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- - -
An Analysis of Handover Performance in Heterogeneous LTE Networks

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ABSTRACT

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As the demand for access to mobile broadband services continues to increase, the use of small-cell network nodes in coordination with more traditional macro-cells provides a promising solution to increase overall network capacity. By offloading users from the macro-cell tier to a chosen small-cell, bandwidth on the macro-cell tier can be freed for other users. Seamless handover is a key component of guaranteeing the expected quality of service while effectively managing resources within these heterogeneous networks. This paper aims to analyze how handover performance is affected by overlapping macro- and small-cell ranges through the simulation of heterogeneous LTE networks using the ns-3 simulation software package.

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LIST OF ABBREVIATIONS

EARFCN	E-UTRA Absolute Radio Frequency Channel Number
E-UTRA	Evolved UMTS Terrestrial Radio Access
eNB	E-UTRA Node B
EPC	Evolved Packet Core
LTE	Long-Term Evolution
PDCP	Packet Data Convergence Protocol
RB	Resource Block
RSRP	Reference Signal Received Power
RSRQ	Reference Signal Received Quality
SINR	Signal-to-interference-plus-noise Ratio
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications System

INTRODUCTION

Heterogeneous Long-Term Evolution (LTE) networks require a much different approach to handover than has been traditionally employed in cellular data networks. Conventionally, the handover process is driven by the user’s mobility and acts to ensure that a mobile user’s connection remain uninterrupted as the user moves between coverage areas of individual physical network access points within the larger service area. In the case of heterogeneous networks however, the boundaries of certain coverage areas partly or completely overlap. In this case, an additional metric for handover presents itself: efficient utilization of network resources.

Smaller, less costly physical network access points can be installed in high-traffic areas and used to offload users who are not significantly mobile from the conventional macro-cellular network tier. This approach frees bandwidth on the macro-cellular tier for users requiring mobility, while maintaining the expected quality of service for all users. It is also cost efficient due to the reduced hardware costs, and reduces the overall energy consumption of the network as the transmission power within the small-cell tier is significantly reduced due to the shorter range [1, 2].

There are, however, several complications that arise from implementing a heterogeneous network topology due in large part to the comparatively more complex and unpredictable radio environment. One of these challenges is that boundaries between individual cells become more difficult to distinguish, and ensuring the handover process is both efficient and effective becomes evermore challenging [3].

This paper will focus on this aspect in particular, and attempt to compare how effective 2 basic handover algorithms are at offloading users from the wide-area macro-cell tier to the local-area small-cell tier while maintaining the expected quality of service. The intent is to develop a quantitative measure of these aspects that can be applied to other handover algorithms.

LITERATURE REVIEW

A multitude of handover algorithms have been proposed to address heterogeneous LTE network architectures and the added complexities that they pose to mobility management. The vast majority of proposed algorithms employ weighting functions derived from some measureable parameter(s) to alter the behaviour of conventional reference signal measurement –based handover algorithms. These parameters can include, for example, UE mobility, channel interference measurements, or network resource load [1, 2]. These weightings are intended to provide a more comprehensive representation of the specific conditions that may cause a simpler algorithm to act unfavourably.

The evolution of these algorithms is the concept of the Self Organizing Network, whereby network parameters – including handover decision parameters – can be dynamically assigned based on feedback from various network elements [4, 5]. This enables the network to self-optimize, and adapt to varying network conditions.

Some consideration must also be given to designing the deployment of small-cell network nodes in an attempt to maximize network efficiency and mobility by reducing the unpredictability [6]. By intentionally configuring small-cell deployments to be more favourable to integration within the larger network, it may be possible to avoid numerous challenges that are presented by heterogeneous networks at the expense of flexibility.

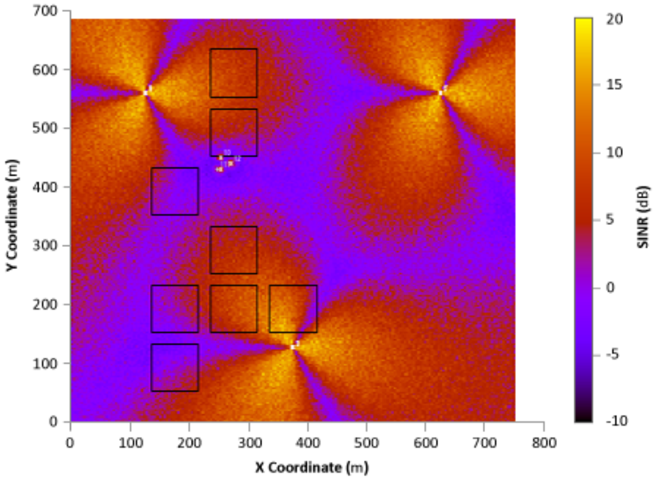
SIMULATION METHODOLOGY

The aim was to simulate an open access local-area small-cell network within a typical wide-area macro-cell network topology using the ns-3 LTE module developed by the LENA Project. To accomplish this, 3 LTE macro-cell sites, each of which was comprised of 3 individual macro-cell eNBs oriented in a 3-sector array at an elevation of 30m, were positioned in a 500m -radius hex-grid topology. A single small-cell site consisting of 3 individual small-cell eNBs all positioned 20m apart and at an elevation of 6m was then randomly located within the larger macro-cell grid.

The downlink transmission power of the macro- and small- cell eNBs was set at 46.0dBm and 20.0dBm, respectively. A proportional-fair scheduling algorithm was installed at each eNB and allocated 25 uplink RBs and 25 downlink RBs corresponding to channel bandwidths of 5MHz each. A common absolute radio channel frequency number (EARFCN) was selected for uplink and another for downlink across all eNBs. It should be noted that no frequency reuse was implemented in this simulation.

Buildings varying in height from 6 to 15 meters were then placed in the topology to simulate a realistic signal propagation environment. Shadowing and pathloss models were implemented as part of the simulation, while channel fading effects were not considered. A radio environment map of the simulation topology is shown in Figure 1.

Figure 1: Radio Environment Map of Simulation Topology



A single UE was created and assigned to follow a randomized path at a constant elevation of 1.75m within a 60m x 60m region centered on the small-cell site. The UE speed was allowed to vary between 0.5m/s and 3.5m/s. These parameters were selected in order to simulate a pedestrian travelling around the topology with the UE.

Lastly, the EPC was implemented in order to enable packet flow within the network. An X2 interface was then installed between each eNB to enable inter-eNB signaling. Individual UDP applications were then configured within the UE to upload and download at a constant rate of 1000 packets (1054 bytes per packet) per second (8.432 Mbps) over the entire duration of the 900-second simulation time.

4 separate simulations were conducted using the above-mentioned basic setup, with all parameters kept consistent. 2 simulations employed a simple A2 / A4 measurement event -based handover algorithm that relies on RSRQ measurement data collected by the UE. Definitions of the A2 and A4 events can be found in Table 1. This algorithm waits until a UE reports both an A2 and A4 event, and then begins looking for the neighbouring eNB with the best RSRQ. A handover to the neighbouring eNB with the best RSRQ will then be requested. The effect of the algorithm is to transfer the UE to the eNB with the highest quality signal.

The remaining 2 simulations employed a simple A3 measurement event -based handover algorithm that relies on RSRP measurement data collected by the UE. The definition of the A3 event can be found in Table 1. This algorithm waits until a UE reports an A3 event and the condition stays asserted for the total time-to-trigger duration. A handover to the neighbouring eNB with the best RSRP will then be requested. The effect of the algorithm is to connect the UE to the eNB with the strongest signal.

Table 1: Relevant Measurement Event Definitions

Event	Definition
A2	Serving cell's RSRQ becomes worse than *threshold.*
A3	Neighbouring cell's RSRP becomes *offset* better than serving cell.
A4	Neighbouring cell's RSRQ becomes better than *threshold.*

Note: *Event* definitions are per section 5.5.4 of ETSI TS 136.331.

The handover algorithm parameters that were varied throughout each simulation are listed in Table 2.

Table 2: Varied Simulation Parameters

Parameter	A2 / A4	A2 / A4	A3	A3
	High	Low	Low / Short	High / Long
A2 / A4 Threshold	30	20	-	-
A3 Offset	-	-	1	3
A3 Time-to-trigger	-	-	100 ms	250 ms

Note: *A2 / A4 Threshold* and *A3 Offset* values correspond to the measurement-value-to-integer mappings outlined in sections 9.1.7 and 9.1.4 of ETSI TS 136.133, respectively.

Custom traces were configured to capture the UE's path throughout the simulation as well as log handover signaling messages from the source eNB, target eNB, and UE. A packet trace was also attached to the PDCP to capture link performance data.

SIMULATION RESULTS AND FINDINGS

From the captured handover signaling and UE mobility traces, a plot of the handover locations for each simulation was produced. The plots distinguish between intra-tier handovers, handovers from the macro-cell tier (Tier 1) to the small-cell tier (Tier 2), or vice-versa. By fitting an ellipse to all handovers that occur when the UE is connecting to a given cell (entering the cell), and doing the same for when the UE is disconnecting from that same cell (exiting the cell), the cell boundaries can be approximated.

Figures 2 and 3 show the plots of the raw handover data and the fitted ellipses for the A2 / A4 event -based algorithm simulations, and Figures 4 and 5 show the same for the A3 event -based algorithm simulations.

Figure 2: A2 / A4 event -based algorithm with high threshold

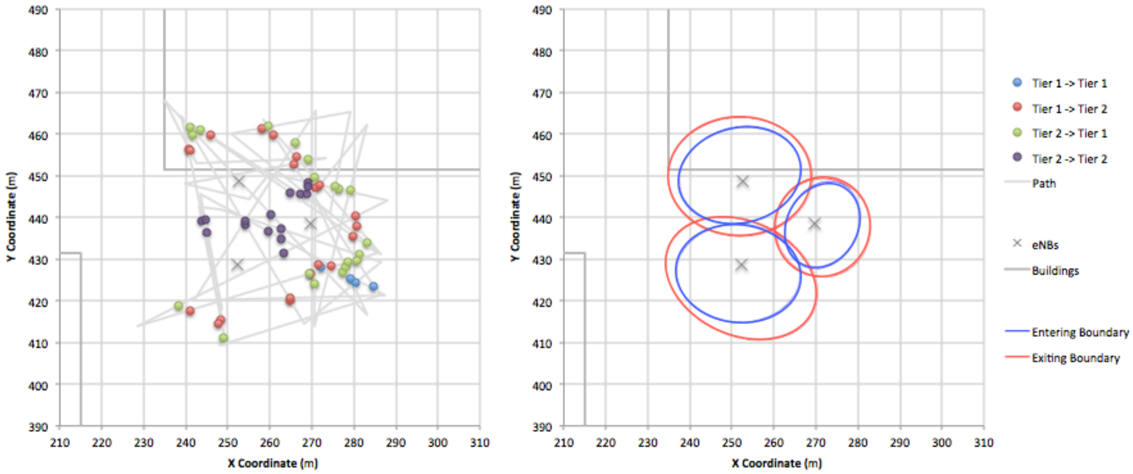


Figure 3: A2 / A4 event -based algorithm with low threshold

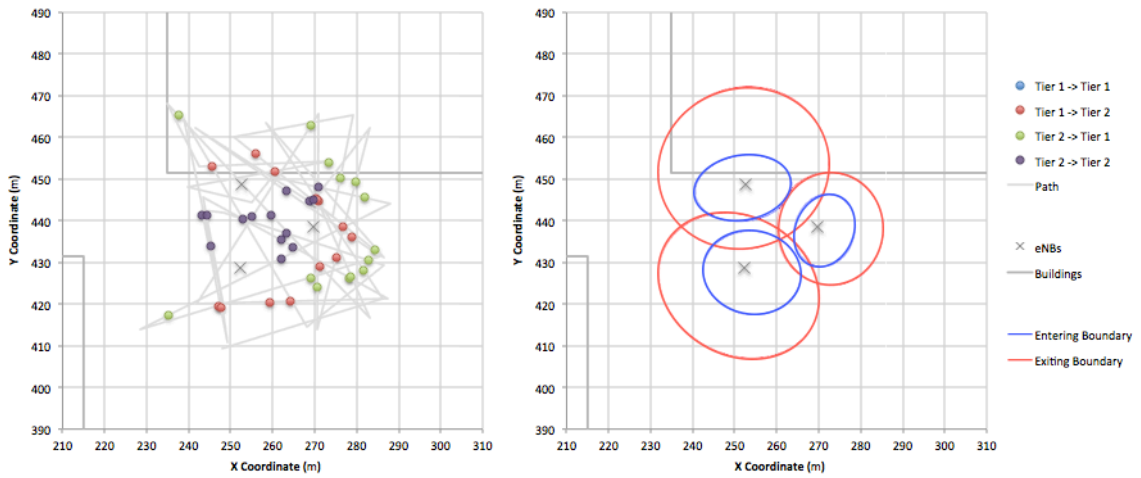
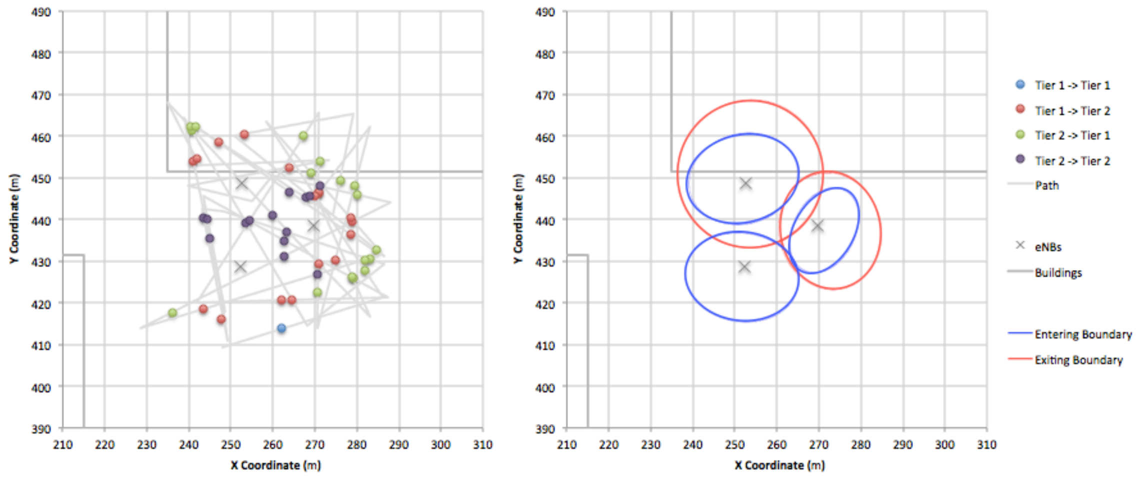
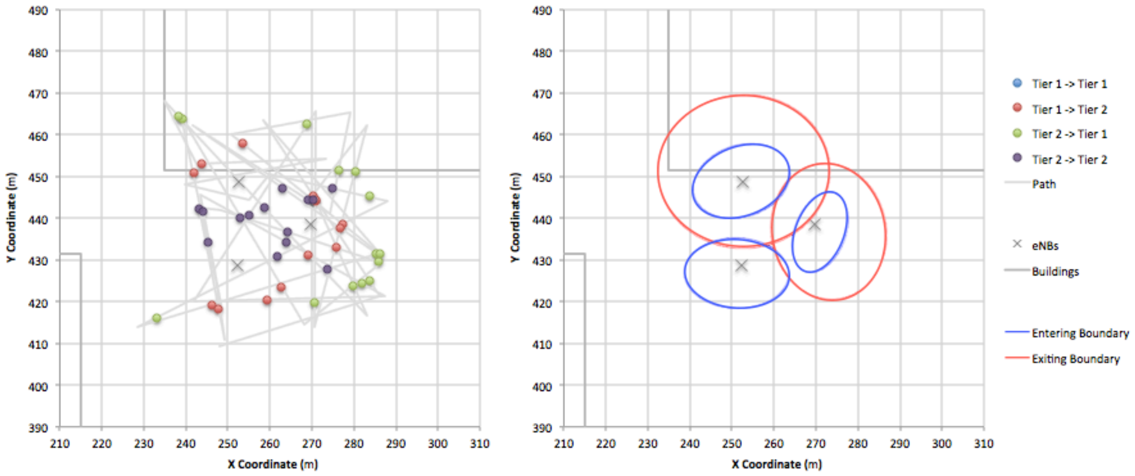


Figure 4: A3 event -based algorithm with low offset and short time-to-trigger



Note: The *exiting boundary* of the node at [252.3, 428.7] could not be determined due to a lack of associated data points surrounding the node.

Figure 5: A3 event -based algorithm with high offset and long time-to-trigger



Note: The *exiting boundary* of the node at [252.3, 428.7] could not be determined due to a lack of associated data points surrounding the node.

From the captured packet traces, average packet delay, average throughput, and total packet loss for each link and simulation can be determined. The total time that the UE was served by each network tier can also be calculated for each simulation by examining both the handover and packet traces. Additionally, by fitting an ellipse to all of the handovers that occur when the UE is either entering or exiting a given node (taking the average of the previously fitted ellipses), a rough approximation of the small-cell coverage area can be calculated by summing the area contained within the fitted ellipses.

Table 3 lists the simulation performance metrics outlined above. Note that '*Time as Serving Tier*' is defined as a percentage of the total simulation time (900 seconds), and '*Coverage Area*' is defined as a percentage of the area to which the randomized UE path was constrained (3600m^2).

Total simulation CPU run times are listed in Table 4. Each simulation required roughly 5-8 times the length of the simulation time to execute.

Table 3: Simulation Performance Metrics

	Network Tier	Link	Avg. Delay (ms)	Avg. Throughput (Mbps)	Packet Loss	Time as Serving Tier	Coverage Area
A2 / A4 High	Small-cell	UL	5.63	8.43	0.03%	62.02%	~ 47%
		DL	35.54	8.27	1.84%		
	Macro-cell	UL	5.66	8.42	0.09%	37.98%	
		DL	81.68	8.19	2.83%		
A2 / A4 Low	Small-cell	UL	5.67	8.43	0.03%	59.18%	~ 51%
		DL	42.49	8.18	3.01%		
	Macro-cell	UL	5.72	8.42	0.07%	40.82%	
		DL	95.43	8.02	4.85%		
A3 Low / Short	Small-cell	UL	5.66	8.43	0.03%	61.77%	~ 35%
		DL	50.21	7.99	2.67%		
	Macro-cell	UL	5.70	8.42	0.12%	38.23%	
		DL	92.38	8.04	3.66%		
A3 High / Long	Small-cell	UL	5.80	8.42	0.07%	62.52%	~ 55%
		DL	50.21	7.99	5.19%		
	Macro-cell	UL	5.73	8.42	0.08%	37.48%	
		DL	92.38	8.04	4.70%		

Note: *Time as Serving Tier* is defined as the cumulative time the UE was connected to the associated network tier, expressed as a percentage of the total simulation time. *Coverage Area* is defined as the sum over all small-cell nodes of the area bounded by an ellipse fit to all entering and exiting handovers for a given node as a percentage of the allowed range of UE mobility.

Table 4: Total Simulation CPU Run Times

Simulation	**Simulation Time**	**CPU Run Time**
A2 / A4 | High	900s (0h, 15m)	5218s (1h, 27m)
A2 / A4 | Low	900s (0h, 15m)	5536s (1h, 32m)
A3 | Low / Short	900s (0h, 15m)	6083s (1h, 41m)
A3 | High / Long	900s (0h, 15m)	7768s (2h, 9m)

DISCUSSION

The simulation that employed the A2 / A4 algorithm with a high threshold setting shows the best packet handling performance. It has the shortest uplink and downlink delays of both tiers, the highest throughput, and the least packet loss. It also proves to be effective at offloading the UE from the macro-cell tier, with the UE being served by the small-cell tier for approximately 62% of the simulation time. The simulation does, however, have the second lowest approximate coverage area. Qualitatively, it can be seen from Figure 2 that this configuration has the smallest handover region with both the entering and exiting handover boundaries being separated by meters only.

The simulation that employed the A3 algorithm with a high offset and long time-to-trigger shows arguably the worst packet handling performance. Despite this, the simulation has the highest approximate coverage area. It also proves the most successful at offloading the UE from the macro-cell tier, slightly edging out the previous simulation, with the UE being served by the small-cell tier for approximately 62.5% of the simulation time. Qualitatively, Figure 5 shows that this configuration has among the largest handover regions being on the order of 10 meters in depth.

The packet handling performance of the remaining A2 / A4 and A3 simulations is similar to that of the A3 algorithm with a high offset and long time-to-trigger. In terms of offloading the UE to the small-cell tier, both perform worse than the previous 2 simulations. Interestingly though, despite substantially less coverage area, the A3 algorithm with a low offset and short time-to-trigger was more successful at offloading the UE to the small-cell tier than the A2 / A4 algorithm with a low threshold setting.

It does appear that, overall, the A2 / A4 algorithm with a high threshold is the more efficient algorithm. Despite the second lowest coverage area, it proves to be the second most effective at offloading the UE from the macro-cell tier, while maintaining relatively high packet handling performance.

CONCLUSION

This project has successfully simulated 4 separate scenarios involving 2 basic handover algorithms in ns-3. The efficiency and effectiveness of each configuration was gauged both quantitatively and qualitatively. The results show that a well-tuned RSRQ measurement -based algorithm can be reasonably effective at offloading traffic from the macro-cell tier.

Future work could include increasing both the UE and small-cell densities to look for any impact on handover performance, or examining the effects of frequency reuse or similar methods to reduce inter-cell interference on handover in heterogeneous networks.

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