sensor data to a remote sink node?" The answer to this big question is the main focus of our research work. Here we have to select a particular network from the pool of networks, according to the requirement of user and application.

Although none of the wireless technologies can satisfy the diverse requirements of user such as low delay, high bandwidth, long range and low cost [4]. It means that there is a need of an optimal mechanism, which while monitoring the availability of network, can recognize the need of handover, whenever it is required by the application. Generally, the vertical hand off between two networks depend on the application based QoS, signal strength, bit error rates, coverage area [5].

1.8 Our Approach

In our research work, we design, an **Intelligent Intermediate Robust Gateway (IIRG)** module, which provides an efficient and consistent QoS based connectivity of sensor applications to outside world. This Gateway defines a decision structure needed by sensor network application to switch over to any other wireless network, in order to make communication with the remote sink. The decisions made for this handover or switching are based on fuzzy logic. Our fuzzy logic based gateway selects the most suitable network among the available ones. The decision is not only based on QoS parameters of available networks but it also depends on application specific criteria for QoS. This comprehensive QoS framework maps application specific QoS requirements to the desired performance attributes of the sensor applications. We are emphasizing the use of computational intelligence to customize the generic network selection criteria in order to achieve optimal application specific performance.

The main contribution of this work is the novel Fuzzy Approach for Network Selection (FANS), which uses computational intelligence for selecting optimal network for every application. The diversity of wireless networks connected to the IIRG as well as the sensor application using IIRG introduces huge number of parameters to be taken into consideration while selecting a particular network to transit the sensor traffic through. Fuzzy logic provides the concept of fuzzy sets which realize a many-to-one mapping between several numerical parameters and their fuzzy counterparts. Secondly, a few fuzzy terms are sufficient to represent the entire domain of data. Here, the decision making process uses Analytic Hierarchy Process (AHP) [13],[14] which use ranking or comparison ratio based criteria for the assigning different priorities and weights from pair wise judgment of different criteria's. These weights show the importance of each parameter over the other. The final decision of network selection is based on this weighted output. Complete details of our methodology works, are provided in Chapter 5.

1.9 Thesis Outline

In this chapter we introduced the challenges and complexities which can arise in transferring of data to a remote sink and presented an overview of our approach to addressing this problem. The remainder of this section provides an outline of rest of the chapters in this thesis.

Chapter 2- Literature Survey.

This chapter surveys the different wireless technologies and their QoS parameters and highlights different approaches used for the vertical handoff of data from one technology to another. The chapter concludes with the discussion of research challenges related to policy based, fuzzy based and neural network based handling of data, which provides motivation and perspective to our research work.

Chapter 3- Overview of Decision Making Problems

This chapter presents different types of decision making problems, Multiple Attributes decision making Problems and Different types of Multiple Attributes decision making Methods. It also encompasses on detail illustration of different Multicriteria decision methods.

Chapter 4- Overview of Fuzzy Logic and its detail features

This chapter introduces the details about the Fuzzy theory which provides a sophisticated framework for describing and processing uncertain or imprecise information in decision problems. Different topics related to fuzzy concept are also discussed such as meaning of Fuzzy set, Membership function and their values, concept of Linguistic Variables, Singletons, Operation of fuzzy set, Fuzzy logic, Implication and Inference.

Chapter 5- Proposed System

This chapter highlights the importance of**,** Sensor networks by focusing on the vision of Wireless World Research Forum (WWRF) and IST Advisory Group (ISTGA) [52] [53], as future communication Network. Discussion about the proposed **Intelligent Intermediate Robust Gateway** module, its architecture and its design details are presents. The basic decision methodology based on fuzzy Analytic Hierarchy Process (AHP) used in designing this approach is also discussed.

Chapter 6- Implementation

This chapter is dedicated to the implementation of our **Intelligent Intermediate Robust Gateway using** fuzzy based Analytic Hierarchy Process (AHP). It presents the working environment and methodology of our work.

Chapter 7- Comparison of Different Techniques

This chapter compares different types of decision making algorithms with our proposed method. Methods used for this comparison are TOPSIS [26], MEW [26] and SAW [27].The results of this comparison is drawn on the bases of Ranking Approach, Stability Factor and Estimation Analysis (Mean squared error, Minimum variance unbiased estimator).

Chapter 8- Conclusion and Future Research Direction

This chapter concludes the thesis and points our future research directions. It also presents our research contribution.

Chapter Two: Literature Survey

As networking trends are moving towards ubiquitous computing, it is expected that future networks will not only consist of one radio access technology like WCDMA (Wideband Code Division Multiple Access) or EDGE (Enhanced Data rate for GSM Evolution) but it may contain different types of technology [15]. This motivation of ubiquitous computing basically arises from the fact that no single wireless technology can provide high band width, low latency rate unlimited coverage and high QoS. Therefore it seems to be necessary to establish such type of smart environment, where mobile terminal has fully control to access any network technology according to its application requirement. The aim behind this control to give mobile terminal an environment where it can maintain its connectivity to the corresponding node at all the time

2.1 Wireless Technologies

Many different types of wireless technologies are available nowadays in terms of range, BandWidth (B_W), frequency, Coverage Area (C_A), Latency, Type of applications (A Type). Categorically, wireless technologies can be divided into three major groups. The range, B_W, frequency, Latency, Cost and A_Types supported by different types of networks are briefly shown in Table 2.1, Table 2.2, and Table 2.3 respectively [17], [18], [16], and [19].

– **Fixed Broadband Wireless Multi service Wide Area Networks:** Some type of wireless networks make use of their own physical layer networks, and take help of something like antennas built into portable devices or having large antennas mounted on towers. 802.11, LMDS, MMDS, WiMAX, PDPP, CDPD, HSCSD are its examples [16].

– **Wireless Personal Area Networks:** Wireless network used for the connection of small device over short distance ranging in to few meters e.g. Blue tooth, Ir DA, Zig Bee and UWB [18].

– **Wide area networks based on Mobile/cellular carriers:** Here voice services as well as data services provided by the cell phone carriers such as Bell Mobility, Telus Mobility and Rogers Wireless. The examples of Mobile wireless are a) GSM/GPRS - the voice plus data network technology offered by Rogers Wireless, updated to EDGE in 2004. B) 1XRTT (usually called 1X) - the latest voice plus data network technology offered by Bell Mobility and Telus Mobility [17]. All these networks technologies differ in bandwidth, frequency, coverage area, cost and power of consumption. Mobile terminal has to move seamlessly in this smart environment so as to maintain QoS requirement of application and user preferences.

Network	Range	B_W and Frequency	Latency	Cost	A_Type
1xRTT	Coverage Area of host Network	144Kb/1.25MHz Frequency of host network	adjustable	low	Data service , voice service
GPRS	Coverage Area of host Network	107.2Kb Frequency of host Network	adjustable	Free	SMS, MMS, WAP, Internet, WAP
GSM	Coverage Area of host Network	200m to macro cells at 35Km-25 MHz(uplink) to 890-915MHz and down-link at 935-960 MHz	adjustable	Monthly charges	Telemetry or Cellular Telephone

Table 2.1: Wireless Personal Area Network

The key point which can be extracted out from this seamless roaming is that if multiple networks are available to the user at any one time, then choosing the most optimal network for particular service delivery and choosing the correct time to execute vertical handover to improve QoS for all uers are important factors[15].

Network	Range	B_W and Frequency	Latency	Cost	A_Type
LMS	4 miles	1.5GB downstream,200Mb Upstream,27.5 GHz - 28.35 GHz,29.1GHz-29.25GHz,31.075GHz -31.225GHz	Low	High	Data service , voice service
MMDS	70 miles	10Mb, 2.5GHz-2.686GHz	Less attenuation due to rain, foliage	Low	SMS, MMS, WAP, Internet, WAP
802.11	Coverage Area of host Network	2 Mb/2.4 GHz	Low	Free	Internet and LAN
WiMAX	31 miles	70 Mbps/10-66GHz,2-11 GHz	Low	Free	Metro area broad band Internet connectivity

Table 2.2: Cellular Networks

Network	Range	B_W and Frequency	Latency	Cost	A_Type
Blue tooth	10 m	3Mb/5GHz-2.4GH,2.472GHz-2.497GHz	Adjustable	free	Replacement of cable
IrDA	0-1m	9600bps to 16 Bps/Infrared	Adjustable	free	Limited data exchange
ZigBee	70-300m	25Kbps/2.4GHz,40Kbps,91.5MHz,20Kbps,868MHz	Weather physical barrier	free	Sensor Network
UWB	10-30m	3.1-10.6GHz	Adjustable	free	Support for audio video data

Table 2.3: Fixed Board Band wireless Multiservice Wide Area Network

2.2 Mobility Management Parameters

The decision to decide the best network depends on different static and dynamic parameters of mobility management. The list of these parameters is shown in Fig 2.1 and Fig 2.2

- Bandwidth (capacity)
- Usage Charges (Cost of Network)
- Power
- Consumption

STATIC PARAMETERS

- Battery Level (Mobile Terminal)
- Coverage Area
- Type of Application (Real Time, Non Real Time)

Fig 2.1: Static Parameters of Mobility Management.

- Received Signal Strength
- Velocity of Mobile User
- Current Network Condition

DYNAMIC PARAMETERS

- Current User Condition

Fig 2.2: Dynamic Parameters of Mobility Management.

The mobility management algorithms decided on the bases of these perceived values of parameter and then decide which optimal network from available ones is and when handover decision is to take place. Different types of schemes have been proposed for the optimal network selection. These schemes are based on policy [20], Fuzzy Logic [21] and Neural Networks. In these entire proposals the optimal network will allow the user to be admitted only if resources are available.

2.3 State of Art (Mobility Management)

Here we will discuss the state of the art proposal needed for mobility management. Mobility management is basically concerned with handover initiation and network selection.

2.4 Handover Process

It is defined as a mechanism in which continuous monitoring of current network connection is done and if there is any degradation in the services of the current network, then the process will recognize it and initiates the steps of handover.

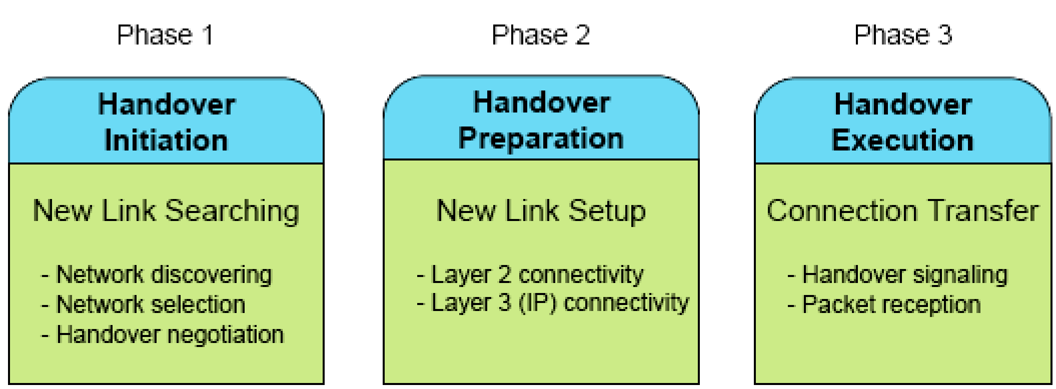

Fig 2.3: Phases of Handover Process [42]

There are three main steps which are involved in handover process as show in Fig 2.3.

1. Handover initiation
2. Handover preparation
3. Handover execution.

1) **Handover initiation** –When a degradation in the working of existing network take place, the mobile terminal starts searching for new links. When it found networks which fulfill the QoS requirements of application as well as satisfies the selected network parameters, then handover negotiation will be underway.

2**) Handover preparation –** After the selection of appropriate network, a new link between the mobile terminal and a base station (or an access point) located in the new network is setup. Connectivity and protocols on Layer medium access layer and IP Layer are established.

3) **Handover execution** – Transfer of connection between old and new link is established. This means that now the control signals and data packets from own wards are going to be handled by the new base station or access point.

Notice that IEEE 802.21 helps with handover initiation, network selection, and interface activation (i.e., phase 1 and phase 2 of a handover process), and network selection happens in phase 1—handover initiation [41].

The author [12] said that handover initiation is generated in three different types of situations.

- To service user request.
- To service system request.
- To service provider request.

To service user request means that for a multimedia application or for any sensitive data a user may request a service from current serving cell, code, technology or network, which is unable to fulfill this request for handover. As an example to service system request such that maintaining a requested call, maintaining network policy regarding user access rights, providing guaranteed QoS to user, selection of optimal network for user request etc, and all these factors give rise to system request. Where as to service a service provider request which can be a delivery of particular service over his preferred network. This request has to be entertained in order to provide service facilities to service provider. Whereas the writer in [22] has specify three main approaches used in vertical handoff procedure.

The first approach is based on the traditional strategies of using RSS that may be combined with other parameters such as network loading. **The second approach** uses artificial intelligence techniques combining several parameters such as network condition and mobile terminal's mobility in handoff decision. **The third approach** combine several metrics such as access cost , power consumption, and bandwidth in a cost function estimated for the available access networks, which is then used in mobile terminal handoff decision.

2.4.1 Fuzzy Logic Related Work

The handover initiation algorithms need to process many parameters and decide whether a handover to another system is required. In [21] a handover initiation algorithms using Fuzzy Logic concept is presented. The algorithm is separated into three different stages. In first stage data from the system is fed into the fuzzifier, to be converted into the fuzzy sets. A fuzzy set is a set without crisp, clearly defined boundary and therefore, has a varying degree of membership. The system data comprises of the values defining QoS perceived by the user, network coverage bit error rate and average signal strength measurements which are mapped into the membership value of the fuzzy set. In the second stage IF-THEN fuzzy rules is applied to the system. These rules are the conditional statements that specify how the fuzzy system works.

The approach in [22] first converts the performance values of the alternatives to fuzzy number, and then makes decision based on heuristic decision rules. Another approach [23] uses Yager's Maximin method to rank candidate network. It is noticed that the use of fuzzy logic in these approaches is not to deal with imprecise information, but to combine and evaluate multiple criteria simultaneously. In fact these problems could be solved using classical Multiple Attribute Decision Making (MADM) [24] methods with out the involvement of fuzzy logic. Majlesi and Khalaj [25] propose an algorithm based on adaptive fuzzy logic. This algorithm takes the velocity and the bandwidth as inputs of the fuzzy logic system, and makes its decision according to the defined fuzzy reference rule base. But the input information is too simple to express the features of heterogeneous cellular system.

In [26], the Vertical Hand Over (VHO) decision is formulated as a fuzzy MADM problem. Fuzzy logic is used to represent the imprecise information of some attributes and user preferences. Two classical MADM methods are proposed SAW (Simple Additive Weighting) and TOPSIS (Technique for Order Preference by Similarity to Ideal Solution). In [27], the network selected is based on Analytic Hierarchy Process (AHP) and Grey Relational Analysis

(GRA). AHP decomposes the network selection problem into several sub-problems and assigns a weight value for each sub-problem. GRA is then used to rank the candidate networks and to select the one with the highest ranking.

2.4.2 Policy Related Work

Wang et al. introduce the policy enabled handoff in [28], which was followed by several papers on similar approaches. Policy enabled handoff systems separates the decision making (i.e. which is the “best” network and when to handoff) from the handoff mechanism. These systems allows users to express policies on what is the “best” wireless system at any moment and make tradeoffs among network characteristics and Dynamics such as cost, performance and power consumption. A generic vertical handoff decision function [29] proposed considering the different factors and metric qualities that give an indication of whether or not a handoff is needed. The decision function enables devices to assign weights to different network factors such as monetary cost, quality of service, power requirements, personal preferences etc.

A decision strategy [30] considers the performance of the whole system while taking VHO decisions by meeting individual needs. This decision strategy selects the best network based on the highest Received Signal Strength (RSS) and lowest Variation of Received Signal Strength (VRSS).thus it ensures the high system performance by reducing the unnecessary handoffs.

A time adaptive VHO decision scheme [31] make right VHO decisions timely through adjusting interface activating intervals based on the user’s movement and the actual network performance. All the schemes presented till now either used only static parameters or used only one dynamic parameter (RSS or velocity) with the static ones to improve the system performance but not both.

So this paper proposed a dynamic decision model which used both RSS and velocity.

A policy-based handover mechanism for mobile multihomed hosts is presented in [32]. The handover decision is based on explicit user defined policies, and considers different criteria in the order of user defined priority. However, this approach does not consider the trade-off between criteria. McNair and Zhu outline in [33] some decision metrics and state the need for decision policy design in the context of vertical handover for a single mobile user running multiple communication sessions. Utility-based functions are commonly used to describe user preference rating relationship for a number of metrics. X. Wang et al [34] consider user preferences to be represented quantitatively through a utility function when comparing two congestion pricing schemes. In [35] Das et al consider users to choose a pricing plan based on their data delay considerations, described by a user utility function. They use their understanding of user behavior to maximize network gains, however they do not consider SOHWNEs but rather look at efficient network resource management with the goal of maintaining a steady customer base (i.e. reducing customer churn) and maximizing wireless network operator revenue. In [36], Ylitalo et al propose a solution for facilitating a user making a network interface selection decision. They focus mainly on a possible architecture for the end terminal, and mention the example of an Always Cheapest Network Selection strategy.

2.4.3 Neural Network Based Work

A technique for handover initiation using neural networks is also presented in [37]. A three-layer back propagation neural network used for pattern recognition [38] is trained using received signal strength measurements and locations where handoffs should be made. In this way, the system requires knowledge of the received signal strength patterns at such locations. A simulation scenario is presented using four identical Base Stations (BS) in a micro cellular environment and a Mobile Host (MH), which is moving from the neighborhood of BS_1 toward BS_2 along a direct path. It is assumed that all BSs can provide the same service to the MH. The neural network takes a number of power samples from each BS and using pattern recognition, selects the BS, which is most suitable, while minimizing handoff delay and ping-pong2 effect. The output of the system is a control signal that is zero as long as the MH is closer to BS_1 and one whenever the MH is closer to BS_2. As in [39], the system requires prior knowledge of the radio environment and needs much configuration before deployment.

2.5 Pros and Cons of Different approaches

Study of these approaches shows that each approach has its own advantages as well disadvantages.

Recently, the use of Fuzzy based logical work, for handover has gained popularity among the researchers as it incorporate the use of imprecise and ambiguous data and can therefore be used effectively to model nonlinear functions with arbitrary complexity. Fuzzy logic is considered as an interesting solution for heterogeneous networks, as fuzzy logic is capable of handling data for objects where the boundaries are not clearly defined. Furthermore it is also sutibale for combining and evaluating several handover criteria simultaneously.
While considering its drawbacks, it has been observed in traditional methods of fuzzy logic such as [63], only Radio Signal Strength (RSS) threshold and hysteresis values are considered and processed in fuzzy logic based algorithms. Where as in the papers like [23], the author uses Yager's Maxmin method to rank the candidate networks. It is noticed that the use of fuzzy logic in these

approaches is not to deal with imprecise information, but to combine and evaluate multiple criteria simultaneously and gives disputable decision results. In general Fuzzy logic methods are cumbersome to use and require much expert knowledge and user involvement in order to make decision rules.

Talking about policy based approach, which was first introduced by Wang et al. in policy enabled handoff in [20], and later followed by several papers, separates the decision making (i.e. which is the "best" network and when to handoff) by using policy based handoff mechanism. These systems allows users to express policies on what is the "best" wireless system at any moment and make tradeoffs among network characteristics and dynamics such as cost, performance and power consumption. Using policy to initiate proposals only consider users perspective. This means that giving total control to user can result in network instability as user compete for network resources regardless of network conditions, while a network management and admission control scheme should encompass both user and network aspects.

Finally the vertical handoff decision based on Neural Network approach uses artificial intelligence techniques combining several parameters such as network conditions and Mobile Terminal mobility in the handoff decision. In [65], Ylianttila et al. present a general framework for the vertical handoff process based on fuzzy logic and neural networks. In [64], Pahlavan et al. present a neural network-based approach to detect signal decay and making handoff decision. In [25], Majlesi and Khalaj present a fuzzy logic based adaptive algorithm that varies the hysteresis margin and averaging window size based on Mobile Terminal velocity and WLAN traffic. It is worth mentioning that some of these artificial intelligence based algorithms are too complex and may be difficult to implement in practical systems.

2.6 Motivation

As it is seen that there have been various vertical handoff algorithms proposed in the literature and each work has its own limitations. While keeping these limitations in view, our work is motivated on the bases of two particular aspects.

- First our work has adopted classical Multi Attribute Decision Making (MADM) methods to overcome the complexity of Fuzzy logic approach, and have made the dimensions of decision process simpler and more reliable.

- Secondly, although much work has been done in vertical handoff but there is lack of comparison study between their performances works. The main contribution behind this work is to make comparison among different decision making techniques based on MADM and check their limitations on the bases of different statistical and mathematical grounds.

Our next chapter will now presents different types Multiple Attributes Decision Making Methods and will also explain a detail illustration of these different methods before going in the depth of our proposed idea.

Chapter Three: Overview of Decision Making Techniques

Decision making is the study of identifying and choosing alternatives based on the values and Preferences of the decision maker. It consists of number of alternative choices which help in evaluation of several criteria. The basic aim behind this evaluation is to choose best alternative from this list which shows or fits with our goals, objectives, desires, values, and so on [40]. Multiple Criteria Decision Method (MCDM) models are best suited for handling such decision problems.

In short it can be said that for any MCDM problem there are four basic generic elements which are always considered i.e. Goal, Objectives, Criteria and Alternatives.

Step 1. Goal

The basic issue of the problem should clear in one single sentence that is it should be capable enough to define the initial conditions as well as the desired conditions. Characteristics of this statement are to be concise and unambiguous. Sometimes, even it can be a long iterative process to come to such a decision. This iterative process becomes crucial before proceeding to the next step.

Step 2. Objectives

Objectives/ Requirements are conditions which state the acceptance of any solution to the Poblem only in the scenario when these objectives are fulfilled. Mathematically, these objectives are describing the set of the feasible solutions of the decision problem. Whether the objectives are qualitative or quantitative, they should be precise and unambiguous.

Step3. Criteria

Decision criteria, which will distinguish among alternatives, must be based on the goals. These criteria's help in the measurement that how well each alternative meet the goal Since the goals are represented by these criteria's, it is must each goal must generate at least one criterion. Whereas in case of complex goals several criteria may be required. Talking about the multi criteria it will be helpful to group together criteria into a series of sets that particularly is helpful if emerging decision structure contains a relatively large number of criteria.

According to Baker [43], criteria should be

1. Able to discriminate among the alternatives and to support the comparison of the performance of the alternatives,
2. Complete to include all goals,
3. Operational and meaningful,
4. Non-redundant,
5. Few in number.

Step 4. Alternatives

Alternatives give different ways for changing the initial condition into the desired condition. It is necessary that the alternative must meet the objectives. If the number of the possible alternatives is finite, we can check one by one if it meets the requirements/objectives. This resulting comparison screen out the infeasible alternatives from the available ones. If the number of the possible alternatives is infinite, the set of alternatives is considered as the set of the solutions fulfilling the constraints in the mathematical form of the requirements.

After calculating the criteria and their alternatives, the decision making process now needs, an input data, and evaluation of these alternatives against different criteria. The next step after this evaluation is to select some decision making tool which can be applied to rank the alternatives or to choose a subset of the most promising alternatives. The alternatives selected by the applied decision making tools have always to be validated against the requirements and goals of the decision problem.

3.1 Single Criterion vs. Multiple Criteria and Finite Number of Alternatives vs. Infinite Number of Alternatives

Before start working on our problem, it is very important to make distinction that whether we have a single or multiple criteria problem. A decision problem may have a single criterion or a single aggregate measure like cost. Then the decision can be made implicitly by determining the alternative with the best value of the Single criterion or aggregate measure. This is also called an optimization problem. Different Optimization techniques can be used for the solution of such type of problems such as linear programming, nonlinear programming, discrete optimization, etc. [44].

Whereas considering the second case when we have a finite number of criteria but the number of the feasible alternatives is infinite. Then this multiple criteria optimization can be used when the number of feasible alternatives is finite but they are given only in implicit form [45]. In other way, it can be concluded that there are two paradigms of MCDM problem i.e. Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). In MADM approach the final alternative selection is done on the bases of attributes (criteria) which are attached with them. Here the alternatives are predetermined and limited in number. Where as talking about MODM, the set of decision alternatives are explicitly defined by the constraints using Multiple Objective Programming. Each alternative, when it is identified is judge how close it is to the objective or set of objectives. In MODM number of objectives is also very large.

Our main focus in this thesis work, has considered the case of decision making problems called MADM problems, when the number of the criteria and alternatives are predetermined, finite and limited in number.

3.2 Multiple Attributes Decision Making Methods

These problems are assumed to have a predetermine, and limited number of decision alternatives. The alternatives are then evaluated against multiple and often conflicting criteria. Finally the selection of the best action against the multiple alternatives is then take place. The main role of the techniques is to deal with the difficulties that human decision maker have to shown in handling large amounts of complex information in a consistent way. Different types of MADM methods are being used. They are classified as follows:

- Single Criterion synthesis approach, where incomparability is excluded AHP (Analytical and Hierarchy Process), TOPSIS (Technique for Order Preference by Similarity the Ideal Solution), DEA, GP, SCORING), local preferences (at each attribute level) are aggregated into unique (utility, value) function which is then optimized.

- Outranking synthesis approach, where incomparability is accepted (French school: PROMETHEE), building outranking (binary) relations using preference thresholds.

- Iterative local judgment with trial and error iterations (MOMP framework).

3.2.1 The Performance Matrix

A Standard feature of multi criteria analysis is a performance matrix, or a consequence table, in which row describes an option and each column describes the performance of the options against each criterion. MCDA techniques commonly apply numerical analysis methods to performance Matrix. If we consider a multi-attribute decision making problem with *m* criteria denoted by C1,…,**Cm** and *n* alternatives denoted as $\mathbf{A}_1$,..,$\mathbf{A}_n$ respectively, then performance matrix (standard feature of multi-attribute decision making methodology) or decision table is shown as in Fig 3.1

		x_1	.	.	x_n
		$\mathbf{A}_1$	.	.	$\mathbf{A}_n$
w_1	$\mathbf{C}_1$	a_{11}	.	.	a_{m1}
.	.	.	.	.	.
.	.	.	.	.	.
w_m	$\mathbf{C}_m$	a_{m1}	.	.	a_{mn}

Fig 3.1: Performance matrix/Decision Table

Where score a_{ij} describes the performance of alternative $\mathbf{A}_j$ against criterion $\mathbf{C}_i$
w_i are the weights against each criterion and x_i describes the decision objectives or goals.

3.2.2 Problem Solving Steps

For solving any type of multi criteria decision making problems, generally following steps are follows.

1) Establish the decision context, the decision objectives (goals), and identify the decision maker(s).
2) Identify the alternatives.
3) Identify the criteria (attributes) that are relevant to the decision problem.
4) For each of the criteria, assign scores to measure the performance of the alternatives against each of these and construct an evaluation matrix (often called an options matrix or a decision table).
5) Standardize the raw scores to generate a priority scores matrix or decision table.
6) Determine a weight for each criterion to reflect how important it is to the overall decision.
7) Use aggregation functions (also called decision rules) to compute an overall assessment measure for each decision alternative by combining the weights and priority scores.

Different types of methods are involved in weighting the criteria's. Examples include: Direct Determination (Rating, Point allocation, Categorization, Ranking, Swing, Trade-off, Ratio (Eigenvector prioritization)) or Indirect Determination (Centrality, Regression – Conjoint analysis, Interactive)

3.3 Ranking Method

In this method, the criteria are simply ranked in perceived order of importance by decision- makers: c1 > c2 > c3 > … > ci. The method assumes that the weights are non-negative and sum to 1.Two common approaches used for ranking methods are

1) Rating method.
2) Pair wise comparison methods.

3.3.1 Rating Method

Here point allocation approach is used. This approach is based on allocating points ranging from 0 to 100 to different criteria's, where 0 indicates that the criterion can be ignored, and 100 represents the situation where only one criterion need to be considered. A second approach used for rating method is called ratio estimation procedure. This approach is basically the modification of the point allocation method. A score of 100 is assigned to the most important criterion and proportionally smaller weights are given to criteria lower in the order. For calculating the ratios; we have to use score, which is assigned for the least important attribute.

3.3.2 Pair wise comparison method

This method involves pair wise comparisons to create a ratio matrix. It uses scale table for pair wise comparisons and then computes the weights. The pair-wise comparisons of the elements are made in terms of

- **Importance**: When comparing objects with respect to their relative importance.
- **Preference** : When comparing the preference for alternatives with respect to an objective
- **Likelihood**: When comparing uncertain events or scenarios with respect to the probability of their occurrences.

The values for comparing the elements using technique of pair wise comparisons can be obtained by using pre-determined scale of relative importance suggested by Saaty, 1980 [46] and shown in Fig 3.2.

INTENSITY OF IMPORTANCE	DEFINITION
1	Equal Importance
2	Equal to Moderately Importance
3	Moderate Importance
4	Moderate to strong Importance
5	Strong Importance
6	Strong to very strong Importance
7	Very strong Importance
8	Very to Extremely Strong Importance
9	Extreme Importance

Fig 3.2: Scale for pair wise comparison (Saaty, 1980) [46]

Usually the various criteria are measured in different units; the scores in the evaluation matrix have to be transformed to a normalized scale before being processed. Some of the methods used for this normalization are summarized in Eq1.

$$\left.\begin{aligned} \alpha_{ij} &= S_{ij} / \sum(S_{ij}) \\ \alpha_{ij} &= S_{ij} / \max(S_{ij}) \\ \alpha_{ij} &= (S_{ij} - \min S_{ij}) / (\max S_{ij} - \min S_{ij}) \\ \alpha_{ij} &= S_{ij} / \sqrt{\sum(S_{ij})^2} \end{aligned}\right\} \quad (1)$$

3.4 Problem Solving Techniques

Some of the problem solving techniques proposed for MADM is:

- SAW (Simple Additive Weighting)
- TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution)
- ELECTRE (Elimination et Choice Translating Reality)
- BAYESIAN NETWORK BASED FRAMEWORK
- AHP (The Analytical Hierarchy Process)
- SMART (The Simple Multi Attribute Rating Technique)
- ANP (Analytic network process)

Brief discussions of few of these techniques are done in this thesis work. Where as the selection of the models are based on the following evaluation criteria suggested by Dodgson et al. (2001):

- Internal consistency and logical soundness;
- Transparency;
- Ease of use;
- Data requirements are consistent with the importance of the issue being considered;
- Realistic time and manpower resource requirements for the analytical process;
- Ability to provide an audit trail; and
- Software availability, where needed.

3.4.1 SAW (Simple Additive Weighting)

It multiplies the normalized value of the criteria for the alternatives with the importance of the criteria .Where the alternative with the highest score is selected as the preferred one. In other words we can say that total score for each alternative is computed by multiplying the comparable rating for each attribute by the importance weight assigned to the attributed. The resultant is obtained by summing these products over all these attributes as shown in Eq 2.

$$S_i = \sum_{j=1}^{M} w_j r_{ij} \quad \text{for } i = 1, 2, .., N \tag{2}$$

Eq 2 gives the mathematical way for calculating the sum these products over all of these attributes. Where

S_i is the overall score of the i^{th} alternative;

r_{ij} is the normalised rating of the i^{th} alternative for the j^{th} criterion, which is computed as $r_{ij} = x_{ij} / (\max_i x_{ij})$ for the benefit and $r_{ij} = (1/x_{ij}) / \left[\max_i (1/x_{ij})\right]$ for the cost criterion representing an element of the normalised matrix **R**;

x_{ij} is an element of the Decision Matrix **A**, which represents the original value of the j^{th} criterion of the i^{th} alternative;

w_j is the importance (weight) of the j^{th} criterion;

N is the number of alternatives;

M is the number of criteria.

3.4.2 TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution)

In this method two artificial alternatives are hypothesized: i.e.

- Ideal alternative (Positive alternative)
- Negative alternative

The basic rule behind these hypotheses is that the chosen alternative should have shortest distance form positive ideal solution and longest distance from negative ideal solution [47].

- Ideal alternative: the one which has the best level for all attributes considered.

- Negative ideal alternative: the one which has the worst attribute value.

TOPSIS selects the alternative that is the closest to the ideal solution and farthest from negative ideal alternative. In this method we assume that we have m alternatives (options) and n attributes/criteria and we have the score of each option with respect to each criterion. For the explanation of the mathematical process we assume that xij score of option i with respect to criterion j. For this we further assume a matrix $X = (x_{ij})$ m×n matrix. Let J be the set of benefit attributes or criteria (more is better and J' be the set of negative attributes or criteria (less is better). The following steps are followed for the calculation of this method.

- Step 1: Construct normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria. The normalize scores or data are as follows:

$$r_{ij} = x_{ij} / \sqrt{(\Sigma x^2_{ij})} \qquad (3)$$

for i = 1, …, m; j = 1, …, n

- Step 2: Construct the weighted normalized decision matrix. Assume we have a set of weights for each criteria w_j for j = 1…n. Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is given as:

$$v_{ij} = w_j \, r_{ij} \qquad (4)$$

- Step 3: Determine the ideal and negative ideal solutions. The positive or Ideal solution can be obtained as

$$A^* = \{ v1^* , \ldots, vn^*\} \quad (5),$$

where $vj^* = \{ \max (vij) \text{ if } j \in J ; \; \min (vij) \text{ if } j \in J' \}$

Whereas the negative ideal solution is given as:

$$A' = \{ v1' , \ldots, vn' \} \quad (6)$$

Where $v` = \{ \min (vij) \text{ if } j \in J ; \; \max (vij) \text{ if } j \in J' \}$

- Step 4: Calculate the separation measures for each alternative. The separation from the ideal alternative is given as :

$$Si^* = [\Sigma (vj^* - vij)2]\ ½ \quad (7)$$

$i = 1, \ldots, m$

and similarly, the separation from the negative ideal alternative is:

$$S'i = [\Sigma (vj' - vij)2]\ ½ \quad (8)$$

$i = 1, \ldots, m$

Step 5: Calculate the relative closeness to the ideal solution Ci*. Select the Alternative with Ci* closest to 1.

$$Ci^* = S'i / (Si^* + S'i) \quad (9)$$

where $0 < Ci^* < 1$

3.4.3 **AHP (The Analytical Hierarchy Process)**

The Analytic Hierarchy Process (AHP) was proposed by Saaty (1980) [45]. The basic idea of the Approach is to convert subjective assessments of relative importance to a set of overall scores or Weights. AHP is one of the more widely applied multi attribute decision making methods and our research work is also based on this judgment methodology. AHP uses a hierarchical structure and pair wise comparisons. An AHP hierarchy has at least three levels:

1) The main objective of the problem at the top.
2) Multiple criteria that define alternatives in the middle. (m).
3) Competing alternatives at the bottom. (n).

Pair wise comparisons of AHP methodology suggest that 'How important is criterion **C***i* relative to criterion **C***j* ?'. Questions of this type are used to establish the weights for criteria and similar questions are to be answered to assess the performance scores for alternatives on the subjective (judgmental) criteria. For each pair of criteria, the decision maker is required to respond to a pair wise comparison question asking the relative importance of the two. The responses can use the following nine-point scale expressing the intensity of the preference for one criterion versus another

1= Equal importance or preference.
3= Moderate importance or preference of one over another.
5= Strong or essential importance or preference.
7= Very strong or demonstrated importance or preference.
9= Extreme importance or preference.

In the process of judgment if criterion C_j is more important than criterion C_i, then the reciprocal of the relevant index value is assigned. Pair wise Comparisons of $½*m(m - 1)$ is establish between the full set of pair wise judgments of m criteria. Next, we have to estimate the set of weights that are most dependable with the relativities expressed in the comparison matrix. The important point to be keep in mind is that as there is complete consistency in the (reciprocal) judgments which is made between any one pair, consistency of judgments between pairs, i.e. $c_{ij}c_{kj}= c_{ik}$ for all i,j,k, is not guaranteed. Thus the task is to search for an m-vector of the weights such that the mxm matrix W of entries w_i/w_j will provide the best fit to the judgments recorded in the pair wise comparison matrix *C*. Several of techniques were proposed for this purpose. These methods include Eigen values and Eigen vectors originally proposed by Saaty (1980) [45], here weights are calculated by using the elements in the eigenvector associated with the maximum eigenvalue of the matrix. A number of other methods are based on the minimization of the distance between matrices *C* and *W*. Some of these approaches either calculate the weight w vector directly or by simple computations, some other ones require the solution of numerically difficult optimization problems. One of the example of this approach includes the logarithmic least squares method, results in a Straight forward way of computing vector *w*: calculate the geometric mean of each row in the matrix *C*, calculate the sum of the geometric means, and normalize each of the geometric means by dividing by the sum just computed [48]. For further references related to distance-minimizing methods and a new approach based on singular value decomposition can be obtained from Gass and Rapcsák [49].

AHP method overcomes the complex problems by making use of hierarchy structure and resolves this problem by deriving ratio scale measures through pairwise relative comparisons. Here weights or priorities are derived from a set of judgments (expressed verbally, numerically or graphically). The relative importance or weight of one sub-criterion with respect to the criterion at one level above can be determined by calculating the eigenvector of the matrix. The solution for eigenvector can be found either by using computer program like MATLAB or by manual calculations. Saaty [46] has developed and suggested the following methods for the calculation of eigenvectors. These methods are

1. Normalization of row average
2. Geometric mean of rows
3. Average normalized column

1 Normalization of row average

The elements in each row are added and then normalized by dividing each sum by the total of all the sums. The results now add up to unity. The first entry of the resulting vector is the priority of the first activity/ alternative; the second of the second and so on.

$$w_i = \sum_{j=1}^{n} a_{ij} \Big/ \sum_{i,j=1}^{n} a_{ij} \tag{10}$$

2 Geometric mean of the rows:

In this method, first the multiplication of n elements against each row is calculated. Then nth root of each row is taken. Normalize the resulting numbers by dividing the sum of the product of all the numbers in every row.

$$w_i = \left(\prod_{j=1}^{n} a_{ij} \right)^{1/n} \Big/ \sum_{k=1}^{n} \left(\prod_{j=1}^{n} a_{kj} \right)^{1/n} \tag{11}$$

3 Average of normalized columns

This is the most commonly used method. Here first we convert the fraction pairwise comparisons to decimal equivalents. Secondly the elements of each column are then added up. In next step we create a normalized matrix by dividing each element by its column total. Further add the elements of the rows of the resulting normalized matrix and finally take average of the normalized columns by dividing the row sum by the number of elements in the row. The resulting column of values is an approximation of the eigenvector, which is actually the weight assigned to each of the factors.

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad (12)$$

Saaty [46] recommends the use of average of Normalized Columns for calculating the Eigen vector for the matrices because of its ease of use and it approximates the values of Eigen vector to a satisfactory level.

3.4.3.1 Consistency of Matrices

During the analysis of matrix at various stages of AHP, the consistency of the matrices must be checked to verify the reliability of the judgments of the decision maker. For a consistent positive reciprocal matrix, the largest Eigen value is equal to the order of the matrix (n) and for an inconsistent positive reciprocal matrix; the Eigen value is greater than the order of the matrix. Saaty [46] has defined a measure of consistency of matrix called the Consistency Index (CI). The Consistency Index can be defined as:

$$\text{Consistency Index} = (\lambda \max - n)\ (n-1) \quad (13)$$

For any matrix, if the value of CI is zero then it said that this matrix is perfectly consistent matrix of pairwise comparisons, because the Eigen value is equal to the order of the matrix [46]. It is difficult to maintain this consistency when the judgments are qualitative in nature. The Consistency of judgments in the pair wise comparisons can be calculated by finding the consistency ratio. The Consistency Ratio can be defined as the ratio of Consistency Index and Random Index [45].

$$\text{Consistency Ratio} = \text{Consistency Index} / \text{Random Index} \quad (14)$$

The Random Index (RI), for the different order random matrices was calculated by Saaty by randomly creating 500 positive reciprocal matrices of various sizes (1 X 1 to 15 X 15) and calculating the Consistency Index of each matrix. The probability distributions of the CIs were then studied and values for Random Index were recommended. These values are listed in Table 3.1

Size of Matrix	Random Index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Table 3.1: Random Index Table

When making judgments concerning a large number of comparisons, it is important to emphasize that the objective in making good decisions is not to minimize the consistency ratio. Good decisions are most often based on consistent judgments, but the reverse is not necessarily true. AHP allows a margin of inconsistency. If the calculated CR for a given matrix is 0.10 or less, the inconsistency is generally considered to be acceptable for the evaluation of the decision hierarchy [46]. If the CR is above 0.10, then the values assigned to the pairwise comparison in the given matrix should be re-examined. The whole procedure starting with the pair wise comparisons, matrix calculations, and consistency checks throughout the entire hierarchy should then be repeated.

3.4.4 SMART (Simple Multi Attribute Rating Technique)

This MADM model is used in an environment in which the time is short and decision makers are multiple and busy. In general SMART is considered as somewhat like AHP Technique where problem is define in hierarchal structure, scores are determine for each criteria, the result which we obtained after aggregation (i.e. set of rules applied on it) provide a ranking against different criteria. This ranking help in making a comparison among different alternatives. However there is a significance difference between AHP and SMART model. The terminology used in SMART at lower level of hierarchy is called attributes rather than sub criteria as used in AHP. The values of the standardized scores assigned to the attributes derived from the value functions are called rating. In case of SMART the value tree strictly follow the structure of tree where each attribute is attached to exactly one high level criterion where as in AHP one sub criteria can belong to more than one higher level criterion. Rather then using standardized scoring method for normalizing data, it uses value function which is explicitly defined. This function defined how each value can be transformed to common model scale. The numerical values assigned to these attributes which are derived from value function are called rating. How ratings of alternatives are interpreted is determined by the value function assigned to each lowest criterion. The value function transforms the rating values between 0-1 scales. The ranking value x_j of alternative **A*j*** is obtained simply as the weighted algebraic mean of the numerical values associated with it, i.e.

$$x_j = \sum_{i=1}^{m} w_i a_{ij} / \sum_{i=1}^{m} w_i, \quad j = 1, \ldots, n. \qquad (15).$$

Chapter Four: Fuzzy Decision Making

Decision making is one of the subjects to which fuzzy set theory has been successfully applied to in the recent years. It has been proved that fuzzy theory provides a sophisticated framework for describing and processing uncertain or imprecise information in decision problems. Various mathematical concepts have been introduced in fuzzy decision theory. Most of these approaches are applicable to a highly specialized class of decision problems and the generalization of these concepts is extremely difficult. Therefore, these approaches are not suitable for the description of decision problems with different classes of uncertainty. Moreover, there is no fuzzy decision model which can be regarded as an extension of the classical approaches to decision theory.

In our work, we have used Saaty [46] AHP process, which is a widely popular technique employed to model subjective decision making processes based on multiple attributes as discussed in Chapter 3. Where AHP in MADM environments involved defining a common hierarchy of criteria, specifying pairwise comparison by members of the group and aggregating those pairwise comparisons for the entire group. Saaty used the principal Eigen vector of the comparison matrix to find the relatives weights among the criteria of the hierarchy systems.

Buckley [60] method is used to fuzzify the hierarchical analysis by using fuzzy numbers for the pair wise comparisons and find the fuzzy weights and fuzzy performance. But before going in the detail of the proposed work, this chapter mainly discussed few terminologies which are use in fuzzy decision making.

4.1 Fuzzy Sets

Lotfi Zadeh, the father of fuzzy logic, claimed that many sets in the world that surrounds us are defined by non-distinct boundary. Zahed decided to extend two valued logic, defined by the binary pair {0, 1} into continues interval i.e. [0, 1]. This logic gives rise to the idea of gradual transition from falsehood to truth. Basically Fuzzy sets are a further development of mathematical sets. Talking about a conventional set, one can say that it can be described in two ways: either explicitly in form of list like A= {12, 13, 14, and 15} or can be expressed implicitly with a predicate like a predicate x >10. But according to Zadeh many sets have more than either –or, criterion for membership. Take for example the maximum coverage area provided by some network can be far, not too much far, close and not too much close. This example shows a grade of membership introduced by Zadeh. Here he proposed that a grade of membership such as the transition of data from membership to non membership is gradual rather than abrupt. This grade of membership for all its members thus describes a fuzzy set and it is denoted by a Greek letter called μ.

4.2 Membership Function

Elements of fuzzy sets are normally taken from a universe of discussion or in other words we can say that universe contains all elements that can come into the consideration. Any function μ(x) -> [0,1] describes a membership function associated with some fuzzy set. The question, that which type of membership function is suitable for fuzzy modeling can be determined according to the specified context. The most commonly used membership functions are "Triangular", "trapezoidal" and "Gaussian". These functions are defined as follows and shown in Fig 4.1 and Fig 4.2

Triangular Membership Function

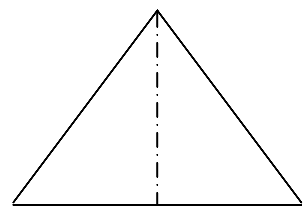

Fig 4.1: Triangular Function

Trapezoidal Membership Function

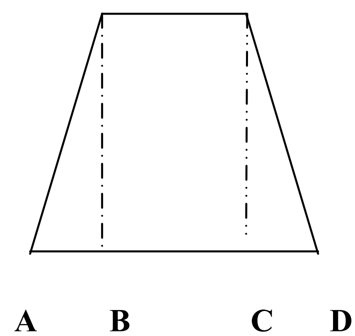

Fig 4.2: Trapezoidal Membership Function

Gaussian Membership Function

This member ship function is often used to represent vague, linguistic terms. It is given by

$$\mu_{A^i}(x) = \exp\left(-\frac{(c_i - x)^2}{2\sigma_i^2}\right), \qquad (16)$$

Where c_i and σ_i are the centre and width of the i^{th} fuzzy set A_i, respectively. Gaussian fuzzy membership functions are quite popular in the fuzzy logic literature, as they are the basis for the connection between fuzzy systems and Radial Basis Function (RBF) neural networks. Its output is very smooth.

4.3 Membership value

The membership values of the function are real numbers which range from[0,1]. Where 0 mean that the object does not belong to set and 1 means that it entirely belong to the set. The membership function can be defining analog. Hence Fig 4.3 represents analog functions of bandwidth which are labeled as Low, Medium and High.

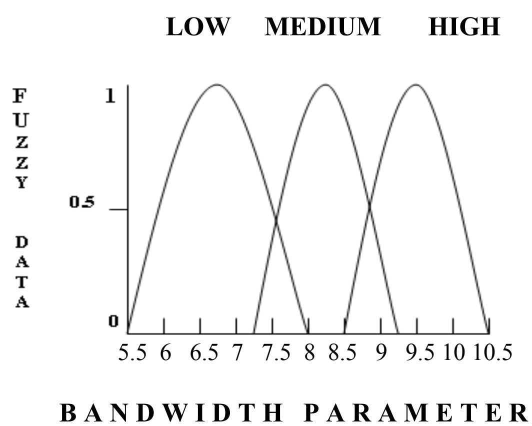

Fig 4.3: Gaussian Fuzzy Member ship values for Bandwidth

In the Fig 4.3 it can be observed that the value 9.5 of bandwidth parameter belong to fuzzy set "Medium" to a degree of 0.4 and at the same time to the set " High" to a degree of 0.7.

4.4 Singletons

Talking about a fuzzy set, it can be said that a fuzzy set A is a collection of ordered pair having values.

$$A= \{(x, \mu(x)\} \tag{17}$$

Where x is an object and $\mu(x)$ is the grade of membership. In this case a single pair of $(x, \mu(x))$ is called the fuzzy singletons and collection of these singletons makes a fuzzy set which are also called support of the fuzzy set.

4.5 Linguistic Variables

As in algebraic variables numbers are used to represent the values whereas in case fuzzy logic linguistic variables take words or sentences as a value [51]. The set of values taken in linguistic variable is called a term set. Each value in the term set is a fuzzy variable define d over a base variable. The base variable defines the universe of discussion for all the fuzzy variables in the term set. In short, the hierarchy is as follows:

Linguistic variable → fuzzy variable → base variable.

As for example consider the case of bandwidth shown in Fig 4.3, if x is linguistic variable with label "Bandwidth". Terms for this linguistic variables, which are fuzzy set are Low, medium and high from the term set. Hence A = {Low, Medium, High}. Each term is a fuzzy variable defined on the base variable, which is scaled from 5.5 to 11.

4.6 Operation of fuzzy set

Different types of operations are defined on fuzzy sets by means of their membership functions. These operations are Intersection (AND), Empty, Equal, and Complement (NOT), Containment, Union (OR).

Let A and B be fuzzy sets on a mutual universe. Then the operations applied on it are as follows

- **Intersection (AND)** : The intersection between A and B is given as

$$A \cap B = a \min b \qquad (18)$$

This operation will do item by item minimum comparison between the corresponding items of a and b.

- Union **(OR)**

$$AUB = a \min b \qquad (19)$$

This operation will do item by item maximum comparison between the corresponding items of a and b.

- **Complement**

$$\overline{A} = 1\text{-}a \qquad (20)$$

Where each membership value in a is subtracted from 1.

- **Equal**

$$\mu_{A\,(u)} = \mu_{B\,(u)} \quad \text{for all u from U(Universe)} \qquad (21)$$

A fuzzy sets are said to be A = B, which shows that membership values assigned to A are equal to the membership values of B.

- **Empty**

$$\mu_{A\,(u)} = 0.0 \quad \text{for all u from U (Universe)} \qquad (22)$$

A fuzzy set A is said to empty, if it does not contain any membership value.

4.7 Fuzzy logic

Logic means to design a program in such a way that mathematically we can proof the correction of data with chain of reasoning. Talking about a two valued logic, the correctness of the result can be either true or false. However, when we talk about fuzzy logic than the result may be either true, false or in between them. This means that we are dealing with multi valued logic and finer subdivision of unit interval may be more appropriate. Keeping this logical point of view, one can say that distance between two areas can be far, not very far, close, very close and not very close. These are the linguistic terms which are used to represent different aspects of the objects.

4.8 Implication

The rules that if bandwidth is high and coverage area is more and security is low then select network2 as an example of implication. This means the values of bandwidth, coverage area and security implies to make use of network2. Examples of implication are Mamdani implication and Gödel implication.

4.9 Inference

In order to draw conclusion from these if else rules we need some mechanism which can help us to find the resultant from the rules. This done by using Compositional Rule Of Inference (CROI). As an example, we think of a function given as y = f (x). Where y is a dependent variable, x is an independent variable and f is a given function. Here value y_o is inferred from x_o for given function.

Chapter Five: Proposed System

Sensor networks are considered to be the future communication Network as visioned by Wireless World Research Forum (WWRF) and IST Advisory Group (ISTGA) [52] [53]. Issues like power consumption, transmission media, coverage area, processing ability and buffer capacity, play a major role in the capabilities and efficiency of sensor nodes [56]. These resources can be very important, when some mission critical data needs to be sent to a remote sink. In this scenario, considerations not only remain limited to unpredicted nature of the area and sensor resources but may also effect the Quality of Service QoS requirements of application and user.

In order to overcome this worse situation, an optimal methodology is required which make use of some other wireless capabilities as an assisting tool for transferring data from sensor node to remote sink. These wireless access technologies may also enable a sink located anywhere on the globe to query a particular sensor field which is deployed in inaccessible regions and collect the event reports. The QoS requirements concerning the real-time applications need right components, protocols and interfaces both at system as well as application levels. The existing infrastructure can be possibly exploited whenever there is a need of sending sensor network based information robustly to a sink located out of the coverage area.

For supporting this remote coverage area of sensor nodes, heterogeneous wireless networks can be utilized. Currently, there are various wireless networks deployed around the world as discussed in detail in Chapter 4. Examples include second and third generation (3G) of cellular networks (e.g., GSM/GPRS, UMTS, CDMA2000), wireless local area networks WLANs (e.g., IEEE

802.11a/b/g), and personal area networks (e.g., Bluetooth). All these wireless networks are *heterogeneous* in sense of the different radio access technologies and communication protocols that they use and the different administrative domains that they belong to [54]. From this fact, it follows that no access technology or service provider can offer ubiquitous coverage expected by users requiring connectivity anytime and anywhere. In heterogeneous wireless networks, flexibility for network access and connectivity is a challenging problem of mobility support among different networks. Users will expect to continue their connections without any disruption when they move from one network to another. This important process in wireless networks is referred to as handover or handoff.

It means that there is a need of an optimal mechanism, which while monitoring the availability of network, can recognize the need of handover, whenever it is required by the application. Traditionally, the handoff process in wireless networks using the same access technology (e.g., among cells of a cellular network) is called Horizontal Handoff (HHO). Whereas in heterogeneous wireless networks using different access technologies is called Vertical Handoff (VHO). To deal with this new vertical mobility problem a new and improved handover techniques are required. Generally, the vertical hand off between two networks depend on the application based QoS, signal strength, bit error rates, coverage area [55].

5.1 Intelligent Intermediate Robust Gateway (IIRG)

An **Intelligent Intermediate Robust Gateway (**IIRG**)** module is designed, which provides an efficient and consistent QoS based connectivity of sensor applications to outside world. This Gateway defines a decision structure needed by sensor network application to switch over to any other wireless network, in order to make communication with the remote sink. The decisions made for this handover or switching are based on fuzzy logic. Details related o fuzzy logic is discussed in Chapter 3. Our fuzzy logic based gateway selects the most suitable network among the available ones. The decision is not only based on QoS parameters of available networks but it also depends on application specific criteria for QoS. This comprehensive QoS framework maps application specific QoS requirements to the desired performance attributes of the sensor applications. We are emphasizing the use of computational intelligence to customize the generic network selection criteria in order to achieve optimal application specific performance.

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5.2 Fuzzy Approach for Network Selection (FANS)

The main contribution of this approach is the use of novel Fuzzy Approach for Network Selection (FANS), which uses computational intelligence for selecting optimal network for every application. The diversity of wireless networks connected to the IIRG as well as the sensor application using IIRG introduces huge number of parameters to be taken into consideration while selecting a particular network to transit the sensor traffic through. Fuzzy logic provides the concept of fuzzy sets which realize a many-to-one mapping between several numerical parameters and their fuzzy counterparts. Secondly, a few fuzzy terms are sufficient to represent the entire domain of data.

5.3 Decision Methodology

The decision methodology used in designing this approach make use of fuzzy Analytic Hierarchy Process (AHP), there is an extensive literature that addresses the situation where the comparison ratios are imprecise judgments [66]. In most of the real-world problems, some of the decision data can be precisely assessed while others cannot. Essentially, the uncertainty in the preference judgments give rise to uncertainty in the ranking of alternatives as well as difficulty in determining consistency of preferences [66]. The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers' judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches. Many researchers [67],[68],[69],[70],[71],[72],[73], who have studied the fuzzy AHP which is the extension of Saaty's theory, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes compared to the traditional AHP methods. In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of this linguistics can be developed as quantitative data; this type of data set is then refined by the evaluation methods of fuzzy set theory. On the other hand, the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment. Therefore, the AHP method does not take into account the uncertainty associated with the mapping [74]. The AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems.

The fuzzy AHP uses ranking or comparison ratio based criteria for the assigning different priorities and weights from pair wise judgment of different criteria's which reflects the thinking style of human. These weights show the importance of each parameter over the other. In the next step, membership functions are constructed for the each criterion value coming from network module. Multiplication between each fuzzed Network Module value and its corresponding application provided weights are done. The final decision of network selection is based fuzzy union operation of all these calculated values. Network having the maximum calculated value is considered to be the final selection.

5.4 Architecture of IIRG

In a nutshell, IIRG is module which runs on 3G core Network. We can access this Module through access point or base station. This Module consists of following components/sub modules as shown in Fig 5.1

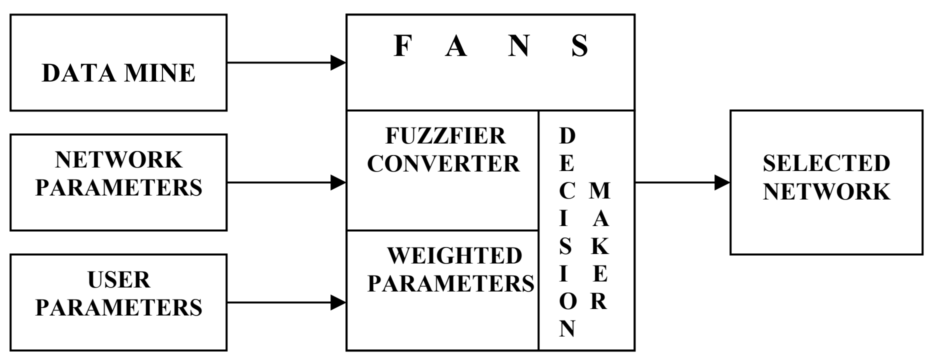

Fig 5.1: Architectural View

- Network Monitor.
- DataMine.
- Sensor Application Based Module.
- FANS
    - Fuzzifier Converter (FC).

- FANS Weighting Module (FANS WM).
- FANS DM (FANS Decision Maker).

5.4.1 Network Monitor

Network Monitor is a monitoring module which provides information related to the condition and availability of wireless networks to IIRG. The information which is provided by this module consists of following network parameters: Latency (D_T), Bandwidth, Application Priority (A_P), Coverage area (C_A) and Criticality (C_R). All these parameters will later feed into the FANS module, where its sub module FC converter will convert their crisp values into normalized fuzzy values called Normalize Weights (N_W).

5.4.2 Data Mine

Data Mine is module containing the historical data of previously selected networks. Indirectly, this module is used to give strength to our decision factors. While observing the information provided by this Data Mine, the pros and cons of previous decisions are considered. These pros and cons help in drawing an analysis graph between current decision and historical decision. The resultant of this analysis graph is the final decision of network selection. This graphical analysis is basically out of the scope of this work.

5.4.3 Sensor Application Based Module

This module defines, parameters related to each specific sensor based application type. The parameters related them are bandwidth requirement, security, Application Priority, Coverage area and Criticality. The values of all these parameter differentiate between Events based, Continues based, Query based and Hybrid applications.

5.4.4 F A N S

The third module of our gateway is FANS. It is considered to be the major part of IIRG Gateway. It is a decision making QoS frame work based on fuzzy logic. It helps in selecting the proper network for particular application for the transfer of data. FANS consist of following parts. Fuzzifier Converter (FC), FANS Weight age Module (FANS WM) and FANS Decision Module FANS DM which are discussed in detail as the following.

5.4.4.1 Fuzzifier Converter (FC)

This module is used to convert the input criteria, injected by network module, into normalized fuzzy sets ranging from [0 1] by using Gaussian Function. A fuzzy set is said to be in its normalized form if the largest membership value of the set is equals to 1 i.e. divide each membership value by its maximum membership value i.e.

$$s_i = s_i/\max(s) \text{ where } i = 1, 2, 3 \qquad (22)$$

Where s_i is membership value calculated against each input value provided by network module and s is the maximum membership value. The parameters for this module are Pri, C _R, B_W, C_A, D_T and A_T. The fuzzy values of these parameters will later be merged with the weighted application provided parameters. The question for utilizing this weightage methodology is explained in Chapter 6.

As, the definition of fuzzy set illustrates that it does not contain classical logical crisp values. But basically, it classifies the input into a form which ranges from [0, 1]. This range works under the concept of degree of membership. To convert these classical set into fuzzy set many different types of membership functions can be used. These types include trapezoidal, triangular and Gaussian or can be user defined, which later grade these membership values in the range of [0, 1]. For the simplicity of our module designing, we have used Gaussian membership function [57] for the conversion of classical set into fuzzy set. The general form of Gaussian membership function is shown by Eq 23

$$\mu E_i(x) = (\exp(-((w_i) - x)2/2))\sigma 2 \qquad (23)$$

Where w_i is the mean or center of the fuzzy set E_i and similarly (σ) is the width or standard deviation of fuzzy set E_i. If we consider the case of B_W, the fuzzy sets related to it can be Low, Medium, and High as shown in Fig 4.3. The membership value for each set is calculated through Gaussian function [57]. Similarly Fig 5.2, Fig 5.3 and Fig 5.4 shows the fuzzy set related to D_T, C_A and C_R parameters.

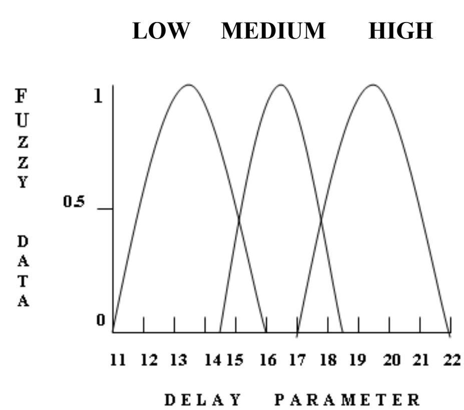

Fig 5.2: Delay Parameters for WLAN

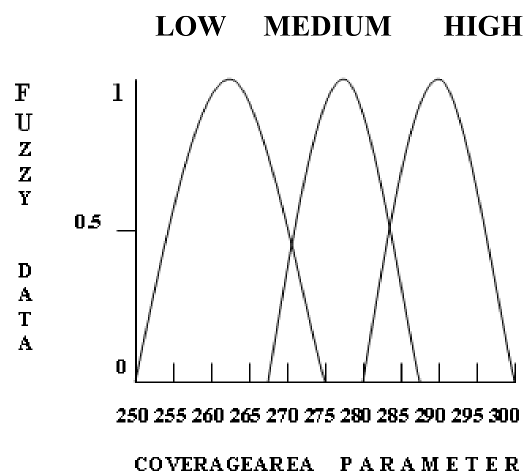

Fig 5.3: Coverage Parameters for WLAN

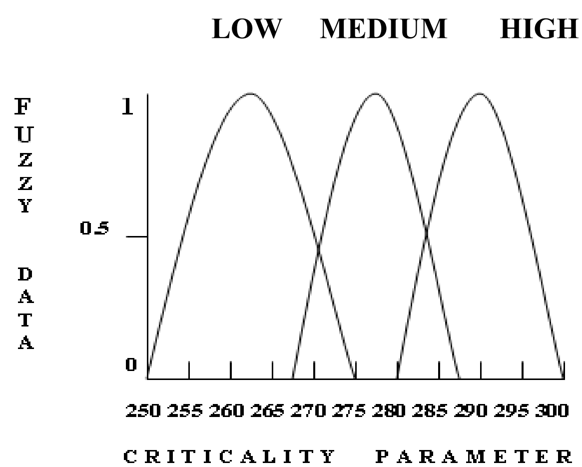

Fig 5.4: Criticality Parameters for WLAN

5.4.4.2 **FANS Weightage Module (FANS WM)**

This module is used to give weightage to user defined parameters such as A_Type and QoS Criteria. Our FANS WM works on the bases of fuzzy tool known as Analytic Hierarchy Process (AHP) suggested by T.L.Saaty [14]. This tool makes ranking or normalized ratio scale for comparison and synthesizes Normalized Priorities (N_P) for the selection of suitable network. Decision of AHP is highly dependable on the quantitative scoring. This scoring plays a vital role in the selection of best option among the available once, which can fulfill the required criteria. It is considered to be the most suitable tool in case of purely analytical and complex decision making, where multiple criteria are to be considered.

Our judgment will start from the top of hierarchy containing a Type and QoS. Later on this hierarchy is further subdivided as mention in Table 6.1 and Table 6.2, which is considered as alternatives rules for decision making. Ranking procedure or comparison of these parameters starts by defining a number of scales. These numeric scale defines that how one parameter is more important or dominant or at equal level as compared to other parameters. Here the judgment scale used for pair wise comparison is as follow [14], [58] and it totally depend on huma based thinking.

- 1 = equally likely to be important.
- 3 = weakly less impact factor of one over the other.
- 5 = strongly influence the other parameter.
- 7 = Dominating importance of one parameter over the other.
- 9 = Supreme control of one parameter over the other.
- 2, 4, 6, 8= Midway values between the two Neighboring Decision.

For calculating Normalized Priorities (N_P) and Normalized Weight (N_W) of the top most hierarchy, the number scale assumed for them shows a relationship of strong importance among them. The calculation for these parameters is done by taking geometric mean of each row. Where geometric mean of n variables is calculated as

$$(X_1 * X_2....X_n)^{1/n.} \qquad (24)$$

In second step, we have to decompose this higher level criterion into their sub criteria and then calculate N P and N W for each individual parameter.

5.4.4.3 FANS Decision Module (FANS DM)

Normally fuzzy system includes a lot of fuzzy rules. Either these rules take Multiple Inputs and extract Multiple Outputs(MIMO) or they include Multiple Inputs and extract a Single Output(MISO). By applying different operators on these rules we can get the resultant for output. Keeping this classification of rule based decision making, we have calculated our final decision of network by using MIMO selection method. This MIMO rule based decision method fed four inputs into our FANS module; those inputs are A Type, Application Specific QoS Parameters, Network Based QoS Parameters and DataMine. When data from sensor device arrives at IIRG Gateway, normalized weight age of all application specific categories are calculated by FANS WM module. On the other side the normalized fuzzy set is generated through FC module for each Network. Each normalized value from network side and each normalized weighed value from application side are then multiplied. Finally sum of all these multiplied values are taken against each network as shown in Eq 25.

$$(N_i) = (W_i) * (n_i) \qquad (25)$$

Where Wi is the weighted parameters from User perspective, n_i is normalized fuzzy values from network perspective. N_i is type of network. Where i = 1...n. These sums are then compared with each other by using Fuzzy OR operator as shown in Eq 26.

$$(Net_s) = \max (N_1 \text{ u } N_2 \text{ u } N_3 \text{ u } N_4 ...) \quad (26)$$

The fuzzy OR operator, which extract Max Value from all available option, helps in finding one suitable network which has maximum sum. Here union OR operator returns Maximum of these values. Net_S stand for network selection.

Chapter Six: Implementation

For checking the performance of our designed gateway, we have used Matlab to simulate the Performance of IIRG. Discussion on the Comparison of this decision technique with other decision making modules is discussed in Chapter 7. For the implementation of our module, two different scenarios are considered. Details of these scenarios are discussed later on in section 6.4 and 6.5

6.1 Methodoly

The basic model of our work depends on fuzzy based Analytical Hierarchal Process (AHP). This method can be compared with a pie chart. Where pie chart represent the goal of decision problem as a whole. The pie consists of wedges where each wedge represents the factors which contribute to ultimate goal. AHP helps to determine the relative weight of each wedge of the pie. Each wedge can be further subdivided into smaller wedges which represent the sub factor and which in turn can be further sub divided. The wedges corresponding to lowest level of sub factors are broken down into alternative wedge, where each alternative wedge represent how much the alternative contributes to hat sub factor . By adding up the priority for the wedges for alternatives, we can determine how much the alternatives contribute to the organization objectives.

In this work, the goal or pie or objective is to select the best network among the available ones which can satisfy the sensor based application requirements. The criteria's or factors wedges of pie on which successful completion of the goal depend are classified as application type (Event, continues, query and hybrid) and QoS requirements added up by the user (Application Priority, Criticality, Delay Tolerance, Bandwidth, Coverage Area).The alternatives which are available here are the set of networks which are currently available such as WLAN, GSM, EDGE etc. The decision making process of AHP consists of following six steps.

I. Develop Decision Hierarchy
II. Make a comparison Matrix
III. Calculate Eigen Vector and Eigen Values
IV. Check Consistencies of Matrices.
V. Evaluate and Compare Alternatives for the Criteria and Decision Making.
VI. Conduct a sensitivity analysis of the model.

6.1.1 Develop Decision Hierarchy

- ***Identify the Objective of the Process***

This process is defined as finding the overall objectives or goals of the process. Here considering the scenario of sensor based applications, our main goal is to provide facility of network among the list of networks, which can give maximum facility to the application according to its requirements. The information against each network and its parameters are provided by the Network Module which is a part of our designed gateway IIRG.

- ***Identify the Criteria to achieve the Objective***

Criteria that contribute for the successfulness of our goal are then identified. These criteria can be divided as application type and QoS requirements added up by the user.

- ***Identify the Sub Criteria***

These two sub criteria are further subdivided to achieve the goal. Where each sub criteria is also a part of the hierarchy. For example, if the main criteria is different types of sensor based applications then their sub criteria will be the types of application which sensor support i.e. Event, continues, query and hybrid. Whereas the QoS parameters can subdivided into Application Priority, Criticality, Delay Tolerance, Bandwidth, and Coverage Area.

- ***Identify the alternatives***

The solution or alternatives that satisfy the overall objectives are then identified. Thus the overall elements are arranged in hierarchal order, descending from overall objective, then criteria, sub criteria and finally the alternative. Fig 6.1 shows the hierarchal distribution or schematic representation of our Decision Hierarchy for network selection.

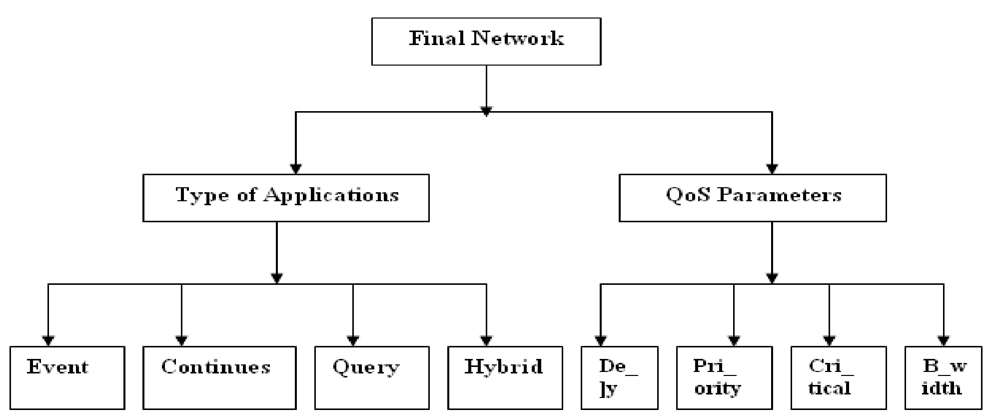

Fig 6.1: Schematic Representation of Decision Hierarchy for Network Selection.

6.1.2 Construction of Comparison Matrix

The concept of constructing this matrix is to show the relationship between the different levels of hierarchy and shows how the elements at lower level have a great impact on the overall decision objectives. Pairwise comparison takes place between the elements at each level which has impact on achieving the objectives of parent element. This pair wise comparison of element at each level is done on the bases of importance, Preference, Likelihood (as discussed before in Chapter 3) and it is basically based on the human based assessment.

For Our Fuzzy decision making method, the pair wise comparison matrix at each level is shown in Table 6.1, 6.2, 6.3. As for example if we consider Table 6.1, which is showing relationship between type of application and QoS parameter, we say that W_{TA}/ W_{QoS} represent pairwise comparison between type of application and QoS parameters. If effect of type of application is considered to be more strong than QoS parameter then relation between them will be: = 5/1 and this also means that relation between QoS parameter and application type will be: W_{QoS} / W_{TA} =1/5.Where as element on the diagonal shows pairwise comparison of each criterion with itself. That is why all elements on the diagonal are 1/1. Here all the elements below the diagonal are reciprocal of the corresponding elements above the diagonal.

PARAMETER	**A_TYPE (n_1)**	**QoS (n_2)**	**P_ri** $(n_1*n_2)^{\wedge 1/n}$	**N_P** $(n_1*n_2)^{\wedge 1/n} / \sum(n_1*n_2)^{\wedge 1/n}$
A_Type	1	5	2.2361	0.8333
QoS	1/5	1	0.4472	0.1667
Sum			2.6833	1

Table 6.1 Level 1: high level parameters

A_Type	Event (n_1)	Cont (n_2)	Query (n_3)	Hybrid (n_4)	P_ri $\prod_{i=1}^{4}(ni)^{1/n}$	N_P $\prod_{i=1}^{4}(ni)^{1/n} / \sum_{i=1}^{4}(ni)^{1/n}$	N_W (N_P)* 0.8333
Event	1	7	2	2	2.30	0.47	0.39
Cont	1/7	1	1/3	1/3	0.35	0.07	0.06
Query	1/2	3	1	½	0.93	0.19	0.16
Hybrid	1/2	3	2	1	1.32	0.27	0.22
Sum					4.9	1	0.83

Table 6.2 Level 2A: classification w.r.t application Type

QoS	A_P (n_1)	C_R (n_2)	D_T (n_3)	B_W (n_4)	C_A (n_5)	P_ri $\prod_{i=1}^{5}(ni)^{1/n}$	N_P $\prod_{i=1}^{5}(ni)^{1/n} / \sum_{i=1}^{5}(ni)^{1/n}$	N_W (N_P)* 0.1667
A_P	1	1	4	4	7	2.57	0.37	0.0610
C_R	1	1	4	4	7	2.57	0.37	0.0610
D_T	¼	1/4	1	1/5	3	0.52	0.07	0.0123
B_W	¼	1/4	5	1	5	1.09	0.15	0.0260
C_A	1/7	1/7	1/3	1/5	1	0.27	0.04	0.0063
Sum						7.0627	1	

Table 6.3 Level 2B classification w.r.t QoS parameter of Event based application

Similarly at our second level, the upper level criteria's are further subdivided. Criteria called type of application is divided in to following sub criteria.

- Event based applications(Event)
- Continues based applications(Cont)
- Query based applications(Query)

- Hybrid based applications(Hybrid)

Pairwise comparison between these different types of application sub criteria is shown in Table 6.2.

Here comparison ratio between event based applications with respect to continues application shows a ratio of 7/1, where it means that event based applications are strongly more dominating as compared to continues application. On other hand at second level, criteria called QoS is divided in to following sub criteria.

- Application Priority (P_ri)
- Criticality (C_R)
- Bandwidth (B _W)
- Coverage Area (C_A)
- Delay Tolerance (D_T)
- Application Type (A_T)

The comparison between these different types of QoS Parameters is shown in Table 6.3. As for example a comparison ratio between Bandwidth and Coverage Area shows a ratio of 1/3, which means that coverage area slightly or weakly more important than bandwidth.

6.1.3 Eigen values and Eigenvectors

The relative Importance (weight) of sub criteria with respect to the criterion at one level above can be determined by calculating the eigenvector of the matrix. Saaty (1980)[46] has developed different methods for calculating eigenvectors like Normalization of Row Average, geometric mean of the rows, average of normalized column (Details of each method has been discussed in Chapter 3).

For calculating the Eigen vector, we have used the method of geometric means of rows. As geometric is invariant under transposition and it can be easily calculated by hand. The geometric mean of n variables can be taken as (X_1* X_2 *X_3 *………. X_n) ^ (1/n).Here taking square root of first row grand product, application type seems to have a priority with respect to overall scores of (1*5)^1/2 =2.2361. QoS parameters has a priority of (1/5*1)^1/2=0.4472.The sum of these priorities are (2.2361 + 0.4472)=2.6833. In order to use this higher level weighting as overall percentages when cascaded to lower level parameters, the priority values are normalized by dividing the column by the sum of the priorities i.e. 2.6833.Thus for this decision process, 83.33 % of decision based on application type and 16.67 % of decision is based on QoS parameters.

At the next level of analysis, it decomposes the higher level components into subcomponents. The same level of mathematical procedure is also applied in lower level also. As for example, type of application which is divided in to event, query, and continues and hybrid. The geometric mean for event application is calculated as (1*7*2*2) ^1/4 =2.30. For continues application its priority will be (1/7*1*1/3*1/3) ^1/4 =0.35. Similarly the priority calculated for query and hybrid application is 0.93 and 1.32 respectively. The overall sums of these priorities are calculated as (2.30+.035+0.93+1.32) =4.9.These priorities are normalized by dividing each priority by the sum of overall prioties. The resultant of this division gives us a normalized priority, which is 0.47 in case event application, 0.07 in continues, 0.19 in query based applications and finally 0.27 in case of Hybrid application. Now normalized weights for these low level criteria are to be calculated. This normalized weight is obtained by multiplying the normalized priority of each type of application with normalized priority of its higher level or parent criteria. Thus the normalized weight for event application become (0.47*0.8333)=0.39 or 39%. Similarly (0.07*0.8333)=0.06 or 6% for continues application and 0.16 or 16% and 0.22 or 22% for query and hybrid applications.

Considering the low level hierarchy of QoS parameters, same procedure is applied as explained in above paragraph. The normalized weights which is calculated for them are 0.03 or 3% for application priority, 0.050 or 5% for criticality, 0.0083 or 0.83 % for delay tolerance ,0.015 or 1.5 % for bandwidth and finally 0.065 or 6.5% for coverage area.

6.1.4 Check consistency of Matrices

Consistency checking plays a vital role in verifying the reliability of judgments of the decision maker. The rule for consistency states that a consistent positive reciprocal matrix is that, in which largest Eigen value is equal to the order of matrix(n) and for inconsistent positive reciprocal matrix the Eigen value is greater that the order of the matrix. The consistency Index also called the measure of consistency given by Saaty (1980) is given as in eq 13. To address the question that how to calculate the maximum Eigen value following method can be adopted (Mclntyre, 1996) [13]

1. Multiply each column in original matrix by the weight vector value associated with the column number (e.g. second column would be multiplied by the second value in the weight vector.)
2. Sum the row of his new matrix
3. Divide each of the sum of the rows by the corresponding value from the weight vector

4. Sum and average the column containing the summed rows. The resulting value is the approximation of the maximum Eigen value.

The consistency of judgment in pair wise comparison can be calculated by finding the consistency ratio. This ratio is defined as in eq 14. Where the table for random Index (RI) developed by Saaty is explained in Table 3.1. AHP allows a margin of inconsistency. If the calculated CR for a given matrix is 0.10 or less, the inconsistency is generally considered to be acceptable but if the CR is above 0.10, then the values assigned to the pairwise comparison in the given matrix should be re-examined. The whole procedure is repeated again as explained in Chapter 3.

For calculating consistency of Table 6.1, we have to follow the rules which are explained above. As for the case of table, the order of the matrix is 2. Hence the consistency checking for a matrix, having order less than two is not required. In order to check the consistency of Table 6.2, we have to calculate the maximum Eigen value of the matrix or table. For calculating max Eigen value, the four steps we have to follow are as under

Step 1: **Multiply each column in original matrix by the weight vector value associated with the column number (e.g. second column would be multiplied by the second value in the weight vector.)**

A_Type	Event	Cont	Query	Hybrid
Event	1*0.39 =0.39	7* 0.06 =0.42	2 *0.16=0.32	2*0.22=0.44
Cont	1/7*0.39=0.06	1*0.06=0.06	1/3*0.16=0.05	1/3*0.22=0.073
Query	1/2*0.39=0.195	3*0.06=0.18	1*0.16=0.16	1/2*0.22=0.11
Hybrid	1/2*0.39=0.195	3*0.06=0.18	2*0.16=0.32	1*0.22=0.22

Step2: **Sum the row of this new matrix**

A_Type	Event+Cont+Query+Hybrid	Sum
Event	0.39+0.42+0.32+0.44	**1.57**
Cont	0.06+0.06+0.05+0.73	**0.24**
Query	0.195+0.18+0.16+0.11	**0.645**
Hybrid	0.195+0.18+0.32+0.22	**0.915**

Step 3: **Divide each of the sum of the rows by the corresponding value from the weight vector**

A_Type	Event+Cont+Query+Hybrid / Weight
Event	1.57 / 0.39 = **4.03**
Cont	0.24 / 0.06= **4**
Query	0.645 / 0.16= **4.03**
Hybrid	0.915 / 0.22= **4.16**

Step 4: **Sum and average the column containing the summed rows. The resulting value is the approximation of the maximum Eigen value.**

A_Type	Event+Cont+Query+Hybrid / Weight
Event	4.03
Cont	4
Query	4.03
Hybrid	4.16
Sum	**16.22**
Average	**4.055**

Now maximum Eigen value we have calculated in this table is 4.055. For checking the consistency of the table, our next step is to calculate consistency index.

$$\text{Consistency Index(CI)} = (\lambda_{max}-n) / (n-1).$$

$$CI = (4.055 - 4) / (4-1).$$

$$CI = 0.01833$$

For verification of finding Consistency ratio, the value for Random Index is taken for Saaty given Table 3.1 as mentioned above

$$CR = 0.01833/0.9$$
$$= 0.020.$$

As the value of consistency ratio <0.1. Hence it is proved that our Table 6.2 fulfills the condition of consistency.

For Table 6.2, same methodology can be used for finding the Eigen Value and verifying the consistency of this table.

Finally, the maximum value for this table is calculated. For finding consistency ratio of Table 6.3 (5 x5) order, the formula applied for this is

$$CR = CI / RI \qquad (27)$$

Here again it is prove that our Table 7 is consistent according to Saaty's rule (as explained above).

For implementing our work, two different types of scenarios are considered.

6.2 Scenario **I**

Four different types of applications are treated by the gateway IIRG simultaneously. Among these four applications, one is from Event class, one from Continue class and last two are from Query and Hybrid classes. To discuss the complete network selection procedure by IIRG, we have discussed Event based application here. Whenever any event occurs, our sensor network immediately transferred the data to the IIRS gateway. The gateway function is to calculate the weighted parameters of application based QoS criteria. Table 6.1 and Table 6.2 show the detailed calculations.

Related to event based application, based on fuzzy AHP. Here the Network Module provides the information related to the status of currently available networks. Networks considered in this scenario are WLAN, GSM, and UMTS. The network parameters read by the Network Module is then injected into the Fuzzy Converter for converting this information into fuzzy set by using Gaussian Function as shown in Table 6.4. These fuzzed network parameters are multiplied with weights provided from Table 6.3 Level 2B and sum of their products is then calculated. The final selection of network is done through union operator, which extracts maximum value from the three calculated values of networks. Fig 6.2 shows the dynamic network selection among four sensor applications running simultaneously. Here, it is observed that event based application, which require real time provision, can be best supported by the UMST/HSPA/HSDPA. The major characteristics of all these three networks are that they not only support higher bandwidth but also support low latency. On the other side, considering the case of GSM, GPRS, EDGE, although their performance is well scaled but their latency time is 3 times more as compared to UMST/HSPA/HSDPA and hence is not selected for important Event based application.

Network	**A_Type**	**A_P**	**C_R**	**D_T**	**B_W**	**C_A**
Net1(802.11a)	0.4	0.6	0.8	0.7	0.9	0.7
Net2(802.11b)	0.6	0.4	0.8	0.3	0.2	0.5
Net3 (Satellite)	0.5	0.4	0.2	0.8	0.9	0.9
Net4(GSM)	0.7	0.5	0.6	0.9	0.6	0.5
NET5(UMTS)	0.8	0.7	0.3	0.7	0.1	0.7

Table 6.4: Network Provided Parameters

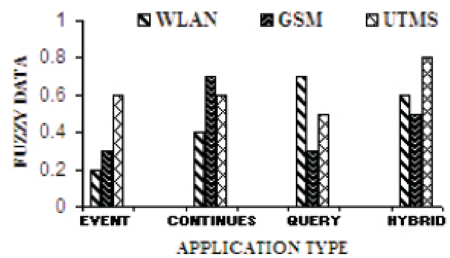

Fig 6.2: Dynamic network selection: Four Sensor Applications Running simultaneously

6.3 Scenario II

These results are taken to compare the network selection decision taken by gateway IIRG when only two types of applications are present simultaneously. These Applications are Continues and Hybrid. The networks that are available to the applications at that time: GSM, UMTS and WLAN. IIRG carries out the network selection procedure and the final selection is shown in Fig 6.3. The gateway now selects the most appropriate network for the two applications based on their QoS requirements and network parameters at that time.

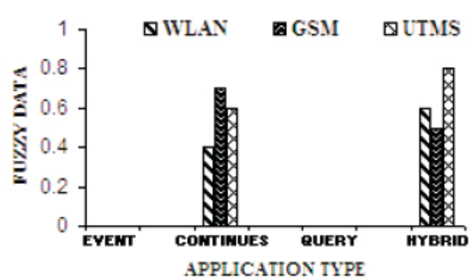

Fig 6.3: Dynamic network selections: Two Sensor Applications running Simultaneously

Chapter Seven: Comparison of Different Techniques

For checking the performance measure of our work, four different types of decision making methods have been used. i.e. AHP [13], TOPSIS [23], MEW [23] and SAW [24], we have considered an example of traffic, which is coming from some remote location sensor devices. According to the authors in [10] sensor devices provide support for many different types of applications such as Event, Continues, Hybrid and Query. The classification of these data types are done on the bases of data driven module. Each application type has a requirement of diverse QoS parameters. Event type application of sensor devices always activate in the presence of some triggers, Query type applications responded when some question is generated from the sink, continues type response continually by sending data at a some fixed rate, whereas hybrid applications are the combination of all these three above applications.

7.1 SAW (Simple Additive Weighting)

In SAW, as discussed in Chapter 3, the overall score of the candidate network is determined by the weighted sum of all the attribute values. The score of each candidate network is determined by adding the normalized contributions from each metric r_{ij} multiplied by the importance weight assigned w_j of metric j. The selected network is:

$$S_i = \sum_{j=1}^{M} w_j r_{ij} \quad \text{for } i = 1, 2, .., N \tag{28}$$

Applying this formula on given data, the

Weights	0.39	0.0610	0.0610	0.0123	0.0260	0.0063
Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.4	0.6	0.8	0.7	0.9	0.7
Net2(802.11b)	0.6	0.4	0.8	0.3	0.2	0.5
Net3 (Satellite)	0.5	0.4	0.2	0.8	0.9	0.9
Net4(GSM)	0.7	0.5	0.6	0.9	0.6	0.5
NET5(UMTS)	0.8	0.7	0.3	0.7	0.1	0.7

The Scores for Net1, Net2, Net3, Net4, and Net5 are calculated as

Net1= (0.4*0.39+0.6*0.0610+0.8*0.0610+0.7*0.0123+0.9*0.0260+0.7*0.0063)

= 0.27782

Net2 = (0.6*0.39+0.4*0.0610+0.8*0.0610+0.3*0.0123+0.2*0.2060+0.5*0.0063)

= 0.31924

Net3 = (0.5*0.39+0.4*0.0610+0.14*0.0610+0.8*0.0123+0.9*0.0260+0.9*0.0063)

= 0.27051

Net4 = (0.7*0.39+0.5*0.0610+0.6*0.0610+0.9*0.0123+0.6*0.0260+0.5*0.0063)

= 0.36992

Net5 = (0.8*0.39+0.7*0.0610+0.14*0.0610+0.7*0.0123+0.1*0.0260+0.7*0.063)

= 0.38862

Calculations show that Net4 i.e. GSM having maximum value is considered to be the best network for selection.

7.2 TOPSIS (Technique for Order Preference by Similarity to The Ideal Solution)

In this method as discussed in Chapter 3, two artificial alternatives are hypothesized: i.e.

- Ideal alternative (Positive alternative)
- Negative alternative

The basic rule behind these hypotheses is that the chosen alternative should have shortest distance form positive ideal solution and longest distance from negative ideal solution [47]. The following steps are followed for the calculation of this method.

Step 1: Calculate $\Sigma\ (x^2_{ij)})^{1/2}$ for each column and divide each column by that to get r_{ij}

$$r_{ij} = xij / \sqrt{(\Sigma x^2_{ij})} \qquad \text{for } i = 1, \ldots, m;\ j = 1, \ldots, n$$

Weights	0.39	0.0610	0.0610	0.0123	0.0260	0.0063
Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.4	0.6	0.8	0.7	0.9	0.7
Net2(802.11b)	0.6	0.4	0.8	0.3	0.2	0.5
Net3 (Satellite)	0.5	0.4	0.2	0.8	0.9	0.9
Net4(GSM)	0.7	0.5	0.6	0.9	0.6	0.5
NET5(UMTS)	0.8	0.7	0.3	0.7	0.1	0.7

The Scores for Row 1 is calculated as

$$0.4/ ((0.4)^2 + (0.6)^2 + (0.5)^2 + (0.7)^2 + (0.8)^2)^{1/2} = 0.29$$

$$0.6/((0.6)^2 + (0.4)^2 + (0.4)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.5$$

$$0.8/((0.8)^2 + (0.8)^2 + (0.2)^2 + (0.6)^2 + (0.3)^2)^{1/2} = 0.61$$

$$0.7/((0.7)^2 + (0.3)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2)^{1/2} = 0.44$$

$$0.9/((0.9)^2 + (0.2)^2 + (0.9)^2 + (0.6)^2 + (0.1)^2)^{1/2} = 0.63$$

$$0.7/((0.7)^2 + (0.5)^2 + (0.9)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.47$$

Similarly scores for Row 2 are calculated as follows

$$0.6/ ((0.4)^2 + (0.6)^2 + (0.5)^2 + (0.7)^2 + (0.8)^2)^{1/2} = 0.43$$

$$0.4/((0.6)^2 + (0.4)^2 + (0.4)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.3$$

$$0.8/((0.8)^2 + (0.8)^2 + (0.2)^2 + (0.6)^2 + (0.3)^2)^{1/2} = 0.61$$

$$0.3/((0.7)^2 + (0.3)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2)^{1/2} = 0.19$$
$$0.2/((0.9)^2 + (0.2)^2 + (0.9)^2 + (0.6)^2 + (0.1)^2)^{1/2} = 0.14$$
$$0.5/((0.7)^2 + (0.5)^2 + (0.9)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.33$$

Scores for Row 3 are calculated as follows

$$0.5/ ((0.4)^2 + (0.6)^2 + (0.5)^2 + (0.7)^2 + (0.8)^2)^{1/2} = 0.36$$
$$0.4/((0.6)^2 + (0.4)^2 + (0.4)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.3$$
$$0.2/((0.8)^2 + (0.8)^2 + (0.2)^2 + (0.6)^2 + (0.3)^2)^{1/2} = 0.15$$
$$0.8/((0.7)^2 + (0.3)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2)^{1/2} = 0.51$$
$$0.9/((0.9)^2 + (0.2)^2 + (0.9)^2 + (0.6)^2 + (0.1)^2)^{1/2} = 0.63$$
$$0.9/((0.7)^2 + (0.5)^2 + (0.9)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.6$$

Scores for Row 4 are calculated as follows

$$0.7/ ((0.4)^2 + (0.6)^2 + (0.5)^2 + (0.7)^2 + (0.8)^2)^{1/2} = 0.5$$
$$0.5/((0.6)^2 + (0.4)^2 + (0.4)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.42$$
$$0.6/((0.8)^2 + (0.8)^2 + (0.2)^2 + (0.6)^2 + (0.3)^2)^{1/2} = 0.46$$
$$0.9/((0.7)^2 + (0.3)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2)^{1/2} = 0.57$$
$$0.6/((0.9)^2 + (0.2)^2 + (0.9)^2 + (0.6)^2 + (0.1)^2)^{1/2} = 0.42$$
$$0.5/((0.7)^2 + (0.5)^2 + (0.9)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.33$$

Scores for Row 5 are calculated as follows

$$0.8/ ((0.4)^2 + (0.6)^2 + (0.5)^2 + (0.7)^2 + (0.8)^2)^{1/2} = 0.57$$
$$0.7/((0.6)^2 + (0.4)^2 + (0.4)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.58$$
$$0.3/((0.8)^2 + (0.8)^2 + (0.2)^2 + (0.6)^2 + (0.3)^2)^{1/2} = 0.23$$
$$0.7/((0.7)^2 + (0.3)^2 + (0.8)^2 + (0.9)^2 + (0.7)^2)^{1/2} = 0.44$$
$$0.1/((0.9)^2 + (0.2)^2 + (0.9)^2 + (0.6)^2 + (0.1)^2)^{1/2} = 0.70$$

$$0.7/((0.7)^2 + (0.5)^2 + (0.9)^2 + (0.5)^2 + (0.7)^2)^{1/2} = 0.47$$

So the table after Step1 will become

Weights	0.39	0.0610	0.0610	0.0123	0.0260	0.0063
Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1	0.29	0.5	0.61	0.44	0.63	0.47
Net2	0.43	0.3	0.61	0.19	0.14	0.33
Net3	0.36	0.3	0.15	0.51	0.63	0.6
Net4	0.5	0.42	0.46	0.57	0.42	0.33
Net5	0.57	0.58	0.23	0.44	0.70	0.47

Step 2: Construct the weighted normalized decision matrix. An element of the new matrix is given as:

$$v_{ij} = w_j r_{ij}$$

Weights	0.39	0.0610	0.0610	0.0123	0.0260	0.0063
Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1	0.1131	0.0305	0.0372	0.0054	0.0164	0.0030
Net2	0.1677	0.0183	0.0372	0.0023	0.0036	0.0021
Net3	0.1404	0.0183	0.0092	0.0063	0.0164	0.0038
Net4	0.1950	0.0256	0.0281	0.0070	0.0109	0.0021
Net5	0.2223	0.0354	0.0140	0.0054	0.0182	0.0030

The Scores for Col 1 is calculated as

0.29* 0.39 = 0.1131

0.43* 0.39 = 0.1677

0.36*0.39= 0.1404

0.5*0.39= 0.195

0.57*0.39= 0.2223

The Scores for Col 2 is calculated as

0.5 * 0.0610 = 0.0305

0.3 * 0.0610 =0.0183

0.3 * 0.0610 = 0.0183

0.42 * 0.0610 =0.0256

0.58 * 0.0610 = 0.0354

The Scores for Col 3 is calculated as

0.61 * 0.0610 = 0.0372

0.61*0.0610 =0.0372

0.15*0.0610 = 0.0092

0.46*0.0610 = 0.0281

0.23*0.0610= 0.0140

The Scores for Col 4 is calculated as

0.44 * 0.0123 = 0.0054

0.19 * 0.0123 = 0.0023

0.51 * 0.0123 = 0.0063

0.57 * 0.0123 = 0.0070

0.44 *0.0123 = 0.0054

The Scores for Col 5 is calculated as

0.63 * 0.026 = 0.0164

0.14 * 0.026 = 0.0036

0.63 * 0.026 = 0.0164

0.42 * 0.026 =0.0109

0.70 * 0.026 =0.0182

The Scores for Col 6 is calculated as

0.47 * 0.0063 = 0.0030

0.33 * 0.0063 = 0.0021

0.6 * 0.0063 = 0.0038

0.33 * 0.0063 = 0.0021

0.47 * 0.0063 = 0.0030

Step 3(a) : Determine the ideal

A* = { v1* , …, vn*}

vj* ={ max (vij) if j ∈ J ; min (vij) if j ∈ J' }

A*= **{0.2223, 0.0354, 0.0372, 0.0070, 0.0182, 0.0038}**

Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1	0.1131	0.0305	**0.0372**	0.0054	0.0164	0.0030
Net2	0.1677	0.0183	0.0372	0.0023	0.0036	0.0021
Net3	0.1404	0.0183	0.0092	0.0063	0.0164	**0.0038**
Net4	0.1950	0.0256	0.0281	**0.0070**	0.0109	0.0021
Net5	**0.2223**	**0.0354**	0.0140	0.0054	**0.0182**	0.0030

Step 3 (b) : Whereas the negative ideal solution is given as :

A' = { v1' , …, vn' }, where

v' = { min (v_{ij}) if j ∈ J ; max (v_{ij}) if j ∈ J' }

A' = {**0.1131, 0.0183, 0.0092, 0.0023, 0.0109, 0.0021**}

Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1	**0.1131**	0.0305	0.0372	0.0054	0.0164	0.0030
Net2	0.1677	**0.0183**	0.0372	**0.0023**	0.0036	**0.0021**
Net3	0.1404	0.0183	**0.0092**	0.0063	0.0164	0.0038
Net4	0.1950	0.0256	0.0281	0.0070	**0.0109**	0.0021
Net5	0.2223	0.0354	0.0140	0.0054	0.0182	0.0030

Step4 (a): Calculate the separation measures for the ideal alternative is given as:

$S_i* = [\Sigma (v_j* – v_{ij})2] ½ \quad i = 1, …, m$

Network	Σ (vj*– vij)^2	(Σ (vj*– vij)^2)$^{1/2}$
Net1	0.011955	0.109339
Net2	0.00351	0.059242
Net3	0.007791	0.088264
Net4	0.00098	0.031308
Net5	0.000541	0.02325

Step4 (b): Separation for the negative ideal alternative is:

S'i = [Σ (vj' – vij)2] ½

Network	Σ (vj*– vij)^2	(Σ (vj*– vij)^2)$^{1/2}$
Net1	0.000976	0.031245
Net2	0.003822	0.061818
Net3	0.000793	0.028169
Net4	0.007141	0.084502
Net5	0.012303	0.110921

Step 5: Calculate the relative closeness to the ideal solution Ci*.

Ci* = S'i / (Si* +S'i),

Network	S'i / (Si* +S'i)	Ci*
Net1	0.031/(0.031+0.109)	0.3170
Net2	0.062/(0.062+0.059)	1.1053
Net3	0.028/(0.028+0.0083)	0.3473
Net4	0.084/(0.084+0.0313)	2.7836
Net5	0.1101/(0.1101+0.0232)	4.8817 (**BEST**) ←

7.3 Multiplicative Exponent Weighting (MEW)

MEW is another way of solving multi attributes problem. Here the attribute problem consists of a matrix having N number of alternative and M number of criteria's against them. The score for each network i can be calculated as

$$S_i = \sum(x_{ij})^{wij} \quad (29)$$

Here x_{ij} is the element or value of j attribute and w_i is the weight assigned to each attribute. The value of w_j will be considered as positive for benefit matrix x_{ij}^{wij} and its value will be negative for cost factor i.e. x_{ij}^{wij}. The selected network is the best value of each matrix. The highest value in benefit matrix is considered as preferred one; where as the lower value in the cost matrix is selected as final option.

Step 1: Calculate Si for each column by using the formula : $(x_{ij})^{wij}$ for the given matrix

Weights	0.39	0.0610	0.0610	0.0123	0.0260	0.0063
	A_Type	A_P	C_R	D_T	B_W	C_A
Network						
Net1(802.11a)	0.4	0.6	0.8	0.7	0.9	0.7
Net2(802.11b)	0.6	0.4	0.8	0.3	0.2	0.5
Net3 (Satellite)	0.5	0.4	0.2	0.8	0.9	0.9
Net4(GSM)	0.7	0.5	0.6	0.9	0.6	0.5
NET5(UMTS)	0.8	0.7	0.3	0.7	0.1	0.7

Weights	0.39	0.0610	0 .0610	0.0123	0.0260	0.0063
Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.6995	0.9693	0.9865	0.9956	0.9973	0.9978
Net2(802.11b)	0.8194	0.9456	0.9865	0.9853	0.9590	0.9956
Net3 (Satellite)	0.7631	0.9456	0.9065	0.9973	0.9973	0.9993
Net4(GSM)	0.8701	0.9586	0.9693	0.9987	0.9868	0.9956
NET5(UMTS)	0.9167	0.9785	0.9292	0.9956	0.9419	0.9978

Network	$S_i = \sum(x_{ij})^{wij}$
Net1(802.11a)	5.6460
Net2(802.11b)	5.6914
Net3 (Satellite)	5.6091
Net4(GSM)	5.7792 (BEST) ←
NET5(UMTS)	5.7596

7.4 Performance Comparison

For making a comparison between these four handover methods i.e. AHP [13], TOPSIS [26], MEW [26] and SAW [26], we have consider an example of traffic, which is coming from some remote location sensor devices. According to the authors in [54] sensor devices provide support for many different types of applications such as Event, Continues, Hybrid and Query. The classification of these data types are done on the bases of data driven module. Each application type has a requirement of diverse QoS parameters. Event type application of sensor devices always active in the presence of some triggers, Query type applications responsed when some question is generated from the sink, continues type response continually by sending data at a some fixed rate, whereas hybrid applications are the combination of all these three above applications.

In the calculation of network selection for this application, different types of QoS parameters are required both from user as well as from network. The parameters which we used for the evaluation of methods are bandwidth, delay tolerance, critical/security, application type, coverage area and priority. Here the values of these parameters, either received from user or from network, are first converted into fuzzy variables by making use of Gaussian membership function [57]. The advantage of using these fuzzy variables is that one can easily express both quantitative and qualitative data. Later on these fuzzy values are normalized to develop a measurement of symmetry among the parameters. For the simplicity of our work, the weights for each criterion provided by each application type are calculated by using AHP Eigen value method based on geometric mean. Simulation of these algorithms is carried out by using MATLAB.

The simulation, consider performance parameters of five different networks i.e. 802.11a, 802.11b, Satellite, GSM, UMTS and User Preference related to QoS parameters. Selection of the final network depends on the values of the above mentioned attributes. The AHP Matrices regarding each traffic class is shown in Table 7.1, 7.2, 7.3 and 7.4 and resulting weights calculated against each traffic class is shown in Table 7.5.

QoS	**App_Pri**	**Critical**	**Delay**	**Bandwidth**	**Coverage**
App_Pri	1	1	4	4	7
Critical	1	1	4	4	7
Delay	¼	¼	1	1/5	3
Bandwidth	¼	¼	5	1	5
Coverage	1/7	1/7	1/3	1/5	1

Table 7.1: Event Based AHP Matrices

QoS	**App_Pri**	**Critical**	**Delay**	**Bandwidth**	**Coverage**
App_Pri	1	1	1/7	1/9	1/3
Critical	1	1	1/7	1/9	1/3
Delay	7	7	1	1/5	5
Bandwidth	9	9	5	1	7
Coverage	3	3	1/5	1/7	1

Table 7.2: Continues Based AHP Matrices

QoS	**App_Pri**	**Critical**	**Delay**	**Bandwidth**	**Coverage**
App_Pri	1	½	1/5	1/9	1/4
Critical	2	1	1/5	1/9	1/4
Delay	5	5	1	1/5	3
Bandwidth	9	9	5	1	7
Coverage	4	4	1/3	1/7	1

Table 7.3: Query Based AHP Matrices

From comparison point of view, three different approaches have been used to check that which algorithm gives better performance as compared to other one.

These approaches are Ranking based approach, Stability checking, Mean squares

QoS	**App_Pri**	**Critical**	**Delay**	**Bandwidth**	**Coverage**
App_Pri	1	½	1/7	1/9	1/4
Critical	2	1	1/7	1/9	1/3
Delay	7	7	1	1/5	2
Bandwidth	9	9	5	1	2
Coverage	8	3	½	½	1

Table 7.4: Hybrid Based AHP Matrices

Sensor App	**App_Pri**	**Critical**	**Delay**	**Bandwidth**	**Coverage**	**CRatio**
Event	0.143	0.143	0.03	0.06	0.15	0.095
Continue	0.0024	0.0024	0.015	0.0344	0.00535	0.079
Query	0.0059	0.0078	0.0332	0.0947	0.0183	0.0823
Hybrid	0.00714	0.0115	0.052	0.1089	0.0408	0.0870

Table 7.5: Consistency Ratio (CRatio) && weights w.r.t Application Type

Error and Minimum-Variance Unbiased Estimator checking in final decision ranking. The behavior of each algorithm is observed in each case. On the bases of there behavior the final conclusion is drawn.

It is observed that although TOPSIS shows a large difference in their ranking values and seems to be more accurate in identifying the alternatives as compared to AHP, SAW and MEW but a large value of TOPSIS standard error of mean, depicts a large gap between mean decision value and other alternative values. This large value of standard error of mean basically is the draw back TOPSIS, which develop an abnormality and non stability factors in the decision making of TOPSIS. Where as on the other hand MEW algorithm is suffering from the problem of panelizing. It fails in making good decision in most of the cases where it cannot make a clear judgment between good and poor QoS attributes. Before discussing further, let's study each algorithm w.r.t its comparison approach.

7.4.1 Ranking Approach

For the simulation of our work, the calculations are done against Event based

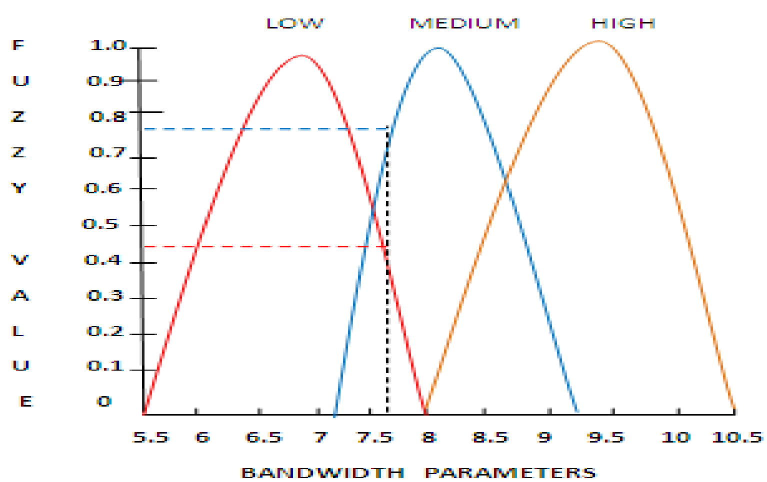

Fig 7.1 Fuzzy values for Bandwidth Parameters

application. First the parameters provided by four different networks against each QoS criteria's are converted into fuzzy set as shown in Fig 7.1. Regarding each parameter, we have defined the range of linguistic variables, as for example the range against bandwidth parameter is shown in Table 7.6A. These linguistic

RANGE b/s [x1-x2]	VALUE x	LINGUISTIC TERM	GAUUSIAN DISTRIBUTION Gaussmf(x,[x1,x2]) FUZZIFIED VALUES
5.5-8	7.53	LOW	0.44
7-9.5	7.53	MEDIUM	0.78
8-10.5	7.53	HIGH	0

Table 7.6A: Fuzzifier values for bandwidth (Gaussian Distribution)

variables are finally converted into fuzzy values. For example in case of bandwidth parameter the range against each linguistic values Table 7.6A. The fuzzfied value of bandwidth 7.53 is calculated against each linguistic variable i.e. Low, Medium and High. Table 7.6B is showing the calculated fuzzfied values against each QoS Parameters, provided by network module. These fuzzfied parameters are then multiplied by the Event based calculated weights as calculated in Table 7.5. The final decision is based on highest ranking factor. This ranking distribution for four different methods i.e. AHP SAW, MEW and TOPSIS are shown in Table 7.7. Here the ranking is done from maximum to minimum values. Highest ranking network is considered to be the final selection.

Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.7869	0.656	0.00004	0.1312	0.4949	0.0383
Net2(802.11b)	0.2274	0.3279	0.8995	0.3137	0.2517	0.433
Net3 (Satellite)	0.8424	0.1845	0.5082	0.4522	0.3256	0.3801
Net4(GSM)	0.8865	0.7613	0.8838	0.4574	0.7992	0.1341
NET5(UMTS)	0.0653	0.3751	0.3735	0.484	0.9695	0.3421

Table 7.6B: Fuzzy values QoS parameters provided by Networks

The results of this table are showing that all four networks have selected Net 4 as

Network	AHP & RANK		SAW&RANK		MEW&RANK		TOPSIS&RANK	
Net1(802.11a)	0.36250	**3**	0.36250	**3**	0.44888	**4**	0.79960	**3**
Net2(802.11b)	0.17694	**4**	0.17694	**4**	0.49208	**3**	0.24901	**4**
Net3 (Satellite)	0.38814	**2**	0.38814	**2**	0.77376	**2**	0.84174	**2**
Net4(GSM)	0.47431	**1**	0.47431	**1**	0.90538	**1**	0.98577	**1**
NET5(UMTS)	0.10452	**5**	0.10452	**5**	0.30011	**5**	0.09807	**5**

Table 7.7: Ranking Distribution by different algorithms

the best option. The ranking distribution of all three algorithms that is AHP, SAW, TOPSIS are the same, where as in the case of MEW, there is a ranking differentiation at the point of Net 1 and Net 2.To find the root cause of this differentiation, it observed that MEW penalizes the alternative which has poor attributes than the other one. Considering the scenario of the above example, Network 1 has poor attributives as compared to network 2, which can be verified by taking the mean/average and variance of these attributes as show in Table 7.8. The table is showing that Net1 has been assigned the lower rank 4 as compared to Net2 is assigned the higher rank i.e. 3. Although it seems to be good decision but by going into the deep analysis , it is can said that MEW, did not make a good decision as it taken over all average of parameters as its decision criteria by giving lower rank to Net 1. Where as it did not consider that which parameter is given more weight age as compared to other one. So according to the higher weight parameters requirement of event application i.e application support, bandwidth and less delay is better provided by net1 as compared to Net 2. Hence MEW makes not good decision in assigning rank to the networks. Keeping this drawback of MEW, we study an other case of data for the verification of our conclusion. The parameters coming from the network module is shown in Table 7.9. The ranking done by all four algorithms are shown in Table 7.10. It is observed from here that again MEW is penalizing the poor attribute values of Network 5 by giving it lower rank as compared to Network 1, which is showing average wise good parameters as well as less variance in its values as compared to Net 1. On the other hand network 5 consists of better parameters than network 1 according to application requirement. We try to check this point on more than 1000 records and found that 85% to 90% times MEW shows similar type of behavior. Thus it due to this behavior of MEW it can be concluded that MEW is taking the decision by taking overall mean or average values or depending on the variance property of the values of parameters without considering the weight age requirement of application.

Network	Mean	STD	Variance	AHP RANK	SAW RANK	MEW RANK	TOPSIS RANK
Net1	0.35	0.34	0.11	**3**	**3**	**4**	**3**
Net2	0.41	0.25	0.06	**4**	**4**	**3**	**4**
Net3	0.45	0.22	0.05	**2**	**2**	**2**	**2**
Net4	0.65	0.30	0.09	**1**	**1**	**1**	**1**
Net5	0.43	0.30	0.09	**5**	**5**	**5**	**5**

Table7.8: Mean, Standard Deviation and Variance of Network Parameters

Network	A _Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.7853	0.4353	0.7104	0.9508	0.7073	0.1381
Net2(802.11b)	0.324	0.7889	0.2877	0.7978	0.2148	0.3854
Net3 (Satellite)	0.9327	0.9835	0.7512	0.6197	0.0556	0.3385
Net4(GSM)	0.2397	0.5343	0.677	0.22	0.6629	0.1194
NET5(UMTS)	0.8537	0.1679	0.6145	0.6366	0.7694	0.5459

Table7.9: Different network parameters

7.4.2 Stability Factor

In this simulation, we concentrate on the non stability ranking problems in the

	Mean	STD	Var	AHP RANK		SAW RANK		MEW RANK		TOPSIS RANK	
Net1	0.6212	0.28944	0.08378	0.408	3	0.408	3	0.83	2	0.76	3
Net2	0.46643	0.25919	0.06718	0.21	4	0.21	4	0.56	4	0.18	4
Net3	0.61353	0.35907	0.12893	0.48	1	0.48	1	0.87	1	0.92	1
Net4	0.40888	0.24505	0.06005	0.19	5	0.19	5	0.52	5	0.13	5
Net5	0.598	0.23842	0.05684	0.413	2	0.413	2	0.81	3	0.80	2

Table 7.10: Mean, Variance and Standard Deviation (Example 2)

algorithms under consideration. In the above example we have seen the problems associated with MEW. Now concentrating on the problem as shown in Table 7.11 and its ranking criteria in Table 7.12, where all these algorithms are showing the same results, we start removing the lowest ranking decision alternative from the Table 7.12. This removal shows very interesting result related to the algorithm called TOPSIS. The result of this step is shown in Table 7.13. Here it is observed that stability factor in the decision of SAW, AHP, and MEW remains the same; where as the result of TOPSIS has changed altogether. For the further confirmation of this step, we remove one lowest rank from Table 7.11 i.e. Rank 4. Here again the stability of SAW, AHP and MEW remains the same, whereas behavior of TOPSIS shows a prominent change in its decision behavior as shown in Table 7.14. This behavior of TOPSIS can be considered as an abnormality behavior of TOPSIS. Deep analysis of TOPSIS shows that due to large difference in its decision ranking and largest variability in its mean standard error, any change in the decision alternative, immediate response is shown by this algorithm. It means that in same situation variability or abnormality exists in its decision.

Network	A_Type	A_P	C_R	D_T	B_W	C_A
Net1(802.11a)	0.6768	0.1947	0.2539	0.3434	0.3434	0.0122
Net2(802.11b)	0.8835	0.8423	0.3335	0.8989	0.8976	0.8986
Net3 (Satellite)	0.7567	0.3312	0.9471	0.2988	0.0133	0.8684
Net4(GSM)	0.9935	0.3951	0.3169	0.0176	0.777	0.8433
NET5(UMTS)	0.8684	0.1509	0.0624	0.754	0.6297	0.5656

Table: 7.11 Parameter for Topsis Analysis

Network	AHP & RANK		SAW & RANK		MEW & RANK		TOPSIS & RANK	
Net1(802.11a)	-		-		-		-	
Net2(802.11b)	0.457316	**2**	2		0.877490	**1**	0.8262	**2**
Net3 (Satellite)	0.383414	**3**	3		0.735045	**3**	0.7362	**3**
Net4(GSM)	0.457721	**1**	1		0.829759	**2**	0.8279	**1**
NET5(UMTS)	0.381852	**4**	4		0.698473	**4**	0.7288	**4**

Table: 7.12 Ranking of TOPSIS Analysis-Case I

Network	AHP & RANK		SAW & RANK		MEW & RANK		TOPSIS & RANK	
Net1(802.11a)		**-**						
Net2(802.11b)	0.457316	**1**	0.457316	**1**	0.877490	**1**	0.844	**1**
Net3 (Satellite)	0.383414	**3**	0.383414	**3**	0.735045	**3**	0.7390	**3**
Net4(GSM)	0.457721	**2**	0.457721	**2**	0.829759	**2**	0.83764	**2**
NET5(UMTS)		**-**						

Table: 7.13 Ranking of TOPSIS analysis-Case II

7.4.3 Estimation Analysis

One of the Branches of statistics and signal processing is Estimation theory. This branch is used to find the estimated value based on empirical data or measured data.

The objective of estimator is to approximate the unknown parameters using the measurements. In this theory, it is assumed that the desired information is embedded in a noisy signal. Where Noise adds uncertainty, which is the root cause of the problem. It means that without this noise the problem would be deterministic and estimation would not be needed. It is also preferable to derive an estimator that exhibits optimality. Estimator optimality usually refers to achieving minimum

Network	**AHP&RANK**		**SAW&RANK**		**MEW&RANK**		**TOPSIS & RANK**	
Net1(802.11a)	0.305290	**5**	0.305290	**5**	0.667105	**5**	0.1314	**5**
Net2(802.11b)	0.457316	**2**	0.457316	**2**	0.877490	**1**	0.6090	**1**
Net3 (Satellite)	0.383414	**3**	0.383414	**3**	0.735045	**3**	0.4702	**3**
Net4(GSM)	0.457721	**1**	0.457721	**1**	0.829759	**2**	0.6083	**2**
NET5(UMTS)	0.381852	4	0.381852	**4**	0.698473	**4**	0.3788	**4**

Table: 7.14 Ranking of TOPSIS analysis-Case III

average error over some class of estimators. However, optimal estimators do not always exist.[61]. List of few Commonly-used estimators are Maximum likelihood estimators, Bayes estimators ,Method of moments estimators ,,Minimum mean squared error (MMSE), also known as Bayes least squared error (BLSE) ,Maximum a posteriori (MAP) ,Minimum variance unbiased estimator (MVUE) and many more. Among these two estimators, we have used mean square error estimator and Minimum variance unbiased estimator (MVUE) for the analysis of our above methods.

7.4.3.1 Mean Squared Error

Mean Squared Error or **MSE** of an estimator also called second moment of error [61] taking both the variance of the estimator and its bias in account. It is considered as one of the way to find how close the difference between estimated and true value is. The difference between estimated and true value is actually the error, which comes due to randomness or malfunctioning of estimator. The MSE for unbiased estimator is a variance. On the other hand the under root of MSE is called the root mean squared error or RMSE and at some places also known as Standard Error (SEM). RMSD or standard error is considered as a good measure of accuracy

Thinking about many practical applications, normally the true value of the standard deviation is not unknown. For this the term *standard error* is often used to and calculates the unknown values. The value of this standard error is very helpful in providing the indication of the amount uncertainty in the decision based on mean value. Another way to do this test is t –distribution, which provides us confidence interval for an estimated mean or difference of means. These tests should be avoided unless the sample size is at least moderately large. Here "large enough" would depend on the particular quantities being analyzed.

SEM is usually calculated as sample estimation of the population standard deviation divided by the square root of the sample size .

$$SE = \frac{s}{\sqrt{n}} \tag{30}$$

where

s is the sample standard deviation and
n is the size (number of observations) of the sample.

While considering the case of our AHP, SAW, MEW and TOPSIS method, the analysis has been drawn against SEM. The results of SEM are basically showing the efficiency of a methodology in relation to its unbiased estimator. The minimum the value of SEM estimator, the more efficient will be the methodology. It is because according to statistical rule in SEM as the value of sample size increases the resultant should move in decreasing order. The lower the SEM estimator value, the lesser will be the error or deviation of the quantity from the true value. Table 7.15 is showing the SEM resultant against different sample sizes and the behavior of this result show that AHP and SAW have the least biased value as compared to other two algorithms. So therefore we can say that AHP and SAW is showing better efficiency as compared to other two algorithms. This result can also be verified after plotting a graph between mean square error and number of inputs for different algorithms coming from different networks. This plotting is shown in Fig 7.1

INPUT (N)	A H P	S A W	M E W	T O P S I S
5	0.0063	0.0062	0.0024	0.0021
10	0.0068	0.0068	0.0118	0.0089
20	0.0036	0.0036	0.0060	0.0059
50	0.0021	0.0021	0.0038	0.0032
100	0.0014	0.0014	0.0027	0.0023
250	0.0009	0.0009	0.0018	0.0014
400	0.0007	0.0007	0.0014	0.0011
700	0.0006	0.0006	0.0010	0.0009
1000	0.0005	0.0005	0.0009	0.0007

Table 7.15: Mean Square Error for Different input values of N

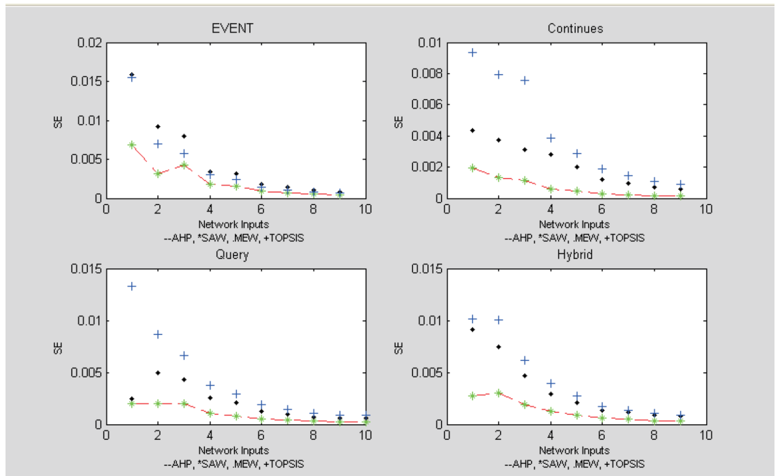

Fig 7.2: Mean Square Error (AHP, SAW, MEW, TOPSIS)

7.4.3.2 Minimum-Variance Unbiased Estimator

A Uniformly Minimum-Variance Unbiased Estimator or Minimum-Variance Unbiased Estimator (UMVU or MVUE) is an unbiased estimator that computes low value of variance as compared with any other unbiased estimator. Similarly the criterion for efficient estimator is to calculate the value of estimation which is close to the true parameter. As the aim behind each optimal estimator is to provide unbiasedness in the resultant. For finding the MVUE usually the comparison is done in terms of ratio between unbiased estimator variances. This comparison ratio is basically the efficiency of estimator. The efficiency for this estimator is normally stated in a relative terms. If we state θ_1 as unbiased estimator of sample 1 and θ_2 as as unbiased estimator of sample 2, then the ratio between their variance states that VAR (θ_1) and VAR (θ_2) represents the measure of relative efficiency of θ1 with respect to θ2. If VAR (θ_1) is less than VAR (θ2) then VAR(θ_1) is considered as more efficient than VAR θ2.

For checking the efficiency factor of our algorithms i.e AHP, SAW, MEW and

TOPSIS, we again calculate their variances against each ranking decision. These results are shown in Table 7.16. For MVUE purpose six different ratio factor related variance have been calculated. These six different pairs are

AHP	SAW	MEW	TOPSIS
0.0328	0.0328	0.1013	0.1568
0.007924	0.007924	0.02208	0.07445
0.01504	0.01504	0.01604	0.1094
0.003039	0.003039	0.004303	0.05114
0.01404	0.01404	0.03041	0.09989
0.009567	0.009567	0.01315	0.08906
0.01608	0.01608	0.06331	0.086
0.02112	0.02112	0.06707	0.1108
0.0103	0.0103	0.01603	0.1006
0.01104	0.01104	0.01497	0.07414
0.01437	0.01437	0.04464	0.1053
0.01781	0.01781	0.06172	0.1217
0.004695	0.004695	0.01065	0.08109
0.01091	0.01091	0.02512	0.08342
0.009408	0.009408	0.03073	0.1325
0.006742	0.006742	0.008407	0.06545
0.007702	0.007702	0.01153	0.08198
0.01008	0.01008	0.03784	0.103
0.01641	0.01641	0.03652	0.09331
0.01242	0.01242	0.05245	0.09822

Table : 7.16 Variances of different algorithms

1. VAR_{AHP} Vs VAR_{SAW}
2. VAR_{AHP} Vs VAR_{MEW}
3. VAR_{AHP} Vs VAR_{TOPSIS}
4. VAR_{SAW} Vs VAR_{MEW}
5. VAR_{SAW} Vs VAR_{TOPSIS}
6. VAR_{MEW} Vs VAR_{TOPSIS}

AHP/SAW	AHP/MEW	AHP/TOPSIS	SAW/MEW	SAW/TOPSIS	MEW/TOPSIS
1.00	0.32	0.21	0.32	0.21	0.65
1.00	0.36	0.11	0.36	0.11	0.30
1.00	0.94	0.14	0.94	0.14	0.15
1.00	0.71	0.06	0.71	0.06	0.08
1.00	0.46	0.14	0.46	0.14	0.30
1.00	0.73	0.11	0.73	0.11	0.15
1.00	0.25	0.19	0.25	0.19	0.74
1.00	0.31	0.19	0.31	0.19	0.61
1.00	0.64	0.10	0.64	0.10	0.16
1.00	0.74	0.15	0.74	0.15	0.20
1.00	0.32	0.14	0.32	0.14	0.42
1.00	0.29	0.15	0.29	0.15	0.51
1.00	0.44	0.06	0.44	0.06	0.13
1.00	0.43	0.13	0.43	0.13	0.30
1.00	0.31	0.07	0.31	0.07	0.23
1.00	0.80	0.10	0.80	0.10	0.13
1.00	0.67	0.09	0.67	0.09	0.14
1.00	0.27	0.10	0.27	0.10	0.37
1.00	0.45	0.18	0.45	0.18	0.39
1.00	0.24	0.13	0.24	0.13	0.53

Table 7.17: MVUE: If VAR (θ_1) is less than VAR (θ_2) then VAR(θ_1) is Considered as more efficient than VAR(θ_2).

Comparison between their variances ratio again shows that AHP and SAW both have minimum variance unbiased estimator as compared to MEW and TOPSIS. Where as this estimator has ranked MEW at the second position and TOPSIS at last or third position.The results are shown in Table 7.17 While drawing conclusion from these results, it is observed that largest unbiased estimator of TOPSIS is the basic reason behind the inconsistent ranking behavior of TOPSIS. Thus the non stability and inconsistency in TOPSIS is due to having largest variability ratio as compared to other algorithms. It means that any small change in it rank create major changes in it decision stability consistency.

Chapter Eight: Conclusions and Future Research Direction

Large ranges of tiny embedded sensor devices which are capable of sensing, communicating and routing data are available now days. Due to higher failure rate of sensor nodes or their mobility, the sink node might not exist in their transmission range. We proposed an approach which uses fuzzy logic to deal with diverse QoS requirements of sensor applications. In this thesis work I have presented an Intelligent Intermediate Robust Gateway module, which provides an efficient and consistent QoS based connectivity to sensor based applications to outside world. This Gateway defines a decision structure needed by sensor network applications to switch over to any wireless network, in order to make communication with the remote sink fulfilling application QoS requirement. The result of our approach shows that it is capable of selecting appropriate network for range of sensor network applications. For making comparison of our decision, with other approaches different parameters are considered. Three different MCDM approach i.e SAW, MEW and TOPSIS has been done with our gateway based on AHP approach. Number of parameters is input to gateway IIRG both from network as well as from application. These parameters include application type, bandwidth, delay, coverage area, security and priority. Matlab is used to conduct this simulation. Results show that more that 80-85% of times the decision made by SAW, MEW, TOPSIS and AHP is same, whereas 20% times they made different ranking decisions. It is observed that the reason for selecting different ranking criteria for decision by different algorithms depends on the abnormality behavior of TOPSIS and penalizing behavior of MEW. The efficiency and consistency of each algorithm is checked by making use of MSE and MVAR estimators. This estimator has proved that AHP and SAW are more consistent and efficient approach for network selection as compared to other two.

8.1 Future Directions

- In future we want to check the consistency and efficiency of our approach by using the estimator such as Method of moment's estimators and Cramér-Rao bound [61].
- We also want to find the weakness and problem in using the AHP approach for decision making
- We have planed to conduct a comparative study of other fuzzed MDCM approaches as well
- An other task we have on the list is to explore other decision making techniques using a list of extensive QoS parameters such cost, bit error rate, jitter etc.
- We are also planning to work on the historical maintaining called data mine part of IIRG frame work So next time the final selection shall be drawn on the bases of historical data as well. This approach will make the decision process faster and more efficient. As estimated and true values will be in hand for making confident and reliable decision.

8.2 Research Contributions

The following contributions have been made during our research.

8.2.1 A new approach for the vertical handoff of Sensor Device

We have proposed a new approach for the transfer of vital data from sensor devices to a remote station. Our approach is based on MCDM technique called AHP. A wide range of Decision Support System (DSS), and applications are supported by AHP procedure such as data mining and machine learning and so many applications. AHP is a powerful procedure suggested by Saaty[46] which provide effective means to deal with complex decision making problems and can assist in with identifying and weighting selection criteria, analyzing the data collected for the criteria and expedite the decision-making process. AHP helps capture both subjective and objective evaluation measures, providing a useful mechanism for checking the consistency of the evaluation measures and alternatives suggested by the team thus reducing bias in decision making.

8.2.2 Comparative study of MCDM Approaches

We carried out comparative study of our proposed approach and the widely used multicrieteria decision making approaches. Our study was based on the comparison of resultant decomposition of three approaches in terms of ranking, stability, efficiency (SME) and consistency (MVUE) in result. In future we want to conduct comparative studies with other MCDM approaches as well.

8.2.3 Efficiency and Consistency in terms of Estimator

We were hardly able to find the research work in MCDM in network selection for sensor based application literature that has formally compared the efficiency and consistency of results based on estimators, generated by different MCDM approaches. In this way, our effort is one of the first ones in this domain that compare the Efficiency and Consistency in results, an important and desirable property of any algorithm.

LIST OF ABBREVIATIONS

Radio Frequency	RF
Radio Signal Strength	RSS
Wireless Sensor Networks	WSN
Industrial Control System	ICS
Supervisory Control And Data Acquisition Systems	SCADAS
Distributed Control Systems	DCS
Automatic Vehicle Location	AVL
Quality of Service	QoS
Infra Red	IR
Intelligent Intermediate Robust Gateway	IIRG
Fuzzy Approach for Network Selection	FANS
Analytic Hierarchy Process	AHP
Wireless World Research Forum	WWRF
IST Advisory Group	ISTGA
Wideband Code Division Multiple Access	WCDMA
Enhanced Data rate for GSM Evolution	EDGE
Bandwidth	B_W
Coverage Area	C_A
Multiple Attribute Decision Making	MADM
Vertical Hand Over	VHO
Simple Additive Weighting	SAW
Elimination et Choice Translating Reality	ELECTRE
The Simple Multi Attribute Rating Technique	SMART
Analytic Network Process	ANP
Technique for Order Preference by Similarity to Ideal Solution	TOPSIS
Grey Relational Analysis	GRA
Received Signal Strength	RSS
Variation of Received Signal Strength	VRSS
Base Stations	BS
Mobile Host	MH
Multiple Criteria Decision Method	MCDM
Multiple Objective Decision Making	MODM
Consistency Index	CI
Random Index	RI
Radial Basis Function	RBF
Compositional Rule Of Inference	CROI
Horizontal Handoff	HHO

Fuzzifier Converter	FC
FANS Weighting Module	FANS WM
FANS Decision Maker	FANS DM
Delay Tolerance	D_T
Application Type	A_T
Application Priority	A_P
Coverage Area	C_A
Criticality	C_R
Normalize Weights	N_W
Normalized Priorities	N_P
Multiple Inputs and extract Multiple Outputs	MIMO
Multiple Inputs and extract a Single Output	MISO

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