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The ANFIS Handover Trigger Scheme: The Long Term Evolution (LTE) Perspective

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Abstract—**With the need for better mobility management strategy to manage increasing demand on efficient data delivery to the user, the Long Term Evolution (LTE) has introduced self-organizing networks (SONs) in order to provide autonomous control over the management of the network. It is important to have a "self-manage" element in the system to provide a "quick-fix" and thus reduce the need of constant human participation in the optimization process of the LTE's mobility management. The existing handover triggering scheme for LTE is not flexible enough to introduce new performance metrics such as user equipment (UE) speed, network jitter or even cell loading. Such requirements for flexibility can only be fulfilled by using flexible tools such as fuzzy logic schemes with adaptive capability to cope with the changes of the fast paced mobile environment. This paper will introduce the use of the adaptive neuro-fuzzy inference system (ANFIS) to provide not only flexibility to LTE for initial deployment, but also the adaptive capability to optimize the efficiency of the handover algorithm with minimal human interference.**

I. Introduction

The Long Term Evolution (LTE) specification defined by the 3rd Generation Partnership Project (3GPP) is currently making its way to offer significant improvements over its predecessor, the Universal Mobile Telecommunications System (UMTS) and the High-Speed Packet Access (HSPA). Theoretically, LTE is designed to offer high speed data access which allows delay sensitive applications such as video streaming and Voice over IP (VoIP) possible in the mobile scenario. The increasing support for all IP networks for LTE, has led to the complexity of LTE networks and therefore requires more complex network management. To manage a complex network with the acceptable operational expenditure (OPEX) and capital expenditure (CAPEX) a self-management approach is introduced and can be achieved using self-organizing networks (SONs) [1]. Reference [1] also suggested the use of SONs to optimize the LTE's handover parameters in order to minimize handover failure, therefore reducing the unnecessary handover and increase the load balancing capability of the system.

The unnecessary handover is frequently referred to as the ping-pong effect as a result of the irregularities of the signal strength in the cell border due to noise and non-stationary nature of the channel. It will incur unnecessary OPEX to the network where handover control signals are exchanged between the user equipment (UE) and the enhanced Node B (eNB). 3GPP LTE specifications TR 36.902 [2] has acknowledged the problems of the ping-pong effect on the LTE's performance. The problem of the ping-pong effect is not new and has been a focus in mobile communication research since the introduction of mobile cellular telephony technology. There were many suggestions proposed in the past, and one of the most common solutions is the introduction of a hysteresis margin where handover will only occurs when the difference of received signal strength indicator (RSSI) from serving and neighboring base station is beyond a predefined margin [3]. However, this method is not suitable for fast pace handover decision making where the handover trigger needs to be timely and precise. The LTE adopts a similar approach, where the handover can only be triggered when a target eNB has a superior reference signal received power (RSRP) beyond the handover margin (HOM) for a period of time, known as the time-to-trigger (TTT). The problem of this method lies in the delay of the handover trigger which can be between the range of 40 to 5120 ms [4]. Coupled with the handover latency introduced by the network process, the amount of packet loss is significant enough to degrade the Quality of Service (QoS) and consequently cause negative effects on user experience when using delay sensitive applications such as VoIP.

The delay in handover also risks radio link failure (RLF) and subsequently call drop before handover procedure can be completed as mentioned in 3GPP LTE specification TR 36.902 [2]. Even if the TTT and HOM can be adjusted and optimized accordingly, there are still potential risks of degrading performance due to the additional handover latency introduced especially in the areas which are prone to the ping-pong effect [4]. To ensure both ping-pong effect and handover delay problems are addressed simultaneously, the handover triggering mechanism needs to be less volatile and at the same time robust enough to fulfill the requirements of high bandwidth and delay sensitive applications. Reference [5] on the other hand proposed the optimization of the HOM which results in the reduction of the ping-pong effect.

The over reliance of RSRP and reference signal receive quality (RSRQ) also negates the vital inputs from the quality of service (QoS) related parameters such as network jitters, packet loss rate, network latency or even cell load [6]. While the RSRP, RSRQ or other existing metric such as signal-to-interference-plus-noise ratio (SINR) and block error ratio (BLER) [7] might be at the acceptable level, the QoS related metric such as the mean opinion score (MOS) [8] for LTE's VoIP might not be satisfactory due to network jitters or network latency.

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Using fuzzy logic for mobility management is not new and most of the proposed implementations are in the heterogeneous networks. Some of the earliest related works on fuzzy logic handover were [9][10][11] while some are as recent as [12] [13][14]. Fuzzy logic in this case has one big advantage; its flexibility in introducing additional performance metrics that have completely different behavior. For instance, the RSRP values are dependent on the channel conditions and the signals decay exponentially with respect to the distance from the eNB. This is different for metrics like cell loading or network jitters which depend largely on network conditions and call arrival rates. The fuzzy logic linguistic nature and flexibility allow engineer to reconfigure the handover criteria based on the current needs and the locality of the situation where a handover is required. However, while fuzzy logic seems to be revolutionary in solving problems for mobility management, it has problems of its own. In order to keep up with the fast changing environment, the membership functions and sometimes the rules need to be constantly tuned. Fuzzy logic needs expert and human knowledge to quantify its membership functions and rules before it can be used to analyze data. Failure to tune the membership functions and rules will cause the algorithm to behave unpredictably. Furthermore, the human intervention is against the very basic requirements of SON in LTE where parameters are configured with minimum human participation. Moreover, it is highly undesirable for any further alteration to be made on the eNB after its initial deployment as it will incur further cost on OPEX.

The contribution of this paper can be summarized as follows. To include adaptive elements in the algorithm, this paper will introduce the use of adaptive neuro-fuzzy inference system (ANFIS) [15] in the LTE's handover trigger algorithm to improve the overall throughput at the UE. The algorithm has been introduced earlier in a more general form by the author [16], and now has been modified and adapted to suits a LTE environment. In comparison to [16], the model design for this paper is that the inputs and rules are based on the readily available performance metrics such as RSRP, BLER, CQI etc. Furthermore the specific protocol requirements for LTE are taken into consideration in this paper. The ANFIS training algorithm allows autonomous control in introducing new rules, and adjusting membership functions and existing rules. This feature is important as far as SONs are concerned. The autonomous controls will enable a "quick-fix" solution to any LTE cells that entail any specific requirements due to local conditions (e.g. terrain, buildings, vegetation, etc.). The process of training is done continuously to achieve optimum performance. For instance, if the handover is triggered too early, in which case causes premature handover and subsequently lead to RLF and the ping-pong effect, the membership functions and rules can be retrained until such effect is minimized.

Section II of this paper will discuss the existing LTE handover triggering scheme and the existing fuzzy logic handover decision algorithm. The proposed system model will be discussed in Section III, while Section IV discusses the handover performance indicator to measure the effectiveness of the proposed model. Experiment methodology and results will be discussed in Section V.

II. Handover Triggering Scheme

A. *Summary of the LTE handover triggering algorithm*

Figure 1 shows the general network architecture of LTE while Fig. 2 shows the summary of the handover procedure at the handover preparation phase in LTE. Once the UE is registered into the network the UE will periodically send the channel performance metric reports to the serving eNB. As indicated by 3GPP LTE Specification TS 36.214, RSRP and RSRQ are the main metrics to determine the condition to trigger a handover. RSRPs are usually averaged by a *L1* filter to reduce the effects from the channel fading before being processed using a *L3* filters. The *L3* filter is given as in Eq. (1)

$$RSRP_n = \left\lfloor 1 - \left(\frac{1}{2}\right)^{4/K} \right\rfloor \times RSRP_{n-1} + \left(\frac{1}{2}\right)^{4/K} \times q_n \tag{1}$$

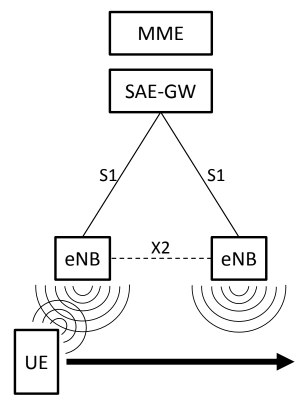

Fig. 1. The LTE network architecture based on S1 and X2 handover protocol. Each eNB is connected to System Architecture Evolution Gateway (SAE-GW) which houses the mobility management entity (MME).

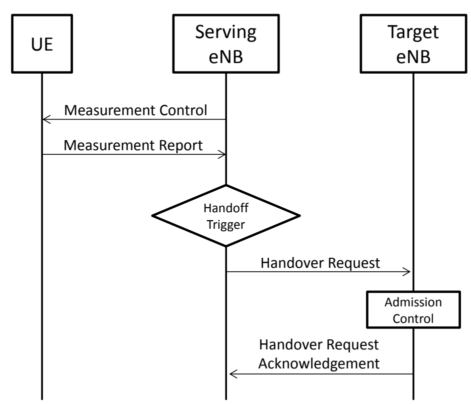

Fig. 2. The figure above shows the summary of the handover procedure in LTE. The above is one part of the three phases the handover procedures of LTE; the handover preparation phase. The subsequent two phases known as the handover execution and handover completion phases, are not the focus of this paper.

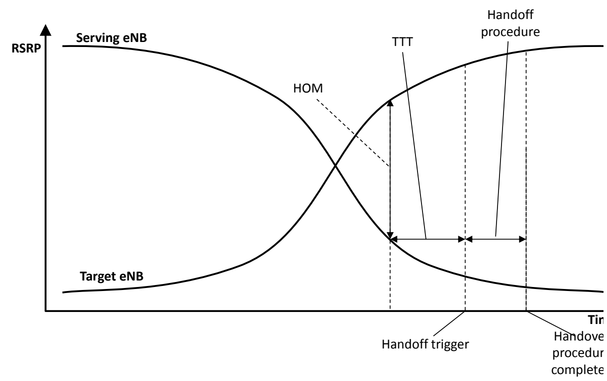

Fig. 3. The handover trigger algorithm for LTE. In order to trigger the handover procedure, the target eNB RSRP must be higher than the HOM for a period of TTT.

where $RSRP_n$ are updated values as compared to the previous values, i.e. RSRP_{n-1} before entering the L1 filter. The q_n are the instantaneous values produced at the output of *L1* filter while *K* is the *L3's* filter coefficient.

In contrast to RSSI, RSRP is a measurement of actual usable average power within the bandwidth without including the power contributed from the interference. The LTE handover timings are illustrated in Fig. 3. A handover is triggered when the target / neighbor eNB has higher RSRP than the serving eNB for TTT. This event is commonly known as the *A3 event* in LTE radio resource control (RRC) management. Correct adjustments of TTT and HOM are important to ensure acceptable level of RLC and the ping-pong effect. Reference [17] suggested of TTT values which corresponds to the effect on the ping-pong handovers. Once a handover is triggered, a handover request will be sent to the target eNB, and concluded with a handover request acknowledgement message to the serving eNB.

B. *Fuzzy Logic Handover Algorithm*

In most literature for handover based on fuzzy logic such as [14] and [18], *handoff factors* are generated at the output after the defuzzification process as illustrated in the block diagram of the fuzzy logic handover decision algorithm (FHDA) in Fig. 4. The handoff factor is a string of values ranging from "0" – least likely to handover, to "1" – most likely to handover. A threshold is established to trigger a handover once the handoff factor is above the threshold. Figure 4 shows the three crispy inputs before the fuzzification process, the RSSI, bit error rate (BER) and the Quality of Service (QoS) respectively and Fig. 5 shows some examples of membership functions for fuzzification as suggested by [14] and [18]. Table I shows some examples of the fuzzy rules in the algorithm.

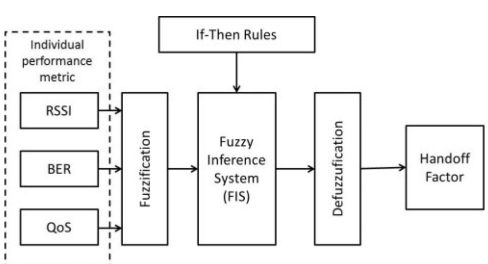

Fig. 4. The block diagram of a fuzzy logic handover decision algorithm. At the output of the defuzzification process, a string of data known as the handoff factors are generated.

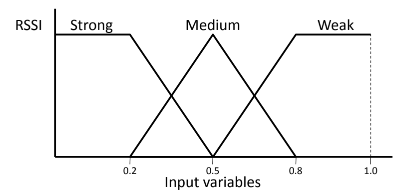

Fig. 5. Example membership functions of RSSI as suggested by [14] and [18].

TABLE I
EXAMPLE OF RULES FOR FUZZY HANDOFF DECISION ALGORITHM

IF	AND	AND	THEN
RSSI = High	BER = Low	Qos = Good	Handoff = Low
RSSI = High	BER = Low	Qos = Medium	Handoff = Low
⋮	⋮	⋮	⋮
RSSI = Low	BER = High	QoS = Bad	Handoff = High

III. SYSTEM MODEL

A. *ANFIS Architecture and Training*

ANFIS is based on Takagi-Sugeno-Kang (TSK) models which are computationally more efficient than the Mamdani model. This is crucial for a fast paced mobile scenario when the whole handover process including the decisions need to be fast and accurate with limited computational power. The TSK model of ANFIS is shown in Fig. 6 and the system implements the following fuzzy rules,

Rule 1: If a is A_i and b is B_i, then $f(1) = r_1 x + s_1 y + t_1$

$\vdots$

Rule N: If a is A_N and b is B_N, then $f(N) = r_N a + s_N b + t_N$

where the r_i, s_i, t_i are the consequent parameters and N are the number of rules. ANFIS architecture incorporates a neural network as its training agent (hence the name neuro-fuzzy). As shown in Fig. 6, the architecture is divided into five layers. In layer 1, i–th of each neuron is adaptive where the x and y are the inputs to the i-th neuron. Both A_i and B_i are the

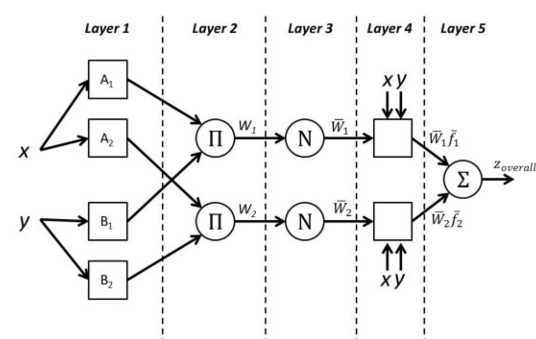

Fig. 6. ANFIS architecture for a two-input first order Sugeno fuzzy model with two rules.

membership functions which can be defined earlier. There are two ways to define the membership functions in ANFIS: using the hypothesized data and using data clustering method. Let say, for instance, the hypothesized data or data clustering generated a bell-curved function given as in Eq. 2 below,

$$\mu(A) = \frac{1}{1 + \left|\frac{x - c_i}{a_i}\right|^{2b}} \tag{2}$$

where the a, b, and c are the premise parameters.

In layer 2, each neuron represents the incoming signals from layer 1 with the firing strength w_i of the i –th rules. Each multiplication process can be achieved using "AND" operation and in layer 3, the firing strength is normalized as shown in Eq. 3.

$$\delta_i = \frac{\delta_i}{\delta_1 + \delta_2 + \ldots + \delta_i} \tag{3}$$

The adaptive neurons in layer 4 are taking inputs from x and y into consideration where its function is given as in Eq. 4 below.

$$\delta_i z(i) = \bar{\delta}_i (x_i r + y_i s + t_i) \tag{4}$$

All signals are summed in layer 5 to give the overall output as

$$z_{overall} = \sum \bar{\delta}_i z_i = \frac{\sum_i \delta_i z_i}{\sum_i z_i} \tag{5}$$

ANFIS adopts two training algorithms: the back-propagation and the hybrid of steepest descent (SD) and the least-square estimator (LSE) algorithms. Generally the back-propagation is a preferred method by the artificial neural network but it takes a longer time for converge, thus the hybrid method is preferred in fast paced applications. The output of the hybrid method can be expressed mathematically as in Eq. 6.

$$\begin{aligned} z &= \frac{\delta_1}{\delta_1 + \delta_2} f(1) + \frac{\delta_2}{\delta_1 + \delta_2} f(2) \\ &= \bar{\delta}_1 (r_1 a + s_1 b + t_1) + \bar{\delta}_2 (r_2 a + s_2 b + t_2) \\ &= (\bar{\delta}_1 r_1 a + \bar{\delta}_1 s_1 b + \bar{\delta}_1 t_1) + (\bar{\delta}_2 r_2 a + \bar{\delta}_2 s_2 b + \bar{\delta}_2 t_2) \\ &= (\bar{\delta}_1 a) r_1 + (\bar{\delta}_1 b) s_1 + (\bar{\delta}_1) t_1 \\ &\quad + (\bar{\delta}_2 a) r_2 + (\bar{\delta}_2 b) s_2 + (\bar{\delta}_2) t_2 \end{aligned} \tag{6}$$

The hybrid method employs the forward and backward passes at every epoch, p, of the training. The update equation for every p is given as in Eq. (7).

$$\frac{\partial E}{\partial \alpha} = \sum_{p=1}^{p} \frac{\partial E_p}{\partial \alpha} \tag{7}$$

with the update function $\Delta\alpha$ as below,

$$\Delta\alpha = -\eta \frac{\partial E_p}{\partial \alpha} \tag{8}$$

η is known as the learning rate that can be expressed as,

$$\eta = \frac{k}{\sqrt{\sum_\alpha \left(\frac{\partial E}{\partial \alpha}\right)^2}} \tag{9}$$

where k is the step size.

B. Proposed System Model for LTE ANFIS Handover Triggering Algorithm

The ANFIS model for handover trigger can be arranged in 3 stages: initialization, handover trigger and optimization.

1) Initialization stage: This stage is initiated when the UE is switched on or entering into a new tracking area (TA) [19]. If the UE is new to the TA, ANFIS will begin the training and adjust the premise and consequent variables based on the optimized reference model, as shown in Fig. 7. If the UE is not new to the TA, it will check if the fuzzy inference system (FIS) is an updated profile, otherwise similar training procedure will commence. After the completion of the training process, it will then proceed to the periodical UE's performance metric measurement as indicated in Fig. 2.

2) Handover Trigger: Fig. 9 shows the flowchart of the handover trigger stage. Theoretically, the number of crisp inputs to the ANFIS controller can be more than three, in this case x_1, x_2 and x_3 as shown in Fig. 8. However too many inputs will cause the algorithm to be "less sensitive" and handovers will not occur when necessary. In this paper, the crisp input data x_1, x_2 and x_3 in Fig. 8 are represented by RSRP, BLER and QoS respectively. These three metrics relate directly to the required performance of LTE. Type of QoS parameters (bandwidth, jitter, etc.) depending on the type of applications used at the UE.

The handover triggering process is based on the threshold set on the handoff factors (see Fig.8), whereby, if the handoff factor is above the threshold, a handover request command will be sent to start the handover procedures. With the measurements obtained from the UE, the serving eNB will be making decisions to handover based on two criterias. Firstly,

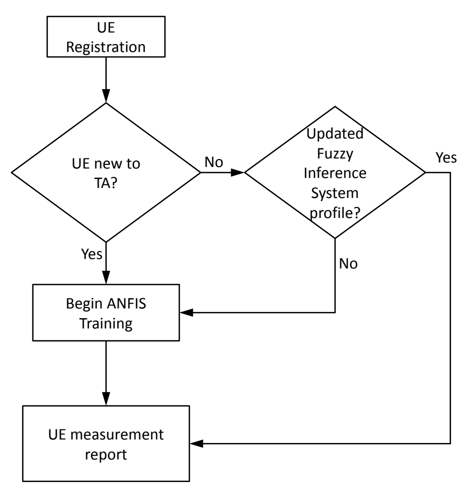

Fig. 7. Flowchart for the initialization phase.

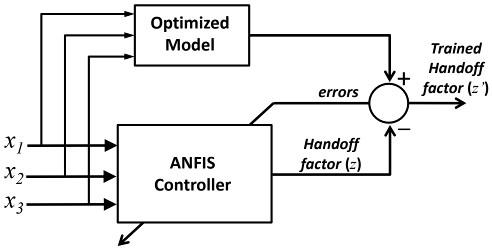

Fig. 8. ANFIS training for the proposed LTE handover trigger algorithm. x_1, x_2 and x_3 can be represented as RSRP, BLER and QoS parameters depending on the local requirements of the UE and service provider.

if the serving eNB's handoff factor is above the preset threshold, then the second criteria will be considered. In the second criteria, the serving eNB will make a decision by sending a handover command containing the cell identification to the neighboring eNB that has the lowest handoff factor.

3) Optimization: The optimization stage is executed periodically, but less frequently than the earlier two phases. Usually this phase is executed as part of the operational and maintenance (O&M) exercise carried out periodically by the engineers. The objective of this phase is to update the optimized handoff factor model (see Fig. 8) to ensure the performance is optimum. There are many optimization technique available but the discussion of such techniques is not the major focus of this paper and interested readers may refer to [20]. The optimization process can also be performed based on the history of the tracking area (TA) on the best rules and membership functions that yield the optimum results [21].

IV. Handover Performance Indicators and Analysis

A. Mean Opinion Score (MOS) for VoIP

The mean opinion score (MOS) is a convenient tool to benchmark the quality of a VoIP transmission. MOS has been used for many years to scientifically obtain the user's perception on the quality of the voice data reception. The International Telecommunication Union (ITU) defines the calculation of MOS using an equation known as the E-model through its recommendation ITU-T G.107 [22]. The E-model can be calculated using Eq. 10,

$$R = R_0 - I_s - I_d - I_{e,eff} + A \tag{10}$$

where R_0 is the basic signal-to-noise ratio, I_s represents all end-to-end impairments related to voice signals, and I_d is the sum of all other impairments that affect the performance of the voice quality. Parameter A is the advantage factor for a given codec while $I_{e,eff}$ is stated as the effective equipment factor, given as,

$$I_{e,eff} = I_e + \left(95 - I_e \cdot \frac{P_{l,eff}}{P_{l,eff} + B_{pl}}\right) \tag{11}$$

where I_e is the impairment factor due to the choice of the codec used for the VoIP and B_{Pl} is the degree of codec robustness to interference and random losses. The original E-model does not include the effect from the network jitters, thus the equation was modified by including additional buffer packet loss, $P_{dejitter}$ based on works by [23], which yields,

$$P_{e,eff} = 1 - (1 - P_{pl})(1 - P_{dejitter}) \tag{12}$$

where Pp_l is the network packet loss given in Eq. 13 below,

$$P_{pl} = 1 - (1 - P_b)^N \tag{13}$$

Reference [24] has investigated and established that the MOS in LTE needs to be 3.5 and above to indicate a satisfactory voice quality.

B. Ping-pong Handover Ratio

The ping-pong handover ratio, H_{PHR} is defined as the number of ping-pong handover, H_{PPH} to the total number of handovers, H_T. H_{PHR} can be expressed as Eq. 14, and it is

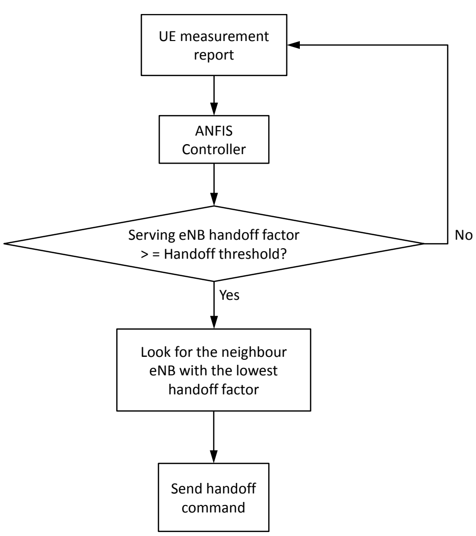

Fig. 9. Flowchart of the LTE handover trigger phase.

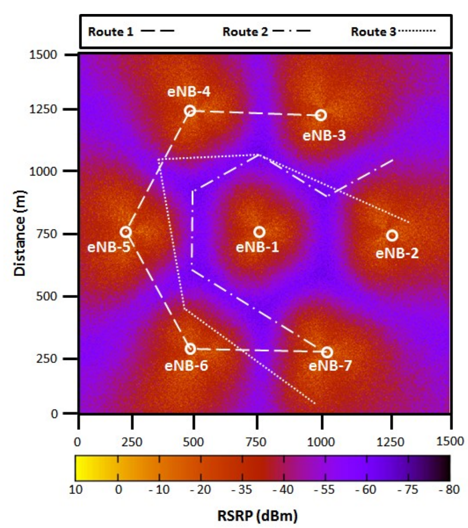

Fig. 10. The radio environment map which consists of seven eNB generated to simulate the scenarios.

TABLE II
SIMULATION DETAILS

Parameters	Specifics
Channel model	COST-HATA
Fading model	Rayleigh
Carrier frequency	2.0 GHz
Number of Macro eNB	7 (single sector)
eNB cell size (diameter)	500 m
UE speed	60 kph
eNB transceiver power	46 dBm
UE transceiver power	2.15 dBm
Modulation scheme	16-QAM
VoIP codec	AMR-WB (12.5 kbps)

usually articulated as a percentage. The aim is to have the ping-pong handover ratio as close to zero as possible [25].

$$H_{PHR} = \frac{H_{PPH}}{H_T} \times 100\% \tag{14}$$

C. Effect of Handover rate on Throughput

The objective of this metric is to provide an analysis on the effect of HOM and TTT on the UE throughput. This can also provide a visual analysis on the reduction of data rate during the handover latency (or handover disruption period). The average throughput can be expressed as,

$$s = \frac{\int_0^T R(t)dt - \sum^N \int_0^{T+\Delta} R(t)dt - \int_0^T p(t)dt}{T} \tag{15}$$

where $R(t)$ is the data generated at the source, N is the number of handovers, $p(t)$ is the probability of packet loss due to both network (including network packet loss, P_{pl}) and channel conditions, Δ is the handover interruption period and T is the ratio of distance to the speed of the UE travelled. The packet error rate occurs when the receive bits are in error as a result of the effect from the channel fading.

V. SIMULATION AND RESULTS

A. Methodology

The summary of the simulation details are in Table II. In this paper, a system level LTE environment is created using MATLAB to simulate the scenarios in order to test the proposed algorithm. We simulate the application of VoIP in LTE with a single UE while travelling at a constant speed of 60 km/h. Three UE routing scenarios are created, as shown in the RSRP radio environment map in Fig. 10. The three scenarios are: -

- Scenario A: Route 1 - eNB-to-eNB
- Scenario B: Route 2 - Worst case
- Scenario C: Route 3 - Random

The eNB-to-eNB routes are for the ideal condition where the UE will travel from one eNB to the next adjacent eNB. This scenario is mainly for validation and optimization of handover factor analysis purpose. The worst case scenarios are specifically designed to force the UE's waypoints along the edge of the cells where the ping-pong effect is at the highest. The random waypoints on the other hand ensures the consideration of the near "real life" experience by the UE. Comparisons are made based on LTE's existing A3 event algorithm, fuzzy logic and ANFIS incorporated handover algorithm into LTE. The LTE A3 event algorithm is simulated with three different conditions, i.e TTT of 0ms (LTE-0), 256ms (LTE-256) and 5120ms (LTE-5120) while HOM is taken as a constant 6 dBm. Simulation results to gauge the performance of each algorithm will be based on average MOS, H_{PHR} and throughput, all from the UE's perspective.

As for the crisp input of the ANFIS controller, i.e. x_1, x_2 and x_3 as mentioned earlier is taken as RSSI, BLER and a QoS parameter represented by the network jitters. The BLER, P_{BLER} can be generally approximated as in Eq. 16,

$$P_{BLER}(\alpha) = 1 - \sum_{i=0}^{t} \binom{n}{i} p(\alpha)^i \left[1 - p(\alpha)\right]^{n-i} \tag{16}$$

Assumingly the measurements are taken at the output of an error correction decoder, α is the signal-to-noise ratio, $p(\alpha)$ is the coded bit error rate, n is the number of bits per block and t is the number of error bits [26]. The network jitters on the other hand is simulated using Generalized Pareto distribution given the probability density function as,

$$f_{(\xi,\mu,\sigma)}(x) = \frac{1}{\sigma}\left(1 + \frac{\xi(x-\mu)}{\sigma}\right)^{\left(-\frac{1}{\xi}-1\right)} \tag{17}$$

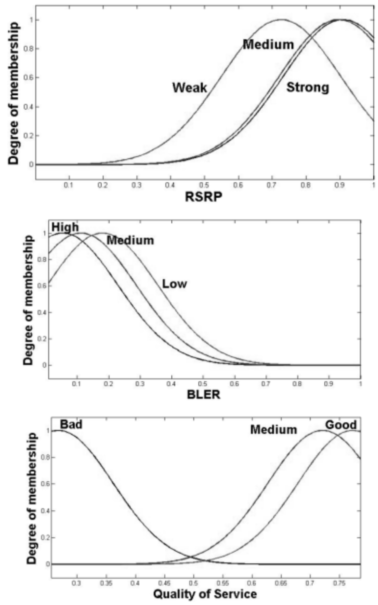

Fig. 11. Membership functions after ANFIS training.

where σ is the standard deviation, ξ is the shape parameter and μ is the location parameter [23].

B. Ping-pong Handover Ratio, H_{PHR}

As a result from the optimization and training, the membership function of the ANFIS controller is as shown in Fig. 11. Figure 12 shows the result of the H_{PHR} where it shows the ANFIS algorithm recorded the lowest H_{PHR} in comparison to all handover algorithms. This indicates that the algorithm adapted until the handover is performed when it is deemed necessary. The fuzzy logic algorithm on the other hand suffers significantly higher H_{PHR} as the rules and membership functions were defined based on hypothetical data and experience. The fuzzy logic algorithm used in this simulation was not tuned, thus it was very unpredictable. For LTE-0, the overall H_{PHR} is higher as compared to other algorithms due to its nature of relying solely on RSRP that suffered from the channel fading effect. There is no TTT delay when the HOM is above 6 dBm, and both neighboring and serving eNB's RSRP are alternately higher than each other in a short period of time that causes the ping-pong handovers. The LTE algorithm with LTE-5120 generally has lower H_{PHR} except in scenario B. The algorithm is effective in reducing H_{PHR} in scenario A as there is ample time where the HOM is continuously more than 6 dBm for approx. 5 seconds, to ensure the handover is necessary.

C. Mean Opinion Score

The result of the MOS is as shown in Fig. 13. Due to the lower ping-pong handover, ANFIS has recorded MOS above 3.5 (i.e. acceptable level) for all three scenarios. The only reason why the MOS values for ANFIS algorithm are not recorded higher is the packet loss, and subsequently higher BLER due to the channel conditions and network jitters. Notice that from all the simulated algorithms, scenario B has lower MOS values as compared to other scenarios except for

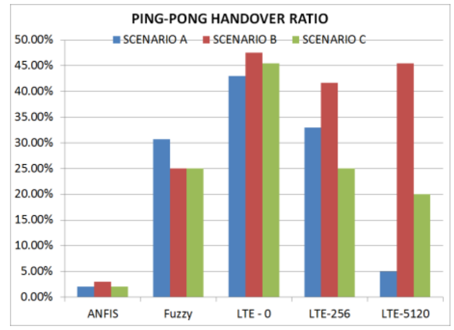

Fig. 12. The graph of comparison of ANFIS, fuzzy and LTE handover decision algorithms for the ping-pong handover ratio, H_{PHR}. LTE handover algorithm is compared with TTT=0ms (LTE-0), TTT = 266ms and TTT= 5120ms (LTE-5120) respectively.

the untuned fuzzy logic algorithm. Again this is expected as the UE is moving along the edge the cells.

D. Effect of handover rate on throughput

In Fig. 14, we can observe that the ANFIS algorithm has recorded average throughput above the 35 kbps level, which is generally higher than what is recorded by other algorithms. This contributed to the higher MOS values as discussed in the earlier subsection. Generally, LTE-5120 has the lowest average throughput due to the additional 5120ms in the TTT delay period in addition to the handover latency introduced during the handover procedure process. The latencies contributed to packet losses which directly affected the throughput.

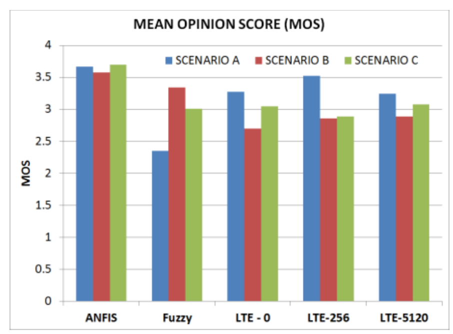

Fig. 13. The graph comparison of the mean opinion score (MOS) for the respective handover decision algorithm.

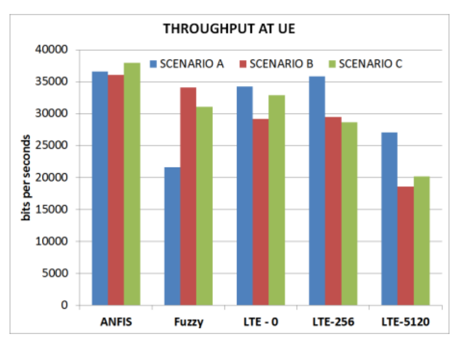

Fig. 14. The comparison of handover algorithms for UE downlink throughput.

VI. CONCLUSION

This paper presented a handover triggering scheme for LTE using ANFIS to improve the performance and reduce the ping-pong effect. The proposed algorithm introduces the adaptive capability of LTE's handover algorithm which is consistent with requirements of SONs. This can be seen in the results section in Fig. 11 where the membership functions adapted to the environment. As a result from this effect, the ping-pong ratio and throughput performance improves as compared to other LTE's existing algorithm, shown in Fig 12 and Fig. 14 respectively. The performance for MOS also improved for the proposed model as shown in Fig. 13. The three figures also show the untuned fuzzy logic algorithm which indicated that the algorithm was unpredictable. This algorithm can be expanded further by including more performance metric in the case of heterogeneous networks and femtocell scenarios.

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