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Ping-pong reduction for handover process using adaptive hysteresis margin: a methodological approach

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Abstract. The technology, Long Term Evolution (LTE) developed by 3rd Generation Partnership Project is considered an improved standard in mobile communications when compared to previously attained network standards. LTE with prospects of decreased latency levels and support of downlink and uplink transmission at data rates exceeding 100Mbps and 50Mbps, an effective handover framework needs to be put in place to improve quality of service rendered to the network users and decrease wastage of network resources. This study examines several works carried out on a handover criteria (hysteresis margin) needed for designing an effective handover framework. This margin is based on the received signal strength between both target and serving eNodeBs, and its proper determination amongst other advantages mitigates the rate of unnecessary and repeated handover (ping-pong effect). The model presented in this research integrates the artificial neural network (ANN) mechanism into the determination of hysteresis margin in the LTE handover process which is to minimize handover delay and ping-pong taking into consideration the speed of the user equipment (UE).

1. Introduction

The technology, Long-Term Evolution (LTE) was developed by 3rd Generation Partnership Project (3GPP). LTE is expected to decrease latency levels associated with packet transmissions and support downlink and uplink transmissions at data rates exceeding 100Mbps and 50Mbps respectively. Two modulation schemes are employed for both uplink and downlink transmissions: Orthogonal Frequency Division Multiple Access (OFDMA) is employed for the uplink while the downlink utilizes Single-Carrier Frequency Division Multiple Access (SC-FDMA). This technology constitutes two duplex modes (time division duplex and frequency division duplex) which is deployed in the separation of the direction of transmission from the User Equipment (UE) in eNodeB and vice versa. In Time Division Duplex (TDD), the transmission direction is separated in the time domain while the uplink and downlink utilize the same frequency. This results in each call direction being allotted distinct timeslots. For Frequency Division Duplex (FDD), transmission in uplink and downlink utilized different frequencies [1], [2]. The LTE architecture, also called System Architecture Evolution (SAE), comprises of three elements; evolved-NodeB (eNodeB), Mobile Management Entity (MME) and the Serving Gateway (S-GW)/Packet Data Network Gateway (P-GW). A systematic review on research works carried out on hysteresis margin dilemma and ping-pong effect in LTE mobile networks is presented and a framework which integrates intelligence into the LTE handover process through the adoption of artificial neural networks is presented. This paper is divided into seven sections as follows; section I introduces the LTE technology, highlights its architecture and discusses the handover process associated with the network. Section II to IV is the extended literature study while section V discusses the proposed framework which adopts the artificial neural network (ANN) for prediction and increasing efficiency in the LTE handover process. The article is concluded in section VI.

2. Literature Study

2.1 LTE Handover Issues and Hysteresis Margin

The steps involved in LTE handover process are as shown in figure 1. The eNodeB executes all radio interface-related functions which includes handover and packet scheduling [3]. In Mobile communications systems, the UE regularly moves through several eNodeBs. As a UE enters the region served by a new BS, the call connection will be reassigned from the BS previously serving that UE to the new BS [4]. The LTE network is geared towards performing uninterrupted and smooth handover processes in order to utilize its network resources to the utmost maximum. The handover process can be carried out either by the network itself or the UE to prevent disruption in services rendered with improved quality [5]. The handover triggered by the UE occurs due to detection of poor signal strength received from the serving cell. Network initiated handovers are performed generally in order to reduce or avoid the probability of dropped calls which may occur due to network congestion as mentioned in [6, 7, 8]. Regardless of user position or attachment point, an active connection is sustained for network users [5].

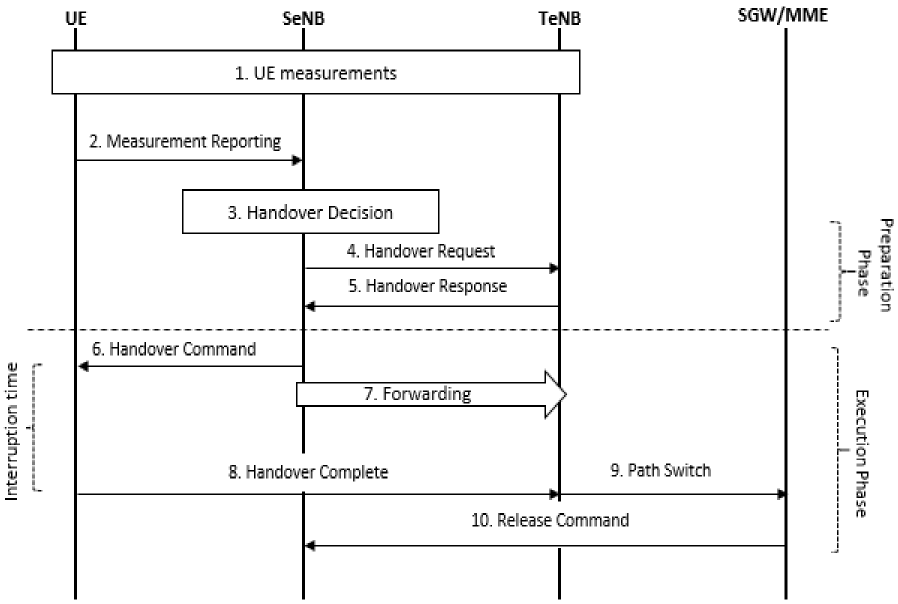

Figure 1. Steps in the handover process, source [23]

Handover in LTE consists of two types; S1 and X2 handover processes. The X2 handover is usually employed for heterogeneous handovers (handover between LTE and other mobile networks) to ensure prevention of interference and ensure network load balance. In the absence of an X2 interface between two eNodeBs, or if a configuration has been carried out on the source eNodeB (SeNB) to utilize the S1 interface in performing handover in the direction of the target eNodeB (TeNB), the S1-handover is triggered. Three stages are involved in both handover processes and they include; preparation, execution and completion. The preparation stage involves the user equipment (UE) sending a periodical measurement report to the SeNB. This report is then examined and based on it, the SeNB makes a decision on which TeNB to handover the UE to. Several criteria asides the measurement report are also put into consideration by the SeNB before sending a control message to the TeNB to brace for the handover. The TeNB prepares a buffer for the UE on receiving the control message sent by the source eNodeB. The execution stage kicks off immediately the preparation stage is concluded. In this stage, the source eNodeB sends a handover command control message to the UE notifying it of its impending transfer to another eNodeB. As the UE receives this message, it disconnects itself from the SeNB and sends a connection request to the TeNB. Simultaneously, all packets associated with the UE is transferred to the target eNodeB by the Source eNodeB. A queue for these packets is then formed by the target eNodeB in the UE buffer [10]. Upon successful connection by the UE to the TeNB, all buffered UE packets accompanied by the packets arriving from the target gateway are transmitted by the TeNB. The UE then sends a handover complete message to the TeNB indicating the completion of the handover. In the completion stage, the TeNB notifies the source eNodeB to release all network resources utilized by the UE and also inform the target mobile management entity (MME) to perform path switching to the target eNodeB [3, 22, 23].

A seamless handover is the goal of all network operators. If this is achieved, wastage of network resources can be averted and brought to a minimum. In the design of handover algorithms a necessary consideration is the link quality which can be analysed in terms of signal strength. For handover algorithms based on Received Signal strength (RSS), the hysteresis margin is an important factor to consider alongside the configured threshold signal strength as mentioned in [11] where signal quality factor was introduced. Hysteresis is a parameter that examines the difference in received signal strength between a serving and a target eNodeB. The hysteresis margin (HM) illustrated in figure 2, is the margin required for maintaining the minimum difference between the strength of the signal received from the serving eNodeB and the target eNodeB [5, 6, 12]. In terms of developing RSS handover algorithms, hysteresis plays a significant role as an improper configuration of this parameter can lead to the occurrence of a high number of handover failure rates [14].

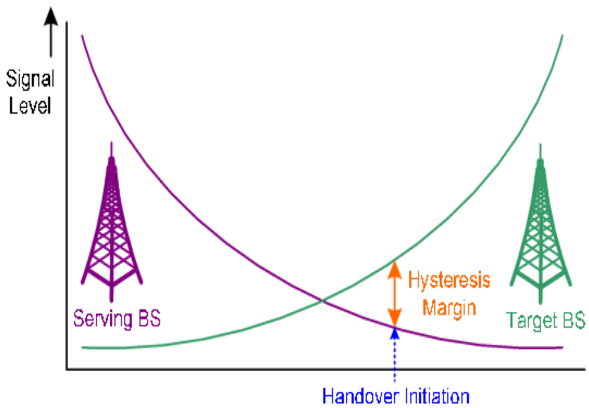

Figure 2. Hysteresis margin for handover procedure, source [16]

Networks in reality, experience a variation in the power of the signal received. This is due to rapid fading of signals and other associated environmental alterations. These variations do not correspond with any recognized pattern involving movement of a particular UE. Hence, the nature of UE movement and the fluctuation of signal strength over time could lead to repeated handovers between two neighbouring cells in short time span. This repeated and sometimes unnecessary handovers is referred to as Ping-Pong handover (PPH) [13]. According to [15], introducing hysteresis margin into an RSS handover algorithm establishes a platform for either increasing the rate of unnecessary handovers (small hysteresis margin) or reducing the number of handovers (large hysteresis margin). The margin can either be fixed or adaptive with each having its own benefits. In [15], the two parameters employed in developing an efficient handover algorithm in micro and macro cells were hysteresis margin and handover delay and in the analysis of the overall performance of cellular mobile network, the efficiency of inter-cell handover algorithms was examined in terms of decrease in unnecessary handovers and handover delay time. The authors outlined various handover initiation parameters as: hysteresis margin, signal threshold, averaging time interval, delay time and average window shape. Out of the aforementioned, two design parameters were portrayed as essential which are hysteresis level and signal strength averaging time. The latter when configured to have a short duration span may likely give rise to an increase in the rate of unnecessary handovers while a long duration span configuration may result in failure to recognize a

required handover. The received signal of a UE can be analysed as a random variable which adopts log-normal distribution, taking into account the averaging out of Rayleigh fading. An analytical procedure was used in the research to determine the best hysteresis margin and signal averaging time for macro and micro cells. The results showed that, taking into account the effect of shadow fading, a concession exists between the two handover parameters examined.
In [9], adaptive hysteresis margin was employed for handover in femtocells. Femtocells which are characterized with minute radius coverage, create a means for a frequent handover initiation process and are usually deployed in networks. According to the authors, the handoff process is triggered when the signal specification of the target eNodeB, STar, exceeds that of the serving eNodeB, SSer, putting into consideration a certain level of hysteresis margin, HM. The expression is given as;

$$S_t^{Tar} > S_t^{Ser} + HM \quad (1)$$

Both signal quality specifications of the target and serving eNodeBs represented in the equation above are acquired at a certain time instant, t. Having portrayed the hysteresis margin as a frequently used parameter for eradicating unnecessary handovers, the research focused on adapting a certain hysteresis margin level which corresponds to user position in a given cell. This adaptive concept used the actual HM value in equation (1) which was modified utilizing user position in the cell. Where HMmax is the value of the hysteresis margin at its maximum, d, the distance between the serving eNodeB and the user equipment (UE) and R; the radius of the serving eNodeB, the modified hysteresis margin, HM, can be acquired using the formula;

$$HM = max\left\{HM_{max} \times \left[1 - \frac{d}{R}\right]^4 ; 0\right\} \quad (2)$$

As a result of difficulty encountered in acquiring the distance parameter, d, and the radius of the serving cell, R either by the UE or the network, hence, the research brought forward metrics that are effective and easy to employ. The modified formula integrating the RSSI was given as;

$$\text{effective } HM = max\left\{HM_{max} \times \left(1 - 10^{\frac{1}{N}(RSSI - RSSI_{min})}\right)^{EXP} ; HM_{min}\right\} \quad (3)$$

So, in [9], radius of the cell, R, represented in the equation by $RSSI_{min}$, was defined as the distance where the minimal allowable level of the RSSI is attained. The research was evaluated using efficiency as regards a decrease in the amount of redundant handovers and also an effect in the throughput of users in the LTE network. The results revealed a considerable decrease in the rate of handovers as well as decreasing effect on the throughput. [5] states that most handover algorithms are based on the receive signal strength (RSS), hence hysteresis margin which deals with minimum received signal strength, plays a vital role in analysing handover performance and also influences the region of coverage of mobile networks. The research, having established the fact that determining a particular value for the hysteresis margin (HM) can be challenging, examines a microcellular region and is aimed at developing an adaptive HM for a handover algorithm centered on the data gotten from the distance between a user equipment and its serving base station in that region. The research was evaluated by examining the effect of HM on handover delay and number of handovers. A simulation model consisting of two hexagonal cells, each having its own base station and a user equipment moving between the cells was developed. Prior to [5]'s research, [3] developed an algorithm to curb the issue of hysteresis margin and load balancing in handover as it concerns LTE heterogeneous networks. It was said that decision on when to carry out a handover between various eNodeBs presents one of the major issues plaguing heterogeneous networks.
The need for an adaptive hysteresis margin is mentioned in the research carried out by [18] and [19]. According to [18], handover algorithms designed taking user mobility into account can be improved upon by integrating not just mobility but also user speed in the design. In his research, the author focused on developing a User Speed Mobility Robustness (US-MRO) algorithm which employed user speed as criteria for allotting different hysteresis margin to user equipment in LTE network for effective and efficient handover process. [20], examined the impact of hysteresis margin and lognormal shadowing,

as regards inter-cell and Intra-cell handover, on residence time in mobile networks which adopt link adaptation. Inter cell hysteresis margins utilize received signal strength difference between target and serving eNodeB while intra cell margins analyze the difference in signal to interference ratios to determine if a handover process should be carried out. It defined residence time, in what is regarded as quality zones, as the time duration of a UE in a cell and is reliant on mobility of user, signal propagation conditions and the handover technique adopted in the network. The authors reiterated the need for the UE to perform regular signal measurements and forward these measurements to the eNodeBs on a regular basis. Just like [14] in what was termed "contradictory", it was stated that a very late initiation of the handover process results in a corresponding radio link failure while initiation which occurs too early results in the ping pong effect. The research takes into consideration the configuration of the neighbouring cell in order to maintain the admissible for Radio Link Failures (RLF) and ping pong rates. Unlike [16, 17, 18] who utilized user speed as a criterion for implementing an adaptive hysteresis margin, [19] presented a handover algorithm that allocated different hysteresis margins based on configuration of target cells.

2.2 Handover Algorithms for Hysteresis Margin and Ping pong Mitigation

LTE networks adopt the hard handover type for handover processes and this informs the need of selecting the best handover parameters for promoting user satisfaction [14] but failure to select appropriate handover parameters could lead to a high radio link failure rate. [21], mentioned user behaviour as a basis for developing a handover algorithm with the capability of selecting the most appropriate handover parameter values. Users are broadly classified in to real time traffic users and non-real time traffic users while user behaviour as stated in the research, is sectioned into four classes; slow speed real time, slow speed non-real time (SN), high speed non-real time and high speed real time users. In [5], Three handover algorithms were examined; The LTE hard handover algorithm, received signal strength based Time To Trigger (TTT) window algorithm and integrator handover algorithm. These algorithms were then evaluated and compared to the algorithm proposed in the research called LTE hard handover algorithm with average RSRP constraint. The LTE hard handover algorithm is simple but efficient handover algorithm that comprises of two parameters: Time to Trigger (TTT) and Hysteresis margin (HM). Two conditions for initiation of handover process were defined in [3] and were also used in the timer approach proposed in [15]. The conditions are as stated in equations (4) and (5) where $RSRP_T$ and $RSRP_S$ represent the reference signal received power of both the target and serving eNodeB respectively while the $HO_{trigger}$ is the timer allocated to the handover process which begins to count once equation (4) is satisfied.

$$RSRP_T > RSRP_S + HM \quad (4)$$

$$HO_{Trigger} \geq TTT \quad (5)$$

The RSRP was calculated by [16] using the equation (6);

$$RSRP = P_{CellTransmittingPower} - P_{PathLoss} - P_{ShadowFadingMargin} \quad (6)$$

In order to ensure effectiveness of the handover hysteresis margin, a value for time interval is created, this value is known as the Time to Trigger (TTT). According to [22, 23, 24] failure to keep this effect in check creates a platform for incurring reduced system throughput, increase in the amount of utilized signaling resources, and increased delay in data traffic which emanates as a result of buffering the traffic coming into the target cell during each handover process. Handover algorithms were classified into five types as regards small cells: RSS-based, speed-based, interference-aware, cost-function, and energy-efficient handover algorithms. [15], defined the probability of an unnecessary handover, Pho, as the likelihood of a UE to perform a handover from its serving eNodeB, eNB0, to a target eNodeB, eNB1, and then triggers another handover back to the previous eNodeB, eNB0. The mathematical expression is given as;

$$prob\{eNB0 \longrightarrow eNB1 = \int_{r=-\infty}^{r=\infty} (prob\{R_{\#1} = r\} \, . \, prob\,\{R_{\#0} < (r-h)\}) \, . dr \tag{7}$$

$$prob\{eNB1 \longrightarrow eNB0 = \int_{r=-\infty}^{r=\infty} (prob\{R_{\#0} = r\} \, . \, prob\,\{R_{\#1} < (r-h)\}) \, . dr \tag{8}$$

[21], defines the rate of ping pong as the ratio of the number of ping pong to the actual number of successful handovers;

$$Ping\ pong\ rate = \frac{Number\ of\ Ping\ pong}{Number\ of\ successful\ handovers} \tag{9}$$

For purpose of analysis, the ping pong handover was defined from the scenario of the UE moving at the cell border causing unnecessary handover is a short time duration, while the rate of handover failure was divided into three scenarios; too early, too late, and handover to wrong cell [26]. In further research work to decrease the ping pong effect, [27], developed an algorithm based on an enhanced handover technique for balancing network load incurred through mobility of users in LTE network. It was further stated that improper traffic distribution schemes lead to network congestion which inturn affects data exchange as mentioned in [28] and [29] resulting in wastage of resources, hence, the need for the mobility load balancing (MLB) algorithm. This algorithm takes the already established mobility robustness scheme and users at the cell border into consideration.

Most handover algorithms these days are integrated with prediction schemes. This enables them store previous data on a UE's handover to a target eNodeB and make future decisions (after undergoing several mathematical estimations) on the right choice of target eNodeB to hand the UE to when such scenarios occur again [30]. Unlike the conventional handover schemes which adopt signal to noise ratio (SNR) for making handover decisions, it takes advantage of Packet Success Rates (PSR) as a means for examining the link between user equipment and eNodeBs. A recent research on adopting the Multi-Layer Perceptron (MLP) technique in neural networks for decreasing handover delays in LTE networks was carried out by [32]. Just like [31], the research utilized the same enhanced technique which adopts historical data for handover delay reduction using criteria such as packet loss, time and region domain, and time it takes an eNodeB to reply.

3. Proposed Handover Model

The need to develop an appropriate hysteresis margin for better performance of LTE networks has been emphasised in this study. The integration of the artificial neural network (ANN) in the determination of an appropriate hysteresis margin in an handover process is presented in the block diagram of figure 3. During traditional simulation methods for determining an appropriate hysteresis margin based on user speed, data can be acquired on the following: different HMs and their corresponding number of successful handovers, received signal strength (RSS) from both target and serving eNodeBs, number of failed handovers and their associated HMs, handover delay associated with different hysteresis margins; and number of ping pong handovers and its associated HMs. The three-stage model utilizes [16]'s modification of the adaptive hysteresis formula, which replaces the cell radius, R, and the distance between source and target eNodeBs with two handover parameters, RSSI and the $RSSI_{min}$. These two parameters along with the velocity of the UE are fed as inputs into the ANN for determination of the hysteresis margin.

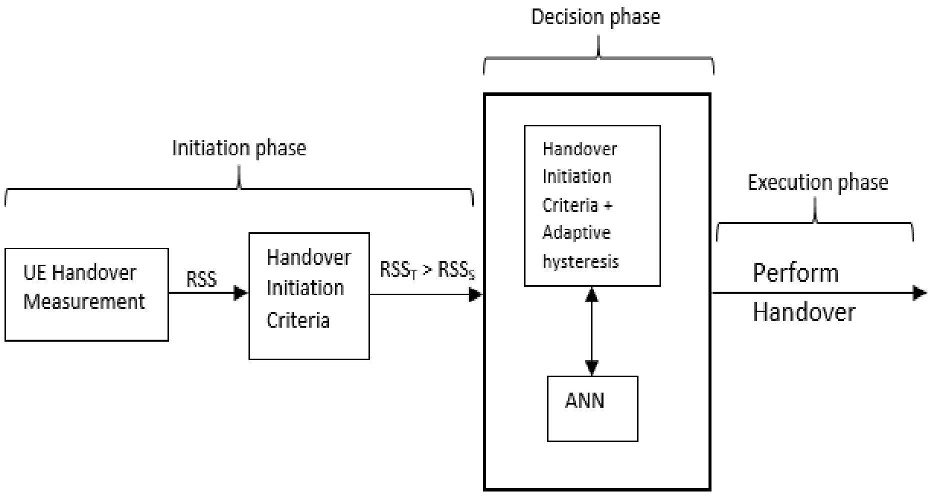

Figure 3. Block diagram of proposed model

3.1 Initiation/Preparation Phase

This stage is used to train the proposed scheme using the conventional RSS based algorithm with adaptive hysteresis. The flowchart of the handover initiation phase is shown in figure 4. The handover metrics involved are RSS, RSS_{min}, and UE velocity, which are used by the neuro-adaptive model to generate an appropriate hysteresis margin for the handover process. Steps involve include:

Step1: Check measurements
Step 2: Check if $RSS_T > RSS_S$
Step 3: If (2) is satisfied, apply adaptive hysteresis margin, h: $RSS_T > RSS_S + h$
Step 4: Input UE handover measurement (RSS, RSS_{min}, V_{UE}) to ANN

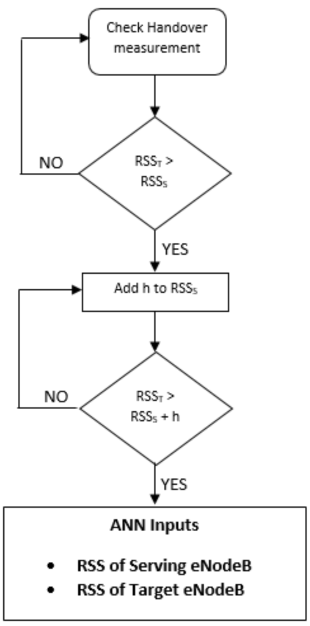

Figure 4. Handover initiation flowchart of the model

The model also proposes the adoption of the dynamic determination of the RSS parameter. The received signal strength (RSS), which is an input to the ANN, can be captured dynamically utilizing the concept of the RSS quality factor adopted in [34] and defined in (12). At every given point in time, as the UE moves across cells, the received signal strength varies based on the user speed and its distance from the serving and target cells. Hence the introduction of the RSS quality factor, α, which captures the RSS of both eNodeBs at every given position of the user. The pathloss of a transmitted signal also varies with distance [34]. So, the RSS quality factor, α, as defined in [34] is given as;

$$\alpha_{Target,Serving} = \frac{RSS_{Target,Serving} - RSS_{threshold}}{RSS_{Target,Serving}} \tag{12}$$

This implies that the pathloss is distance dependent that is PL(d) and based on this the RSS can be captured dynamically. The RSS takes into consideration the transmitting power and the pathloss given as in (13);

$$RSS_{Target,Serving} = P_{t(Target,serving)} - PL(d) \tag{13}$$

3.2 Neuro-Adaptive Decision and Execution Phases

After the ANN is trained, the framework determines the adaptive hysteresis margin based on the set criteria. This stage also includes the integration of a timer in the system for further mitigation of ping pong handovers. Figure 5 is the flowchart of the neuro-adaptive hysteresis algorithm and it adopts two criteria for performing handover. Inclusion of a timer establishes a duration in which the system decides if the current initiated handover is associated with the ping pong movement (repeated oscillation of a UE between two cells within a short time duration) or the conventional type of movement. The RSS between the target eNodeB and the serving eNodeB is constantly measured and system continuously checks if the RSS of the former is adequately greater than that of the latter. If the timer runs out and the RSS of the target eNodeB is still sufficiently stronger than that of the serving eNodeB, the movement is termed to be the conventional UE movement and the handover process is allowed to be executed. On the other hand, if the timer runs out and the difference between the two eNodeBs reveals that the target is not satisfactorily greater than the serving, the movement is tagged eNodeB and the system withholds the handover execution.

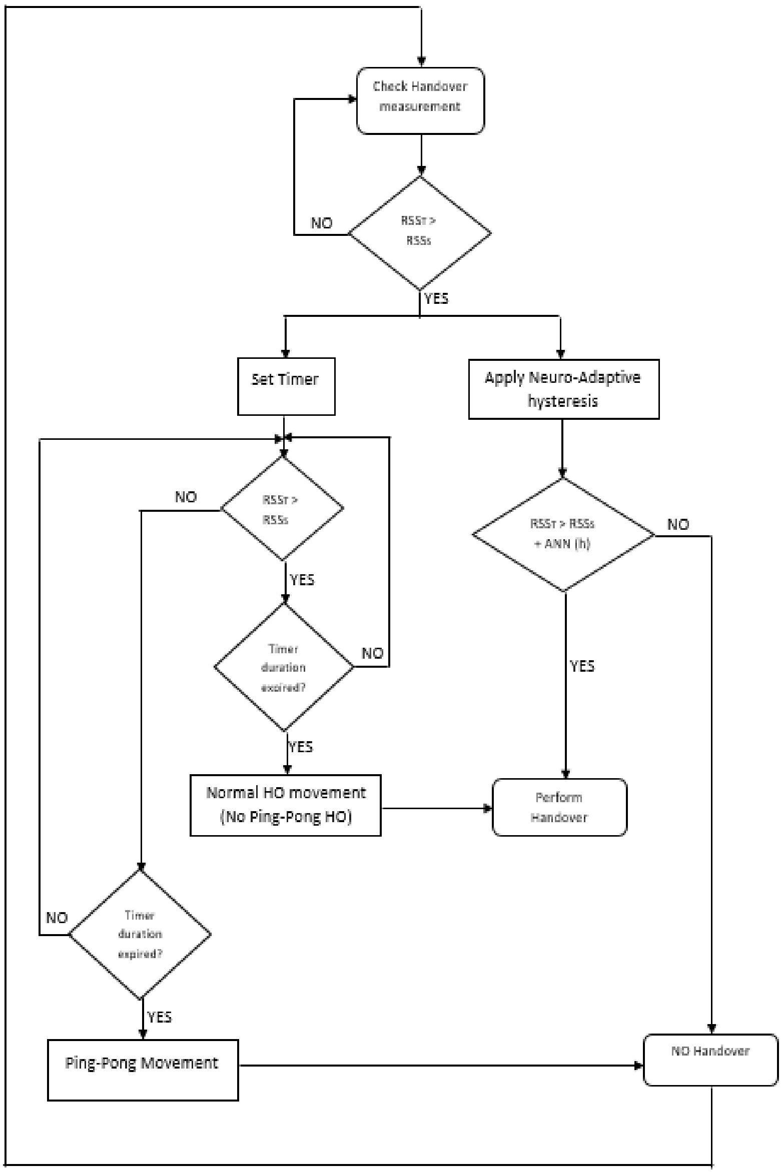

Figure 5. flowchart of Timer-based Neuro-Adaptive model

4. Conclusion

This study expressed the need for an appropriate hysteresis margin, to mitigate ping-pong effect for effective handover. Previous research works on hysteresis margin, ping-pong effects and neural networks in handover were analyzed. Different simulation processes previously carried out and their corresponding results were also discussed. A Neuro adaptive hysteresis margin approach has been proposed for the purpose of reducing ping-pong effect in LTE network during handover. This model integrates ANN in the traditional design of an LTE handover framework focused on initiating handover based on the hysteresis margin. The integration of the ANN in handover process in conjunction with various hysteresis margins is to enhance intelligent based successful handover in the era of 5G network where smart devices will form the bulk of UEs [35].

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