Vertical Handover Algorithm in OpenAirInterface and Neural Network for 4G and 5G Base Stations

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***Abstract*—The fifth generation (5G) mobile network has been designed to offer individuals and objects with nearly ubiquitous, ultra-high bandwidth, and low latency access. In heterogeneous wireless networks, the demand for wireless communication devices has increased dramatically. This paper provides a Vertical Handover Algorithm (VHA) in OpenAirInterface (OAI) and Neural Network (NN) for heterogeneous 4G and 5G Radio Access Networks (RANs). The framework of the algorithm is built by configuring the network environment in which we employ network resources when switching between OAI 4G and OAI 5G base stations. Each base station establishes its three-layer backpropagation neural network model. Then, the user's speed, signal-to-interference, and noise ratio (SINR), maximum transmission rate, minimum delay, coverage area, bit error rate, and packet loss rate are used as reference objects to participate in the setting of VHA using a backpropagation neural network model. The measured download/upload speeds are used to compare the performance of the two wireless networks, and the vertical handover algorithm then chooses the best wireless network for performing the vertical handover decision.**

Keywords—4G, 5G, Neural Network, OpenAirInterface, Radio Access Network, Vertical Handover Algorithm

I. INTRODUCTION

The deployment of various wireless technologies (2G, 3G, 4G, LTE, etc.) in conjunction with the evolution of Mobile Terminals (MTs) with multiple network interfaces and the development of non-real-time or real-time Internet Protocol (IP)-based applications has enabled users to access IP services from any network, anywhere at any time. The fifth generation (5G) of wireless communications is one breakthrough step enabling such global wireless access [1]. Many types of wireless networks have existed concurrently with the fast growth of wireless networking technology and heterogeneous convergence in the network architecture for access technologies in recent years [2], [3]. Different networks compete and complement one another, resulting in the coexistence of multiple types of networks [3], [4]. To adapt to various user requirements and the development of various types of business, wireless networks with different designs form multiple heterogeneous integrated networks [5]-[9]. Perhaps the most representative of this phenomenon is the integration of two types of heterogeneous networks: Wireless Local Area Network (WLAN) and mobile networks [10]-[12]. WLAN networks have relatively wide bandwidth and small coverage. In contrast, cellular networks such as currently widely spread 3G/4G wireless networks have comparatively small bandwidth and wide coverage [13], [14], [15]. Combining cellular networks and WLAN networks can complement each other [16], [17], maximizing their respective strengths while reducing their limitations [18], [19], [20]. Furthermore, with the advent of 5G technology, the integration of numerous networks with disparate architectures is expected to make significant strides [21]-[26]. As a result, a vertical handover method should be examined against a variety of disrupting variables and candidate network types [27], and used in conjunction with intelligent algorithms [28]. The appropriate neural network algorithms from the machine learning field are now used to create the algorithm in [29]-[38].

There are numerous vertical handover algorithms (VHAs), each with its own set of pros and downsides. Most current VHAs in the engineering area do not consider all the environmental conditions that can affect the efficient operation of wireless networks. Most existing VHAs have an impact on the performance of 5G networks [37]. However, the associated variables of 5G networks are not included. Therefore, most existing VHAs will be unable to switch to the 5G network when selecting the network in the 5G network's coverage region. For decision selection, the vertical handover method suggested in [2] is based on a visible light communication system. Using an analytical hierarchy approach and a cooperative game model of two people to consider many factors, such as changing network parameters and actual traffic preferences. It took into account fewer handover considerations. The paper [3] proposed a vertical handover decision algorithm for multi-terminal cooperation based on fuzzy logic and an analytic hierarchy approach. Although it could properly reflect application needs and user preferences, it did not consider the upcoming 5G network. Algorithms with similar problems are discussed for example in [7], [17]. As one target network exists during vertical handover, the paper [6] advocated maximizing and optimizing network use. They also demonstrated how network parameters could be incorporated into IEEE 802.21-based signalling protocols to offer smooth connectivity during a handover. However, the algorithm failed to consider the critical issue of network transmission rates.

The work [4] reviewed and classified the most important multi-criteria decision-making algorithms for network selection in next-generation wireless networks. It also demonstrated an understanding of the significance of network-criteria weighting and current research trends in the utilization of multi-criteria decision-making algorithms to address network-selection issues in heterogeneous wireless networks. The vertical handover method developed in [8] relied heavily on a "New Composite Rule Inference Based Logarithm" to improve the quality of service between WLAN and UMTS (Wireless Local Area Network and Universal Mobile Telephone System) networks. Despite having a high handover performance rate, it failed to integrate the 4G and 5G networks. The paper [11] presented an adaptive VHA based on an artificial neural network (ANN) comparable to the system designed in this research paper, although it only included LTE and WLAN networks as candidate networks. Similarly to the multi-attribute-based vertical handover method, the paper [16] suggested a heterogeneous network selection algorithm based on a mix of network properties and user preferences. The work [20] constructed a sophisticated algorithm for seamless vertical handover in vehicular networks. This algorithm was based on a hybrid model that combined biogeography-based optimization (BBO) with the Markov chain and was applied to vertical handover between numerous access technologies such as WiMAX, Wi-Fi, and UMTS. The work [9] was comparable to works [3], [7], [8]. It used fuzzy logic theory and multi-attribute decision-making to choose the optimum network to enhance the vertical handover method. However, it did not include an important network attribute signal-to-noise-and-interference ratio (SINR).

It is important to address the shortcomings of existing vertical handover algorithms, such as the high complexity and the exclusion of 5G network systems. This research paper proposes a vertical handover algorithm using ANN and is intended for heterogeneous OpenAirInterface (OAI) 4G and 5G base stations. The algorithm's framework is built by configuring the network environment where we employ network resources by transitioning between 4G and 5G OAI base stations. Each network constructs its own three-layer Back Propagation (BP) neural network model. The user's speed, signal-to-interference, and noise ratio (SINR), maximum transmission rate, minimum delay, coverage area, bit error rate, and packet loss rate are used to participate in the setting of BP neural network input layer neurons and the learning process of subsequent neural network data. Finally, to make a choice for the vertical handover, the network download speed is used as a prediction objective. To evaluate the performance of the two wireless networks, which will aid the vertical handover method described in this study to select the appropriate wireless network. This vertical handover technique is utilized in network selection for a variety of network configurations. As a result, when undertaking relay selection between networks with various architectures, two networks are represented by seven network parameters set at the ANN model's input. They are used to execute a decision strategy, that is, to estimate the download speed of the two networks based on the measured seven network attributes that were originally input into the neural network model, to select the existing two networks for their reliability. The network with the highest download speed is selected as the final changeover destination and is expected to provide an improved user experience.

The novelty of the vertical handover algorithm designed in this paper is to include the OAI 5G network in the switching range of the heterogeneous integrated networks [38]. The use of superior learning capability, and the independently designable framework incorporates most of the main variables that affect the performance of the wireless network into this vertical handover algorithm. As a result, the set of environmental elements associated with wireless network performance evaluated by the algorithm in this research is more extensive.

This paper is structured as follows. Section II presents the proposed methods. Section III contains the results of the experiments. Section IV finally presents the conclusion and future work.

II. METHOD PROPOSED

A. Model of a Neural Network

This paper proposes a vertical handover method for OAI 4G and OAI 5G networks. We assume two heterogeneous networks. Each network creates its own three-layer BP neural network models. The network parameters of the user's speed (V), signal-to-interference and noise ratio (R), maximum transmission rate (T), minimum delay (D), coverage area (C), bit error rate (B), and packet loss rate (P) are used to establish the neuron weights of each layer. When the user moves into the network environment where the two heterogeneous networks interact, the user terminal retrieves the user's speed (V), signal-to-interference and noise ratio (R), maximum transmission rate (T), minimum delay (D), coverage area (C), bit error rate (B), and packet loss rate (P) and inputs the values to the developed neural network model. The anticipated values of network download speeds for each of the two types of networks are determined, and the wireless network with the greatest predicted network download speed value is chosen as the pre-switched network. Fig. 1 depicts the expanded three-layer BP neural network model.

The BP neural network model is built using the transfer function as equation (1). The error backpropagation technique and the error equation (2) are used in this research, and the neural network's weights are consistently constrained by error feedback. The value of the offset of the error function is closer to the anticipated error feedback. Here, a_i denotes the anticipated values of the network parameter outcomes and z_i denotes the neural network's correlated output values. The associated neural network model must be solved for the algorithm to work. As a result, the principle of operation of the BP neural network model depicted in Fig. 1 was subsequently given, where the network weights are currently set to *Wij, Tij*, and the neuron threshold is set to P_j which is the jth input layer node. Q_j is the jth hidden layer node, Z_j is the jth output layer node, and *RR* is the error function. Then the appropriate calculation equations of the aforementioned three-layer BP neural network model are given as follows, the neurons are configured, the input vector is $P = (p1, p2, p3, \ldots\ldots, pm)$, and the weights value associated with the input vector in the input neuron is $W = (w1, w2, w3, \ldots\ldots, wm)$, and the neural network's output is expressed by equation (3). Here, g represents the initialization function, and its mathematical form is given by equation (1)

$$g(p) = \frac{1}{e^{-p} + 1} \quad (1)$$

the error backpropagation technique and the error equation (2):

$$RR = \sum_i \left(\frac{a_i + z_i}{2}\right)^2 \quad (2)$$

the neural network's output is expressed by equation (3):

$$q = g\left(\sum_{i=1}^{v} W_i P_i - U\right) \quad (3)$$

Equation (4) is the output of the hidden layer node:

$$q_i = g\left(\sum_j W_{ij} P_j - U\right) = g(net_i) \quad (4)$$

Equation (5) is the output of the output layer node:

$$z_i = g\left(\sum_j T_{ij} P_j - U_l\right) = g(net_l) \quad (5)$$

The inaccuracy of the output layer node is thus given by equation (6):

$$RR = (0.5) \sum_l (a_l - z_l) \quad (6)$$

seven neurons are set in the hidden layer according to equation (7):

$$l = \sqrt{a + b + c} \quad (7)$$

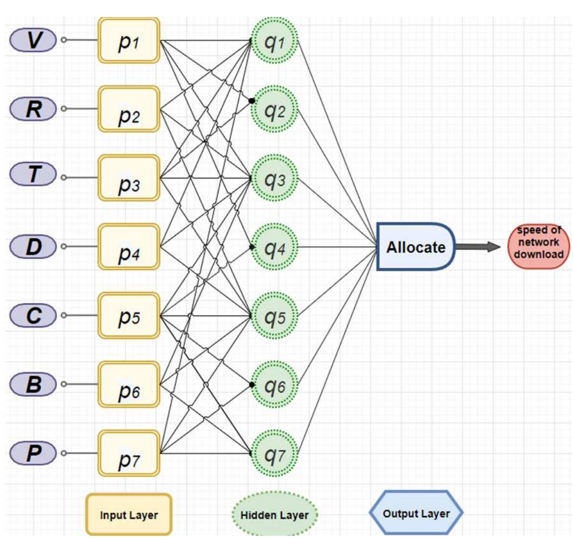

Fig. 1. Framework diagram of the three-layer backpropagation neural network model

B. *Process of a Vertical Handover*

The handover process can be divided into three phases, as shown in Fig. 2:

- *Handover Initialization*: used to gather all of the information needed to determine the requirement for handover and then initially start it.
- *Handover Decision*: utilized to determine if and how to perform the handover by choosing the best access network, considering some parameters, such as user preferences, and then to instruct the execution phase.
- *Handover Execution*: utilized to switch channels following the details provided from the decision phase.

The process of handover can be classified into several forms. When the BS is only attached to one point of attachment at a time, handover can be difficult. It is known as a break before handover. On the other hand, the break before handover might be soft when the BS is temporarily attached to two points of attachment, known as make-before-break handover. The handover must be seamless to achieve the seamlessness aspect in mobility scenarios. It means that the user's transfer to the new network point of attachment has no discernible service deterioration. As a result, it is the make-before-break handover that executes a quick handover, low handover latency, and a smooth handover, with low packet loss.

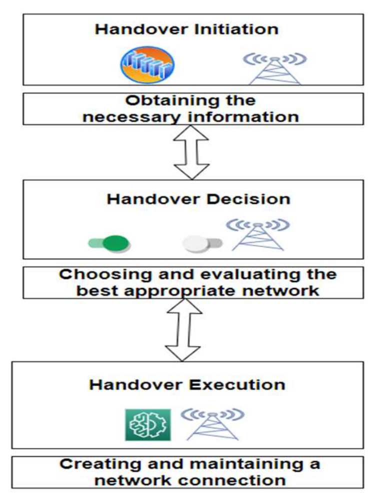

Fig. 2. Phases of Vertical Handover

III. EXPERIMENTAL RESULTS AND ANALYSIS

Fig. 3 shows a high-level design of the heterogeneous OAI 4G and OAI 5G networks. The OAI network has been implemented at the Council for Scientific and Industrial Research (CSIR) indoor lab. The setup uses the following components: Catalyst 3560 Series Switch, OAI 4G configuration (eNB), OAI 5G configuration (gNB), OAI 4G Core Network, and Huawei P40 Pro 5G capable phone.

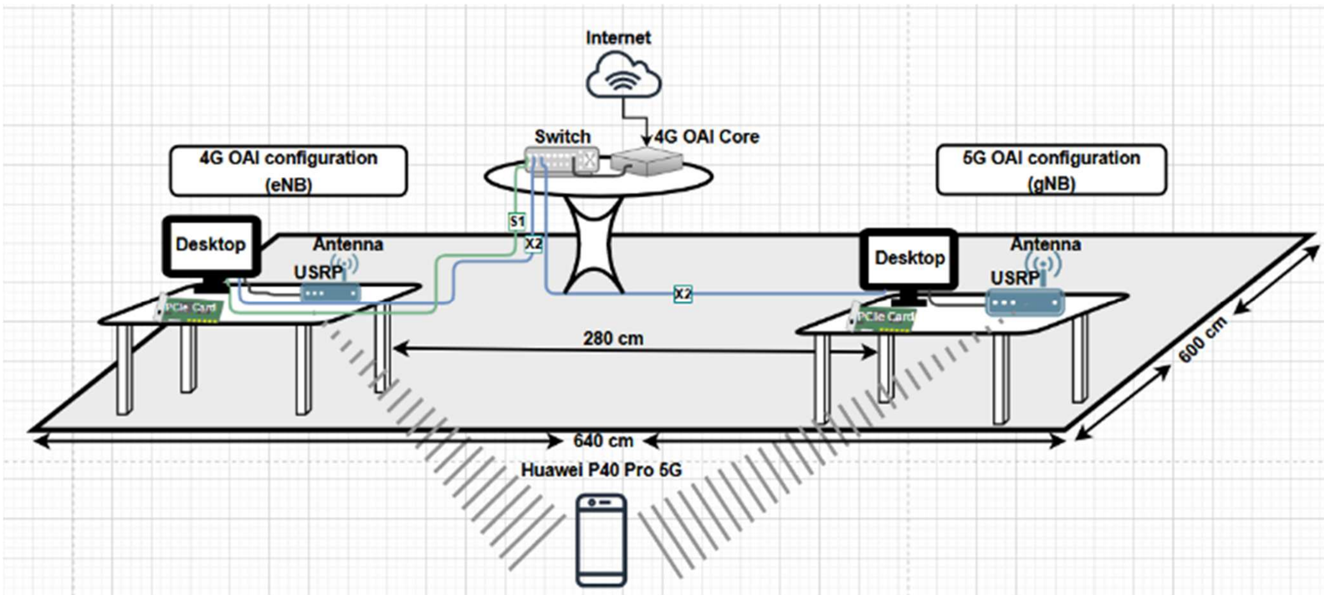

Fig. 3. High-level architecture of an indoor VHA setup.

The laboratory measurements are as follows: the overall setup's length is 640 cm, and the width is 600 cm. The distance between the two OAI base stations is 280 cm. The OAI 4G Core Network is configured to connect the two OAI base stations. The most significant parameters that have been configured in the two base stations also configured in the OAI 4G Core Network (CN) are Tracking Area Code (TAC), Mobile Country Code (MCC), S1 interface, and Mobile Network Code (MNC).

TAC identifies a tracking area within a particular network. MCC is used in wireless telephone networks to identify the country in which a mobile subscriber belongs. To uniquely identify a mobile subscriber's network, the MCC identifies the geographic region of the Subscriber Identification Module (SIM) card, and this is combined with an MNC, which identifies the operator. The S1 interface is used as communication between the OAI 4G CN and the OAI 4G base station to have a complete 4G OAI mobile network. The Huawei P40 Pro 5G phone is used to test the vertical handover algorithm to utilize the best-calculated network download speed from the neural network model. The Huawei P40 Pro 5G carries a sysmoUSIM-SJS1 SIM card. The SIM card is programmed solely to connect to our heterogeneous OAI network. The Huawei P40 Pro 5G phone wirelessly connects to the OAI network, using the Omni-85 Poynting antennas.

OAI 4G configuration (eNB) – The configuration in the eNB is done using the following components: USRP with a PCIe Kit (able to operate at 10 to 6000 MHz with simultaneous bandwidth of 160 MHz, using the MXI Express interface), Linux server (Dell Precision 3630 with Intel i9-9900 processor with 8-core and 16 MB cache, supporting 3,1 GHz; and two solid state drives); Omni-85 Poynting antennas responsible for transmitting and receiving signals, computer monitor for information display, a table to put all the items, and Software Defined Radio (SDR) NI USRP-2944R. The SDR is also responsible for functions such as front-end processing of the signals. That is, the signals received by the SDR are amplified, down-converted, filtered, digitized, and decimated before being passed to the Linux server.

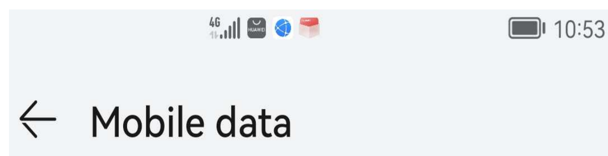

Fig. 4. A print-screen from a Huawei P40 Pro 5G connecting to a 4G OAI network.

OAI 5G configuration (gNB) – The components used for gNB are similar to a standard eNB, but the difference is that we added a Catalyst 3560 Series Switch to connect the eNB and gNB to test the proposed vertical handover algorithm using a neural network model. As shown in Fig. 3, the X2 interface is configured to establish a connection. The gNB is not configured to use the S1 interface, because it is not necessary to configure such an interface in the gNB configuration.

After completing the OAI 4G and OAI 5G configurations, we programmed the sysmoUSIM-SJS1 SIM card using a computer running Ubuntu Linux 20.04, with Pysim software installed. We also configured the Huawei P40 Pro 5G to connect to the two base stations. The Huawei P40 Pro 5G is able to connect to the OAI 4G configuration network, as shown in Fig. 4, and perform vertical handover to connect to the 5G OAI configuration network, as shown in Fig. 5. The best-selected OAI network is done using the highest calculated value of the download speed in the neural network model.

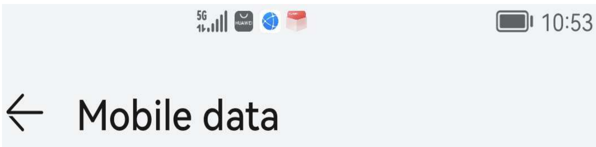

Fig. 5. A print-screen from a Huawei P40 Pro 5G connecting to a 5G OAI network.

The download speed during the vertical handover process is important to compute for critical applications such as video conferencing and voice-over-internet protocol systems. In the case of the work [35], [36], the download speed is computed for an entire vertical handover process. Therefore, in the case of the proposed algorithm, we also estimated the download speed to show the performance compared to the work [35], [36]. As we can see in Fig. 6, the processed throughput values using the MATLAB platform, the vertical handover download speed of the proposed algorithm is significantly high compared to the work [35], [36]. There are two main reasons for this significant vertical handover download speed, namely less frequent handovers and connection to a network for a longer time. During the experiments, we noticed that the Huawei P40 Pro 5G phone, in the case of the proposed algorithm, is connected for a longer time to a network. One of the reasons for this is that as soon as the Huawei P40 Pro 5G opens a security-constrained application, it switches to the OAI 5G network, which provides a larger coverage area compared to the OAI 4G network. However, in the case of the work [35], [36], the mobile user frequently switches between the available networks and thus causes frequent disruption during the transfer of the connection.

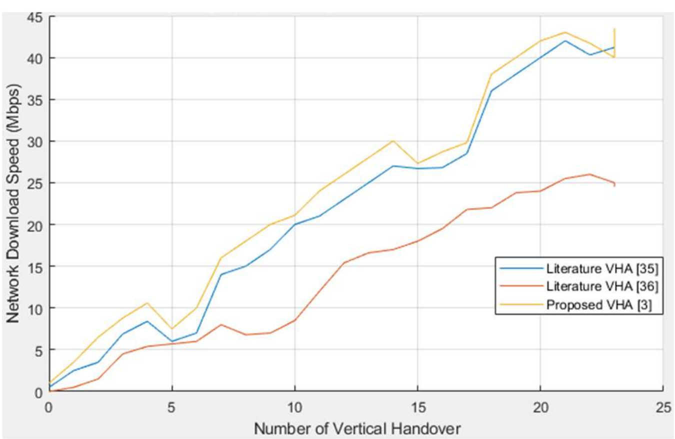

Fig. 6. Comparison of the proposed VHA's throughput results with that discovered in the literature.

To ensure that the Huawei P40 Pro 5G used as the user equipment is sufficiently fast, we tested the download speed achievable by the Huawei P40 Pro 5G on a live commercial mobile network, using *www.speedtest.net*. The test was carried out at the location with a latitude of -25.76523º and a longitude of 28.2876º at around 14h30 in the afternoon. The Huawei P40 Pro 5G was located at a distance of 150 cm away from the two base stations. The average measured values are as follows: 28.3 Mbps for a commercial 4G network, and 38.1 Mbps for a commercial 5G network. The measured values estimated in the proposed method are as follows: the 4G setup gave 31.2 Mbps, and the 5G setup gave 42.4 Mbps. A comparison of measured values for the commercial mobile network and our OAI mobile network is presented in Fig. 7.

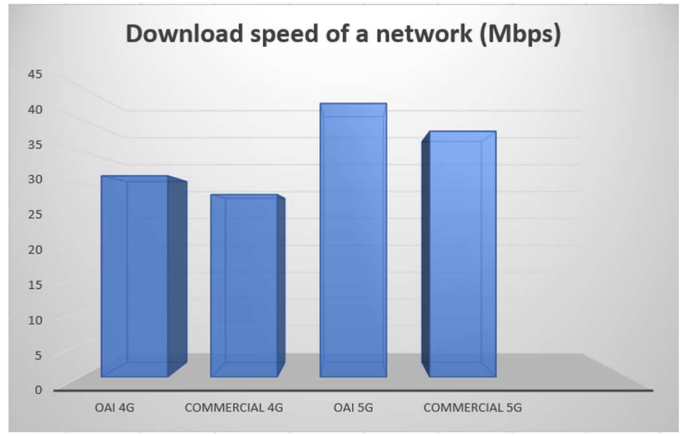

Fig. 7. The proposed heterogeneous OAI network is compared to a commercial network.

IV. Conclusion and Future Work

The vertical handover algorithm proposed in this paper incorporates the concept of a backpropagation (BP) neural network model into the operating process, forming a three-layer BP neural network based on the OpenAirInterface (OAI) 4G and OAI 5G network. We included the user's speed, the signal-to-interference and noise ratio (SINR), the maximum transmission rate, the minimum delay, the coverage area, the bit error rate, and the packet loss rate, for network training and data learning. We used the network download speed value as the ultimate performance metric to compare the two main networks to predict the results. Also to complete the process of examining the optimal network to finalize the handover decision, and finally the average network download speed was implemented on the MATLAB platform. In the future, this vertical handover algorithm will be tested in the outdoor environment to assess the performance of the proposed method.

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