An overview of LTE and 5G Handover Protocols And The Power Budget Handover Algorithm

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Abstract –

This paper aims to have a look at the existing LTE X2 handover protocol and some proposed 5G handover protocols. The comparison between these handover protocols will be then interpreted into Quality of Service and Quality of Experience metrics and presented in the conclusion of this paper.

Introduction –

What is 5G? That is a question that is asked by consumers and researchers alike. "5G is an evolution considered to be the convergence of Internet services with legacy mobile networking standards leading to what is commonly referred to as the 'mobile Internet' over Heterogeneous Networks" [Introduction, Fundamentals of 5G Mobile Networks, Rodriguez, J et. al. 2015]. "A heterogeneous network is a network for which an area is covered simultaneously by cells of different sizes (macro-cell, micro-cell, pico-cell, femto-cell)" [Synchronization Principles p229-240, André Perez 2017]. The new generation of mobile and telephony communication, proposed as "5G", promises to significantly increase individual user throughput by a factor of 20 as well as a 10x increase to the capacity of users on networks. It aims to do this by increasing the frequency bands up to a maximum of 80-90GHz. This is a necessary step as the number of users on the Internet surpassed 4.5 billion in June 2019 [https://www.internetworldstats.com/stats.htm 2019 Accessed on: 26/11/2019] and the expected annual data rate will surpass 3.3 Zettabytes in 2021, an increase of 175% from 1.2 Zettabytes in 2016 [CISCO Global 2021 Forecast Highlights, 2016. Cisco and/or its affiliates]. With the introduction of new ideas such as the Internet of Things (IoT), Internet of Everything (IoE) and Device to Device communications, not only will the number of devices and the amount of data transmitted increase, but the number of connections between devices will rise dramatically. That is why it is imperative to re-evaluate existing concepts.

This paper aims to look at the difference in handover between the X2 Based handover protocol of LTE, and some proposed handovers of 5G.

Literature Review –

With the emergence of 5G, a number of previously established protocols must be re-evaluated. One area of research is handover procedure. Current LTE standards for handover protocols, such as the UE X2 & S1 Handover protocols, stand to benefit from the increased research into 5G and SBS (Small cell Base Stations) as the need for more frequent and more efficient handover protocols becomes more apparent.

During the movement of User Equipment (UE), the handover protocol is constantly active. Depending on the device, telecommunication technology, service provider and geographical location, the protocols and their details may vary. The most widespread LTE handover standard is the UE X2 handover protocol.
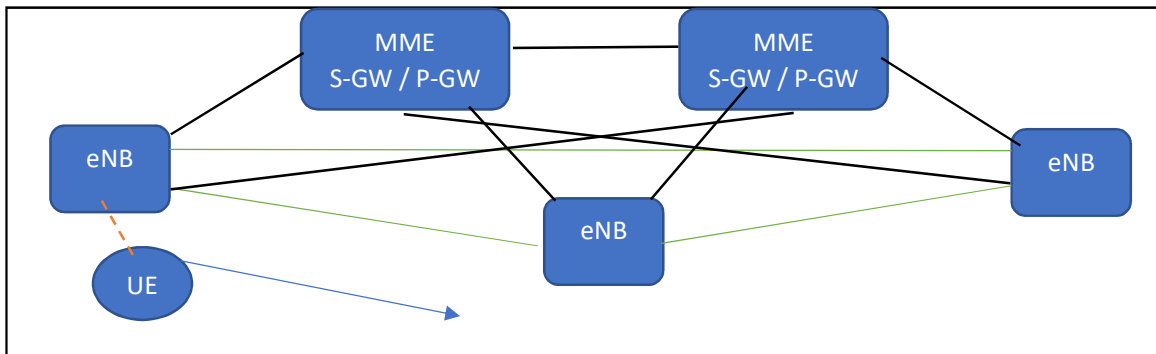
eNB = Evolved Node B (Base Station)   MME = Mobility Management Entity
S-GW = Serving Gateway   P-GW = PDN (Packet Data Network) Gateway

As the UE moves away from the Source eNB(S-eNB) it is currently connected to, the handover protocols determine which Target eNB(T-eNB) to connect to. There are 2 different types of handovers:

Hard Handover: Also known as a break-before-make connection. The connection between the S-eNB + MME and the UE is temporarily broken before being instantaneously remade with the closer T-eNB. This is usually the case in FDMA (Frequency Division Multiple Access) and TDMA (Time Division Multiple Access) based systems. As LTE and 5G are less reliant on FDMA and TDMA, this type of handover is very rarely if ever used.

Soft Handover: Also known as a make-before-break connection. A connection is established to other eNBs as the UE gets within range. When the handover protocol determines that it would be advantageous to change from the S-eNB to a T-eNB, the old connection is terminated and the handover is complete.

There are also several subtypes of handovers, including:

Intra-eNB – This means handovers between different eNBs while maintaining the connection to the same MME and S-GW/P-GW. The handover involving the X2 interface is an example of Intra-eNB handover.

Inter-eNB – This means a handover between a S-eNB and a T-eNB that are connected to different MMEs. This can involve also changing S-GWs, however that is not entirely necessary in some cases. The S1 based handover is an example of this type of handover.

As mentioned earlier, one of the most common handover protocols involves the use of the X2 interface to perform Intra-eNB handovers. The X2 interface consists of the following components that facilitate a handover:

X2-AP (Application Protocol) [ETSI TS136.423 V12.5.0 2014] – This protocol provides application layer support for the X2 interface to perform the following:

-Mobility Management (i.e. the Handover Protocol)

-Load Management – Indication of resources, overload, traffic load statuses

-Reporting of General Error Situations

-Setting and Resetting of the X2
-eNB Configuration Updates – Making sure two eNBs have interoperable X2 interfaces
-Mobility Parameter Management – Enables coordination of mobility parameter settings
-Mobility Robustness Optimisation – Allows for feedback related to mobility failure events
-Energy Efficiency – Energy consumption optimisation options
-X2 Release – Enables an eNB to be aware of signal unavailability
-Message Transfer – Indirect transport of X2AP messages between eNBs
-Registration – Registration of eNB to allow support for Message Transfer
-Removing X2

X2-CP (Control Plane) [X2 interfaces Function in LTE – A connection between two eNodeBs http://teletopix.org/4g-lte/x2-interface-function-in-lte-a-connection-between-two-enodebs/ Accessed on: 28.11.2019] – This is the transport layer protocol of X2 that uses the Stream Control Transmission Protocol IP (SCTP IP [RFC 4960 & RFC 8540]) to manage and exchange overloads and traffic loads and corresponding information between eNBs to increase the efficiency of traffic load handling. It also enables the establishment and release of tunnels between S-eNBs and T-eNBs during a handover operation. The full list of functions is as follows:
-Intra mobility support for UE
-Context transfer from S-eNBs to T-eNBs
-Control X2-UP tunnels between S-eNBs and T-eNBs
-Handover cancellation
-Uplink load management
-X2 general management
-Error handling

X2-UP (User Plane) – This protocol, located on the Radio Network layer, tunnels and identifies end-user packets travelling between eNBs and manages potential packet loss. This protocol is used for conveying control information related to data flow management.

A typical handover procedure in LTE would consist of three phases: handover preparation phase, handover execution phase and handover completion phase.
Below is an example of how an X2 Intra-eNB handover process would look (Data interpreted from [Event Helix Handover Sequence http://www.eventhelix.com/lte/handover/x2/lte-x2-handover-sequence-diagram.htm Accessed on: 28.11.2019]:

UE	T-eNB	S-eNB	MME	SGW + PGW	Description
					RRC (Radio Resource Control) Measurement Control & Report
					X2AP Handover Request
					X2AP Handover Request Acknowledgement
					X2 Bearer channel establishment

	←				RRC Connection Reconfiguration Request
		←			X2AP SN Transfer Status
		←	←		Downlink Data during Handover Preparation
	→		→		Uplink Data during Handover Preparation
	→				Begin Switching to T-eNB
	→				RRC RACH Preamble
	←				Random Access Response
	→				RRC Connection Reconfiguration Complete
	←				End Switching to T-eNB
	←				Queued Downlink Data downloaded from T-eNB
		→			S1AP Path Switch Request
			→		S11 GTP-C Update Bearer Request
			←		S11 GTP-C Update Bearer Response
		←			S1AP Path Switch Request Acknowledgement
		←			X2UE Context Release

Figure 2 depicts the same event as the table above [Analyzing X2 Handover in LTE/LTE-A, Alexandris Konstantinos et. al.]———
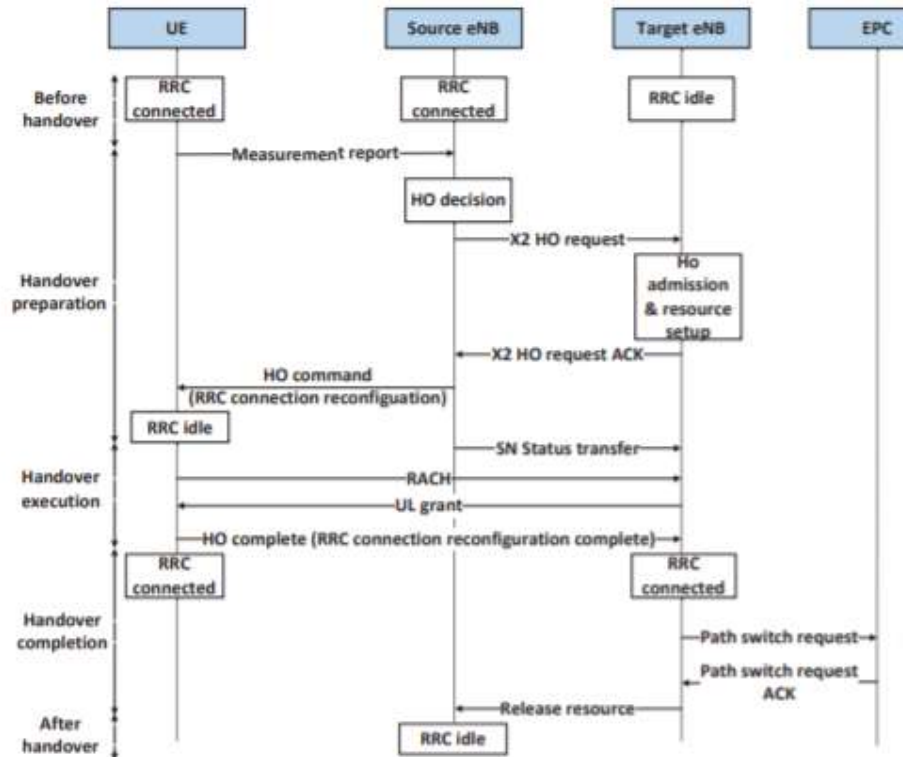
Fig. 2.   X2 handover procedure

During a mobility event that leads to a handover, the RSRP (Reference Signal Receive Power) of the T-eNB must be larger than RSRP of the S-eNB combined with the A3Offset + A3Hysteresis – CellIndividualOffsetEUTRAN
(RSRT>RSRS+A3Offset+A3Hysteresis-CellIndividualOffsetEUTRAN)
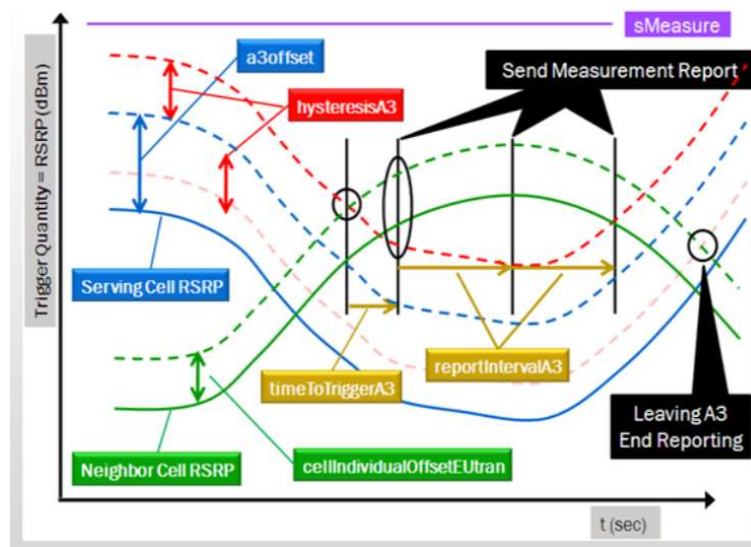
A3Offset [3GPP 36.331] - The role of this offset is to make the S-eNB look better than its

current measurement in comparison to the neighbour, to provide more robust handovers. [Rodriguez, J 4G Seminar p75]

A3Hysteresis – The role of the hysteresis is to make the measured neighbour look worse than measured to ensure it is much stronger before the UE decides to send a measurement report to initiate a handover. [Rodriguez, J 4G Seminar p75]

TimeToTriggerA3 – This is to avoid a ping-pong effect (At expiration, if the UE does not receive an RRC connection reconfiguration message, another timer is started (ReportingIntervalA3). If this timer expires, the measurements are repeated and transmitted again. If a number of retransmissions occur (ReportingAmount) without a response, the process is cancelled.

CellIndividualOffsetEUTRAN – The higher this value, the "more attractive" the eNB will look to the UE.

For 5G, there are several proposed handover types, some of these include:

UE Initiated Handover and Network Initiated Handover (as per specifications published from Verizon 5G Technical Forum document TS V5G.300.) These are not unlike the X2 LTE handover described above.

Another type is a Request-Based Handover Strategy Using NDN for 5G proposed by Fan Jia and Xialoin Zheng [Wireless Communications and Mobile Computing Volume 2018, Article ID 4513070]. This protocol uses a Request-Based Handover Strategy (RBHS) that promises around 30% higher cache hit rate and 20% more traffic reduction compared to Signal-to-Interference-plus-Noise-Ratio (SINR) of previous handover types.

Yet another proposed handover is the mmHandover, which would be a pre-connection-based handover protocol for 5g millimetre wave vehicular networks [Xiong Wang, Linghe Kong, Jintao Wu et.al. 2019]. mmHandover aims to alleviate the problems occurring with frequent handover changes and signal blockages by providing a real-time handover protocol.

Lastly, A Flat Mobile Core Network for Evolved Packet Core Based SAE Mobile Networks [Mohammad Al Shinwan, Trong-Dinh Huy, Kim Chul-Soo, Journal of Computer and Communications, 2017, 5, 62-73] proposes to combine the P-GW and S-GW into a "Cellular Gateway" (C-GW) and increase the distribution of these C-GW in a mobile core network, and to increase MME functionality to include centralizing mobility anchor and allocation of IP addresses for UEs.

Scenario Definition –

The focus of this scenario will be Power Budget Handover Algorithm derived and greatly simplified from The Received Signal Strength-based TTT Window algorithm for LTE-A systems outlined in Optimized Performance Evaluation of LTE Hard Handover Algorithm with Average RSRP Constraint [Cheng-Chung Lin et.al. International Journal of Wireless & Mobile Networks (IJWMN) Vol.3, No.2, April 2011 p.4]

The Power Budget Handover Algorithm is used to perform a Hard Handover UE over LTE systems. The basic premise of this algorithm is to provide a simple yet effective When the RSRP of the T-eNB becomes greater than that of the S-eNB (and an additional offset (HOM)), the HOTrigger will begin counting. If the RSRP of the T-eNB falls under that of the S-eNB, the

timer will be stopped and reset. However, if the HOTrigger runs for TTT*ms*, the handover protocol will go ahead.
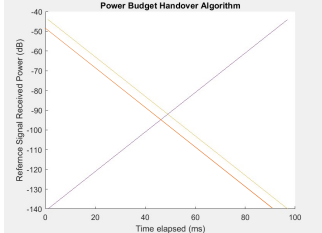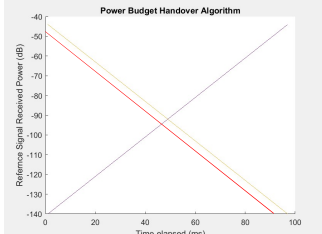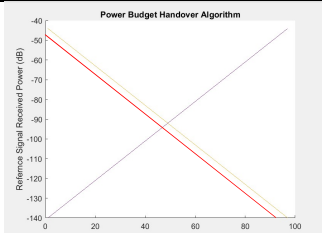
$RSRP_T > RSRP_S + HOM$
$HOTrigger >= TTT$

Received Signal Strength-based TTT Window Algorithm Parameters

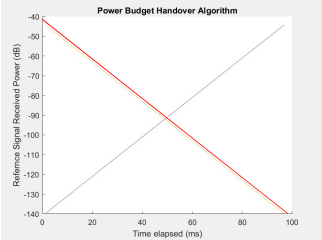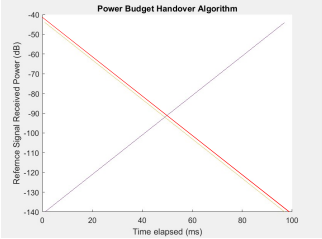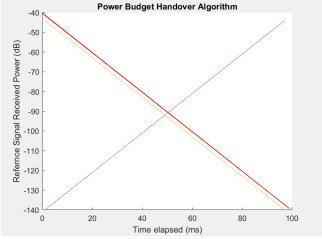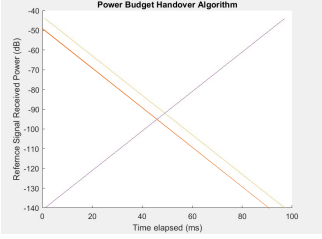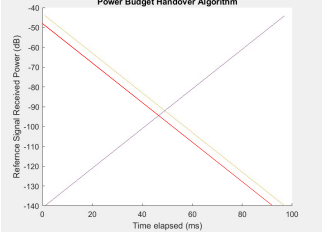| Parameter Explanation	Parameter	Value(s)
Duration of the simulation	Duration	100ms
How often the RSRP will be measured	Sample Frequency	1 ms
Reference Signal-Received Power	$RSRP_T$ & $RSRP_S$ (dBm)	[-44 to -140]
RSRP with Threshold and Handover Margin	HOM (dBm)	[-5 to 5]
Time-To-Trigger	TTT (ms)	[10 to 40]
HandOver Trigger	HOTrigger	V
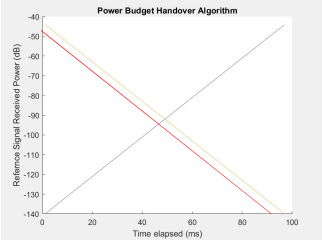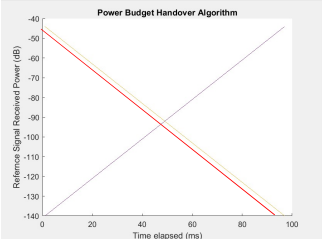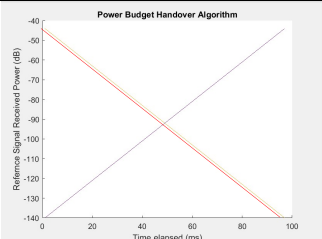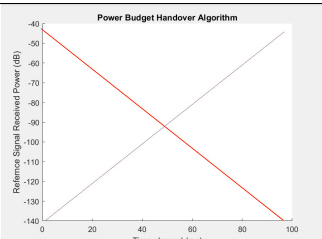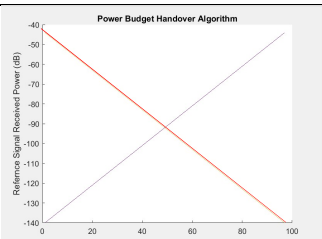
In the scenario being simulated, the RSRP of the S-eNB (RSRS) is reducing at a rate of 1dBm per ms, while the RSRP of the T-eNB (RSRT) is increasing at a rate of 1dBm per ms. The signals will cross over at an RSRP of -92. After the signals cross over and a value of *HOM* is added onto the T-eNB, the HOTrigger will begin counting. Once the HOTrigger reaches the value of the TTT, the handover is deemed as necessary and the handover protocol is initiated.
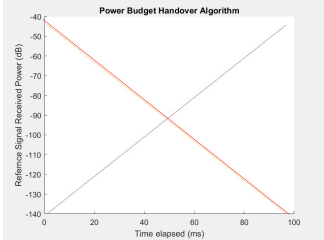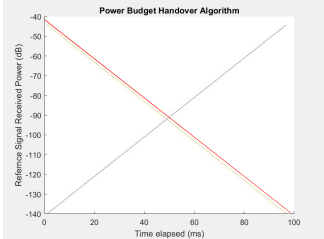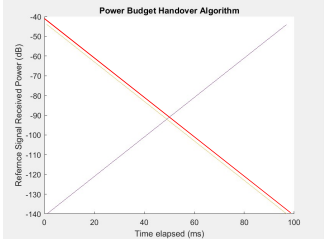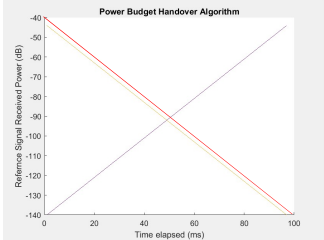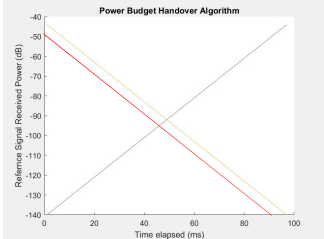
Simulations –
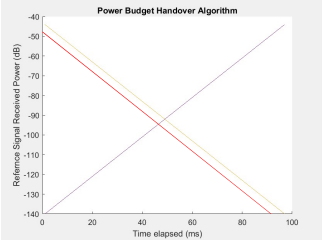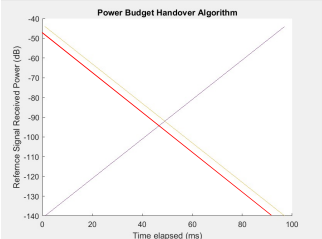
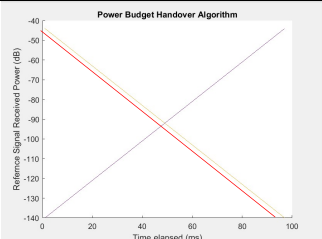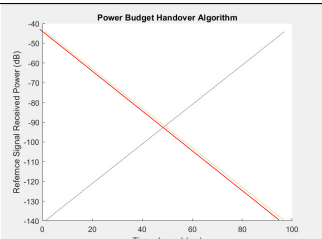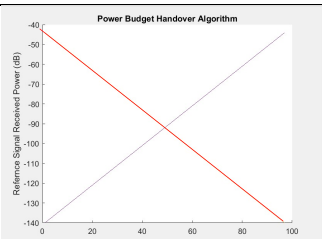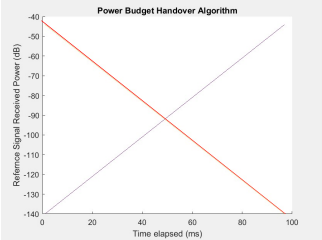| TTT	HOM	Simulation	
10	-5		HOTrigger activated at RSRS -97dB, TTT of 10ms means HOTrigger completes at -107dB RSRS & -87dB RSRT (difference of 20dB)
10	-4		HOTrigger activated at RSRS -96dB, TTT of 10ms means HOTrigger completes at -106dB RSRS & -86dB RSRT (difference of 20dB)
10	-3		HOTrigger activated at RSRS -95dB, TTT of 10ms means HOTrigger completes at -105dB RSRS & -85dB RSRT (difference of 20dB)

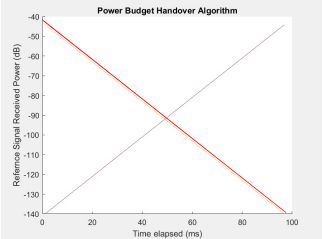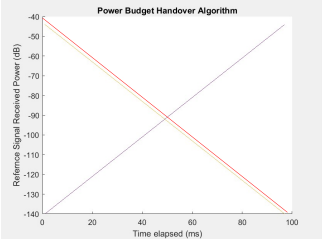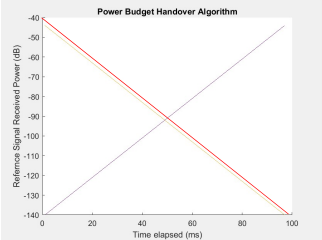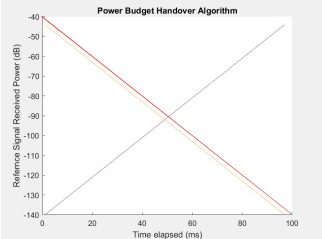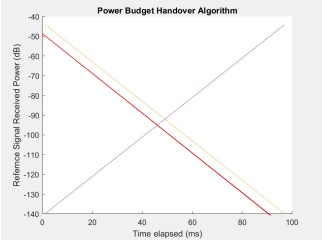| 10	-2		HOTrigger activated at RSRS -94dBm, TTT of 10ms means HOTrigger completes at -104dBm RSRS & -84dBm RSRT (difference of 20dBm)
10	-1		HOTrigger activated at RSRS -93dBm, TTT of 10ms means HOTrigger completes at -103dBm RSRS & -83dBm RSRT (difference of 20dBm)
10	0		HOTrigger activated at RSRS -92dBm, TTT of 10ms means HOTrigger completes at -102dBm RSRS & -82dBm RSRT (difference of 20dBm)
10	1		HOTrigger activated at RSRS -91dBm, TTT of 10ms means HOTrigger completes at -101dBm RSRS & -81dBm RSRT (difference of 20dBm)
10	2		HOTrigger activated at RSRS -90dBm, TTT of 10ms means HOTrigger completes at -100dBm RSRS & -80dBm RSRT (difference of 20dBm)

10	3		HOTrigger activated at RSRS -89dBm, TTT of 10ms means HOTrigger completes at -99dBm RSRS & -79dBm RSRT (difference of 20dBm)
10	4		HOTrigger activated at RSRS -88dBm, TTT of 10ms means HOTrigger completes at -98dBm RSRS & -78dBm RSRT (difference of 20dBm)
10	5		HOTrigger activated at RSRS -87dBm, TTT of 10ms means HOTrigger completes at -97dBm RSRS & -77dBm RSRT (difference of 20dBm)
20	-5		HOTrigger activated at RSRS -97dBm, TTT of 20ms means HOTrigger completes at -117dBm RSRS & -77dBm RSRT (difference of 40dBm)
20	-4		HOTrigger activated at RSRS -96dBm, TTT of 20ms means HOTrigger completes at -116dBm RSRS & -76dBm RSRT (difference of 40dBm)

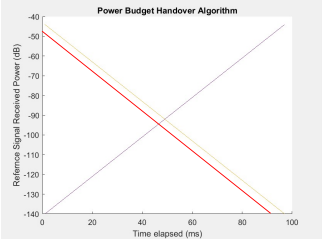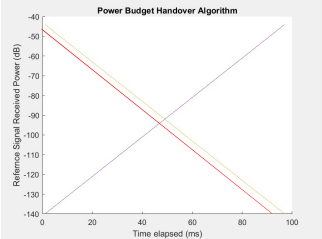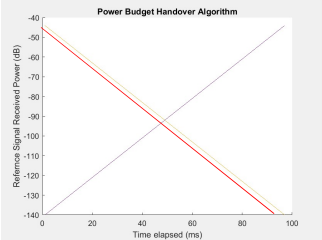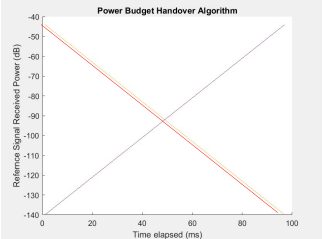| 20	-3		HOTrigger activated at RSRS -95dBm, TTT of 20ms means HOTrigger completes at -115dBm RSRS & -75dBm RSRT (difference of 40dBm)
20	-2		HOTrigger activated at RSRS -94dBm, TTT of 20ms means HOTrigger completes at -114dBm RSRS & -74dBm RSRT (difference of 40dBm)
20	-1		HOTrigger activated at RSRS -93dBm, TTT of 20ms means HOTrigger completes at -113dBm RSRS & -73dBm RSRT (difference of 40dBm)
20	0		HOTrigger activated at RSRS -92dBm, TTT of 20ms means HOTrigger completes at -112dBm RSRS & -72dBm RSRT (difference of 40dBm)
20	1		HOTrigger activated at RSRS -91dBm, TTT of 20ms means HOTrigger completes at -111dBm RSRS & -71dBm RSRT (difference of 40dBm)

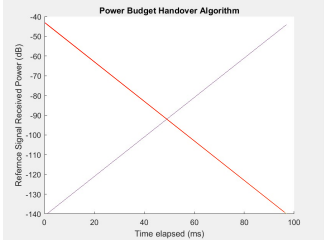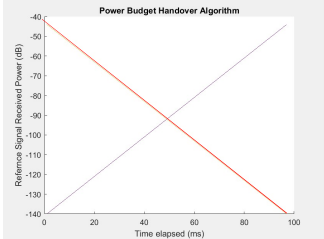| 20	2		HOTrigger activated at RSRS -90dBm, TTT of 20ms means HOTrigger completes at -110dBm RSRS & -70dBm RSRT (difference of 40dBm)
20	3		HOTrigger activated at RSRS -89dBm, TTT of 20ms means HOTrigger completes at -109dBm RSRS & -69dBm RSRT (difference of 40dBm)
20	4		HOTrigger activated at RSRS -88dBm, TTT of 20ms means HOTrigger completes at -108dBm RSRS & -68dBm RSRT (difference of 40dBm)
20	5		HOTrigger activated at RSRS -87dBm, TTT of 20ms means HOTrigger completes at -107dBm RSRS & -67dBm RSRT (difference of 40dBm)
30	-5		HOTrigger activated at RSRS -97dBm, TTT of 30ms means HOTrigger completes at -127dBm RSRS & -67dBm RSRT (difference of 60dBm)

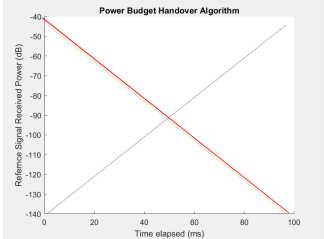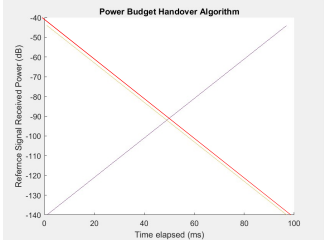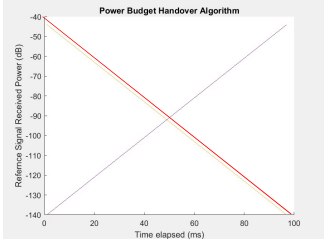| 30	-4		HOTrigger activated at RSRS -96dBm, TTT of 30ms means HOTrigger completes at -126dBm RSRS & -66dBm RSRT (difference of 60dBm)
30	-3		HOTrigger activated at RSRS -95dBm, TTT of 30ms means HOTrigger completes at -125dBm RSRS & -65dBm RSRT (difference of 60dBm)
30	-2		HOTrigger activated at RSRS -94dBm, TTT of 30ms means HOTrigger completes at -124dBm RSRS & -64dBm RSRT (difference of 60dBm)
30	-1		HOTrigger activated at RSRS -93dBm, TTT of 30ms means HOTrigger completes at -123dBm RSRS & -63dBm RSRT (difference of 60dBm)
30	0		HOTrigger activated at RSRS -92dBm, TTT of 30ms means HOTrigger completes at -122dBm RSRS & -62dBm RSRT (difference of 60dBm)

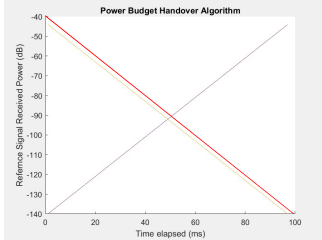| 30	1		HOTrigger activated at RSRS -91dBm, TTT of 30ms means HOTrigger completes at -121dBm RSRS & -61dBm RSRT (difference of 60dBm)
30	2		HOTrigger activated at RSRS -90dBm, TTT of 30ms means HOTrigger completes at -120dBm RSRS & -60dBm RSRT (difference of 60dBm)
30	3		HOTrigger activated at RSRS -89dBm, TTT of 30ms means HOTrigger completes at -119dBm RSRS & -59dBm RSRT (difference of 60dBm)
30	4		HOTrigger activated at RSRS -88dBm, TTT of 30ms means HOTrigger completes at -118dBm RSRS & -58dBm RSRT (difference of 60dBm)
30	5		HOTrigger activated at RSRS -87dBm, TTT of 30ms means HOTrigger completes at -117dBm RSRS & -57dBm RSRT (difference of 60dBm)

40	-5		HOTrigger activated at RSRS -97dBm, TTT of 40ms means HOTrigger completes at -137dBm RSRS & -57dBm RSRT (difference of 80dBm)
40	-4		HOTrigger activated at RSRS -96dBm, TTT of 40ms means HOTrigger completes at -136dBm RSRS & -56dBm RSRT (difference of 80dBm)
40	-3		HOTrigger activated at RSRS -95dBm, TTT of 40ms means HOTrigger completes at -135dBm RSRS & -55dBm RSRT (difference of 80dBm)
40	-2		HOTrigger activated at RSRS -94dBm, TTT of 40ms means HOTrigger completes at -134dBm RSRS & -54dBm RSRT (difference of 80dBm)
40	-1		HOTrigger activated at RSRS -93dBm, TTT of 40ms means HOTrigger completes at -133dBm RSRS & -53dBm RSRT (difference of 80dBm)

40	0		HOTrigger activated at RSRS -92dBm, TTT of 40ms means HOTrigger completes at -132dBm RSRS & -52dBm RSRT (difference of 80dBm)
40	1		HOTrigger activated at RSRS -91dBm, TTT of 40ms means HOTrigger completes at -131dBm RSRS & -51dBm RSRT (difference of 80dBm)
40	2		HOTrigger activated at RSRS -90dBm, TTT of 40ms means HOTrigger completes at -130dBm RSRS & -50dBm RSRT (difference of 80dBm)
40	3		HOTrigger activated at RSRS -89dBm, TTT of 40ms means HOTrigger completes at -129dBm RSRS & -49dBm RSRT (difference of 80dBm)
40	4		HOTrigger activated at RSRS -88dBm, TTT of 40ms means HOTrigger completes at -128dBm RSRS & -48dBm RSRT (difference of 80dBm)

40	5		HOTrigger activated at RSRS -87dBm, TTT of ms means HOTrigger completes at -127dBm RSRS & -47dBm RSRT (difference of 80dBm)

Results –

The results obtained from this simulation follow the expected behaviour of this algorithm. The HOM is a linear value and its change results in a simple "offset" of the RSRT. This means that the HOM can be used by LTE operators to establish a specific threshold in which the difference in RSRP strength between the S-eNB and the T-eNB must be at least a value of HOM. This is one way in which the Power Budget Handover Algorithm attempts to prevent a "ping-pong effect" occurring.

The other change seen is resulting from the changes of the TTT values. The TTT signifies the window of time which must elapse with a continuous value of RSRT>RSRS+HOM before the handover algorithm deems the scenario eligible for handover. This is the other main counter to the "ping-pong effect" which this particular algorithm is designed in mind with. In this scenario, the difference of signal strength between the Source RSRP and the Target RSRP is always double the TTT value. This is because in this particular scenario, the rate of change of each of the RSRP values is 1dBm/ms. However, since each RSRP value is changing in a different direction, the combined rate of change is 2dBm/ms, or 2000dBm/s.

Conclusions –

Typically, a loss of 3dBm means a halving of signal strength (relative to itself). This is due to the logarithmic nature of dBm. Therefore, in this scenario, the signal strength would have halved every 1.5ms. While the HOM does not have a large impact on the time taken to decide to perform the handover, the TTT definitely does. Even with the lowest value of TTT investigated here, the signal would have been reduced to 1/10th of its original strength. This would make most signals utterly unusable. In this scenario and due to the rate of change of RSRPs, the TTT value would have to be less than 0.75ms in order to avoid a reduction of signal strength by more than half