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A Self-Optimizing Fuzzy Logic Model For Managing Vertical Handover In Heterogeneous Mobile Cellular Networks

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Abstract

Network optimization is an ongoing process crucial to maintaining Quality of Service in Heterogeneous Networks (Het-Nets). Vertical Handover Optimization (VHDO) specifically addresses mobility-related challenges to ensure seamless service. To further mitigate congestion and enhance VHDO, a mathematical model was developed, designed to function as an intelligent system capable of learning, adaptation, and decision-making. This model also generates algorithms for various VHDO scenarios. The research reviewed existing optimization models and related works, including Multi-Attribute Decision-Making approaches, Pareto optimality (from game theory), and type-2 fuzzy logic, aligning them with the study's theoretical foundation. Data analysis and testing were conducted using a nondeterministic approach, involving data discretization and model simulation. The findings and scenarios demonstrated the effectiveness of the proposed model. The study concludes with a summary of enhancements and provides recommendations for future research directions in optimizing vertical handovers within Het-Nets.

Keywords: Vertical Handover Optimization (VHDO), Heterogeneous Networks (Het-Nets), Type-2 Fuzzy Logic, Multi-Criteria Decision Making, Pareto Principle

Introduction

Vertical handover is critical for enabling seamless transitions between different mobile operators without losing connectivity, as highlighted by [1]. This process allows mobile devices to roam between cells and operators using a handoff mechanism within cellular networks, thereby facilitating increased cell boundary crossings, especially in densely deployed small geographical areas with enhanced capacity. Horizontal handoff, on the other hand, occurs within the same link layer technology, primarily involving machine-to-machine (M2M) communication [2]. In heterogeneous wireless networks (HWNs), the Radio Resources Management (RRM) mechanism plays a pivotal role in selecting the most reliable and high-performing Access Network (AN) for a handoff service request, known as Vertical Handoff (VHO) [3]. This process is particularly challenging in heterogeneous cellular networks, where mobile subscribers need to switch between different network technologies, such as WiMAX, Wi-Fi, and UMTS/LTE [4]. Despite the integration of Heterogeneous Networks, handover management remains a significant issue for both academia and the mobile telecommunications industry [5,6,7]. The goal of this research is to design an enhanced model that allows for the consideration of additional metrics to achieve seamless handover and improved spectrum management in heterogeneous wireless networks.

REVIEW OF RELATED WORKS

This section reviews various studies conducted by researchers across different generations of networks, from analog (1G) to digital (4G) and extending to 5G. It delves into the underlying theories supporting self-optimization in VHO and identifies the gaps that this research aims to address, as summarized in a table that aligns with the research objectives, summary, and findings.

Key Performance Indicators (KPIs) Based on Quality of Service Metrics

Quality of Service (QoS) KPIs are essential for evaluating network performance from the user's perspective, as outlined by [8]. These KPIs are organized into six phases:

a. **Network Availability**: The probability that a network service is available when required by the subscriber.
b. **Network Accessibility**: The likelihood that a service consumer is successfully registered on the network.
c. **Service Accessibility**: The ability of an end-user to set up calls and access radio resources, measured by call setup rate and time.
d. **Service Integrity**: The quality of service experienced by the user, encompassing metrics that describe service quality.

e. **Service Retainability**: The ability to maintain a call regardless of the subscriber's will, with KPIs including call dropping rate and holding time

f. **Network Coverage**: The probability that the system service is available in a specific geographic location, meeting all KPI conditions.

Game Theory Application in Self-Optimization

Game theory, as defined by [9], involves the study of mathematical models of strategic interaction between rational decision-makers. It has applications across social sciences, logic, and computer science. Initially focusing on zero-sum games, where one participant's gain is another's loss, game theory has broader implications in self-organizing optimization (self-optimization) in cognitive networks [10]. It offers:

- **Modeling and Analysis**: Of interactions among multiple decision-makers.
- **Prediction and Control**: Of game outcomes to enhance system performance by managing the utility function and action updates of individual decision-makers.

The optimization models developed for mitigating GSM congestion in Nigeria significantly enhance service providers' ability to deliver quality services [11]. However, GSM self-optimized algorithms must be continually improved to meet increasing service quality demands. On handover optimization, [12] emphasized the growing challenges in handover performance due to the daily increase in mobile terminals, which contributes to network congestion. [13] proposed a combined scheme of fuzzy logic and TOPSIS for multi-criteria vertical handover in heterogeneous networks, resulting in an adaptive, flexible, and scalable algorithm. However, the limitation of fuzzy logic hindered accurate results. Similarly, Sunisa and Raungrong [14] studied vertical handover decision management using Learning Vector Quantization Neural Network (LVQNN), considering criteria for real-time and non-real-time services in diverse network scenarios. However, they did not incorporate additional handover parameters beyond the Received Signal Strength Indicator (RSSI).

THE SEVEN MEMBERS OF HET-NET, 1-4G, AND HOW IT ALL STARTED

Wi-Fi, short for Wireless Fidelity, is a wireless network technology used to connect devices to the internet and each other without the need for cables. It is based on the IEEE 802.11 standard for Wireless Local Area Networks (WLAN). Wi-Fi networks transmit data using radio waves, with various standards such as IEEE 802.11b, 802.11a, and 802.11g, each offering different speeds and ranges. For example, IEEE 802.11b, introduced in 1999, operates on the 2.4 GHz spectrum and provides speeds of up to 11 Mbps. However, it is prone to interference from other devices. IEEE 802.11a, released in 2001, operates on the 5 GHz spectrum, offering faster speeds (up to 54 Mbps) and better performance, though with a shorter range. IEEE 802.11g, introduced in 2003, combines the advantages of both previous standards, offering compatibility with 802.11b and faster speeds at a range of up to 150 feet indoors.

A typical Wi-Fi network comprises several elements, including access points (A.P.), which function like base stations linking devices to the internet, and Wi-Fi cards (internal or external), which allow devices to send and receive radio signals. The elements of a Wi-Fi network also include antivirus and firewall software to protect against unauthorized access, and various network topologies like peer-to-peer (ad-hoc mode), which allows devices to communicate directly without an A.P. Hotspots are specific geographic locations equipped with A.P.s, providing internet access via Wi-Fi.

Worldwide Interoperability for Microwave Access (WiMAX): WiMAX, an acronym for Worldwide Interoperability for Microwave Access, is a technology based on the IEEE 802.16 standard, designed for wireless metropolitan area networks (MANs). WiMAX enables high-speed internet access over long distances, supporting both fixed and mobile connections. Initially introduced in 2001, the IEEE 802.16 standard allowed for fixed WiMAX with a roof-mounted antenna, providing data communication across various transmission modes, including point-to-point and full cellular coverage. Later, the standard was upgraded to include mobile WiMAX (IEEE 802.16e), which supports mobility, allowing users to maintain connectivity while on the move (ALECU, 2010).

UMTS/LTE/WLAN: Universal Mobile Telecommunication Service (UMTS) is a third-generation (3G) wireless network that facilitates advanced services like video conferencing, video calls, and online gaming. UMTS operates on Time Division Multiple Access (TDMA) technology and represents a significant leap from the second-generation (2G) networks, which primarily supported digital transmission. With the advent of UMTS in the early 2000s, data transmission speeds improved significantly, reaching up to 2 Mbps, addressing the limitations of 2G networks, which were inadequate for multimedia services requiring fast internet connections. Despite the emergence of 4G networks, UMTS remains widely used, particularly in developing countries.

Historical Background of UMTS: The development of UMTS began with the Research and Development in Advanced Communication Technologies in Europe (RACE) initiative in 1987, aimed at building a global information network. The European Telecommunications Standards Institute (ETSI) developed the initial UMTS standards in 1991, later handed over to the Third Generation Partnership Project (3GPP) in 1998. 3GPP standardized UMTS Terrestrial Radio Access (UTRA), which operates on both Time Division Duplex (TDD) and Frequency Division Duplex (FDD) modes. Japan was the first country to deploy a commercial 3G network in 2001, with NTT DoCoMo launching the first Wideband Code Division Multiple Access (WCDMA) system. UMTS supports a wide range of devices, including PCs, tablets, laptops, and mobile phones.

UMTS ARCHITECTURE: UMTS architecture comprises several logical components, organized into the core network (CN), User Equipment (UE), and UTRAN (UMTS Terrestrial Radio Access Network). The UMTS architecture builds upon the existing GSM network, integrating the General Packet Radio Service (GPRS) to enhance data services. This architecture allows UMTS to offer improved data rates and support for a broader range of services compared to GSM, making it a crucial step forward in mobile communication technology (Rhee, 2009).

The Evolution of Wireless Networks: UMTS, HSPA, LTE, and Wi-Fi

Wireless networks have undergone significant evolution, from basic Wi-Fi standards to advanced mobile networks like UMTS, HSPA, and LTE. These technologies have been instrumental in providing high-speed internet access, enabling complex online services, and supporting the ever-growing demand for mobile data.

Wi-Fi Standards and Their Properties

Wi-Fi, an abbreviation of Wireless Fidelity, is a widely used wireless technology for connecting devices to the internet. It operates on the IEEE 802.11 standard and has evolved through several versions:

- **IEEE 802.11b**: Introduced in 1999, it operates at 2.4 GHz with a theoretical speed of 11 Mbps and a range of 100-150 feet. It's the most popular and cost-effective standard, though it suffers from interference from other devices like mobile phones and Bluetooth.
- **IEEE 802.11a**: Launched in 2001, it operates at 5.0 GHz with a theoretical speed of 54 Mbps but a shorter range of 50-75 feet. It is not compatible with 802.11b and is more expensive.
- **IEEE 802.11g**: Released in 2003, it combines features of both 802.11b and 802.11a, offering a speed of 54 Mbps at 2.4 GHz with a range of 100-150 feet.

Wi-Fi networks consist of several key elements:

- **Access Point (AP)**: Acts as a base station, linking multiple devices to the internet.
- **Wi-Fi Cards**: These can be internal or external and facilitate communication between devices and the AP.

- **Antivirus and Firewalls**: Essential for protecting the network from unauthorized access.
- **Wi-Fi Topologies**: Include peer-to-peer (ad-hoc) and hotspot topologies, which define how devices connect and interact within a Wi-Fi network.

Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is a wireless communication standard designed for providing high-speed internet access over long distances. It operates on the IEEE 802.16 standard, developed by Intel and Alvarion, and offers various modes of transmission, including point-to-point and broad cell access. The standard has evolved from fixed WiMAX (802.16d) to mobile WiMAX (802.16e), allowing for enhanced mobility and broader coverage.

Universal Mobile Telecommunication Service (UMTS)

UMTS is a third-generation (3G) wireless network that revolutionized mobile communication by offering higher data speeds and supporting advanced online services like video streaming and conferencing. It operates on Time Division Multiple Access (TDMA) and was developed as part of the European Union's Research and Development in Advanced Communication Technologies in Europe (RACE) project in 1987. The UMTS architecture builds on existing GSM networks, incorporating General Packet Radio Service (GPRS) and offering improved data rates of up to 2 Mbps. It supports a range of devices, including personal computers, tablets, and smartphones.

Table 1: GSM applications and their level of compliance

UMTS Target	GSM Compliance
Small affordable hand portables	Yes
Deep penetration (50%)	Yes
Anywhere, anytime (indoor, office)	Yes
Anywhere, Satellite mobile interwork	Yes
Hotspot capacity	Yes
Wireline voice quality	Yes
Global roaming	Yes
IN Services	Yes
Multimedia, entertainment, non-voice	Yes
Flexibility to mix different types (non-real-time and real-time)	No
High bit rate services (200 Kbps)	No

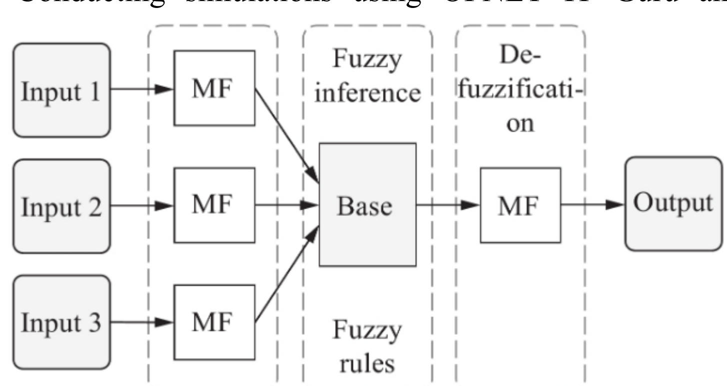
High-Speed Packet Access (HSPA) and Long-Term Evolution (LTE): The growing demand for mobile broadband has led to the development of technologies like HSPA and LTE. These technologies focus on improving network capacity and efficiency by either adding extra spectrum or enhancing the utilization of existing spectrum resources.

HSPA Enhancements: 3GPP (Third Generation Partnership Project) has made significant advancements in HSPA, leading to better cell edge performance, increased network efficiency, and higher peak data rates. Some key features include: Supports up to four downlink carriers in Release 10, with Release 11 allowing up to eight carriers. Enhances data rates at the cell edge by allowing simultaneous downloads from multiple base stations. Uses dual antenna beamforming and MIMO (Multiple Input Multiple Output) to improve uplink data rates and overall network performance.

LTE Advancements: LTE has made significant strides in mobile communication, offering higher data rates and improved network efficiency. Key features include: Allows up to 100 MHz of total LTE bandwidth in the downlink in Release 10, with further enhancements in Release 11. Supports offloading between the macro network and local access links, improving overall network efficiency. Enhance network management and reduce interference. These advancements in HSPA and LTE have been crucial in meeting the increasing demand for mobile broadband, ensuring seamless coverage, and optimizing network performance.

Research Methodology

This study aims to develop a fuzzy-based self-optimizing model for seamless vertical handover (VHO) in heterogeneous wireless networks. The model will use fuzzy logic to address the uncertainties in handover parameters, such as Signal to Noise Ratio (SNR), Received Signal Strength Indicator (RSSI), and bandwidth. The methodology includes: Creating a model for network congestion scenarios using Multi-Attribute Decision Approach (MADA) and implementing it via TOPSIS. Developing algorithms for VHO optimization across different wireless technologies like WiMAX, Wi-Fi, LTE, and HSPA. Conducting simulations using OPNET IT Guru and benchmarking the results against existing theses.This new model is necessary due to the dynamic nature of mobile networks, the phasing out of traditional handoff schemes, and the



impending deployment of 5G technology. **Figure 1: Block diagram of the fuzzy logic module**

Ethical Considerations: This study was conducted in strict adherence to the guidelines of the Babcock University Health Research Ethics Committee (BUHREC). It ensured the preservation of privacy and data confidentiality by using anonymized data, thereby eliminating any risk of harm to participants. The research is anticipated to benefit society by enhancing the economic value of Quality of Service (QoS) provision by mobile operators and improving the Quality of Experience (QoE) for mobile subscribers. Moreover, this study aligns with the mobility-oriented handover optimization procedures outlined by regulatory bodies, particularly the Nigerian Communications Commission (NCC) and the International Telecommunications Union (ITU).

Fuzzy Rule Architecture: In the context of this study, fuzzy logic was applied to decision-making processes involving variables that are probabilistic or stochastic in nature. The fuzzy logic system allows for varying degrees of uncertainty and membership functions, particularly in the realm of handover decisions. Each value—Low (L), Medium (M), and High (H)—is represented by a binary system where Low is 0, High is 1, and Medium (M) represents a degree between 0 and 1, denoted as a probabilistic value. This system supports Multi-Attribute Decision Making (MADM), incorporating methods such as Simple Additive Weighting (SAW), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Weighted Product Method (WPM) to optimize vertical handover (VHO) scenarios, aiming for the "Always Best Connected Network" based on the attributes of each candidate network.

Tables for Fuzzy Rule Architecture

Table 2: Fuzzy Rule Architecture for Wi-Fi

Speed	QoE	QoS	Latency	Battery	Handover Probability
Low	Medium	Medium	Medium	Medium	Probably Yes
Low	Medium	High	Medium	Low	Probably Yes

Table 3: Fuzzy Rule Architecture for LTE/HSPA or LTE

Speed	QoE	Energy/Battery	Latency	Handover Probability
Low	Medium	Medium	Medium	Probably Yes
Low	Medium	High	Medium	Probably Yes

In these tables, each value (Low, Medium, High) corresponds to binary values where Low is 0, High is 1, and Medium is represented by a value between 0 and 1, depending on the context of the decision.

Legend

- **0 (Low)**: Represents total exclusion or the lowest membership level.
- **1 (High)**: Indicates full membership or the highest level.
- **M (Medium)**: Represents a probabilistic value between 0 and 1, allowing for a degree of uncertainty.

Handover Decision Parameters

The handover decision in mobile networks is influenced by several factors, including Received Signal Strength (RSS), Bandwidth, Quality of Service (QoS), and Network Coverage. These parameters are critical in determining the optimal point for handover, ensuring that mobile subscribers remain connected to the best available network. As cited by Geutam, Unnkrishnan, Prabavathy, and Kudu (2019), these elements collectively determine the effectiveness of handover mechanisms, particularly in heterogeneous wireless environments where seamless connectivity is crucial.

$$HV = f(RSS + Bandwidth + QoS + NC) \quad (1)$$

In multivariate linear regression, equation (1) can be written as

$$HV = \lambda_0 + (\lambda_1 * RSS) + (\lambda_2 * B) + (\lambda_3 * NC) + (\lambda_4 * QoS) \quad (2)$$

Where HV denotes Handover Value, RSS is Received Signal Strength, B is Bandwidth, NC is Network Coverage, and QoS is Quality of Service. QoS is a function of Latency (L), Jitter (J), and Packet Loss (PL): QoS = f(L, J, PL).

$$QoS = f(L + J + PL) \quad (3)$$

By multivariate linear regression, equation (3) can be written as

$$QoS = \Theta_0 + (\Theta_1 * L) + (\Theta_2 * J) + (\Theta_3 * PL) \quad (4)$$

Ethical Considerations

This study adhered to the ethical standards set by the Babcock University Health Research Ethics Committee (BUHREC). Privacy and data confidentiality were strictly maintained through the use of anonymized data, ensuring no harm to participants. The research aims to benefit the community by enhancing Quality of Service (QoS) and Quality of Experience (QoE) for mobile subscribers. It also supports policy development related to handover optimization procedures as per guidelines from regulatory bodies like the Nigerian Communications Commission (NCC) and the International Telecommunications Union (ITU).

Fuzzy Rule Architecture

Table 4: Fuzzy Rule Architecture for Wi-Fi

Speed	QoE	QoS	Latency	Battery	Handover (Probability)
Low	Medium	Medium	Medium	Medium	Probably Yes
Low	Medium	High	Medium	Low	Probably Yes

Table 5: Fuzzy Rule Architecture for LTE/HSPA

Speed	QoE	Energy/Battery	Any Other Metric	Latency	Handover (Probability)
Low	Medium	Medium	Medium	Medium	Probably Yes
Low	Medium	High	Medium	Low	Probably Yes

Note: In fuzzy logic notation, Low (L) is represented as 0 and High (H) as 1. If L = 0 and H = 1, Medium (M) is typically denoted as 0.5.

Model Implementation

Model Validation Method: Model validation can be executed using Pareto charts or Pareto distribution diagrams, which include bar graphs, histograms, or flowcharts. In bar charts (Pareto distribution diagrams), variables are plotted in descending order of frequency or importance. This visualization helps in analyzing the primary challenges of vertical handover optimization in heterogeneous networks (Het-Nets). For this study, input variables are VHDO parameters with data extracted from Globacom Nigeria Limited. The variables are ranked by frequency, with Quality of Service (QoS) emerging as the most critical factor.

Findings and Interpretation: Quality of Service (QoS) is identified as the variable with the highest frequency, followed by Cost. The prominence of QoS may vary with different data sets or models. The proposed mathematical model is a non-deterministic model following a data mining approach.

Model Validation: Model validation ensures that a mathematical model accurately represents a real system, imitating system behavior reliably. Validation involves:

- **Assumptions:** Evaluating the foundational assumptions of the model.
- **Input Parameter Values and Distributions:** Checking the accuracy and relevance of input data.
- **Output Values and Conclusions:** Ensuring that the model's outputs align with expected results.

Validation techniques include expert intuition, real system measurements, theoretical results, and ad-hoc methods tailored to specific models.

Mathematical Model Validation: Mathematical model validation is critical for developing accurate representations of physical systems. It replaces costly simulations with accurate model predictions, essential for vertical handover optimization given the multi-criteria nature of the system. The model must ensure that modifications produce acceptable system behavior.

Techniques for Verification and Validation of Non-Simulation Models

Data Validity: Data is crucial for developing and validating conceptual models. Accurate data collection and maintenance are essential for reliable model validation. Challenges include ensuring data precision and completeness.

Conceptual Model Validation: Validating a conceptual model involves verifying that: a. Theories and assumptions underlying the model are accurate. b. The model's representation and structure realistically address the defined problem.

Effective model validation involves rigorous data handling, verification of assumptions, and alignment with real-world behavior to ensure the model's utility in optimizing vertical handovers in heterogeneous networks. Vertical handover (VH) management in heterogeneous networks (HetNets) is a critical aspect of ensuring seamless user experience and efficient resource utilization. As the number of heterogeneous networks, such as Wi-Fi and cellular networks, proliferates, the complexity of managing VH decisions increases. Traditional handover mechanisms often struggle to adapt to dynamic network conditions and prioritize multiple quality of service (QoS) metrics. To address these challenges, this study proposes a fuzzy-based self-optimizing model for VH management in HetNets.

Model Formulation: The proposed model leverages fuzzy logic to handle the inherent uncertainties and complexities associated with VH decisions. Fuzzy logic allows for the representation of imprecise or vague information, making it well-suited for capturing the subjective nature of QoS metrics and network conditions.

The model incorporates the following key components:

a. **QoS Metrics:** The model considers a set of relevant QoS metrics, including latency (L), jitter (J), and packet loss (PL). These metrics are essential for evaluating the performance of different networks and making informed handover decisions.
b. **Fuzzy Sets:** Fuzzy sets are defined for each QoS metric, representing different linguistic terms such as "low," "medium," and "high." These sets capture the subjective nature of QoS perception and allow for flexible decision-making.

c. **Membership Functions:** Membership functions are defined for each fuzzy set, assigning degrees of membership to different values of the corresponding QoS metric. These functions quantify the degree to which a particular value belongs to a given fuzzy set.
d. **Fuzzy Rules:** Fuzzy rules are established to relate the fuzzy sets of QoS metrics to the decision of whether to initiate a VH. These rules capture expert knowledge and decision-making logic.
e. **Inference Engine:** The inference engine processes the fuzzy rules and membership values to generate a fuzzy output representing the degree to which a VH should be initiated.
f. **Defuzzification:** The fuzzy output is defuzzified to obtain a crisp decision regarding VH initiation.

Model Implementation and Validation: The proposed model is implemented using a suitable fuzzy logic toolkit, such as MATLAB or Python. The model is validated using real-world data collected from a heterogeneous network environment. Pareto charts or distribution diagrams can be employed to analyze the frequency of different problem areas related to VH optimization.

Model Validation Techniques:

a. **Expert Intuition:** Validation through the insights and judgments of domain experts.
b. **Real System Measurements:** Comparison of model predictions with actual network performance data.
c. **Theoretical Results:** Verification of model outputs against established theoretical frameworks.
d. **Combination of Techniques:** A combination of these methods can be used for comprehensive validation.

Findings and Interpretation: The validation process involves comparing the model's predictions with actual network behavior. Key findings may include:

a. **Identification of critical QoS factors:** The model may reveal which QoS metrics have the most significant impact on VH decisions.
b. **Assessment of model accuracy:** The model's accuracy in predicting optimal VH decisions can be evaluated.
c. **Comparison with existing methods:** The performance of the fuzzy-based model can be compared to traditional VH mechanisms.

The proposed fuzzy-based self-optimizing model offers a promising approach for vertical handover management in heterogeneous networks. By effectively handling uncertainties and incorporating multiple QoS metrics, the model can improve network performance, enhance user experience, and optimize resource utilization. Further research and experimentation are needed to refine the model and explore its applicability in various network environments.

Combined Tabular Form for Fuzzy Logic System Parameters and Handover Decision Criteria

Table 6: Universe of Discourse for Parameters of Fuzzy Inference System (FIS)

Parameter	Minimum Values	Maximum Values
RSS (dBm)	-98	-86
Bandwidth (Mbps)	1	12
Network Coverage (Meters)	1	150
QoS	0	7
Latency (M/Sec)	0	6
Jitter (M/Sec)	0	6
Packet Loss (%)	0	6

Table 7: Members of Het-Net

UMTS/WLAN/LTE	WiFi	HSPA	WiMax	WCDMA	3G	4G
✓	✓	✓	✓	✓	✓	✓

Table 8: Handover Decision Criteria for WCDMA

RSSI	Bandwidth	MS	MC	Handover Decision
L	M	L	L	HO
L	H	L	L	HO
M	L	L	L	L
H	L	L	L	L
M	M	L	L	HO
M	M	M	L	HO
M	M	H	L	NOHO
H	M	L	M	NOHO
H	M	L	H	NOHO

Table 9: Handover Decision Criteria for WLAN/LTE

RSSI	Bandwidth	MS	MC	Handover Decision
L	M	L	L	HO
L	H	L	L	NOHO
M	L	L	L	NOHO
H	L	L	L	NOHO
M	M	L	L	NOHO
M	M	M	L	NOHO
M	M	H	L	HO
H	M	L	M	NOHO
H	M	L	H	NOHO

Table 10: Comparison of Handoff Simulation Parameter Values for Heterogeneous Networks

Parameters	WCDMA	LTE	WLAN
Frequency (GHz)	2.1	2.6	2.4
Coverage Area (m)	5000	1000	100
Transmission Power (W)	1.0	0.5	0.1
Bit Rate (Mbps)	0.384	35	54
Latency (ms)	35	25	3
Mobile Speed (m/s)	80	130	5
Bit Error Rate (per 10^8)	50	100	200
Monetary Cost Rate ($)	0.8	0.7	0.4

Handover and Fuzzy Logic System Parameters: The data provided in Tables 6 to 10 offer a comprehensive overview of the parameters relevant to fuzzy inference systems (FIS) and handover decision-making in heterogeneous networks (Het-Nets). These tables highlight crucial metrics including signal strength, bandwidth, network coverage, and Quality of Service (QoS), alongside comparative handover criteria across various network technologies.

Universe of Discourse for Fuzzy Inference System Parameters: This table delineates the range of values for critical parameters utilized in the fuzzy inference system. The parameters—Received Signal Strength (RSS), Bandwidth, Network Coverage, QoS, Latency, Jitter, and Packet Loss—are all essential in evaluating the performance of network handovers. The specified ranges provide a basis for setting the operational thresholds and determining the system's response under varying conditions. For instance, RSS values range from -98 dBm to -86 dBm, which indicates the system must operate effectively within a low signal strength range. Bandwidth spans from 1 Mbps to 12 Mbps, reflecting varying data transmission capacities that can impact handover decisions. The QoS range of 0 to 7, combined with latency, jitter, and packet loss ranges, underscores the diverse network performance factors that the fuzzy logic system needs to accommodate.

Members of Het-Net: This table lists the network types within the heterogeneous network (Het-Net) environment. It includes Universal Mobile Telecommunications System (UMTS), Wireless Local Area Network (WLAN), Long-Term Evolution (LTE), WiFi, High-Speed Packet Access (HSPA), WiMax, Wideband Code Division Multiple Access (WCDMA), 3G, and 4G. The inclusion of multiple network types emphasizes the complex environment in which vertical handovers occur, necessitating a versatile approach to handle diverse network characteristics and requirements.

Handover Decision Criteria for WCDMA: This table illustrates the decision-making criteria for handovers within the WCDMA network. The criteria are based on RSSI (Received Signal Strength Indicator), Bandwidth, Mobile Speed (MS), and Mobility Class (MC). The decision outcomes—Handover (HO) or No Handover (NOHO)—are dependent on these parameters. For example, when RSSI is low and Bandwidth is medium, a handover decision is made, whereas a high RSSI combined with high Bandwidth and other factors results in a "No Handover" decision. This indicates that the WCDMA network has specific thresholds for making handover decisions based on varying signal and network conditions.

Handover Decision Criteria for WLAN/LTE: This table presents handover decision criteria for WLAN and LTE networks, showing how different combinations of RSSI, Bandwidth, MS, and MC affect the handover decision. For instance, a low RSSI with medium Bandwidth in a WLAN/LTE network typically results in "Handover," whereas high RSSI and high Bandwidth might lead to "No Handover" decisions. This table illustrates that WLAN/LTE networks have distinct criteria from WCDMA, emphasizing the need for tailored handover strategies across different network technologies.

Comparison of Handoff Simulation Parameter Values for Heterogeneous Networks: The table compares key parameters across WCDMA, LTE, and WLAN networks. It highlights significant differences in frequency, coverage area, transmission power, bit rate, latency, mobile speed, bit error rate, and monetary cost rate. For instance, WCDMA offers a broad coverage area but with higher latency and bit error rates compared to LTE, which provides higher bit rates and lower latency but with a smaller coverage area. WLAN, on the other hand, has the smallest coverage area but the highest bit rate and lowest latency. These differences underline the trade-offs between network performance metrics and costs, which are critical for optimizing handover decisions. These tables provide valuable insights into the parameters influencing fuzzy logic-based handover decisions in Het-Nets. The results underscore the necessity for a nuanced approach to managing handovers across various network types, considering the specific characteristics and requirements of each network technology. Understanding these parameters aids in developing more effective handover strategies, ultimately enhancing network efficiency and user experience.

Conclusion

Vertical handover optimization (VHDO) is intrinsically linked to mobility and requires a robust approach for enhancing its efficacy. To advance the vertical handover process, a mathematical model incorporating various algorithms for different vertical handover scenarios has been developed. This model supports self-organizing networks by facilitating learning, adaptation, and decision-making processes.

Recommendations

1. The detailed implementation of the proposed mathematical model in both theoretical and practical settings will assist network providers, modelers, and system analysts in making informed decisions.
2. It is recommended that future research consider additional model validation methods, such as expert intuition, real system measurements, and theoretical results, or combinations thereof, to enhance the robustness of VHDO models.

Contribution to Knowledge: The study demonstrates that VHDO decision-making is significantly improved through the application of game theory, Pareto optimality principles, and Type 2 fuzzy logic, all of which address high degrees of uncertainty.The incorporation of multi-criteria or multiple parameters has refined the decision-making logic in vertical handover optimization scenarios. Data discretization has facilitated the quantification and analysis of discrete VHDO parameters, contributing to more precise optimization. A comprehensive mathematical model incorporating key VHDO parameters was developed to aid the vertical handover optimization process effectively.

Limitations of the Study and Further Work: The use of simulated data may have limited the accuracy of the study's outcomes to some extent. Interference remains a significant factor affecting signal strength and quality in cognitive heterogeneous networks, warranting further investigation. This summary encapsulates the key aspects of the study, highlighting its contributions, recommendations, and limitations while maintaining the original structure and focus.

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