

Soft Computing-Based Schemes for Handover Management in Future Networks

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ABSTRACT

The progression to next generation networks is replete with abundant co-existing technologies. To comply with the always best connected paradigm, several vertical handover decision approaches have been proposed in literature, using advanced techniques and tools. This paper discusses the application of soft computing techniques in the vertical handover decision-making process with emphasis on the state-of-the-art techniques. For a comprehensive evaluation, the algorithms are classified into three sets based on the soft computing technique used, namely fuzzy logic, machine learning, and evolutionary algorithms, and representative handover algorithms in each group are discussed. These papers are categorized in a well-defined structure to bring out their contribution, to underline the pretermitted notions, and to bring forth the emerging issues for future research. This paper summarizes the soft computing concepts and reviews its applications in candidate network selection, QoE enhancement, and reducing the unnecessary handovers.

KEYWORDS

Evolutionary Algorithm, Future Networks, Fuzzy Logic, Heterogeneous Wireless Networks, Machine Learning, Mobility Management, Soft Computing, Vertical Handover

INTRODUCTION

Recent advances in technologies have witnessed the emergence of mobile and wireless networks, including mobile ad hoc networks, vehicular networks, 5G cellular networks, etc., which have the probability to facilitate several novel mobile and wireless services and applications (Agiwal et al., 2016), (Fersi et al., 2013). We have transcended into an era where computers are essentially involved in our daily lives (Augusto, 2010). The incessant technological advancements in ICT (Information and Communications Technology) has initiated the development of computing devices of various types to be embedded in different devices that we interface with and use (Aztiria et al., 2011). The rapidly growing network of connected objects such as home appliances, actuators, electronic gadgets that are able to accumulate and transfer data using in-built sensors has evolved into IoT (Internet of Things) (Čolaković & Hadžialić, 2018). The IoT with smart objects of computational and communication capabilities built into everyday things has immense applications in our daily lives (Guo et al., 2012).

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In a similar sense AmI (Ambient Intelligence) that is built upon pervasive computing, ubiquitous computing, context awareness has enabled an environment where technology gradually disappears into the surroundings and provides integrated solutions(Cook et al., 2009),(Liu, et al.,2017).

The Internet architecture is the backbone for these services and needs to be constantly updated to offset the future challenges (Al-Fuqaha et al., 2015).In order to realize these contemporary paradigms, the requisite features are gradually developed and integrated into the infrastructure, thereby transforming it into an infrastructure for providing constant connectivity for these services. The demand for constant connectivity necessitates the adoption of wireless technologies. The increased adoption of wireless technologies is basically due to factors such as increased proliferation and access of smart devices, availability of multifarious networking interfaces and availability of numerous wireless heterogeneous technologies, like, LTE, Wi-Fi, wireless interoperability for microwave access (WiMAX) and Universal Mobile Telecommunication System (UMTS)(Tuncer et al.,2012). The next-generation networks portray a heterogeneous environment with the prevalence of diverse access networks technologies that vary in terms of latency, throughput, cost or bandwidth(Mahmood et al.,2018) .With the unprecedented rise in user demands for bandwidth and the meteoric rise in the number of bandwidth warranting applications such as video streaming and multimedia, the extents of the current systems are being tested(Tehrani et al., 2014).Many applications also expend huge amounts of network resources and create several significant issues for heterogeneous wireless networks. These include mobility management, interoperability, Quality of Service and provision of Quality of Experience (QoE) .The challenge is to provide robust services in hugely dynamic environments and to develop applications and lightweight algorithms which are intelligent and self adaptive.

MOBILITY MANAGEMENT SCENARIO IN FUTURE NETWORKS

Mobility is an essential feature of Next Generation wireless network systems. Mobility Management techniques that support Quality of Service (QoS) are an obligatory feature in Next Generation Networks (NGN) because users are required to be able to move between divergent networks employing different technologies (Mueller et al., 2012). Hence deciding upon the relevant access network is an intricate task for the users since network conditions are apt to change rapidly. Moreover, a provision of appropriate connection for diverse types of applications with varying requirements for bandwidth as well as functioning of real-time and non real-time applications is a liability. Multi-access Edge Computing (MEC) or Mobile Edge Computing is one such technology that addresses these issues by transporting the processing and storage abilities of the cloud to the edge of the mobile network (Satyanarayanan, 2017). The key attribute of MEC is to drive the computation task facility, network storage and control to the network edges. These are the base stations and access points that facilitate the servicing of computation exhaustive and latency-critical applications away from the mobile devices with limited resources. This proximity to end users permits quick response to dynamic changes in the network environment (Rimal et al., 2017).MEC depicts significant reduction in latency and mobile energy consumption, thus enabling the key requirements for implementing the 5G vision (Mao et al., 2017).

With the unprecedented growth in the count of mobile users, wireless access technologies are developing to provide exalted data rates and to support diverse applications. Subsequently 5G is contemplated as a solution to provide users with high coverage and enhanced network capacity, by facilitating the integration of heterogeneous networks, that may exhibit different wireless access technologies or coverage area sizes(Akkari&Dimitriou,2020) .5G has evolved gradually with the ability to provide many more adequate services than 4G. Encompassing many fundamental performance enhancement mechanisms since 4G, it has already been deployed in many parts of the world. The complete deployment of 5G worldwide is expected at the close of 2020. To overcome the shortcomings of 5G, a sixth-generation (6G) wireless system will need to be reinforced with salient features, such as network densification, augmented throughput, reduced energy consumption, and substantial connectivity(Chowdhury et al.,2019). The 6G system would proceed with the trends

of the preceding generations, with the amalgamation of new services and technologies including Artificial Intelligence, smart wearable gadgets, implants, autonomous vehicles, sensing, and 3D mapping (Saad et al., 2019). This expanding count of mobile devices is going to cause significant amends to applications running on the networks as well as the infrastructures. A fundamental design goal of such mobile networks is to facilitate and assist in seamless access and handover for existent and emerging services. It therefore becomes mandatory to address the complexities of evolving network architectures while also taking into consideration the requirements of the developers and users (Beshley et al.,2021). This is also a challenging aspect in dealing with the issues of seamless Internet connectivity in High Speed Trains with user demanding connectivity while onboard trains. High speed train wireless networks are confronted with ordeals such as high node mobility, track-side obstacles such as track side trees, buildings, etc. (Banerjee, 2016).Thus railways prefer network heterogeneity to offer seamless connectivity to their passengers. Improvisation of intelligent features in mobility management techniques and solutions are needed to handle various new concerns such as location update, signaling overhead, handover latency, security, and privacy (Chen et al., 2017).

BACKGROUND

Wireless networks have emerged as the quintessential technology in the pursuit for ubiquitous connectivity, empowered by the vision of being Always Best Connected (ABC), i.e. getting uninterrupted service at all times(Lahby et al., 2012). Presently a very eclectic mix of radio access technologies is available for broadband wireless access and they all support mobility. To realize the ABC concept, there has to be a close integration between the heterogeneous cellular networks (WCDMA,GPRS, LTE, WiMAX) and wireless local area networks (WLANs), so that the users might link to the best accessible heterogeneous access technologies(Haider et al.,2013). To achieve this seamless interoperability among these heterogeneous technologies, the employment of distinct vertical handover (VHO) techniques is imminent. A handover takes place whenever a mobile node goes from one wireless cell to another, discarding the connection with the initial base station and getting attached to the new one. A vertical handover pertains to handover among heterogeneous wireless access networks (Barja et al., 2011).

Seamless mobility in heterogeneous networks, depends not only on the handover initiation time, but also on selection of the most optimal network based upon certain suitable criterion for the handover (Chandavarkar & Reddy.,2012).A handover scheme is essential to sustain connectivity as the mobile terminals move about, while simultaneously curb any disturbances to ongoing transfers(Dhand et al.,2021). Therefore, an optimal handover scheme must demonstrate low latency; protract minimal data losses with the ability to even scale large networks while maintaining the cost at a minimum. A vertical handover (VHO) decision process ascertains when and where to embark upon a handover in a heterogeneous network (Kassar et al., 2008). Different options are evaluated on the basis of decision criteria that may include user specifications and preferences, network conditions, application requirements in terms of bandwidth or latency and terminal capabilities. For this there are many methodologies like Fuzzy Logic and Neural Networks, context-aware approaches etc., that can be explored.

SOFT COMPUTING TECHNIQUES FOR VERTICAL HANDOVER DECISION MAKING

Soft Computing is a heterogeneous collection of concepts, techniques and applications. Its main aim is to exploit the uncertainties, impreciseness in complex real life problems and deliver reliable, robust and low cost solutions. Soft computing techniques comprise of fuzzy logic, genetic algorithms, artificial neural networks, machine learning, and expert systems (Ibrahim, 2016). Soft computing techniques exhibit features that can achieve outstanding performance in the evolvement of intelligent

and automatic heterogeneous networks that effectively solve problems such as resource management, fault tolerance etc. Subsequently these techniques are being extensively applied to heterogeneous networks for optimization of networks in disparate settings and intricate environments.

Application of Fuzzy Logic Techniques in Handover Process

Fuzzy Logic (FL) is an approach that attempts to solve problems with imprecise data and makes it possible to obtain accurate solutions. Fuzzy logic can be used in VHO decisions. Fuzzy Logic techniques are applied to choose when and to which network to handover among different prospective networks. These can be conjoined with multiple criteria or attributes in order to generate advanced decision making schemes for both non-real-time and real-time applications (Kassar et al., 2008). Fuzzy based algorithms are intelligent, functional and reliable, which always keeps decision delay at a minimum even when the number of RATs and input parameters are increased. This minimizes unessential handovers and decision delays and maximizes the percentage of user satisfaction. Fuzzy-logic-based algorithms are highly accurate and offer higher network efficiency, but they are also highly complex (Attaullah, 2008). Fuzzy logic can be employed to develop mobility management solutions that are both cost-effective and utilitarian.

(Coqueiro et al., 2019) proposed an intelligent fuzzy based system that extends the battery life of mobile devices while maintaining the quality of experience (QoE) at a satisfactory level for the users to ensure the continuity of services. The simulations for the Fuzzy based architecture are compared with other architectures in terms of power consumption, QoS and QoE. With the implication of the Fuzzy System the energy gain occurs because the handover in the network is executed when the battery level of the device is low. (Liang & Yu, 2018) developed a network selection algorithm based on service parameters and user preferences. This algorithm uses the entropy method to calculate the subjective and objective weights of network attributes. FAHP is used to obtain the utility values of various network attributes and user preferences. Finally it uses MADM techniques to rank the networks to select the most appropriate network while diminishing the number of network handovers. (Subramani & Kumaravelu, 2018) developed a two phase fuzzy logic based algorithm to select most eligible access network based on QoS requirements. The target network is selected based on Fuzzy Logic scheme. The most suitable network to handover to is decided on the basis of available bandwidth which also improves the data rate. The scheme performs better than the conventional multi-attribute decision making techniques. (Prithviraj et al., 2016) introduced a fuzzy logic based scheme considering the RSS, distance and space parameters. The packet loss is reduced by using two separate buffers for data buffering. This also moderates the sequence problem on data retransmission. A seamless end to end connectivity is ensured while reducing the handover delay and packet loss which in turn improves the transmission quality.

(Kaleem et al., 2013) proposed a Vertical Hand-Off Necessity Estimation (VHONE) scheme based on fuzzy logic & AHP to ensure session continuity and quality. This scheme gave better results in comparison to other algorithms by improving the over-all systems outage probability and handover rate. (Naeem et al. 2018) used RSS, user speed and a user path prediction parameter to design fuzzy handover decision system which reduces the Ping-Pong effect. A reduction in the average call drop rate is recorded as compared to timer based technique. The study proved that the involvement of the frequently traversed path in the fuzzy system improved the handover success metric as compared to Monte-Carlo method from 0.3 to 0.6. (Farid et al., 2014) adopted the FAHP and SAW techniques to quantify the network QoS level with a unified value for both homogeneous and heterogeneous networks. Results show that it computes QoS values more accurately as compared to MADM QoS evaluation methods by covering wider range of criteria and considering network uncertainty also. (Vasu et al., 2012) presented a QoS aware fuzzy logic based vertical handover scheme that considers available bandwidth, end-to-end delay jitters and bit error rate as the QoS parameters. A new evaluation model using non-birth-death Markov Chain is also proposed with states representing the available networks that can be used for comparing different vertical handover mechanisms. The proposed system gives

a better performance for different traffic classes. (Zhang et al.,2017) adapted a Fuzzy Logic based scheme for a trunking system that helps in decision making for a vertical handover. The performance evaluation values of the network are calculated to make the handover decision. Simulation results illustrate that the suggested algorithm greatly minimizes the number of handovers and unnecessary handovers, and improves the ping-pong handover effect. The QoS is also ensured during the handover.

(Mubarak et al.,2013) have proposed a self adaptive handover based on fuzzy logic (FuzSAHO). The propounded protocol efficiently handled issues like, handover delay and handover ping-pong. The proposed algorithm initially self-adapted the parameters of handover, which were based on multiple criteria such as, Mobile Station (MS) velocity and Received Signal Strength Indicator (RSSI). Using the measures of handover parameters, the handover decision was executed. The results indicated that the proposed algorithm could significantly diminish the handover ping-pong as well as the handover delay. Authors (Dhand&Mittal,2016) have proposed a Fuzzy Logic based smart handoff framework for the provision of seamless connectivity in a smart city. Simulation results demonstrate that the proposed framework is able to solve the problems of Ping-Pong and Corner effect after the inclusion of additional parameters with RSSI, hysteresis and adaptive threshold.

Table 1 lists the above mentioned techniques and implementations with their features.

Application of Machine Learning in Handover Process

Machine Learning(ML) is a fundamental technique for enabling artificial intelligence (AI). Machine Learning facilitates a system to automatically learn and advance with experience, devoid of any explicit programming(Sun et al.,2019). Machine learning techniques are characterized by the ability to learn and adapt to an environment with erratic changes and ambiguities and can be easily applied to wireless networks(Jiang et al.,2017). Artificial Neural Network is one set of

Table 1. Methods and Techniques based on Fuzzy Logic

Proposed scheme	Parameter	Tools	Technique	Feature/ Description
(Coqueiro et al., 2019)	Mobile speed, QoE, remaining battery power	NS2, Evalvid tool	Fuzzy Logic	Increased battery time, improved QoE
(Liang & Yu,2018)	Bandwidth, Delay, Jitter packet loss,service price	MATLAB	FAHP, SAW, MEW TOPSIS	Reduced number of network handovers
(Subramani& kumaravelu,2018)	RSS, Data rate, latency	MATLAB 2017 a	Mamdani based fuzzy system	Reduce h/o decision delay, improved data rate
(Prithviraj et al.,2016)	RSS, Distance, speed	NS-2.29, NIST mobility module, MIH	Fuzzy Logic	Low handover delay, Reduced packet loss
(Kaleem et al.,2013)	RSS,Speed, Direction, Distance between POA & MS, QoS	MATLAB RUNE	Fuzzy Logic & AHP	Improved System outage and handover rate.
(Naeem et al.,2018)	RSS, user speed	MATLAB	Fuzzy handover decision system	Reduced call drop rate, ping pong mitigation.
(Farid et al.,2014)	Delay, Jitter, packet loss Bandwidth	MATLAB OPNET modeler	Fuzzy Logic	Computes QoS values more accurately
(Vasu et al.,2012)	Bandwidth, End to End delay, Jitter, BER	MATLAB	Fuzzy Logic	Improved QoS for delay sensitive applications
(Zhang et al.,2017)	Delay, battery life, current RSS, forecasting RSS, speed, network load	MATLAB	Fuzzy Logic	Reduced number of handovers, Ping Pong avoidance
(Mubarak et al.,2013)	RSSI, MS velocity	Qualnet 5.0	Fuzzy Logic (FuzSAHO)	Reduced number of handovers and delay Increased performance rate
(Dhand& Mittal,2016)	RSSI, Data Rate, Bit error Rate	MATLAB	Fuzzy Logic	Reduced Ping- Pong and Corner Effect

algorithms used in machine learning for modeling the data using graphs of Neurons. Artificial neural networks are computing systems that attempt to emulate biological neural networks that are present in the brain. These systems are based on artificial intelligence to predict and model external systems accurately by the use of gathered knowledge acquired during learning process from user experiences. Artificial Neural Networks exhibit the ability to learn from unsupervised environments so they can be used in heterogeneous networks to effectively manipulate parameters that change randomly in number or behavior (Chen et al., 2019). Thus neural networks can be applied to almost any machine learning problem.

(Elechi et al., 2021) proposed an approach making use of artificial intelligence-based techniques, Fuzzy Logic and Artificial Bee Colony (ABC) to determine when and where handover would be initiated and an algorithm to determine the best access network for the user. For the decision phase parameters network parameters such as RSSI, throughput were used. QoS parameters like bandwidth, latency, cost, power etc. were used for the selection stage. Simulation results showed that the selected network provided the lowest cost and highest throughput to the user. The number of unnecessary handovers was minimized and the execution time of the ABC algorithm showed better results than the Genetic Algorithm.

(Benaatou et al., 2019) proposed an intelligent handover scheme based on ANFIS (Artificial Fuzzy Neuro Inference System) to select the most suitable candidate network. The algorithm provides a better performance as compared to other existing algorithms by diminishing the number of any inessential handovers generated by path loss and signal fading. The hybrid fuzzy approach effectively moderates the energy consumption in the network. (Zakaria et al., 2018) presented an ANFIS based vertical handover scheme that considers multiple parameters like speed, delay, jitter, bandwidth and RSS. Here, a vertical handover decision support system has been realized with three ANFIS networks that can indicate candidate network among WiMAX, UMTS and WLAN networks. The performance is compared against the TOPSIS technique and it is observed that ANFIS minimizes the time delay, has a simple design and is faster by 50% thereby improving the overall QoS of the system. (Modi & Murmu, 2017) proposed a spectrum handover scheme for cognitive radio networks based on ANFIS for the selection of the next channel. The results depict that the algorithm improves the channel selection accuracy, minimizes number of handovers, provides better spectrum utilization and therefore maximized throughput. (Zineb et al., 2017) offered a QoE based vertical handoff scheme for cognitive radio networks. Comparisons with the classical Fuzzy Logic and MADM techniques show an improved accuracy in the vertical handover decision. The mechanism shows improved final QoS/QoE metrics while reducing BER, PLR, handover delays as well as number of unnecessary handoffs. The authors (Alotaibi & Alwakeel, 2015) proposed a Neural Network Based Handover Management Scheme (NNBHMS). Different parameters related to network, terminal and applications are considered. The scheme produces a better throughput than the RSS based traditional schemes in all performance measures. The scheme provides an enhanced QoS level for the user for both voice and data services while also fulfilling the user preferences. (Calhan & Caken, 2013) presented an ANFIS based vertical handoff decision algorithm for heterogeneous networks. The three parameters, i.e., monetary cost, data rate and received signal strength (RSS), are fed as inputs into their neural networks. A comparison with pure Fuzzy Logic and SAW techniques shows minimization of the number of handoffs while fulfilling the user, application and network requirements.

(Aibinu et al., 2017) developed a hybrid handover decision algorithm based on artificial neural networks and Fuzzy Logic. The ANN-based RSS prediction system was fed with the Received Signal Strength (RSS) values collected over a period of time. This output was then fed to the Fuzzy inference system for making necessary handover decisions. Comparison of the results obtained showed that the proposed approach was able to carry out the necessary handover decisions and avoid ping-pong effect when evaluated against other standard handover techniques. (Mahira & Subedar, 2017) used a multilayer feed forward artificial neural network algorithm for handover decision in wireless heterogeneous networks. The feed forward ANN architecture with is based on Levenberg Marquardt

back propagation algorithm is fast and repetitive neural network algorithm. Results showed an effective reduction in the number of unnecessary handovers as compared to other proposed techniques. It was found that probability of handover decision also improved. The simulation study showed that the proposed multicriterion improves reduction in number of handovers by 93.75%. The scheme exhibited a reduction in number of handover reduces call dropping probability as well as delay in processing of handover initiation requests effectively.

(Aljeri et al.,2019) considered handover management scheme for vehicular networks that uses machine learning .The first tier is used in forecasting RSSI data sequences to stimulate an early handover trigger decision, thus reducing handover latency or any service disruptions in vehicles. The second tier uses a Hidden Markov Model to determine the access point the vehicle should commit to. The machine learning handover trigger scheme also results in improved network performance as compared to various other forecasting models.(Kene&Haridas, 2020) presented a machine learning based algorithm that optimizes the QoS of the network while minimizing the number of handovers. Authors use the standard game theory technique to score the candidate networks on the basis of various parameters. A comparison with some standard algorithms shows considerable reduction in ping pong effect.(Wu et al.,2015) proposed a fuzzy based Q-Learning algorithm for mobility management in small cell networks. Performances of the algorithm for different UE speeds and TTT have been compared. The simulation results in FLC and Q-Learning are also compared to show the improvement of the Q-Learning algorithm. Results show that the Q-Learning algorithm can decrease the handover ratio while keeping the call-dropping ratio at a minimum level.

(Ali et al.,2016) presented a machine learning based handover scheme for improved QoE in LTE scenarios with challenging propagation conditions, e.g., in presence of obstacles in the coverage area of eNB. A two level Feed-Forward Neural Network is used for the implementation of learning capabilities. The handover algorithm is able to select the eNB that is expected to yield better QoE, based on the experience gained from past handover decisions. The scheme substantially improved QoE in terms of number of effectual downloads and average download time with respect to SOTA handover schemes, which take decisions based on signal strength. It was observed that the Machine Learning based handover scheme achieved a 75% increment in the number of completed downloads, and a decrease of 84.16% in file download times.

(Sharma et al.,2017) used a reinforcement learning (RL) based decision making policy (DMP) for dynamic switching of small base stations(BSSs) in the heterogeneous networks consisting of small and large Macro BS. Furthermore, a transfer learning based technique is used to enhance energy saving. Simulation results depict that the proposed approach leads up to 82% savings in energy of the network. To ensure required quality of service it is necessary to take care of the trade-off between the system energy consumption and delay.

Authors(Chen et al.,2018) presented a Q-Learning based vertical handover algorithm QoE-Q to maximize the QoE of the users. A Random Neural Network is used for mapping between the QoS and QoE values. The proposed scheme performs better than the existing schemes like classic algorithms Fuzzy Q-learning Admission Control (FQAC) and Markov Decision Processes (MDP). The scheme offers improved call blocking probability and handoff dropping probability property. It also obtains better QoE capability in terms of service charges and terminal power consumption. Table 2 summarizes the above mentioned techniques and implementations with their features.

Application of Evolutionary Algorithm (EA) Techniques in Handover Process

An evolutionary algorithm utilizes the principles of evolution prevalent in nature around us to the problem of devising an optimal solution for a problem. In this, the decision variables and problem functions are used directly. Evolutionary algorithms are optimization algorithms that search for optimal solutions by evolving multiple sets of candidate solutions (Câmara, 2015). They generally look for solutions that are optimal in terms of two or more possibly conflicting objectives. Genetic Algorithms (GA) is just one of many approaches of Evolutionary Algorithms. Genetic algorithm is an optimization

Table 2. Methods and techniques based on Machine Learning

Proposed Scheme	Parameters	Tools	Technique	Description
(Elechi et al.,2021)	RSSI, Throughput, Bandwidth, Cost, Power	MATLAB	Fuzzy+ Artificial Bee Colony	No. of handovers less, Improved throughput
(Benaatou et al.,2019)	SINR, Bandwidth, Energy Consumption	ANFIS	Neural Networks	Reduced number of handovers and energy consumption
(Zakaria et al.,2018)	RSS, Jitter, Speed, Bandwidth, initial delay	ANFIS	Neural Networks	Reduces time delay to improve QoS, higher speed
(Modi &Murmu,2017)	Vacant channel duration,Data rate, SINR	NS2,MATLAB	ANN	Improved channel and spectrum utilization, minimized handovers
(Zineb et al.,2017)	Packet delay variation, packet loss ratio, BER	MATLAB	ANN	Decreased packet loss delay, BER
(Alotaibi& Alwakeel,2015)	RSS, Speed, Direction, distance between POA & MS, QoS	-----	ANN +Fuzzy logic	Improved System outage and handoff rate
(Calhan &Caken,2013)	Data rate, monetary cost, RSSI	MATLAB, OPNET modeler	ANN	Reduced number of handoff, correct handoff
(Aibinu et al.,2017)	Delay, Jitter, pacekt loss, Bandwidth	MATLAB	ANN +Fuzzy logic	Reduced ping-pong better prediction-ahead of RSS value
(Mahira&Subedar,2017)	Data rate, service cost, RSS, velocity of mobile device	MATLAB	ANN	Reduced number of handoffs, Reduced call drop probability
(Aljeri et al.,2019)	RSSI	NS2	Machine Learning	Improved network performance, reduced handover latency
(Kene&Haridas,2020)	RSSI, SNR, Bandwidth, data rate, network coverage cost per byte	NS2	Machine Learning	Reduced ping pong effect, improved overall QoS
(Wu et al.,2015)	Signal reference power	LTE system level simulator	Fuzzy Q- learning	Minimized call dropping rate, reduced number of handoffs
(Ali et al.,2016)	Reference Signal Received, Power,Reference Signal Received Quality	LENA LTE-EPC simulator	Machine Learning	Improved QoE
(Sharma et al.,2017)	Power consumption	-----	Reinforcement Learning	Improved Energy saving
(Chen et al.,2018)	Power consumption, Network charge	-----	Q- Learning	Reduced Ping pong effect, Maximize QoE

technique of iterative search and finding solutions to problems by a method based on natural selection, mutation, crossover and reproduction. GAs are versatile and exhibit significant generality and can thus be applied to problems in a huge variance of settings in wireless networks(Mehboob et al.,2016). They can converge to optimal (or suboptimal) results, in shorter time in most cases compared with other bio-inspired algorithms.

Wang et al.(2021) proposed a multi-objective genetic algorithm for vertical handover decision making. The algorithm NSGA-II takes into account the dynamic nature of the networks as well as the requirement of desired QoS on the user side. Simulation results show that the algorithm significantly increases the throughput while lowering the blocking rate in comparison to other handover strategies. The algorithm can effectively improve the user’s service quality and the resource utilization of heterogeneous network systems. Almutairi et al.(2017) proposed a genetic algorithm based scheme for multi-attribute vertical handover decision making. The application of the genetic algorithm optimizes the weighting of the network attributes. In contrast to the conventional AHP technique, the proposed GA optimization is used to generate dynamic weights for SAW and TOPSIS MADM techniques. It is observed that integrating the GA in MADM methods reduces the subjectivity in assigning weight

values. Thus dynamic values for weights are generated that help to reduce unnecessary handovers and ranking abnormalities. (Goudarzi et al., 2016) addressed the problem of selecting a suitable candidate wireless network during vertical handover using Markov decision process (MDP) with genetic algorithm while addressing the users preferences as well. The proposed scheme named the improved genetic simulated annealing vertical handover (IGA-SA), shows a decrease in the count of unnecessary handovers thereby reducing the ping pong effect while also minimizing the cost in the solution to find the optimal network. (Fayyazi & Sabokrou, 2012) offered a handover management scheme that uses Fuzzy Logic to determine the most suitable time to commence the handover procedure. The application of the Genetic Algorithm helps to reduce the total number of handovers and the ping pong effect. This also helps in improving the quality of the handover process in heterogeneous wireless networks.

(Chandralekha & Prafulla, 2010) used Genetic Algorithm to minimize the number of handovers in the candidate network selection. Authors present a context-aware vertical handover scheme which uses the context information about networks, users, user devices and applications. The network with minimum latency, cost, SNR, power consumption is selected so as to maintain the desired QoS levels. The proposed approach reduces delay and number of handovers which eludes the deterioration in signal quality and excess loads on the network. The handover procedure is simple, reliable and has less computational complexity. (Alkhwilani & Ayesh, 2008) presented a network selection scheme that incorporates Fuzzy Logic techniques and Genetic Algorithms. The proffered scheme is scalable and can handle any number of RATs. Since the access network selection is a multicriteria problem in nature, Genetic Algorithm is used to optimize the different objectives. In this paper three different objective functions are proposed to cover the different objectives. It provides better and more robust performance while also considering the user, operator and QoS viewpoints.

(Fachtali et al., 2016) propounded a new concept in which MTs can uphold a database (archive table) of available networks ordered by their quality. A QoS aware decision algorithm based on ant colony optimization is proposed which considers parameters such as RSS, service cost, bandwidth, velocity, power consumption and security. Simulation results demonstrate that it not only meets the individual demands of users in terms of QoS, but also improves the overall system performance by minimizing the handover failures and inessential handovers. (Kumar & Murthy, 2016) employed the cuckoo search algorithms for selecting the access network among the available networks. The scheme greatly reduced the number of unnecessary handovers in case of heterogeneous networks by choosing the best network in a limited duration. The algorithm also achieves to maximize throughput of network with minimum latency, cost, power consumption, and improved SNR so as to have less number of handovers for all networks and thus maintain better QoS levels. (Baharudin et al., 2015) proposed a handover scheme based on the ant colony probabilistic equation. It employs the received signal strength and the mean opinion score to initiate the handover. The efficacy of the proposed approach was compared with an existing method. The results reveal that the proposed approach resulted in better performance as compared to the existing scheme. (Asuquo & Robinson, 2017) presented a genetic algorithm based framework for a seamless and less power consuming handover. The method provides faster handover decision making with reduced latency while also satisfying the QoS requirements of both users and network operators. Table 3 lists the above mentioned techniques and implementations with their features.

Comparison of Soft Computing Based Techniques

An evaluation of the various proposed handover schemes reflect a heterogeneous choice of parameters and methodologies employed by various authors based on their particular research objectives. Table 4 provides a comparative summary of the various techniques based upon soft computing. To present an overall comparison of the three groups, their features are summarized on seven aspects: delay, packet loss, throughput, reduced unnecessary handovers, ping pong mitigation, improved QoS/QoE and corner effect.

Table 3. Methods and Techniques based on Evolutionary Algorithms

Proposed scheme	Parameters	Tools	Technique	Feature/ Description
(Wang et al.,2021)	Bandwidth,delay	MATLAB 2018 a	Genetic Algorithm	Improves throughput, reduced Blocking Rate
(Almutairi et al.,2017)	Data rate, packet delay Jitter, packet loss	-----	Genetic Algorithm	Reduced ranking abnormalities, reduced unnecessary handovers
(Goudarzi et al.,2016)	Bandwidth, BER, SNR Cost	MATLAB R 2014 b	MDP +Genetic Algorithm + Simulated Annealing	Prevent Ping Pong effect
(Fayyazi& Sabokrou,2012)	Velocity, Distance, no. of free channels available	-----	Fuzzy Logic + Genetic Algorithm	Ping pong effect avoidance
(Chandralekha& Behera,2010)	Bandwidth, Latency, SNR Throughput, Cost	MATLAB	Genetic Algorithm	No. of handovers minimized, reduced handover delay
(Alkhawlani& Ayes,2008)	RSS, MT speed, bit rate Price	MATLAB RUNE	Fuzzy Logic + Genetic Algorithm	Improved user satisfaction, Improved QoS
(Fachtali et al.,2016)	RSS, cost, bandwidth, MT velocity, power consumption, security	MATLAB	ACO	Minimize no. of handover failures and unnecessary handovers
(Kumar & Murthy,2016)	Bandwidth, power consumption,SNR,cost, latency, throughput	-----	Optimized Cuckoo algorithm	Reduced unnecessary handovers
(Baharudin et al.,2015)	RSS, QoE	OMNeT++	Ant Colony	Better overall average MOS
(Asuquo& Robinson,2017)	No. of channels, traffic intensity, avg call duration, no. of dropped calls	MATLAB optima	Genetic Algorithm	Maintain QoS levels

RESULTS AND DISCUSSION

The following points discuss the suitability of various parameters in different scenarios and under different category of schemes:

1. The different categories of techniques considered are generally suited to heterogeneous wireless environments (LTE, Wi-MaX, Wi-Fi etc.) where users experience varied network environments. RSS is used as the primary input parameter in Fuzzy Logic based VHD algorithms, in combination with network or terminal related parameters.
2. In the soft computing techniques, majority of the approaches obtain fewer handover delays due to the pre-selection of the handover target networks and usually anticipated handovers. Handover delay is associated with the complexity of the handover management process. The Fuzzy Logic schemes have focused on reducing the handover delay. The reduced handover delay is especially critical to delay-sensitive voice or multimedia sessions.
3. For throughput, Fuzzy Logic techniques have proved capable of attaining higher throughput levels than any other schemes.

Table 4. Comparative Summary of Soft Computing Based Vertical Handover Decision (VHD)Schemes

Group	Scheme	Delay	Packet Loss	Throughput	Reduced Unnecessary Handovers	Ping Pong mitigation	Improved QoS/QoE	Corner Effect
Fuzzy Logic Based VHD Algorithms	(Coqueiro et al., 2019)						✓	
	(Liang & Yu,2018)				✓			
	(Subramani& kumaravelu,2018)	✓		✓				
	(Prithviraj et al.,2016)	✓	✓					
	(Kaleem et al.,2013)				✓			
	(Naeem et al.,2018)		✓			✓		
	(Farid et al., 2014)						✓	
	(Vasu et al.,2012)						✓	
	(Zhang et al.,2017)					✓	✓	
	(Mubarak et al.,2013)	✓		✓	✓	✓		
(Dhand& Mittal,2016)	✓		✓	✓	✓		✓	
Machine Learning Based VHD Algorithms	(Elechi et al.,2021)			✓	✓			
	(Benaatou et al.,2019)				✓			
	(Zakaria et al.,2018)	✓					✓	
	(Modi &Murmu,2017)				✓			
	(Zineb et al.,2017)	✓	✓					
	(Alotaibi& Alwakeel,2015)							
	(Calhan &Caken,2013)				✓			
	(Aibinu et al.,2017)					✓		
	(Mahira&Subedar,2017)					✓		
	(Aljeri et al.,2019)	✓		✓				
	(Kene&Haridas,2020)					✓	✓	
	(Wu et al.,2015)					✓		
	(Ali et al.,2016)							✓
(Sharma et al.,2017)						✓	✓	
(Chen et al.,2018)						✓	✓	
Evolutionary Learning Based VHD Algorithms	(Wang et al.,2021)			✓			✓	
	(Almutairi et al.,2017)				✓			
	(Goudarzi et al.,2016)					✓		
	(Fayyazi& Sabokrou,2012)					✓		
	(Chandralekha& Behera,2010)	✓				✓		
	(Alkhawlani& Ayes,2008)						✓	
	(Fachtali et al.,2016)					✓		
	(Kumar & Murthy,2016)					✓		
	(Baharudin et al.,2015)			✓				
	(Asuquo& Robinson,2017)							✓

4. The unnecessary number of handovers, can be kept at a low level by minimizing the ping-pong effect. Frequent handovers cause wastage of network resources. Reducing the count of unnecessary handovers has been preferably achieved in Fuzzy Logic schemes. Mitigation of ping-pong effect is apparent in this scheme.
5. An important aspect of Corner effect has been effectively handled only by the Fuzzy Logic schemes.
6. Machine Learning techniques base their decision on multiple criteria such as bandwidth, delay, throughput, cost etc. and the aim remains not only to provide connectivity but also to satisfy users in terms of QoS. ML techniques have been found useful in linking QoE to network and application-level QoS, and understanding the impact of the latter on the former.
7. The implementation of Machine Learning approaches works effectively in complex, dynamic environments in networks offering both real time traffic and data traffic.
8. The Evolutionary algorithms have been able to effectively reduce unnecessary handovers and optimize system performance. These algorithms demonstrate remarkable predictive capabilities as well.

Issues and Challenges

Various handover solutions have been devised to provide seamless transfer of services across heterogeneous networks. However there are certain issues like security, user privacy, interoperability between different standards etc. which are critical but yet to be dealt with:

1. **User experience:** In earlier studies, there was no distinction between user experience and the network QoS. User experience was then measured in terms of network parameters (e.g. bandwidth, delay, jitter), and application parameters, such as bit rate for multimedia services. While monitoring and controlling QoS parameters is essential for delivering high service quality, it is more crucial, especially for service providers, to evaluate service quality from the user's perspective. User experience is a determinant of the level of success of a service. An accurate assessment of user QoE (Quality of Experience) is complex as individual experience depends on individual perception and expectation. Both of these are subjective in nature, and hard to quantify and measure.
2. **QoS parameters:** It is crucial for service providers to constantly monitor and control QoS parameters for provision of high-quality service. Soft Computing techniques have been found useful in mapping QoS metrics gathered from the network onto QoE, and thereby understanding the impact of QoS on the QoE.
3. **Battery Power:** The next generation network devices with their capabilities of sensing environments rapidly spawn out data at high rates. They drain out their batteries very briskly. Protocols, networks and handover strategies for seamless connectivity in future networks need to be designed keeping the concept of energy efficiency in mind.
4. **Selection of parameters:** It is known that the performance of ML algorithms is affected by the selection of hyperparameters like learning rate, loss functions, and so on. Trying different hyperparameters directly is a time-consuming task, especially when the training time for the model under a fixed set of hyperparameters is long.

Future Scope

In the future networks, which are going to be resplendent with multiple domains and technologies, the vertical handover requests could be based on a number of different requirements or priorities such as cost, network resource optimization, service provision, etc. The following considerations could help improve the prospects of handover decision making:

1. **Assigning weights to attributes:** The assignment of weights to the attributes can be improved in future studies so as to give suitable importance to each one as per the requirements of the desired parameters in different situations. This will ensure attaining the best access network satisfying all the criteria to deliver an improved QoS every time.
2. **Incorporating predictive analytics in handover decision making:** In future works, the algorithm can be enhanced using machine learning and analytics for predicting optimal network and mobility management.
3. **Changing network environments:** In future networks, the heterogeneous network environment will tend to be more complex. With the development of the Internet of Things, a massive number of terminals will be connected to heterogeneous networks. To preserve the balance between terminal QoS and network resource utilization, future VHO algorithms should have the ability to process large amounts of data. Although the current neural network based algorithms can handle huge amounts of data, the high level of complexity limits the speed of calculation and it is thus not suitable for high-speed motion scenarios.

CONCLUSION

Deploying soft computing techniques in wireless communications in a heterogeneous scenario improves the overall network performance. Improvements have been noticed in quality, latency, data, throughput, QoS etc. In this paper, a review of the current soft computing techniques used in wireless heterogeneous networks has been performed and their advantages, disadvantages, challenges, and future scopes have been presented. Based on soft computing techniques, the proposed schemes in this area were categorized into three groups i.e Fuzzy Logic, Machine Learning and Evolutionary Algorithms. These were compared in terms of their features and parameters. The existing decision-making schemes either lack an adequate deliberation of various network parameters or the studies fall short of details for the actual implementation of these techniques in the real world. However research in decision making and prediction mechanisms in heterogeneous wireless networks is still a challenging field. The major intricacy is the formulation of a scheme which is favorable in diverse network conditions and user/application preferences. Robust and sophisticated handover mechanisms need to be designed in the future in order to make handovers more efficient and reliable.

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