Performance Evaluation of A2-A4-RSRQ and A3-RSRP Handover Algorithms in LTE Network

Hendrawan [a, *], Ayu Rosyida Zain [b], Sri Lestari Harja [c]

[a] School of Electrical Engineering & Informatics
Institut Teknologi Bandung
Jalan Ganesha 10
Bandung 40293, Indonesia
[b] Politeknik Negeri Jakarta
Jl. Prof. Dr. G.A Siwabessy, Kampus Baru UI
Depok 16424, Indonesia
[c] Universitas Pendidikan Indonesia
Jl. Dr. Setiabudhi No. 299
Bandung 40154, Indonesia

Abstract

In LTE Network, users can move freely in the network through fast and seamless handover (HO). This research focuses on intra-LTE handover which occurs using interface X2 to move an EU between two eNBs, i.e. source eNB and target eNB without any changes in MME and SGW at EPC level. Two popular algorithms of intra-LTE handover namely A2-A4-RSRQ and A3-RSRP were evaluated and compared through simulations as well as direct measurements in the field. Simulation is conducted using NS3 simulation tool where performances of various scenarios from both algorithms were evaluated. The performance metrics studied include the average number of HOs that occur, throughput and optimized ratio. Simulations carried out for various scenarios in term of EU numbers, user speeds, and channel conditions. In addition, the results of one-month measurement of three eNBs were also presented. The measurement results are then compared and used to verify the simulation results. Furthermore, by using the optimizing ratio metric, the optimal pair of parameter values of Threshold as well as Offset and Handover Margin (HOM) along with Time-to-Trigger (TTT) are sought for the A2-A4-RSRQ and A3-RSRP respectively.

Keywords: LTE, Intra-LTE Handover, A2-A4-RSRQ, A3-RSRP.

I. INTRODUCTION

LTE is a cellular network standard of 3GPP which is the fourth generation of mobile cellular networks (4G) that implements all packet network architecture. This system is an evolution from the previous legacy mobile cellular networks (3G) designed to deliver higher data rate to allow high speed connections at anytime, anywhere [1]. LTE has a slimmer flat architecture compared to the previous generation, as shown in Figure 1, which is mainly built from two main parts, Evolved Universal Terrestrial Radio Access (E-UTRAN) and Core Network, namely Evolved Packet Core Network (EPC) [1]. EUTRAN consists of a number of eNBs where interconnections between adjacent eNBs are built through the X2 interface. While EPC consists of the main components of MME, SGW/PGW, where interconnection between eNB and EPC (MME, S-GW) is carried out via the S1 interface.

Meanwhile, User equipment (UE) on the LTE network, which can be any mobile device, is connected to the eNB via radio interface to access network services.

Users have mobility capabilities and can move freely in the LTE network across eNBs and through MME/SGWs via rapid and seamless handover (HO) to guarantee the service continuity. Mobility is among the important Key Performance Indicators (KPIs) on LTE cellular networks, in addition to other KPIs such as accessibility, retainability, integrity and availability [2].

These capabilities can be achieved by the handover mechanism that is in keeping with the movement of the EU from one cell to another cell, it will be followed by the process of transferring eNB that serves the EU. Two handover types are known in LTE, i.e. Intra-LTE Handover and Inter-LTE Handover. In the first category that will be the focus of this research, handover occurs using interface X2 to move EU from a source eNB (S-eNB) to a target eNB (T-eNB) without any changes in MME and SGW at EPC level.

More attention is given to Intra-LTE Handover because more handovers take place more frequently through eNBs than across core networks because the area covered by MME/SGW operates for a large number of eNBs [3]. Furthermore, Intra-LTE handover procedure can be apportioned into three phases : handover preparation, handover execution and handover completion [4]. Handover is initiated by the EU by sending a measurement report that is triggered by one or more events, that is conditions where the results of measuring channels in the form of RSRP and or RSRQ

meet some certain criteria. The RSRP (Reference Signal Received Power) measurement provides cell-specific signal strength metric defined for a specific cell as the linear average received power (in Watts) of the signals that carry cell-specific Reference Signals (RS) within the considered measurement frequency bandwidth [5].
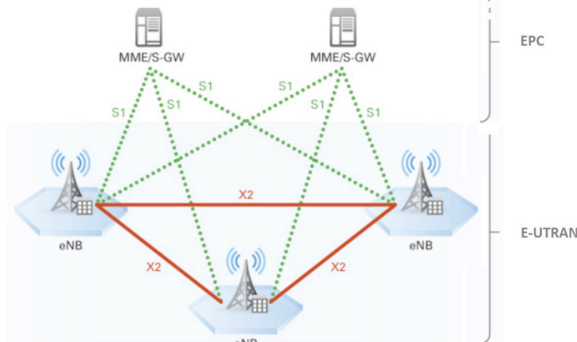

Figure 1. LTE Architecture [1]

TABLE 1
EVENTS AND TRIGGERING CONDITION

Event	Trigerring Conditions
A2	Signal quality in the serving cell < than a specified threshold
A3	Signal quality in neighbouring cell > than that in the serving cell
A4	Signal quality > than a specified threshold in neighbouring cell

In addition, Reference Signal Received Quality (RSRQ) considers the interference level into account and is defined as the multiplication of the number of blocks of LTE carriers with RSRP divided by the total received wide-band power (RSSI). Based on signal quality measurements in term of RSRP and RSRQ, there are three identifiable events, which can be used for handover decisions, namely Event A2, A3 and A4 as shown in Table 1.
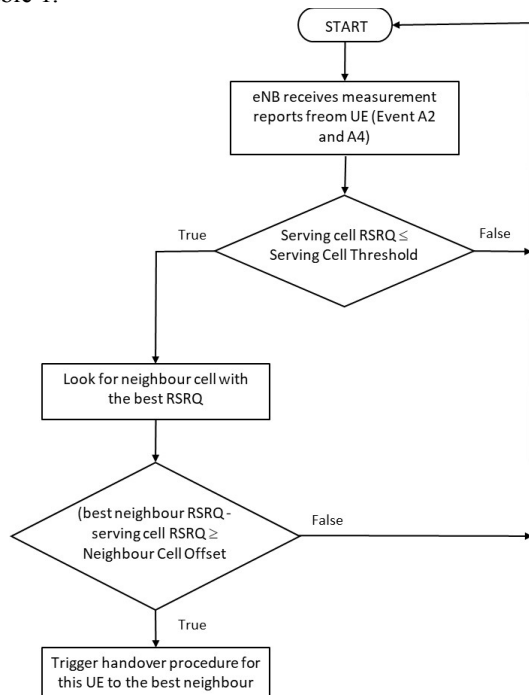

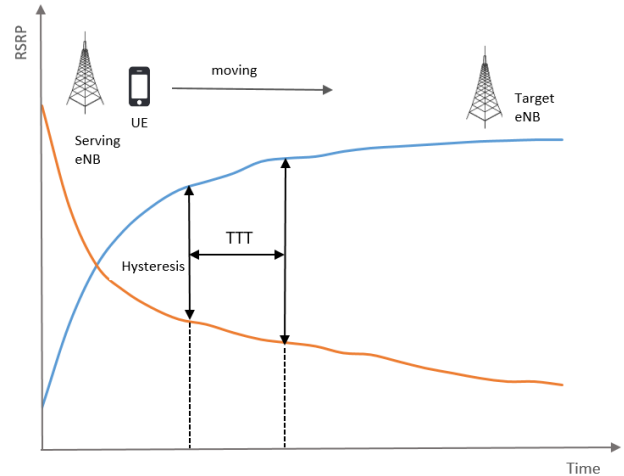Figure 2. A2-A4-RSRQ handover algorithm

Figure 3. A3-RSRP handover algorithm

There are two handover algorithms commonly used in LTE networks based on the above events, i.e. A2-A4-RSRQ and A3-RSRP. Explanation of the first Algorithm which is built on the event of A2 and A4, can be seen on the flowchart in the Figure 2.

On the otherhand, the second HO algorithm is initiated if the serving eNB receives an A3 event report. Then there are two variables that will determine the handover will occur, namely *Hysteresis* and *Time-to-Trigger* (*TTT*) timer. The former variable which also called handover margin (HOM) is a constant threshold value that shows the difference between RSRP service and target RSRP. Handover occurs if HOM is greater than a certain value for a period of time of at least *TTT*. The working method of the A3-RSRP process is illustrated as shown in Figure 3.

In this study, the two algorithms mentioned earlier were evaluated and compared using simulations and also direct measurements in the field. Simulation uses NS3 simulation tool and evaluates various performance scenarios from both algorithms. The performance metrics studied included the average number of HOs that occur for each EU during a given period of time, throughput and optimized ratio. Simulations carried out for various scenarios include variations in EU numbers, user speeds, and channel conditions (with and without fading). In addition to the simulation, the results of a one-month measurement of three eNBs were also evaluated. The measurement results are then compared and used to verify the simulation results. Furthermore, by using the optimizing ratio metric, the optimal values for the *Serving Cell Threshold* (SCT) as well as *Neighbour Cell Offset* (NCO) for the A2-A4-RSRQ algorithm and the values of *Handover Margin* (HOM) or *Hysteresis* along with *Time-to-Trigger* (*TTT*) variables for the A3-RSP algorithm are sought.

Some researchers have conducted research related to the A2-A4-RSRQ and A3-RSRP handover algorithms on LTE networks. Generally the research is carried out only on one algorithm, whether A3-based event or A2-A4 event. [6]-[9]. Although there is also a researcher who make comparisons between the two algorithms [10]. Furthermore, most studies are based on simulations, generally using NS3 simulator, though there are also some researchers using other simulation tools such as

Matlab [11]-[12], or other simulation languages such as C ++ [13]. Some researchers also conducted research related to other aspects of the effect of handover on LTE. For example, [12] evaluates the TCP and UDP transmission performance due to the effects of handover implementation on the LTE network. While other researcher conducted a study related to handover on High Speed Railway system [14]. In addition, another researcher [15] focused on optimization of RSRP-based handover parameters based on user behavior.

Conversely, there are no research have been reported that verify or compare the results of the simulation with the results of real measurements related to the performance of the handover algorithms. Likewise, none of the studies that have been conducted have seen the influence of channel conditions on the evaluation of simulation results. To cover these shortcomings, this research completes the study by validating the simulation results with the results of direct measurements taken from the interconnection of three eNBs directly in the field. Additionally, optimization to obtain various parameters of the A2-A4-RSRQ and A3-RSRP algorithms is done that are validated using measurement results.

II. METHOD

A. Simulation Method

To evaluate various handover scenarios on LTE network, NS3 LTE module was used [16]. The simulation configuration scheme carried out refers to the LENA model as shown in the Figure 4. Simulation uses seven macrocell with three cells each where the inter-macrocell distance is 500 m. Furthermore, the EU is distributed randomly around the site and automatically connected to the network. All parameters used in the simulation and their corresponding values are given in Table 2.

After being set with these parameter values, the EU will move at speeds varying from 20 up to 120 km per hour, where the speed is increased gradually with an increase of 20 km/hour. Likewise the EU number will be varied and two canal conditions are considered, namely by considering the fading effect and without any fading effect.

The fading model used in the simulation refers to 3GPP fading propagation conditions [17]. In this study, the fading model used is vehicular fading model (Extended Vehicular A model - EVA) and urban fading model (Extended Typical Urban model - ETU) [17] with user speeds 20-60km/h and 60-120 km/h respectively.

Furthermore, the parameters related to the handover algorithm, i.e. *Serving Cell Threshold*, *Neighbour Cell Offset*, *Hysteresis* and *Time-to-Trigger* are varied to observe the effect on various scenarios as a function of the number and speed of user movements and channel conditions. The optimum value of the handover algorithm parameters is also sought and identified. Performance metrics used for evaluation include Throughput, ANOH and Optimize Ratio.
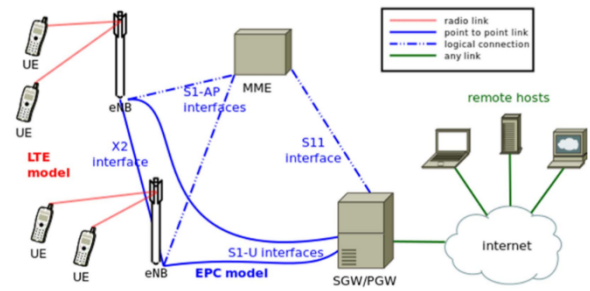

Figure 4. LENA model overview [16].

TABLE 2.
SIMULATION PARAMETERS

Parameter Name	Value	Description
simTime	50	50 seconds simulation duration
nMacroEnbSites	7	Number of microcell sites (each site has 3 cells)
nMacroEnbSitesX	2	The microcell sites will be positioned in a 2-3-2 formation
interSiteDistance	500	500m distance between adjacent microcell sites
macroEnbTxPowerDbm	46	46 dBm Tx power for each microcell
epc	1	Enable EPC mode
epcDl	1	Enable full-buffer DL traffic
epcUl	1	Enable full-buffer UL traffic
useUDP	0	Disable UDP Traffic and enable TCP instead
macroUeDensity	0.00002	Determines number of UEs (41 UE and 0.00001 for 20 UE)
outdoorUeMinSpeed	16.6667	Minimum UE movement speed in m/s (60 kmph), 30 kmph, 120 kmph
outdoorUeMaxSpeed	16.6667	Maximum UE movement speed in m/s (60 kmph), 30 kmph, 120 kmph
Fadingtrace	fading_trace_EPA_3kmph	fading_trace_EPA_3 kmph, fading_trace_EVA_60kmph, fading_trace_ETU_3 kmph
macroEnbBandwidth	25	5 MHz DL and UL bandwidth

B. Performance Metrics

Performance of the two handover implementations alluded above is evaluated based on the average number of handovers per EU per second (*ANOH*), *Throughput* of the system and *Optimization Ratio*. A detailed description of each metric used is explained as follows.

ANOH
ANOH is the average number of handovers that occur in one second for each EU and can be expressed mathematically as:

$$X[k] = \sum_{n=0}^{N-1} x[n] \exp\left(\frac{-i2\pi kn}{n}\right), \qquad (1)$$

$$ANOH = \left(\frac{HO_{Total}}{N \times T}\right), \qquad (1)$$

Where HO_{total} is the total number of successful handovers, while N and T correspondingly refer to the number of EU and total simulation time in second. Handover is said to be successful when EU moves from eNB source to eNB target with continuous service without breaking or terminating data transmission.

Cell Throughput

Cell throughput is defined as the total number of bits received by the EU per second and measured on an eNB, mathematically stated as follows:

$$CellThroughput = \frac{1}{T} \sum_{n=1}^{N} \sum_{t=1}^{T} tput_j(t) \quad (2)$$

Where $tput_j(t)$ is the total size of the packet received (in bits) of the user n at the time interval t, while T is the total simulation time and N is the total number of users. Throughput of the system in total is the sum of all cell throughputs as stated below:

$$Throughput_{Total} = \sum_{c-1}^{C} CellThroughput_c \quad (3)$$

Where $CellThroughpt_c$ is the *CellThroughput* of cell c and C is total cell in the simulation (7 in our case).

Optimize Ratio

The optimization parameter shows how well the handover algorithm performs, which is the ratio between Total Throughput and Average number of handover per UE per second, which can be expressed as follows:

$$OptimizeRatio = \left(\frac{Throughput_{Total}}{ANOH}\right) \quad (4)$$

Optimize Ratio is a performance metric that can be used for A2-A4-RSRQ and A3-RSRP handover algorithms and is calculated for certain user (UE) speed scenarios. In the former algorithm *Optimize Ratio* is calculated for particular *Neighbor Cell Offset* and *Serving Cell Threshold* values and the latter for particular *Hysteresis* and *Time-to-Trigger* values. Hence, *Optimize Ratio* will produce different values for different EU speeds and different settings of handover parameters. Therefore, in the handover algorithm optimization process, the handover parameter values that provide optimum values for certain EU speeds must be looked for.

C. Measurement Method

In this study, direct measurements were carried out to evaluate the performance of the X2-based handover mechanism on existing LTE networks in one of the cellular operators in Indonesia located in the Cirebon area. Measurements were made on three eNBs where observations were conducted on an hourly basis for one month by observing measurement parameters, namely Throughput, Average Number of Handover (ANOH) and Optimize Ratio. Details of the measurement scenario and

the handover parameters used are shown in Table 3. Measurements are made through the Centralized Task Management mechanism of the NMS through the U2000 device which manages and coordinates all the tasks to collect network performance data within a specified period. Handover performance is observed by setting hysteresis, time-to-trigger, SCT and Offset parameters with values as shown in Table 1.

The existing network that is monitored using *TTT* and *Hysteresis* as a trigger for the occurrence of the X2 handover, where their value is 480 ms and 2 dB respectively. Besides, the provider also sets the threshold and offset values i.e. Threshold = 30dB and Offset = 2dB. The measurement results observed are the Throughput value, Average Number of Handover (ANOH) and Optimize Ratio. The evaluation results are then used as a comparison value to verify the simulation results. The measurement results for Downlink (DL) Throughput for each eNB are shown in Figure 6. Because the DL Throughput varies for each hourly observation in one month, the measurement results are described in the Box and Whisker chart. Using this chart, the shape of the distribution can be shown and summary of a set of one-month data in term of the minimum, first quartile, median, average, third quartile, and maximum can be observed.

From the measurement results, the value of DL throughput for each eNB is 15.99 MBps, 13.27 MBps and 16.39 MBps respectively. So that the overall DL Throughput for the three eNB is 15.22 MBps. For other parameters related to the performance of the handover algorithm, that is ANOH and Optimize ratio, the average values of the three eNBs are 0.01 and 1077.32 respectively.

TABLE 3.
MEASUREMENT SCENARIO AND PARAMETERS USED

Parameter Name	Value
number of eNB	3
number of Cell per eNB	3
distance between eNB	2 km
eNB Power	43 dBm
Bandwidth	5 MHz (each for UL and DL
Number of UE	46
Hysteresis	2 dB
Time-To-Trigger	480 ms
ServingCellThreshold	30 dB
NeighbourCellOffset	2 dB

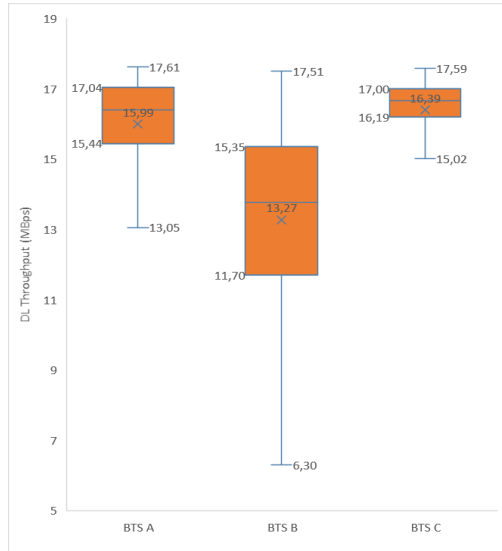Figure 5. Map of the Three eNBs used for Measurement

Figure 6. Box and Whisker chart for DL Throughput

D. HO Parameter Optimization

From the two handover algorithms observed, namely RSRP-based A3-RSRP and RSRQ-based A2-A4-RSRQ, the optimum value of the parameters that provide the best performance will be sought. The handover parameters optimized in the RSRP Algorithm are *Hysteresis* and *Time-to-Trigger* (*TTT*), while in the RSRQ algorithm is a *Serving Cell Thershold* and a *Cell Offset Neighbor*. Whereas the best performance measure that is the cost function of the optimization process is *Optimize Ratio* as formulated in equation (5). The values of the handover algorithm parameters that will be tested are valid parameter values in their range as follows.

1. A3-RSRP Algorithm
   - *TTT* = 256 ms, 320 ms, 480 ms, 512 ms, 640 ms.
   - *Hysteresis* = 1 dB, 2 dB, 3 dB, 4 dB, 4 dB, 5 dB, 6 dB, 7 dB, 8 dB, 9 dB, 10 dB, 11 dB, 12 dB, 13 dB, 14 dB, 15 dB
2. A2-A4-RSRQ Algorithm
   - *ServingCellThreshold* = 28 dB, 29 dB, 30 dB, 31 dB, 32 dB
   - *NeighbourCellOffset* = 1 dB, 2 dB, 3 dB, 4 dB, 4 dB, 5 dB, 6 dB, 7 dB, 8 dB, 9 dB, 10 dB, dB, 12 dB, 13 dB, 14 dB, 15 dB.

The EU number for this test is 46 which is randomly distributed to the nearest eNBs. EU speed is set randomly also from a minimum speed of 10 Kmph to a maximum speed of 120 Kmph. From this optimization process, a combination of *TTT* and *Hysteresis* values for the A3-RSRP algorithm and *Serving Cell Threshold* and *Neighbour Cell Offset* values for the A2-A4-RSRQ algorithm which produce the best *Optimize Ratio* for EU movements in the range of 10 to 120 Kmph will be obtained.

III. RESULT AND DISCUSSION

A. Simulation

1. A2-A4-RSRQ Algorithm

For evaluation of the A2-A4-RSRQ algorithm the scenarios evaluated include various variations of the EU number, EU movement speed, and channel conditions

(with and without fading). The results of the simulation that show the performance of the algorithm in term of *ANOH* and Optimize Ratio are shown in the Figure7 up to Figure 14 below.
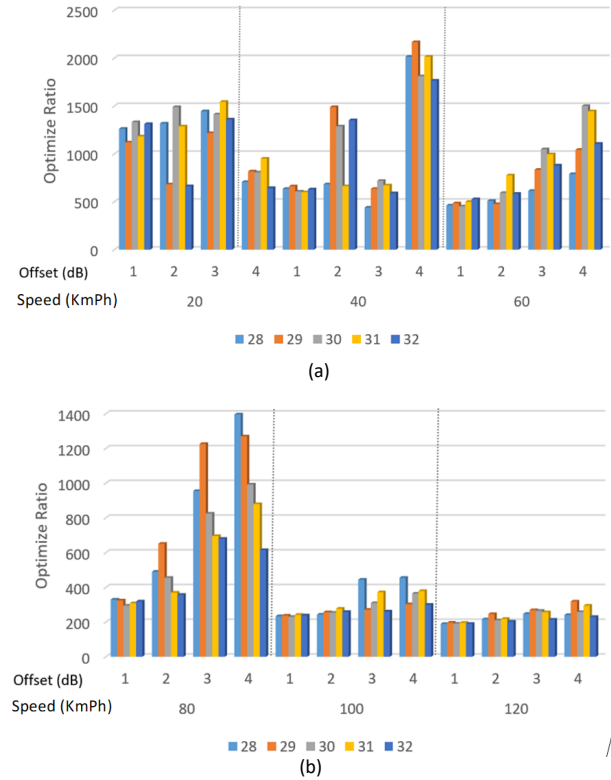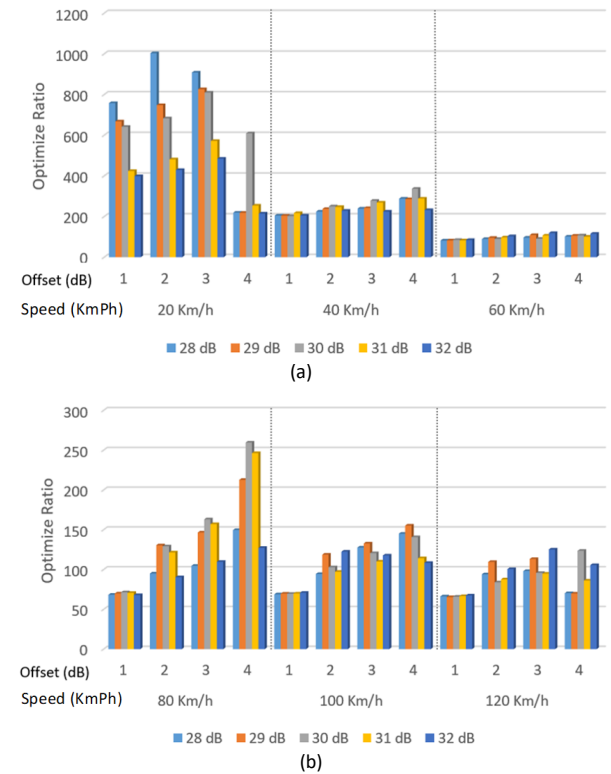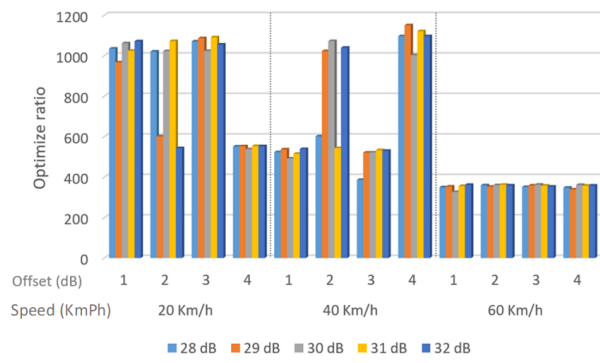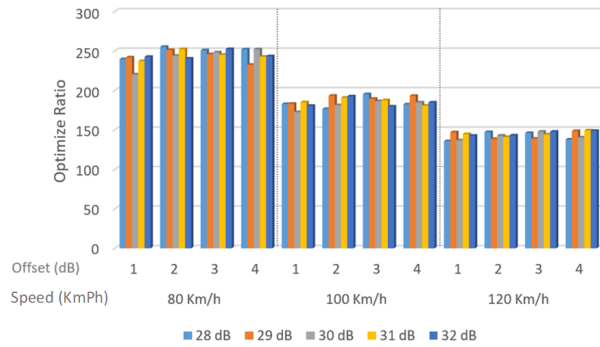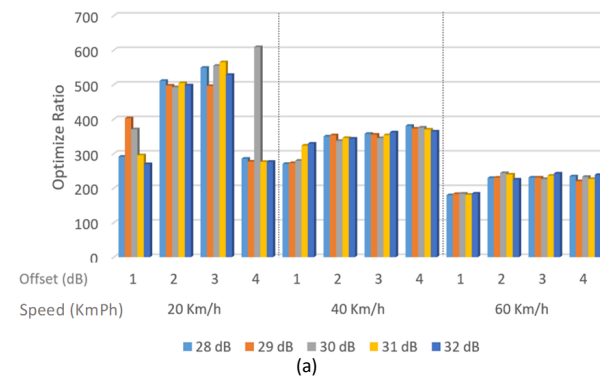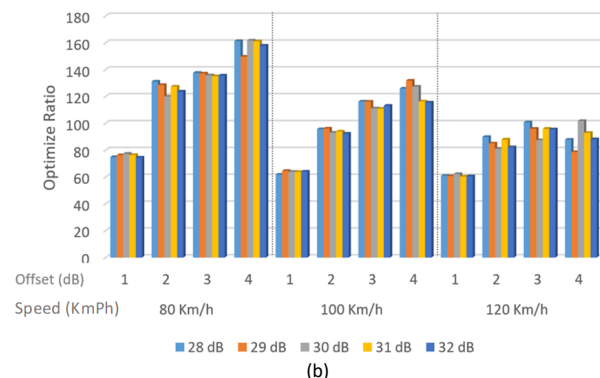

(a)

(b)

Figure 7. Optimized Ratio for various Offset and Threshold parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs without considering Fading Effect.
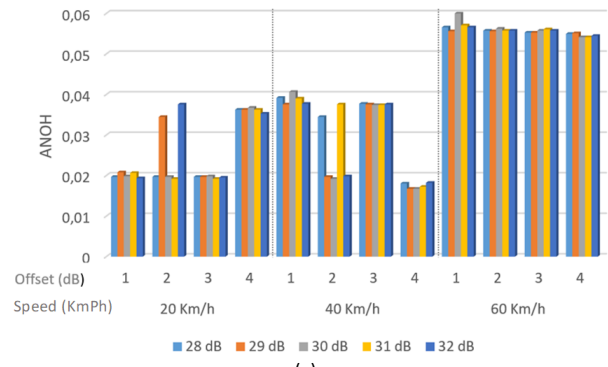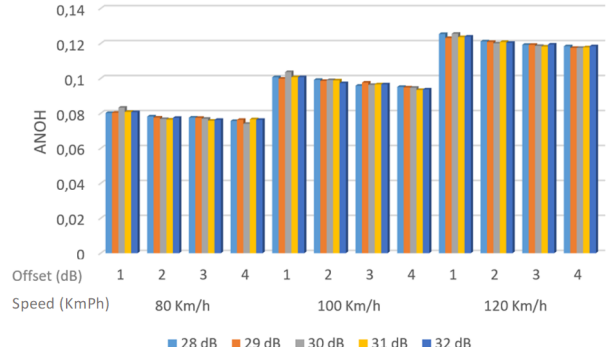

(a)

(b)

Figure 8. Optimized Ratio for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs by considering Fading.

(a)

(b)

Figure 9. Optimized Ratio for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs without considering Fading Effect.
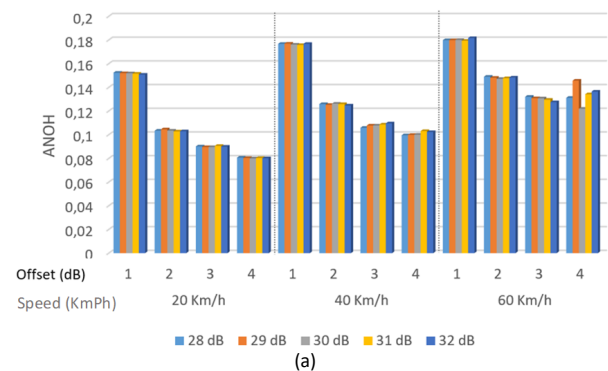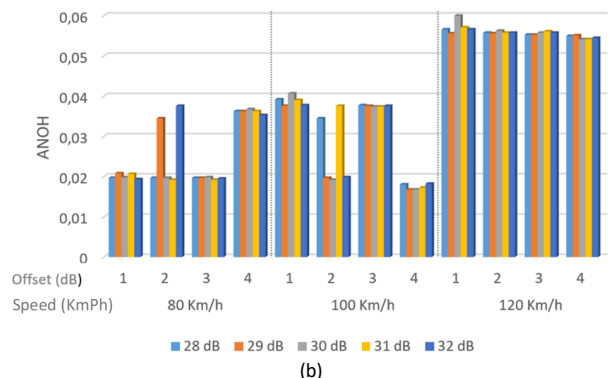

(a)

(b)

Figure 11. ANOH for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs without considering Fading Effect.

(a)

(b)

Figure 10. Optimized Ratio for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-spedd: 80-120 Kmph of 41 UEs by considering Fading.

(a)

(b)

Figure 12. ANOH for various *Offset* and Threshold parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs by considering Fading Effect.
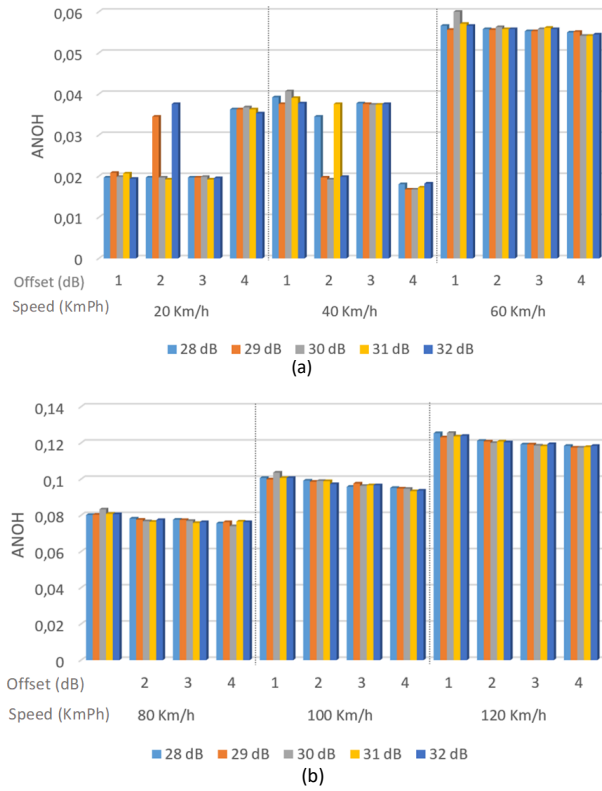
Figure 13. ANOH for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs without considering Fading Effect.
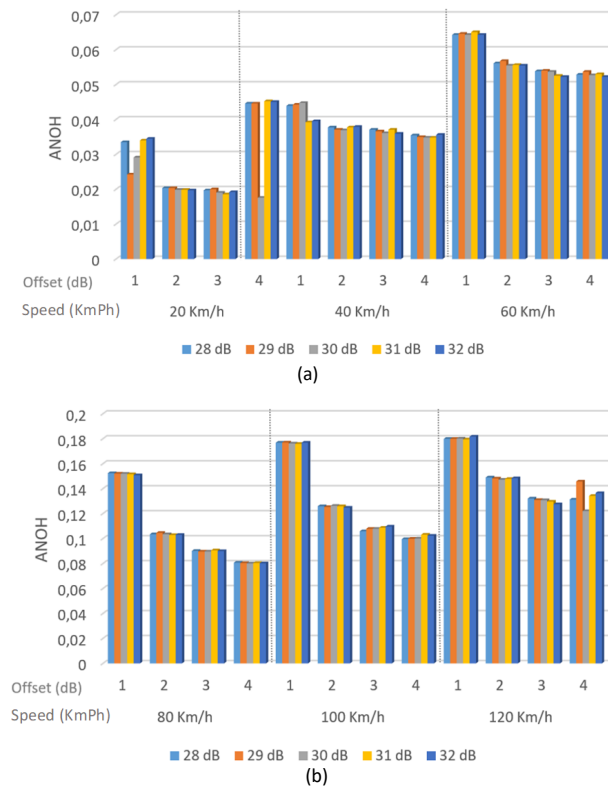

Figure 14. ANOH for various *Offset* and *Threshold* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-spedd: 80-120 Kmph of 41 UEs by considering Fading Effect.

TABLE 4
SIMULATION RESULTS FOR VARIOUS SCENARIOS FOR THE A2-A4-RSRQ ALGORITHM

UE Movement Speed	41 User		20 User	
	[Threshold;Offset]		[Threshold;Offset]	
	Fading Effect considered	Fading Effect is not considered	Fading Effect considered	Fading Effect is not considered
20 kmph	[32;3]	[32;4]	[28;2]	[29;4]
40 kmph	[28;4]	[28;2]	[30;4]	[31;4]
60 kmph	[31;2]	[30;3]	[32;3]	[30;4]
80 kmph	[28;4]	[28;2]	[30;4]	[28;4]
100 kmph	[29;4]	[29;4]	[29;4]	[28;4]
120 kmph	[30;4]	[31;4]	[32;3]	[29;4]

From the results in Figure 7 to 14, the best *Serving Cell Threshold* and *Cell Offset Neighbor* parameter values for various speed and channel conditions are shown in Table 4.

2. A3-RSRP Algorithm

In like manner, for evaluation of the A3-RSRP algorithm the scenarios evaluated include various variations of the EU number, EU movement speeds, and channel conditions (with and without fading). The results of the simulation that show the performance of the algorithm in term of *ANOH* and *Optimize Ratio* are shown in the Figure 15 up to Figure 22 below.
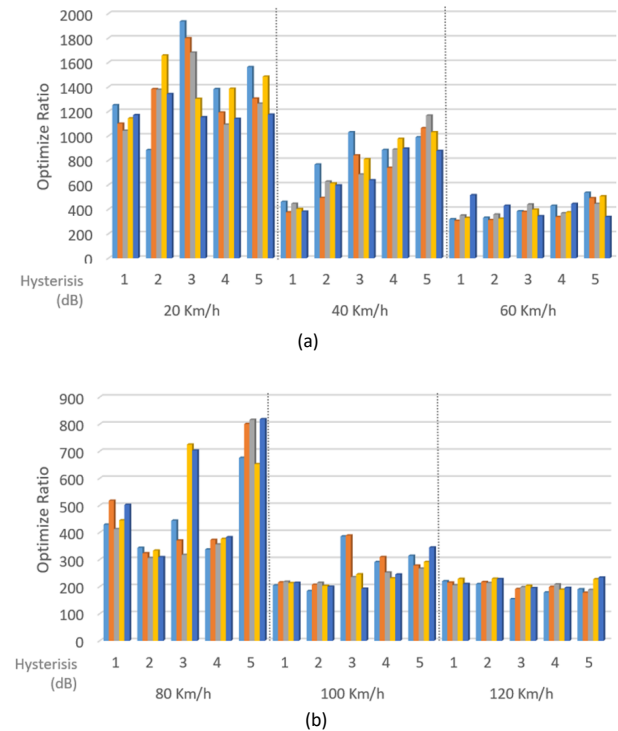

Figure 15. Optimized Ratio for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs without considering Fading Effect
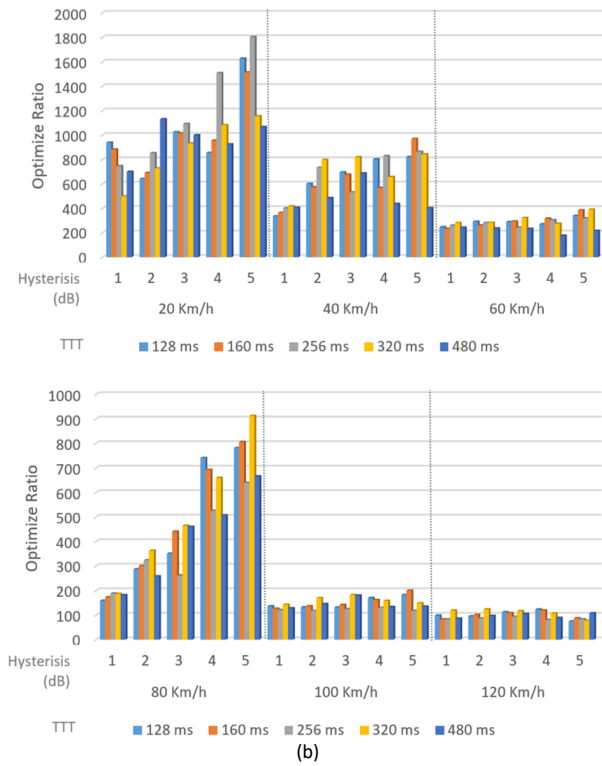
Figure 16. Optimized Ratio for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs by considering Fading Effect.

Figure 17. Optimized Ratio for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs without considering Fading Effect.
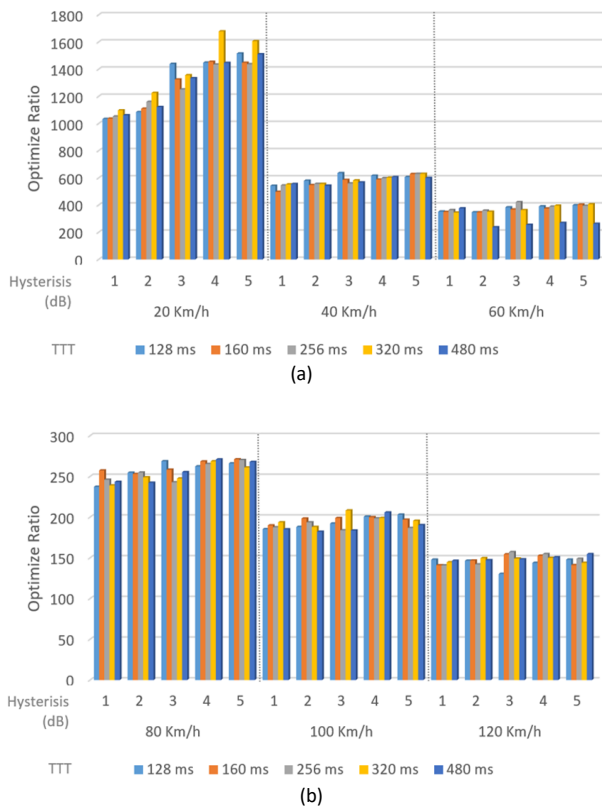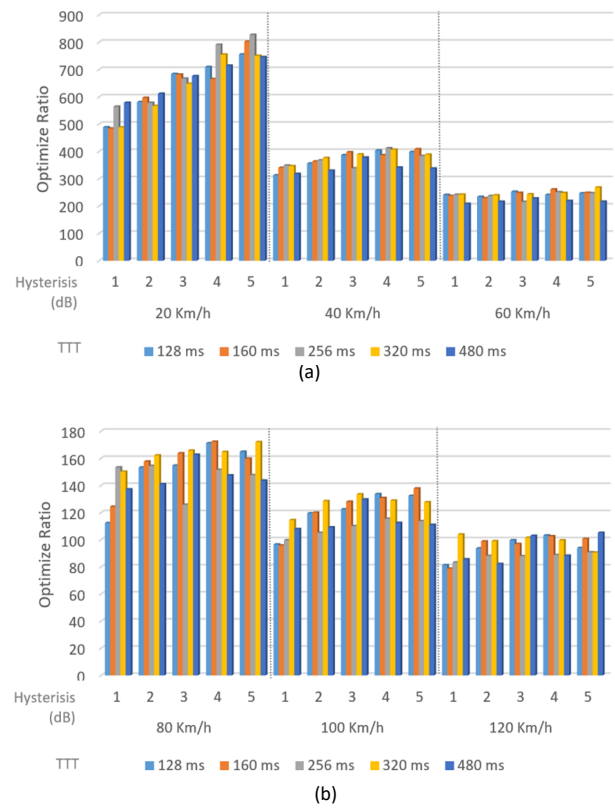

Figure 18. Optimized Ratio for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs by considering Fading Effect.

Figure 19. ANOH for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs without considering Fading Effect

(a)

(b)

Figure 20. ANOH for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 20 UEs by considering Fading Effect.
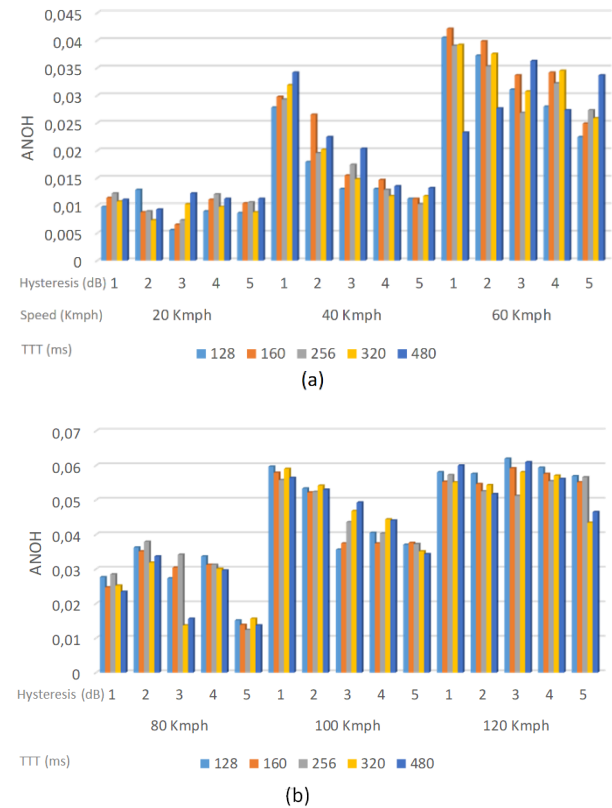

(a)

(b)

Figure 21. ANOH for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs without considering Fading Effect
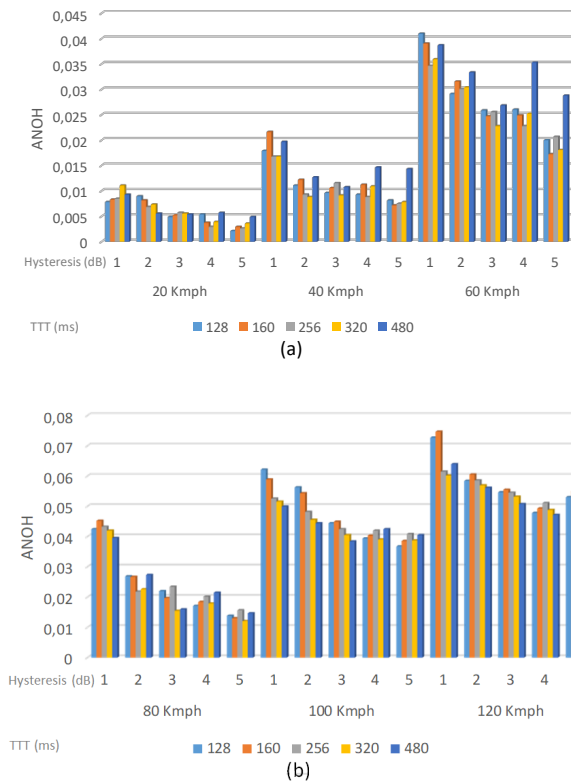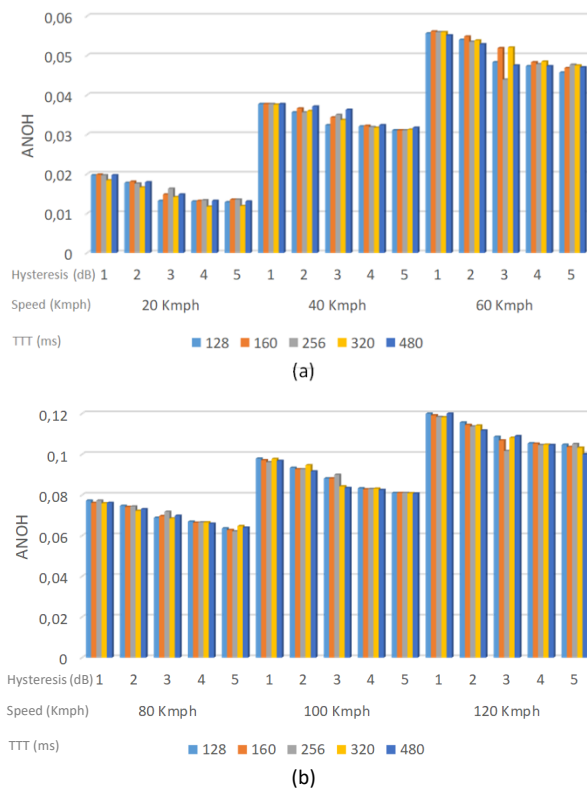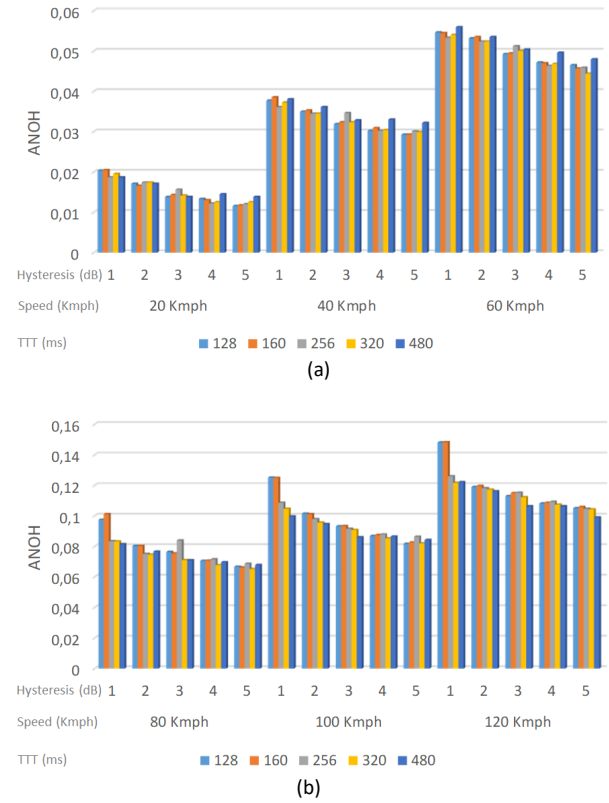

(a)

(b)

Figure 22. ANOH for various *Hysteresis* and *TTT* parameter values at various speeds of EU movements (a) Low speed: 20-60 Kmph, and (b) high-speed: 80-120 Kmph of 41 UEs by considering Fading Effect.

TABLE 5
SIMULATION RESULTS FOR VARIOUS SCENARIOS FOR THE A3-RSRP ALGORITHM

UE Movement Speed	41 User		20 User	
	[Hysteresis;TTT]		[Hysteresis;TTT]	
	Fading Effect considered	Fading Effect is not considered	Fading Effect considered	Fading Effect is not considered
20 kmph	[5;256]	[3;128]	[5;256]	[3;128]
40 kmph	[4;256]	[5;320]	[5;160]	[5;256]
60 kmph	[5;320]	[3;256]	[5;320]	[3;480]
80 kmph	[4;160]	[4;480]	[5;320]	[5;480]
100 kmph	[5;160]	[3;320]	[5;160]	[3;160]
120 kmph	[5;480]	[3;256]	[2;320]	[5;480]

From the results, the best Hysteresis and Time-to-Trigger (TTT) parameter values for various speed and channel conditions are shown in Table 5.

B. Analysis of Simulation Results

Simulation results for various scenarios to see the effect of increasing EU speed on the performance of the A3-RSRP and A2-A4-RSRQ algorithms for channel conditions with and without fading are summarized in the form of graphs above. In addition, it can also be seen how the effect of increasing the number of users for various EU movement speeds on performance. In the A3-RSRP algorithm there is a significant decrease with increasing user speed for channel conditions without fading compared to channels with fading.

Likewise, the same phenomenon occurs for the A2-A4-RSRQ algorithm, however the performance of this algorithm is better than the A3-RSRP algorithm. Equally, the effect of increasing the number of users will decrease performance worse on the A3-RSRP algorithm compared to the A2-A4-RSRQ algorithm. The weakness of the A3-RSRP algorithm compared to the A2-A4-RSRQ algorithm is because of the ping-pong phenomenon on the A3-RSRP algorithm which is especially noticeable for fading channel conditions. In general, it can be concluded that the performance of A2-A4-RSRQ handover algorithm is better than A3-RSRP handover algorithm.

C. Handover Parameters Optimization for A2-A4-RSRQ and A3-RSRP Algorithms

Parameter optimization in the A2-A4-RSRQ algorithm is intended to find the most optimum Serving Cell Thershold and Cell Offset Neighbour values that provide the best ANOH value. Graph in Figure 23 shows a plot of the Optimize Ratio as a function of Serving Cell Thershold and Cell Offset Neighbour. From the graph it can be identified that the value of Serving Cell Thershold and Cell Offset Neighbour which gives the most optimum ANOH value are 30 dB and 10 dB respectively.

On the other hand, parameter optimization in the A3-RSRP algorithm is intended to find the most optimum Hysteresis and TTT values that provide the best ANOH value. Graph in Figure 24 shows a plot of the Optimize Ratio as a function of Hysteresis and TTT. From the graph it can be identified that the value of Hysteresis and TTT which gives the most optimum ANOH value are 12 dB and 480 ms respectively.
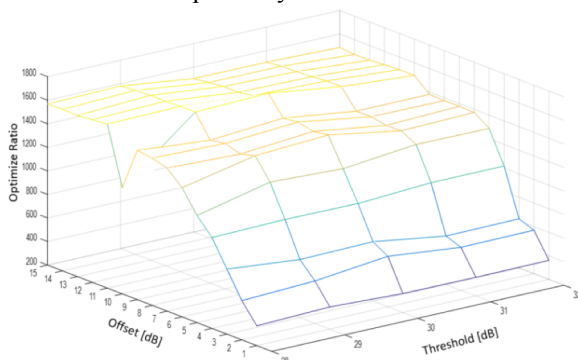

Figure 23. The value of Optimize Ratio as a function of *Offset* and *Threshold* for the A2-A4-RSRQ algorithm.
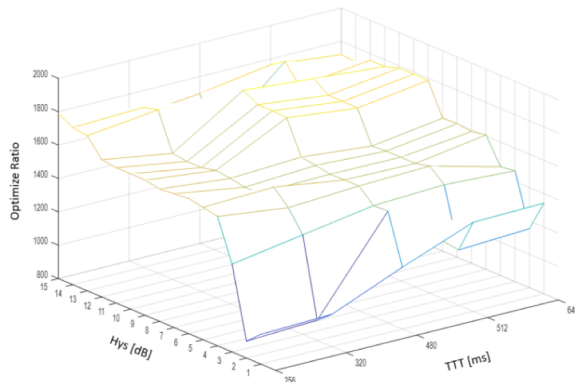

Figure 24. The value of Optimize Ratio as a function of *Hysteresis* and *TTT* for the A3-RSRP algorithm

TABLE 6
COMPARISON OF MEASUREMENT RESULTS AND SIMULATION RESULTS OF RSRP AND RSRQ ALGORITHMS

Parameter	Measurement	RSRP Algorithm	RSRQ Algorithm
Troughput (Mbps)	15.223	15.98	15.721
ANOH	0.014130435	0.010869565	0.025
Optimize Ratio	1077.32	1470.16	628.84

D. Comparison of Measurement and Simulation Results

The network that was evaluated by direct measurements in the field is set at the *TTT* parameter value of 480 ms and *Hysteresis* value of 2dB for the A3-RSRP algorithm, in the same way, is set at the *Threshold* value of 30 dB and *Offset* value of 2dB for the A2-A4-RSRQ algorithm. Performance metrics observed are *Throughput* value, *Average Number of Handover (ANOH)* and *Optimized Ratio*. Comparison of measurement results with simulation results is presented in Table 6.

From Table 6, it can be seen that the measurement results are not exactly the same as the simulation results, but give a value that is close enough. The measurement results and simulations for the RSRP algorithm provide closer values compared to the RSRQ algorithm. Therefore, the simulations for the RSRP algorithm provide more accurate results which better represent the true value of the measurement results.

CONCLUSION

In this study, the performance of the A2-A4-RSRQ and A3-RSRP algorithms was evaluated through simulation and measurement. For a variety of scenarios from the simulation, the best handover parameter values are obtained which give the best system performance. The results of the simulation also provide values that are not much different from the measurement results especially for RSRP-based algorithms. Therefore, a simulation is then performed to find the HO parameter values which gives the best performance for the scenario where each EU has a random speed in the range of 20 to 120 KmPh. It has been shown that, for the A3-RSRP algorithm a combination of *TTT* value of 480 ms and *Hysteresis* of 12 dB gives the best HO performance, while for the RSRQ algorithm the combination of *Neighbour Cell Offset* of 10 dB and *Serving Cell Threshold* of 30 dBm gives the best HO performance.

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