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Self-optimizing Mathematical Model for Energy-Efficient Vertical Handover Management (VHM) in Mobile Heterogeneous Networks (Het-Nets)

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Abstract: Energy is one of the parameters considered for the Vertical Handover Optimisation (VHO) in Heterogeneous Networks (Het-Nets). Newer generations of Radio Access Technologies (RATs)- notably 4G, consume more power and mitigate the users' Quality of Experience (QoE) compared to the older generations of mobile Het-Nets. Consequently, low-end Mobile subscribers with older RATs cannot enjoy the same Quality of Service (QoS) in Het-Nets. Therefore, the energy-efficient Vertical Handover (VH) method, which increases the QoS is highly required in this present age of Het-Nets. In order to show a strong relationship between Energy and Handover, mathematical model for VHO was developed from which algorithms were deduced. The developed mathematical model was evaluated by simulation. Q-learning algorithm was formulated for vertical handover. The result of the experiment performed on the base stations showed that the sleep mode has maintained 97 percent energy consumption when the algorithms were tested with data. The Dynamic Bandwidth Allocation (DBA) application has reduced electricity usage from 5000 Kilowatts to 170 Kilowatts. The method developed improved 96.6% DBA. The study concluded that the enhanced mathematical optimization model has effectively promoted energy efficiency in the handover process. It is therefore recommended for mobile network operators, modelers and system analysts.

Keywords: *Energy, Heterogeneous Networks (Het-Nets), Passive Optical Network (PON), Sleep Mode, Vertical Handover.*

1. Introduction

The rate of power consumption in a mobile cellular network is called Energy. Energy-efficient Vertical handover (VH) is highly demanding and difficult in Heterogeneous Networks (Het-Nets) since the mobile customer has to change the selected network from a different system setting and technology [1].

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Homogeneous networks in mobile cellular systems are owned and operated by the same mobile operator. Every node plays the same role in the network with a single operating system and architecture, using the same protocols and configurations. A typical example is a half-duplex intra-cellular communication over a single base station within a Universal Mobile Telecommunication Service (UMTS); whereas, Heterogeneous system is a collection of dissimilar network technologies characterized by classes of terminals of varied configurations and protocols. An example is a full-duplex communication between UMTS and Long Term Evolution (LTE) over multiple base stations [2]. Despite integrating Het-Nets to promote interoperability, energy-efficient transfer management is still a challenge for both the academy and the mobile telecommunication engineering domain [3]. This article intends to optimise energy consumption utilising multi-attribute parameters in the Het-Nets environment consisting of Long Term Evolution-Advanced (LTE-A in 4G) and Passive Optical Network (PON) in order to improve vertical handover performance. Mobile operators use this new and promising technology called the

Self-Organising Network (SON) to increase the Het-Nets' Operational Expenditure (OPEX) capability while improving their mobile users' Quality of Experience (QoE) [4]. Energy consumption in a network is often ascribed to traffic flow among network equipment; however, with the fast and dynamic development of new broadband services and Traffic flows, there is a demand for integrated mobile wireless and optical access networks that effectively use Energy. Conversely, handover management is needed to address this issue.

1.1 Statement of the Problem

Optimization is a global phenomenon which cuts across every sphere of knowledge, and as it applies in the telecommunication industry, most especially; in relation to energy being a part of handover requirements, an in-depth study of optimized energy-efficient handover is essential in this present age of Het-Nets. Network optimisation is dependent on network efficiency relative to QoE. In contrast, mobile subscribers' movement patterns determine vertical handover optimisation in Het-Nets[5]. For the successful combination of Het-Nets, modeling energy-efficient vertical handover optimisation is essential to determine the best-connected network at various instances in Het-Nets. With the increasing number of mobile subscribers subjected to handover on a daily basis, vertical transfer becomes a challenge sequel to network traffic congestion.

Previous studies attempted to achieve energy-efficient Vertical Handover Optimization (VHO), but failed as a result of issues relating to single and multi-objective decision making schemes [6]. Meanwhile, none of the previous works have considered an in-depth study depicting a strong mathematical relationship between energy as a requirement for vertical handover. Newer generations of Radio Access Technology (RATs)-especially 4G, consume more power and diminish the users' QoE compared to the older generations of mobile cellular networks. As a result, low-end Mobile subscribers with various generations of networks find it difficult to enjoy the same QoS in Het-Nets. Therefore, the energy-efficient VH scheme, which upturns the QoS is extremely necessary in this era of Het-Nets.

Consequently, it is critical to model the combined PON and LTE-A access network so that the network's energy efficiency can be readily assessed while QoS stays high based on the Fuzzy optimality principle. The Fuzzy principle was applied in Het-Nets as a trade-off for distribution and optimisation to attain a timely and cost-effective handover optimisation strategy, reduce call dropping probability, and improve the handover success rate in Het-Nets by reducing the average energy consumption. This is necessary to improve the QoS and QoE for mobile operators and subscribers respectively. The main aim of this paper is to develop a self-optimising energy model for vertical handover management in mobile Het-Nets, while the specific objectives are to:

1. develop a set of mathematical equation linking handover and Energy. This is intended to depict in various ways, strong mathematical relationship between energy and handover.
2. evaluate 1. above by simulation experiment, using Doze mode, Dynamic Bandwidth Allocation (DBA) and Sleep mode as industrial standards based on fuzzy principle.

Subsequently, Section two gives the review of the existing works, section three shows the methodology employed in this study through the development of a VHO Model for vertical transfer. Section four presents data analysis, results at various scenarios and discussion of findings, while section five gives the summary, conclusion and recommendations.

2. LITERATURE REVIEW

Various research works have been conducted on handover management throughout the years. The problem of inequalities in the QoS experienced by users and power consumption due to a different network and device configurations for various cellular technologies was addressed by [7]. In this Paper, VH was used as the energy optimisation technique in Het-Nets comprising Wireless Local Area Network (WLAN) and LTE. In this case, the integration of Het-Nets promotes interoperability to attain the dream of UMTS as specified by the International Telecommunications Union (ITU). To further address energy consumption as a critical issue in Het-Nets consisting of wireless networks of diverse configurations, [2] proposed an energy-aware vertical handover method based on vector normalised preferred performance that operates on VIKOR Algorithm- peak-to-peak voltage (V-VPP) to process VH. For the purpose of increasing the QoS and improving the energy consumption during VH process, [5] proposed a Fuzzy Logic-oriented VH decision algorithm that measures numerous input parameters and decides the best connected network preference between LTE and WLAN for handover performance. Moreover, a smart interface activation method which operates based on prediction by Recurrent Neural Network (RNN) model was also developed to mitigate unnecessary system measurements all through perfect network conditions of the current system, thereby enhancing the power consumption rate in mobile stations.

[8] proposed network coverage gaps and over-provisioning as the optimisation points and evaluated their weights' properties. The method's performance based on energy savings was assessed in a long-term urban evolution (LTE) setting with diverse base stations. In this study Fuzzy

principle was implemented as a trade-off between Energy and QoS. The simulation outcomes depicts that the proposed method can increase energy efficiency in Het-Nets. At the same time, the QoS was guaranteed. [9] formulated a multi-level optimisation problem that collectively maximises the Energy Efficiency (EE) and Spectrum Efficiency (SE) for two-tier Het-Nets. The optimization problem was formulated by convex optimisation techniques to derive the Fuzzy-optimal result for various system parameters. The work of [10] overviewed the interference system in relation to the Poisson Point Process (PPP). It analysed the efficiency in terms of energy reliability in multitier networks. As an effective method for optimizing the performance of Het-Nets, both the supportive communication and cognitive wireless schemes to reduce the interference in Het-Nets were measured.

3. SYSTEM DESIGN

The following steps were strategically followed to implement the research work:

Step 1: Development of Mathematical equation for the energy model with respect to vertical handover based on an existing model,

Step 2: Experimental set-up for data capturing- A set of experimental data was used to get all the energy consumption for all networks.

Step 3: Identification of the network equipment modeled

Step 4: Definition of the features of all the equipment in step 3

Step 5: Assigning of profile configuration to the properties of the equipment, application configuration to the programs run on them and quality of service profile to the level of satisfaction of users.

Step 6: Modeling step 4 to step 5 on Optimum Network Engineering Tool (OPNET) software

Step 7: Applying the profile configuration features to all equipment used

Step 8: Applying the application configuration to all equipment used

Step 9: Developing routing and optimization Algorithm using C++ programming language for all the transceiver equipment used

Step 10: Develop Q-learning Algorithm for routing in MATLAB

Step 11: Develop Qlearning Algorithm Formulation for vertical handover

Step12: Development of Decision model for handover using Fuzzy logic

Step13: Evaluation based on Doze mode, Dynamic Bandwidth Allocation (DBA) and Sleep mode

3.1 Development of Mathematical Equation

The following mathematical tools were used:

i. Laplace Transform
ii. Max and Min function

3.2 Mathematical Relationship between Handover and Energy

Let E_{ACCESS}, E_{OLT} and E_{ONU} denote the amount of energy consumed by the access network, the Optical Line Terminal (OLT), and the Optical Network Unit (ONU) respectively. As a result, the total energy used by the network can be expressed as follows:

$$E_{ACCESS} = E_{OLT} + \sum_{i=1}^{n} E_{ONU} \tag{2.1}$$

(Hamzeh, David, Sebastia and Jose, 2020)

where n is the number of ONUs in the network.

ASSUME that the OLT is in active mode instantly and it is not at the turned off (or its components) for energy saving.

Let us denote EONUi(k), the energy expended by the ith ONU throughout cycle k.

The total energy consumed by one ONU for cycle k is denoted by:

$$E_{ONU,}(k) = E_{OH}(k)| + E_{R_{OLT}}(k) + E_{R_W}(k) + E_{R_E}(k) + E_{T_E}(k) + E_{T_W}(k) + E_{BF}(k) \tag{2.2}$$

where EOH(k) indicates the energy used up by ONU through the summative overhead time (OH).

The OH is the cumulative time requisite to switch components at the ONU from the passive state to the active mode in one cycle k; it comprises the free-running clock drifts, the ONU clock loss time, and the synchronization system after improving the OLT clock.

E_{ROLT} (k) = energy used up by the: Ethernet receptor for load coming from OLT

E_{RW} (k)= Wireless receptors for traffic coming from end-users

E_{RE}(k) = Ethernet receptors for load inflow from subscribers,

E_{TE}(k) = Ethernet receiver

E_{TW} (k) = wireless receiver and

E_{BF} (k) = ONU modules at on state all-time, respectively.

Finally, we derived

$E_{OH}(k)$ as per $E_{OH} = T_{OH} * P_{total}$ (2.3)

T_{OH} = total overhead time

P_{total} = aggregate power for one ONU using all its transceivers and the rest of the modules in active status.

Let $E_{tr}(k)$ be the energy expended for one transmitter or receiver.

Let P_{tr} and AP(k) be the power used up by the transceiver and the on state period for one cycle k, respectively. Etr(k) can be given as

$$E_{tr}(k) = P_{tr} * AP(k) E_{tr}(k) \quad (2.$$

Multi Criteria Decision Making in this study is a function of multiple attributes considered at various stages involved in the VHO process. For instance, to choose a target network with respect to the cost of network based on Simple Additive Weighing (SAW); having selected the indicators- weights are assigned respectively. Therefore, the cost of the network connection is given by the summation of all the normalized weighted values of the system.
It takes this format:

$$C = \sum_{J=1}^{N} P_i (S_i, J) \quad (2.5)$$

Where :

C = cost of the network

N = the number of parameters measured,

i = the order of importance of the individual parameter with respect to P_i and S_i respectively

Pi symbolises the parameter's weight to the i^{th} term, and

Si,j represents the rate of the i^{th} factor from the j^{th} duration of the target network.

For modelling the power consumption of each component, the following equations were used:

$$P(r) = (1+a)(r/R)P_{active} + (1-(1+a)r/R)P_{sleep} \quad (2.6)$$

$$P_{sleep} = b\, P_{active} \quad (2.7)$$

with

$P(r)$: Average electricity usage as a subscriber rate function. This count the amount of time while the component is active,

P_{active} : Energy usage if the component transfers complete data (active state),

P_{sleep} : Power consumption in the sleep saving mode of the component,

b: Proportional factor in estimating idle power as an active power percentage,

r: Average subscriber rate (we modelled upstream 50 Mbit/s and upstream 10 Mbit/s)

R: Max. component rate (e.g. downstream 2.5 Gbit/s and upstream 1.25 Gbit/s in EPON, 1 Gbit/s in particular user rate processing blocks)

a: Superficial (a ratio of listening state to total sleep cycle plus a preamble time for synchronising the component).

3.3 Development of Routing and Optimization Algorithm

For the development of routing and optimization Algorithm, C++ programming language embedded in the Adaptive Network Fuzzy Inference System (ANFIS) Matrix Laboratory (MATLAB) Version 2021 was used. Hence, the power consumed by the base station leads to the effective handover management which is shown in the Algorithms 1. Algorithm 1 describes the Adaptive Hybrid-learning Algorithm Formulation for vertical handover, and it performs artificial intelligent-based handover decision.

Algorithm 3.1: Adaptive Hybrid-learning Algorithm Formulation for vertical handover Source: Author

```
%g% Hybrid -learning Algorithm


% Initialise the Hybrid-table with arbitrary values ~ N(0,1)

% Set learning ratio at 1 and rebate factor to 0.9

% The highest number of occurrence is set at 50


q = randn(size(reward));

gamma = 0.9;

alpha = 1;

maxItr = 10000;

epsilon_initial = 0.2;

% cs -> current state

% ns -> next state

%

% Repeat until Convergence OR Maximum Iterations

for i=1:maxItr
```

```
epsilon = epsilon_first/(1+i/500);
% Starting on joint position
cs=73;
% Repeat for t times
for k=1:t
% possible actions for the chosen state
n_actions = find(reward(cs,:,k)>=0);
% select an action by arbitrary with stochastic epsilon and fix it as the
% next state
if rand(1)<epsilon
    ns = n_actions(randi(length(n_actions)));
else
    ns = n_actions(find(q(cs,n_actions,k)==max(q(cs,n_actions,k))));
    if length(ns)>1
        ns = ns(randi(length(ns)));
    end
end
    if k<t
        % Search all the likely actions for the chosen position
        n_actions = find(reward(ns,:,k+1)>=0);

        % find the highest q-value, i.e., succeding state per the finest action
```

3. RESULT AND DISCUSSION OF FINDINGS

This section present the evaluation of the developed energy-efficient vertical handover optimization model based on doze mode, Dynamic Bandwidth Allocation and sleep mode as industrial standards and fuzzification. The network filter and Attenuation enable more power consumption at the base station equipment, adopted Hybrid learning Algorithm was developed to reduce power consumption and improve energy efficiency for self-optimization with fuzzy logic.

4.1 Result Based on mathematical relationship between Handover and energy

The combination of EPON with LTE improves the access network's energy efficiency, resulting in lower data rates for LTE. It also improves self-optimization for vertical handover in heterogeneous networks. The integrated energy consumption efficiency is affected by differences in split ratios, FeedBack communication System (FBS) range, diffusion factor, and modulation technique. By raising the split ratio, the network's total energy consumption may be reduced, and energy efficiency can be improved via better equipment sharing. However, caution must be used to ensure that the increased range does not degrade signal quality.

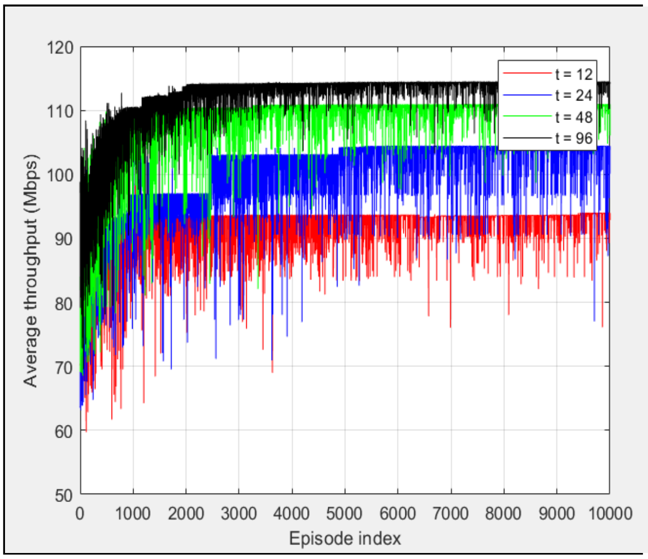

Fig 4.1: Average throughput for Vertical Handover based on Signal Level Hybrid-learning Handover

Source:

Author's Experimental Work

Figure 3.1 shows the average throughput for vertical Handover on signal level. The x axis represents the episode index which is the signal level at each layer of the base station. It can be deduced from the result that the average throughput increases with the signal level which is the episode index. More average throughput increases the self-optimizing system for the vertical transfer in the mobile heterogeneous network. Multimodal M.T.s may now transition between WLAN and cellular networks in real-time and choose their preferred network. M.T.s needs effective vertical Handover (V.H.) Algorithms to utilise the heterogeneity of the wireless environment. From Figure 4.1, the best and the highest average throughput at which handover cannot be affected was 114Mbps at 98 Sec.

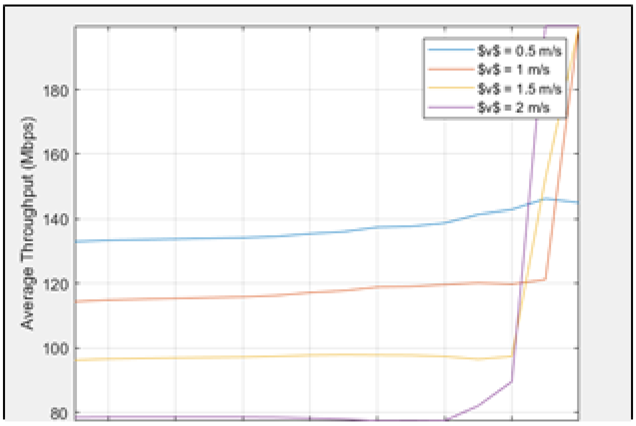

Fig 4.2: Average throughput on Vertical Handover based on one base station Source: Author's Experimental Work

From Figure 4.2, the index at the x-axis shows the signal symbol rate while the y-axis shows the average throughput for a single base station. At higher symbol rate of 1m/s, 1.5m/s and 2m/s, the throughput reach the optimum level of 200Mbps. Figure 4.2 shows the vertical Handover throughput when one base station is used. The best average throughput based on the iteration was 200Mbps at 14sec. Handover is affected by throughput such that, the higher the rate of time sampling, the lower the signal level.

5. Conclusion

Optimising the vertical transfer is a mobility function. For further development of a vertical optimisation process, an enhanced optimisation model was also developed to provide the handover method for the typical self-organising system with respect to learning, adaptation and decision, based on various Algorithms for different verticals hobby scenarios. A collection of generated algorithms operating on the established key performance indicators (KPI) for transfer optimisation involves creating a new class of coupled Vertical Handover optimization Algorithms based on a well-defined Fuzzy Multi-Criteria Decision Making logic to provide a scalable, adaptable and flexible Het-Nets technology. The collection of discrete data has also assisted in quantifying and analyzing discrete optimization factors for vertical handover. Detailed application in the theory and practice of the suggested VHO model will also assist decision-making network providers, modellers and system analysts. For the purpose of knowledge expansion in the implementation of Self-Optimizing Network features with respect to energy-efficient handover management, future work should also consider 5G, 6G and 7G technologies respectively.

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