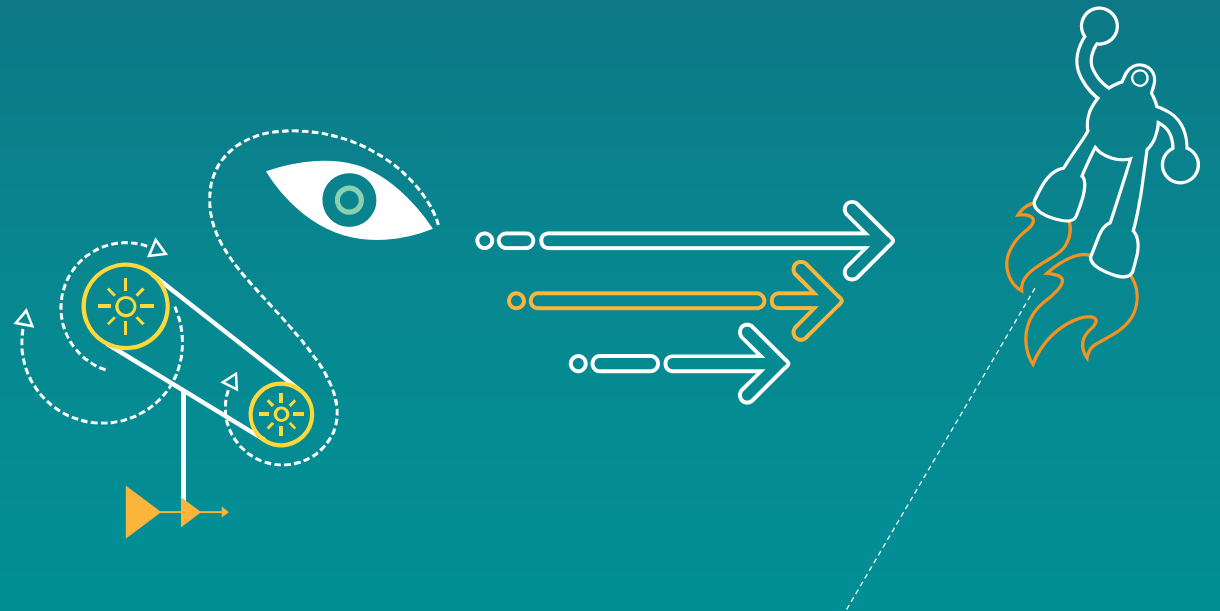


Qualcomm Technologies, Inc.

LTE-U Forum Technical Report Overview

May 28th, 2015



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Technical Report Overview

- Background of LTE-U operation
 - 5GHz band definition, channel numbers (EARFCN), LTE-U SDL CA band combinations
- LTE-U coexistence evaluation methodologies
 - Evaluation scenarios and performance metrics
- Evaluation results
 - Outdoor and indoor simulation results from multiple companies
- Recommendations for coexistence mechanisms (non-LBT waveform requirement regions)
 - Channel selection
 - Medium-sensing-based SCell duty cycle in unlicensed spectrum (e.g. CSAT) with max on-time limit
 - Opportunistic Secondary Cell OFF in unlicensed spectrum.
- Conclusions:
 - For a given operator, replacing LTE/Wi-Fi bearer selection by LTE + LTE-U carrier aggregation leads to substantial improvement in user experiences in terms of data throughput.
 - For a high density Wi-Fi deployment, if part of the nearby Wi-Fi nodes are replaced by LTE-U nodes, the remaining Wi-Fi nodes throughput is no worse than before, and, in many cases, improved.

List of LTE-U Evaluation Scenarios

Outdoor scenarios				
Scenarios	Deployments	Frequency Elements	#nodes/ Operator	Private Wi-Fi
SO1-4	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	10	8	N
SO5-8	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	10	4	N
SO9-12	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	4	8	N
SO13-14	3 operators: Wi-Fi/Wi-Fi/Wi-Fi => LTE-U/LTE-U/Wi-Fi	4	4	N

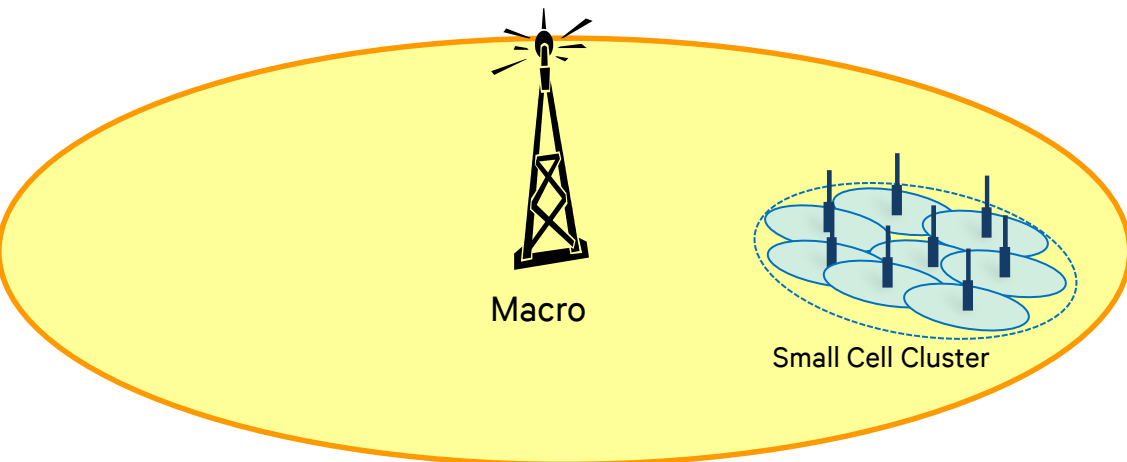
Indoor scenarios				
Scenarios	Deployments	Frequency Elements	#nodes/ Operator	Private Wi-Fi
SI1-4	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	10	4	Y
SI5-8	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	4	4	Y
SI9-12	2 operators: Wi-Fi/Wi-Fi => LTE-U/Wi-Fi => LTE-U/LTE-U	4	4	N

Summary of evaluation scenarios from LTE-U Forum Technical Report

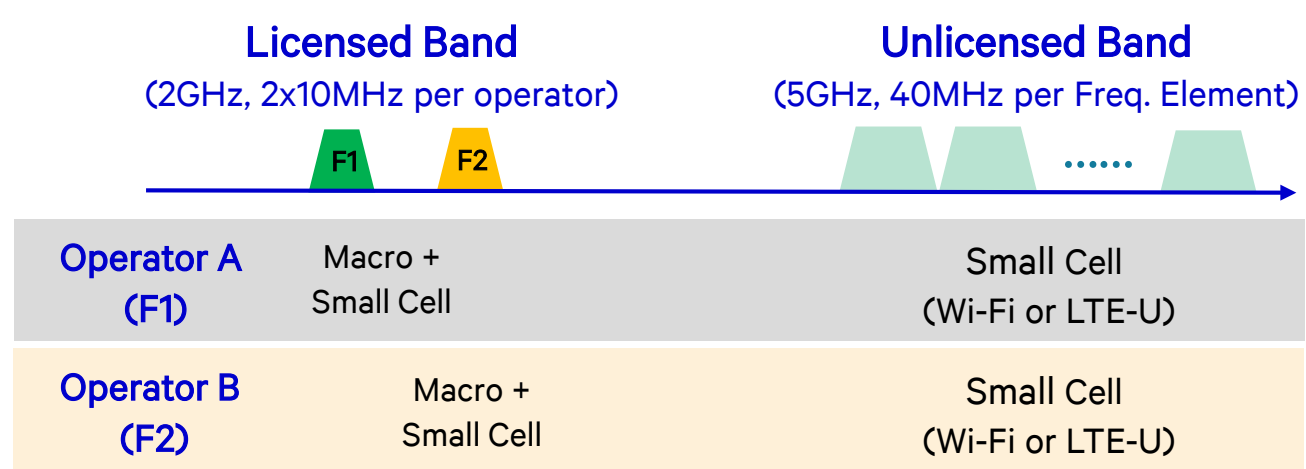
Notes: 1 Frequency Elements = 40 MHz. For 2 operators cases, each set defines 4 scenarios: Wi-Fi/Wi-Fi (baseline), LTE-CA (without coexistence) / Wi-Fi, LTE-U / Wi-Fi, LTE-U/LTE-U. Tx power on unlicensed for eNB and AP is 24 dBm except SO9-14 where 30 dBm is used.

LTE-U Outdoor Simulation Scenarios (SO1-12)

- Two operators (A/B) deployment
 - 2x10MHz HetNet in Licensed band
 - Wi-Fi or LTE-U SDL in Unlicensed band
 - Wi-Fi model applies to enterprise or operator deployment
 - 4 or 10 FE (Freq Element) total in each hotspot
- All Wi-Fi with LDPC & Channel Selection
 - Wi-Fi: 802.11ac
 - LTE & Wi-Fi: 2x2 MIMO with max rank 2 transmissions
- Bursty traffic model based on modified 3GPP model 2
 - Traffic load increased to load all the cells
- 3GPP model* with 500m macro ISD
- Clustered Pico model
 - One hotspot cluster per Macro cell
 - 50 meter radius
 - 8 or 4 Picos per operator in a cluster
 - 10m minimum distance between Picos from different operators
- User distribution
 - 60 UEs per Macro cell per operator
 - 2/3 UEs are in 70m radius of cluster center



Clustered Pico Scenario



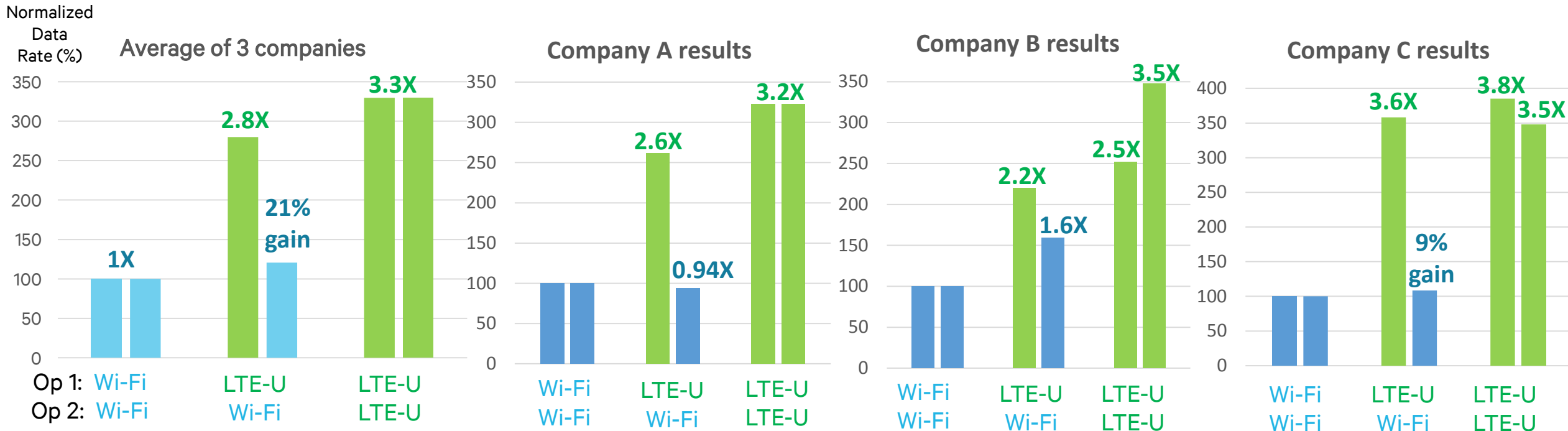
* 3GPP TR 36.872, LTE pico transmit power: 30dBm+5dBi antenna gain. LTE-U Pico//WiFi AP Tx power (outdoor SC): 24dBm+5dBi antenna gain. UE Tx power in licensed band is 23dBm while Wi-Fi STA Tx power is 18dBm.

Simulated LTE-U and Wi-Fi Outdoor Performance

Very High Density Scenario (SO9-12) from Technical Report

Median DL User Throughput

(2 deployments x 8 outdoor Picos / cluster, 4x40MHz unlicensed spectrum)



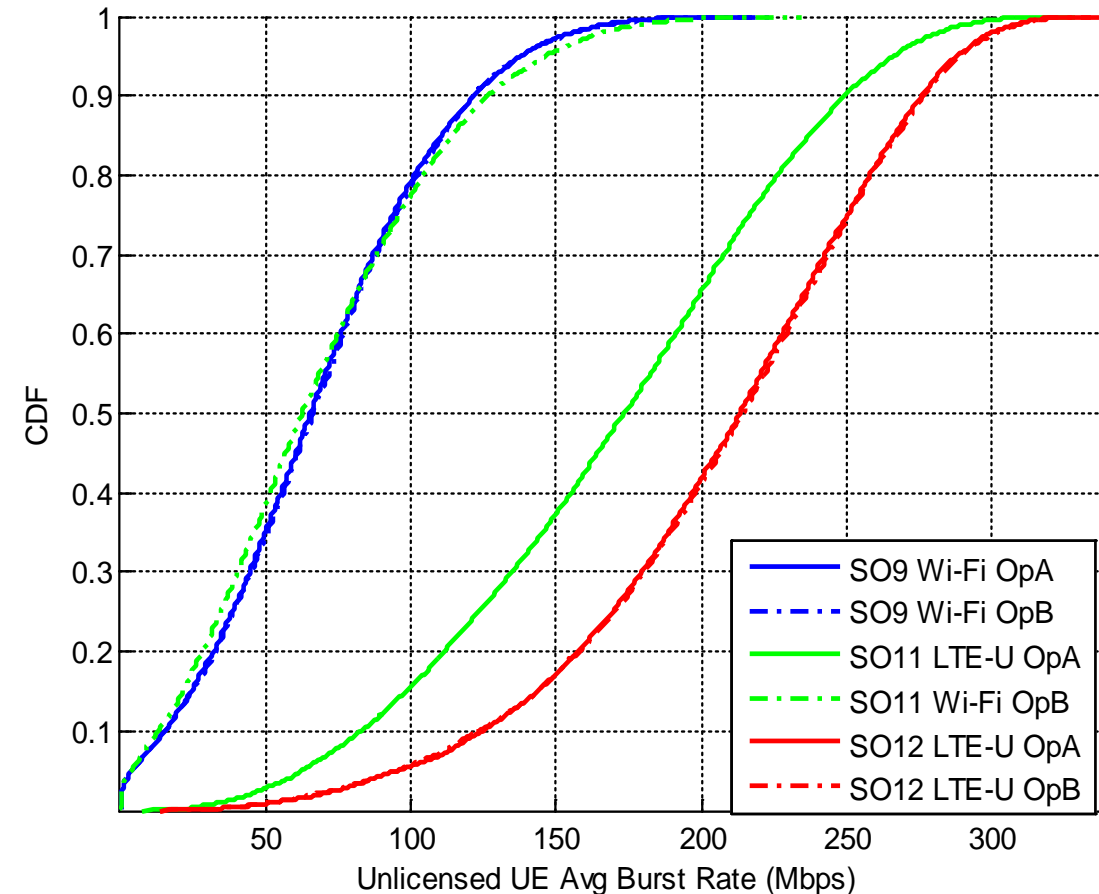
In the LTE-U/Wi-Fi coex case, Wi-Fi performance is maintained/improved, while LTE-U's average gain is 180%

Outdoor results from test cases SO9-12: 2 operators with 8 nodes per operator in one cluster, 4 channels of 40MHz. LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

SO9 (W+W), SO11(W+L), SO12 (L+L) - 4x40MHz, 8 nodes/op/cell

Additional Statistics from Qualcomm Simulation: User throughput

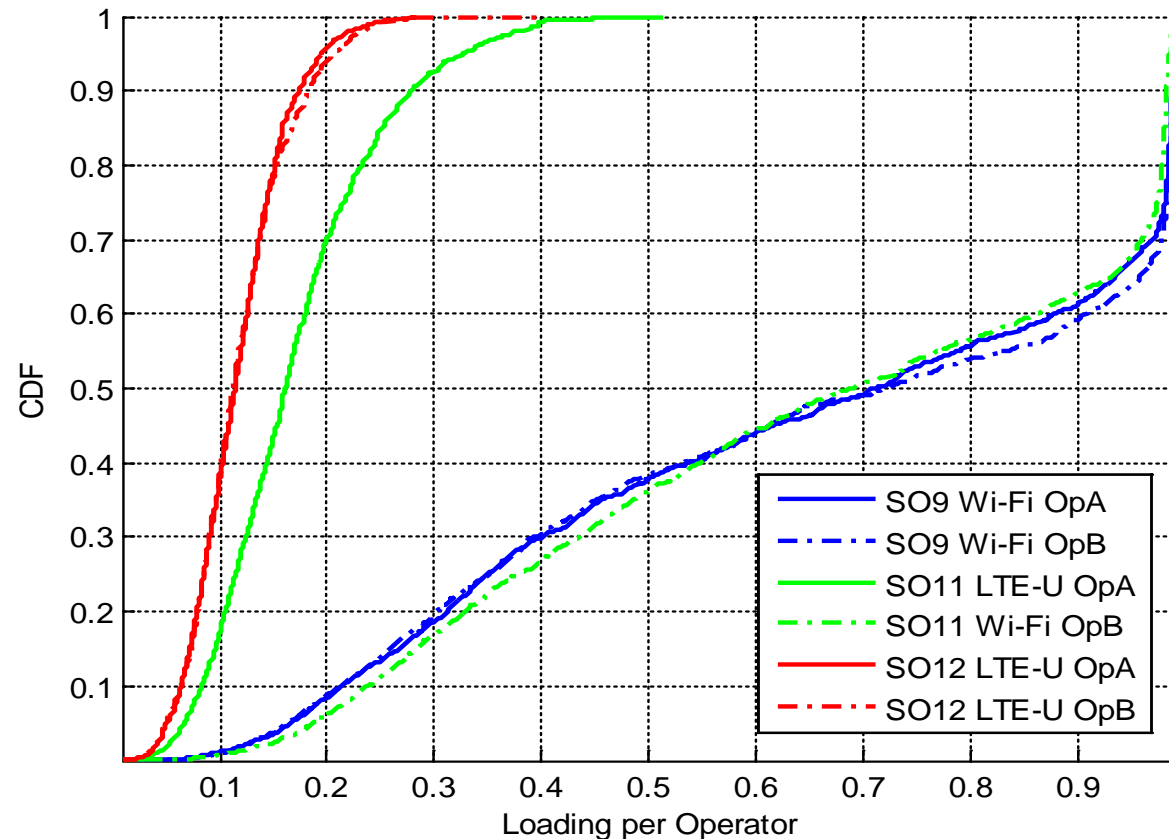
- Arrival rate per user: 0.5MB burst every 1.5s (3GPP TM2) resulting in 70% WiFi network loading
- On average 6-7users per AP (87% off-load WiFi, 89% off-load LTEu)
- Compared with Wi-Fi + Wi-Fi baseline, the Wi-Fi throughput is almost unchanged when the other operator is LTE-U.
- Compared to Wi-Fi (in Wi-Fi + Wi-Fi), LTE-U has roughly 3X gains in terms of median burst rate
 - This is due to the fact that with more density (number of nodes per channel), Wi-Fi performance is very poor (in Wi-Fi + Wi-Fi) due to inefficient MAC and preamble detection failure that can results in collisions and increase in retransmissions



SO9 (W+W), SO11(W+L), SO12 (L+L) - 4x40MHz, 8 nodes/op/cell

Additional Statistics from Qualcomm Simulation: Network Loading

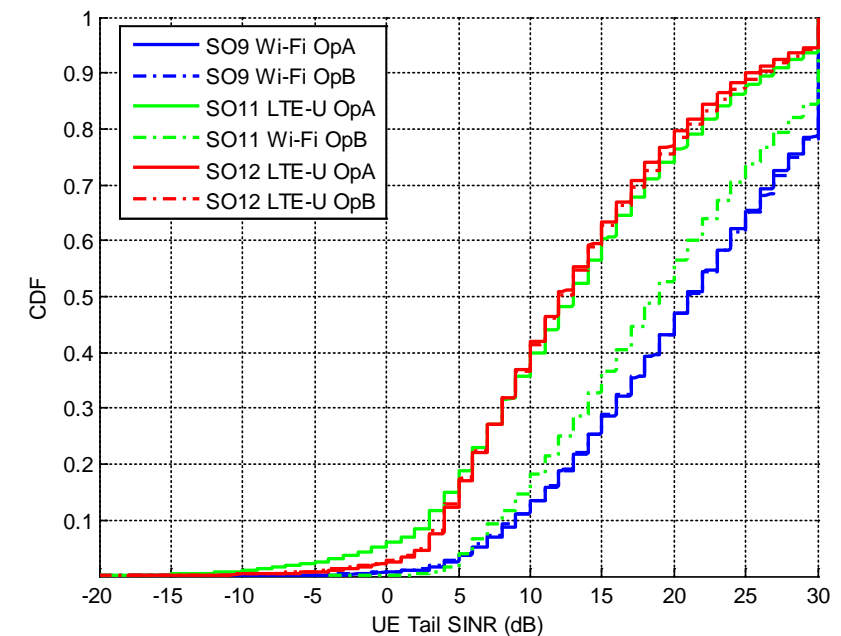
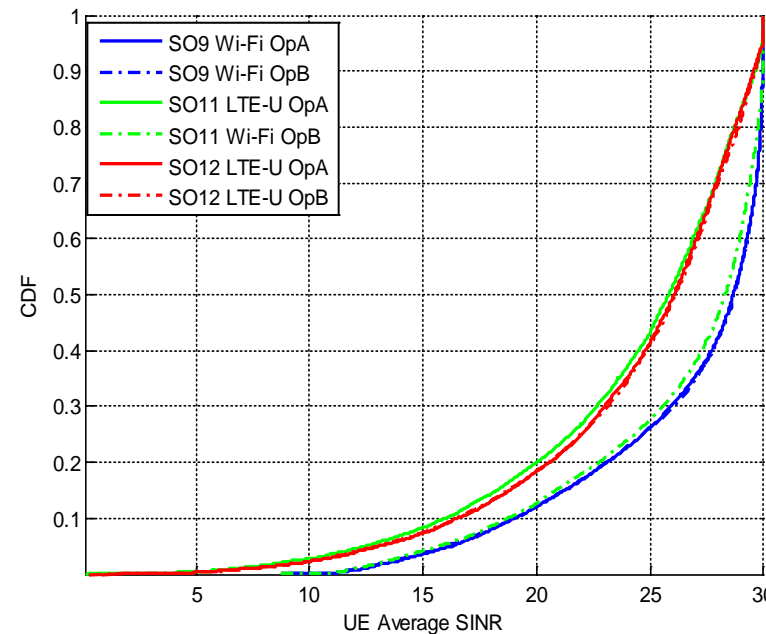
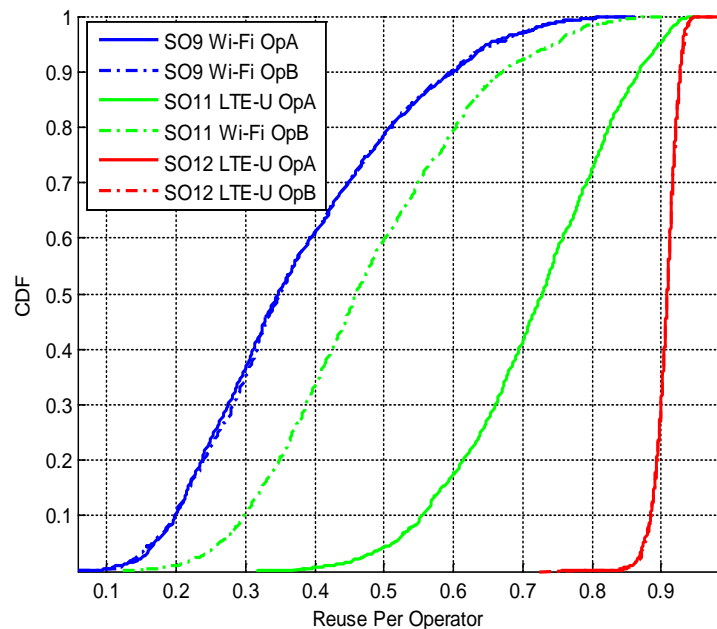
- **Loading:** The percentage of time a SC has non-empty buffer to the total time
- Compared with Wi-Fi + Wi-Fi baseline, the Wi-Fi loading is increased when the other operator is LTE-U



SO9 (W+W), SO11(W+L), SO12 (L+L) - 4x40MHz, 8 nodes/op/cell

Additional Statistics from Qualcomm Simulation: Reuse & SINR

- **Reuse:** Time of data in buffer to time of medium access
- There is small degradation in average (and more in tail) user SINR distribution for Wi-Fi with LTE-U neighbors compared to Wi-Fi neighbors. This can be understood as Wi-Fi does not back off to LTE-U below -62dBm
- The loss in user tail SINR dominates WiFi rate control decreasing MCS. On the other side reuse of WiFi gets better and total impact on throughput is almost a wash

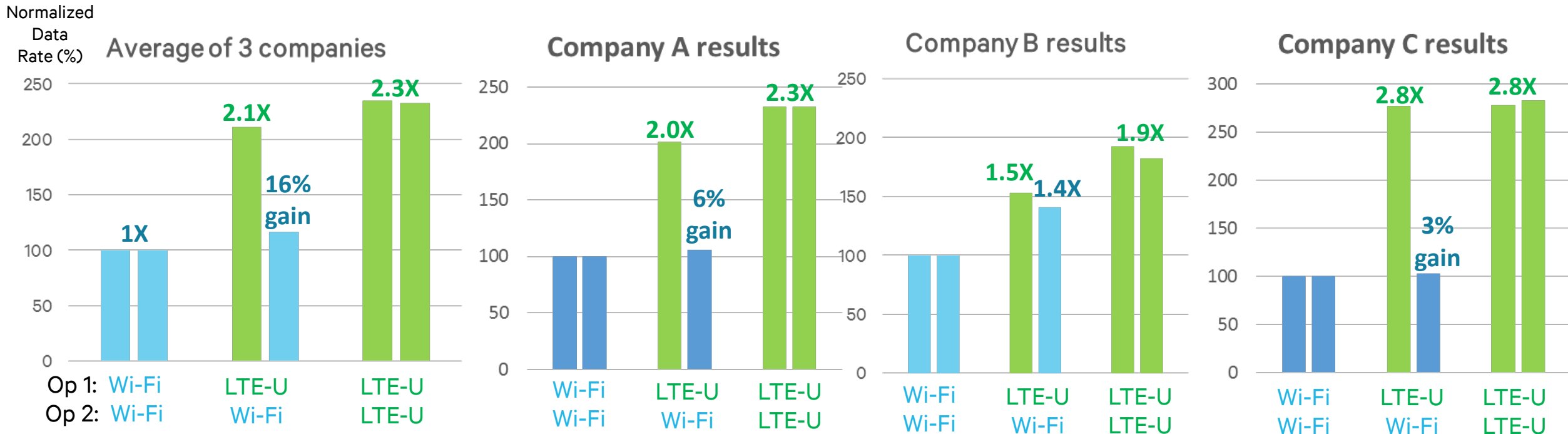


Simulated LTE-U and Wi-Fi Outdoor Performance

High Density Scenario (SO1-4) from Technical Report

Median DL User Throughput

(2 deployments x 8 outdoor Picos / cluster, 10x40MHz unlicensed spectrum)



In the LTE-U/Wi-Fi coex case, Wi-Fi performance is maintained/improved, while LTE-U's average gain is 110%

Outdoor results from test cases SO1-4: 2 operators with 8 nodes per operator in one cluster, 10 channels of 40MHz.
LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

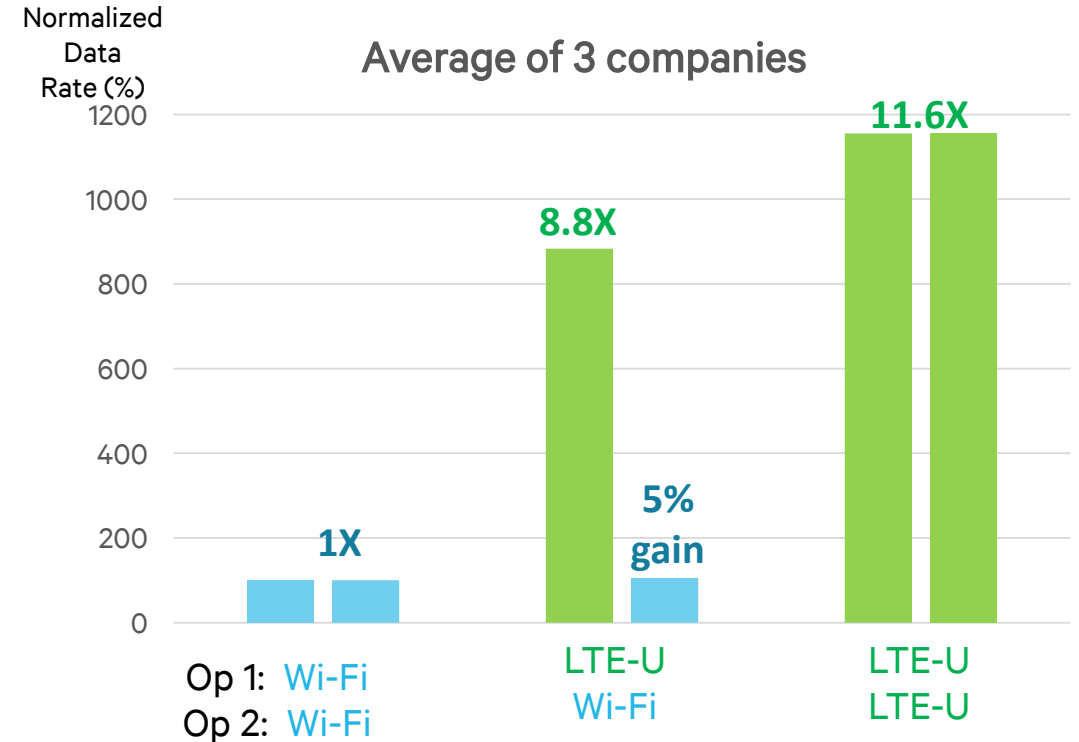
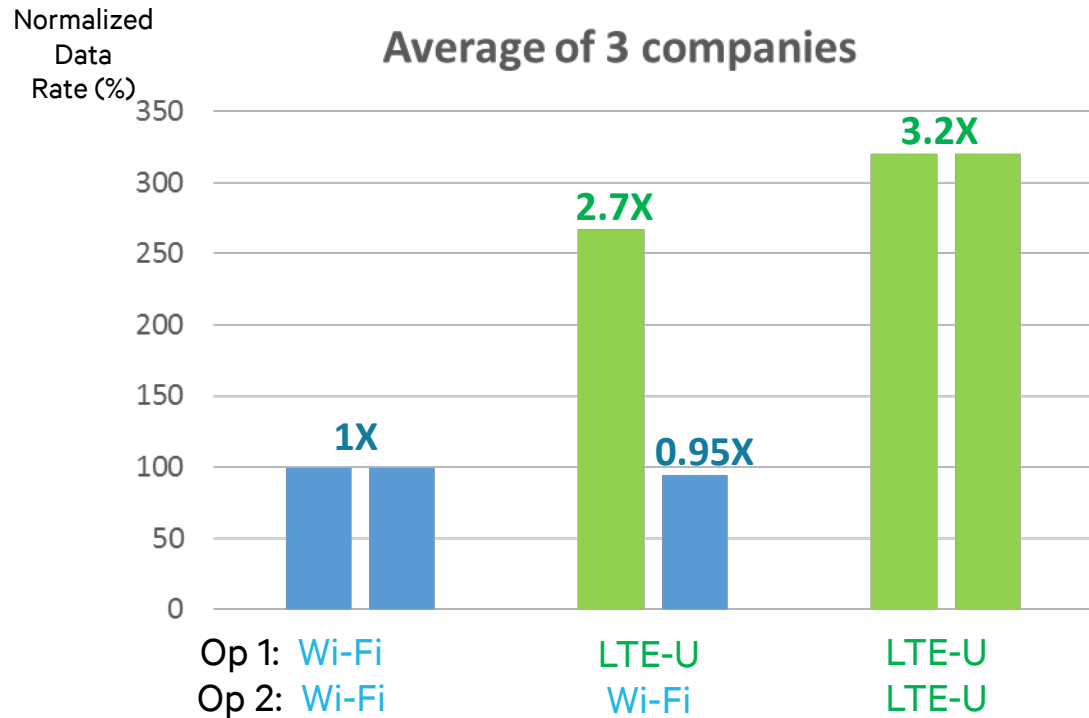
Simulated LTE-U and Wi-Fi Outdoor Performance (Tail Users)

Highlights of the Technical Report

5-percentile Tail DL User Throughput (2 deployments x 8 outdoor Picos / cluster)

High Density (SO 1-4, 10x40MHz unlicensed spectrum)

Very High Density (SO 9-12, 4x40MHz unlicensed spectrum)



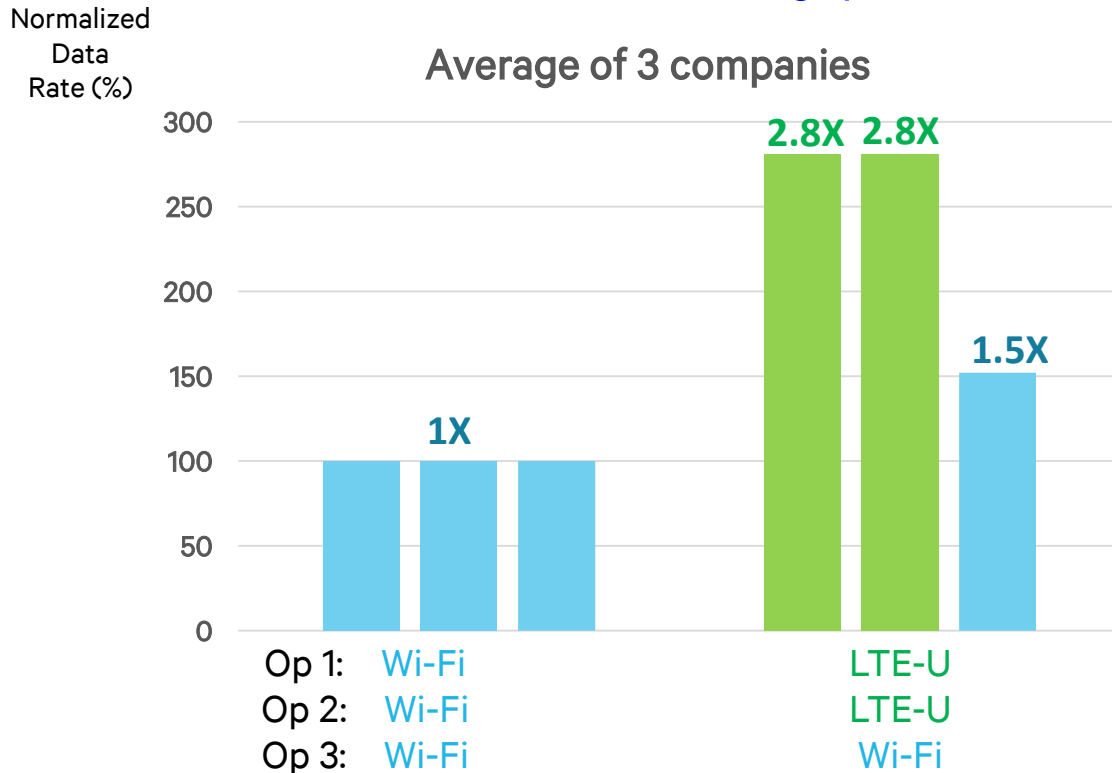
LTE-U delivers more gains to tail users while maintaining or improving Wi-Fi performance

Simulated LTE-U and Wi-Fi Outdoor Performance

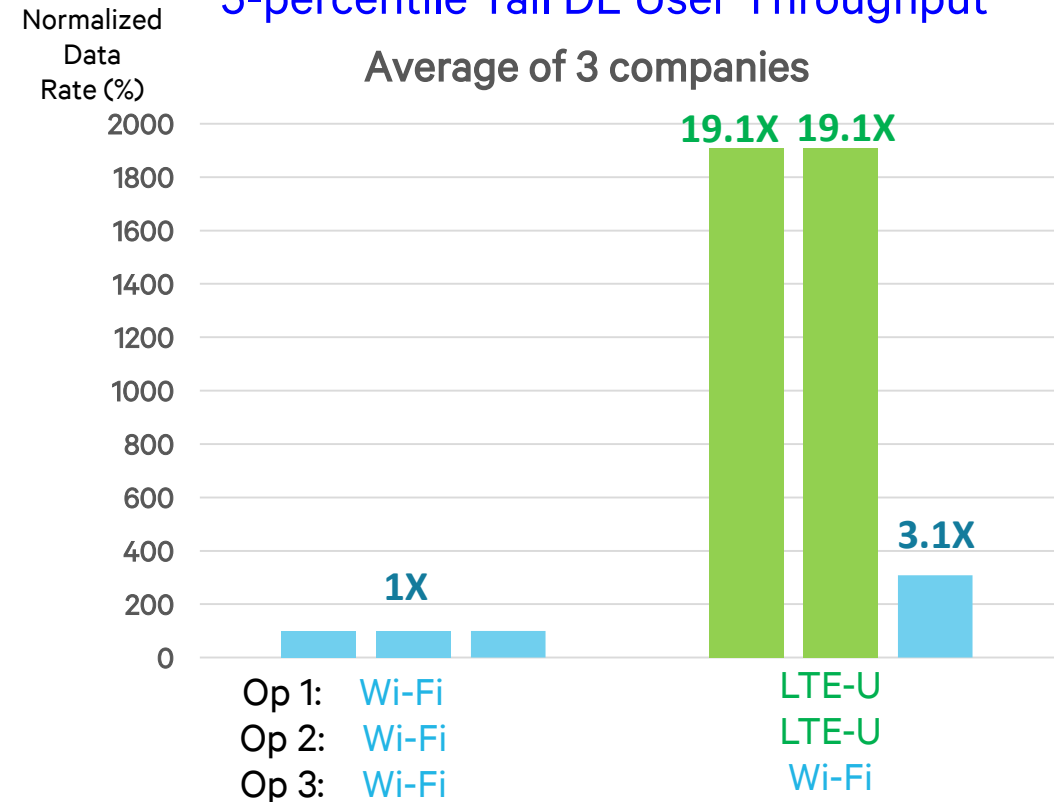
3 Deployments Scenarios (SO13-14) from Technical Report

Very High Density (3 deployments x 4 outdoor Picos / cluster, 4x40MHz unlicensed spectrum)

Medium DL User Throughput



5-percentile Tail DL User Throughput

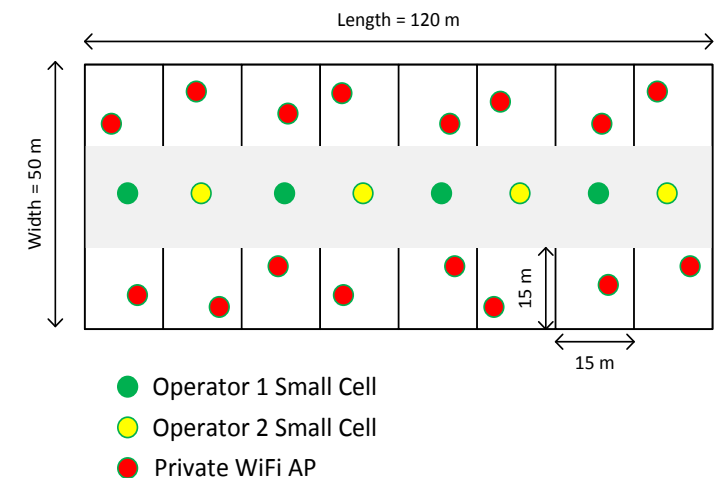


LTE-U delivers 3X gains to medium user rate while improving Wi-Fi performance

Outdoor results from test cases SO13-14: 3 operators with 4 nodes per operator in one cluster, 4 channels of 40MHz. LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

LTE-U Indoor Simulation Scenarios (SI1-8)

- Indoor hotspot scenario based on InH model from 3GPP 36.872
 - Single floor building with building plan close to shopping malls, enterprise or airport
 - 4 FE (SI5-8) or 10 FE (SI1-4) total shared by 2 operators in these scenarios
 - Serving node dropping: 4 access points or small cells per operator (denoted as operator 1 and 2)
 - Operator 1: regularly dropped in the middle of the hall
 - Operator 2: randomly dropped in the middle of the hall
 - Min. separation distance 3m between Op1 and Op2 small cells and Min separation distance 3m between Op2 small cells
 - Additional 16 private Wi-Fi APs: one per shop/office with random dropping
 - One Wi-Fi STA for each Wi-Fi AP in the same shop
- ITU propagation model: 3GPP 36.872 and 36.814
- LTE primary carrier will be co-channel with Macro (2GHz)
 - 21 cell Macro layout
 - Randomly drop 1 building per Macro
 - 60 UEs per macro cell per operator
 - 2/3 UEs are uniformly dropped inside the building
 - 1/3 UEs are dropped uniformly in the cell

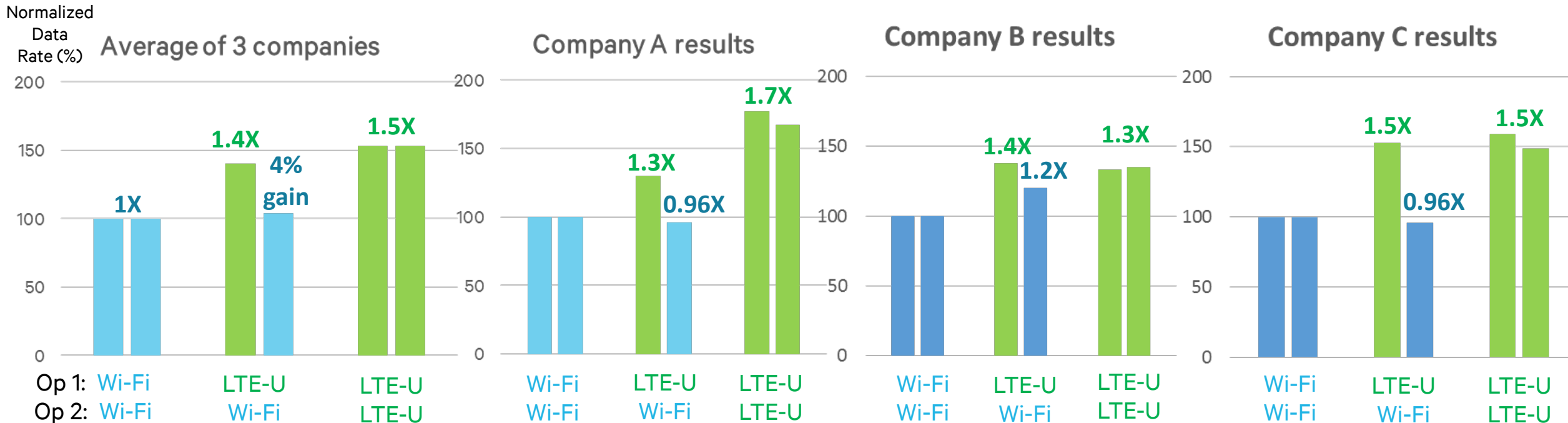


Simulated LTE-U and Wi-Fi Indoor Performance

High Density Scenario (SI5-8) from Technical Report

Median DL User Throughput

(2 deployments x 4 indoor small cells + 16 private Wi-Fi APs per building, 4x40MHz unlicensed spectrum)



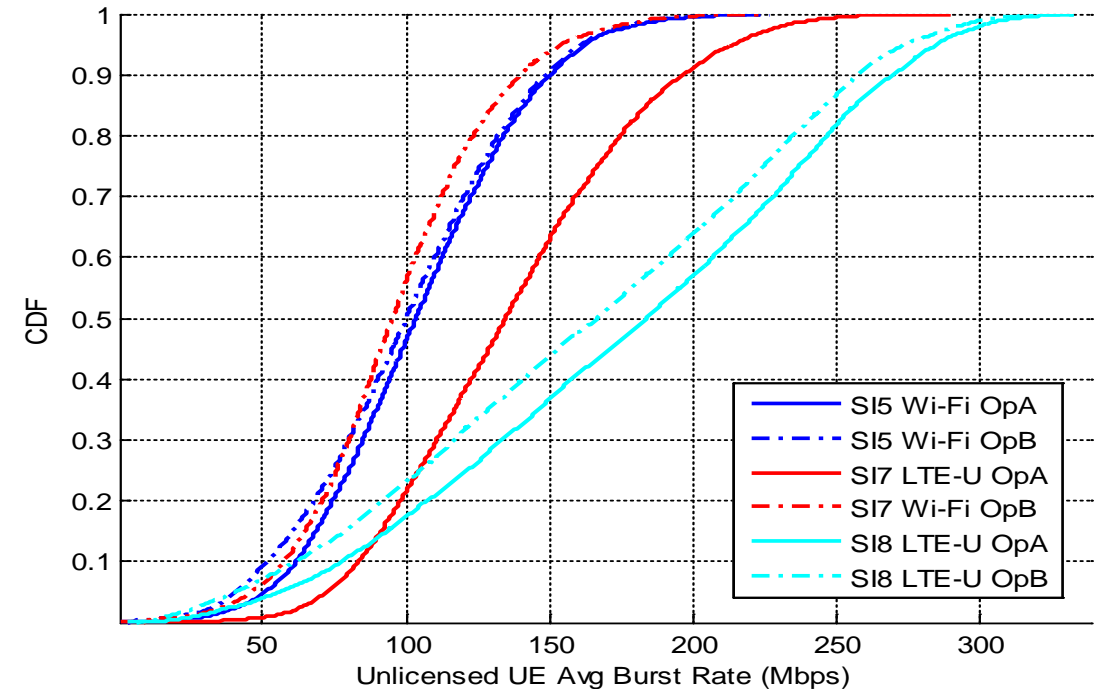
In this indoor LTE-U/Wi-Fi coex case, Wi-Fi performance is maintained, while LTE-U's average gain is 40%

Indoor results from test cases SI5-8: 2 operators with 4 nodes per operator in one building, and 16 private WiFi APs, 4 channels of 40MHz. LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

SI5 (W+W), SI7(W+L), SI8 (L+L) - 4x40MHz, 4 nodes/op/cell+16private WiFi APs

Additional Statistics from Qualcomm Simulation: User throughput

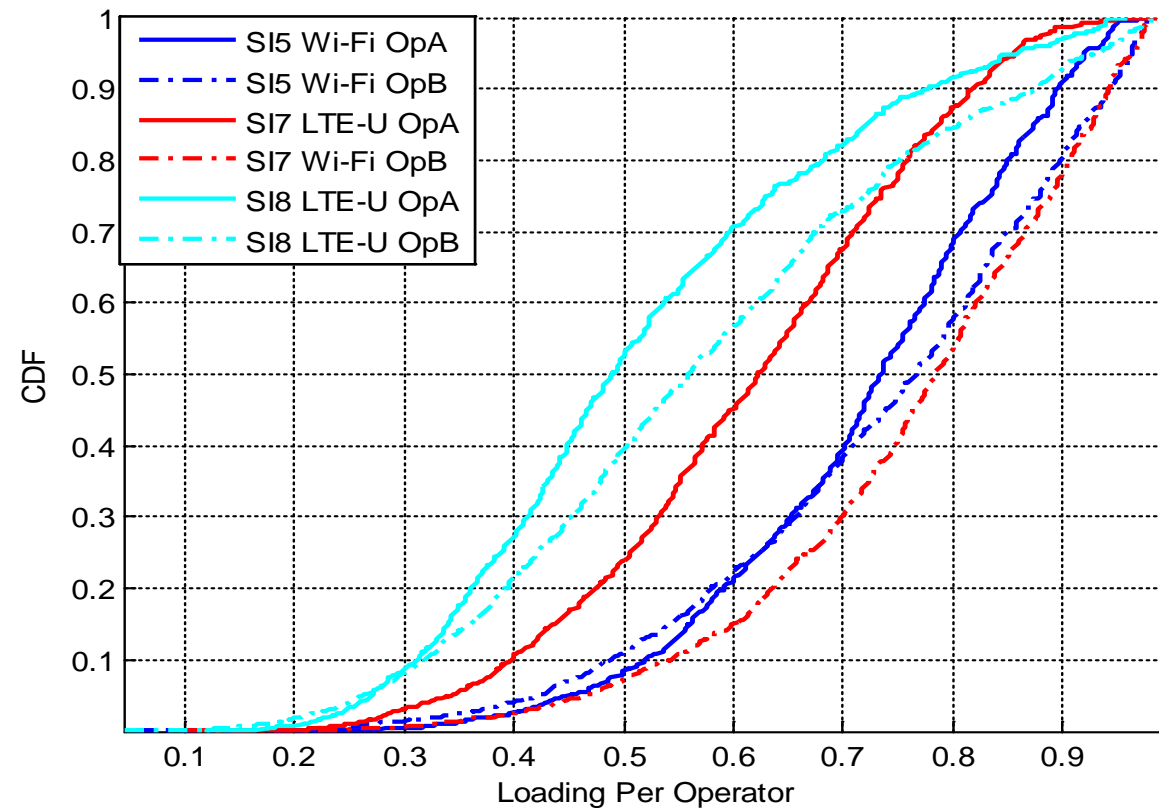
- Arrival rate per user: 0.5MB burst every 0.45s (3GPP TM2) resulting in 70% WiFi network loading
- Almost 10users per AP (almost 68% off-load on both)
- The performance of Wi-Fi in SI7 is same as Wi-Fi in SI5 and the performance of LTE-U in SI7 is 30% better than Wi-Fi in SI5 scenario
- Impact on the Operator Wi-Fi is marginal at the median however LTE-U improves the tail performance of Operator Wi-Fi (compared to Wi-Fi in SI5)



SI5 (W+W), SI7(W+L), SI8 (L+L) - 4x40MHz, 4 nodes/op/cell+16private WiFi APs

Additional Statistics from Qualcomm Simulation: Loading

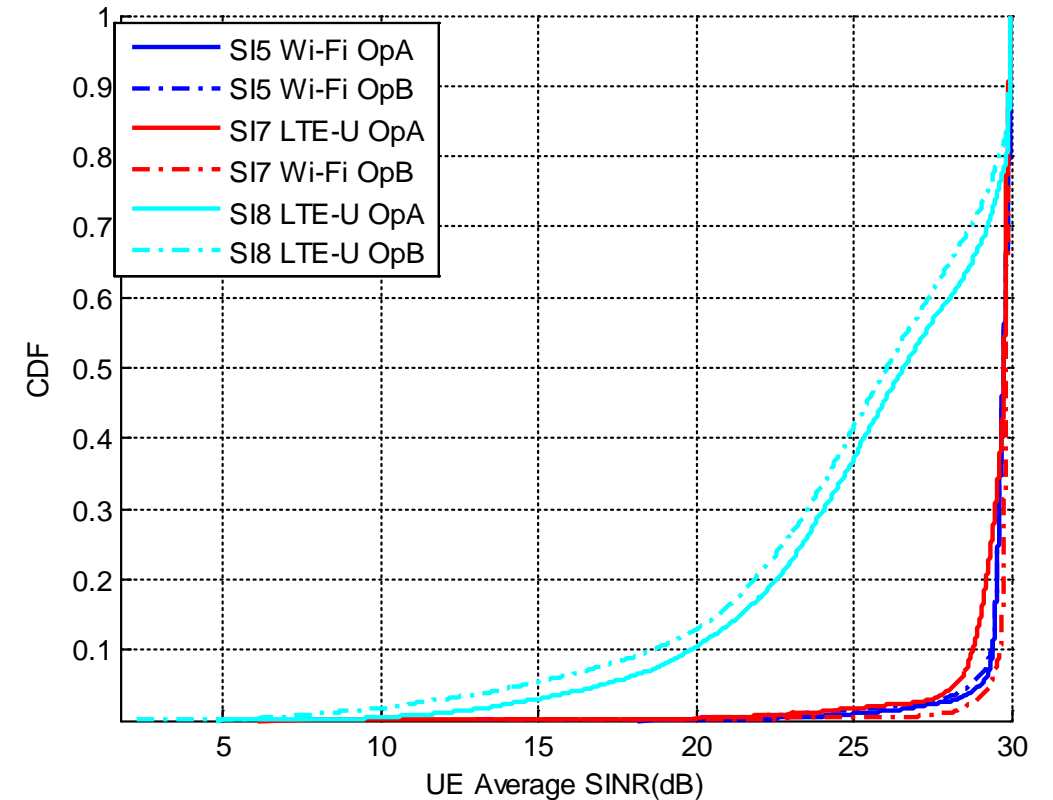
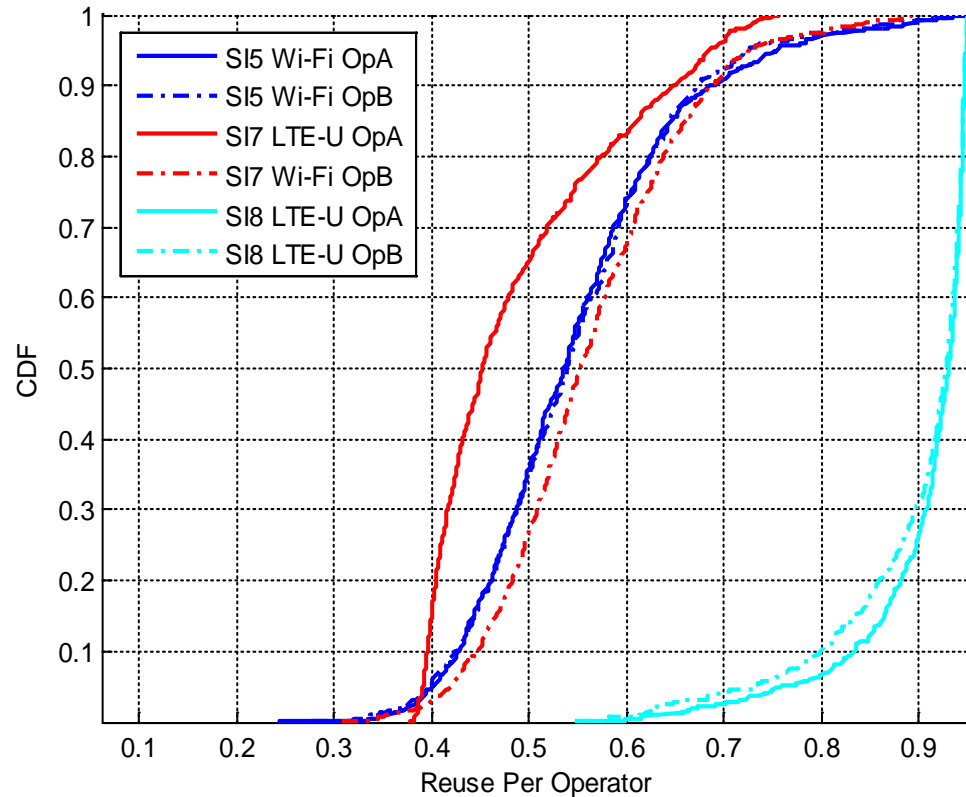
- Loading of WiFi is ~ 75%



SI5 (W+W), SI7(W+L), SI8 (L+L) - 4x40MHz, 4 nodes/op/cell+16private WiFi APs

Additional Statistics from Qualcomm Simulation: Reuse & SINR

- Observe that the reuse Metric of Operator Wi-Fi is improved with LTE-U as neighbor
- No Impact on the Wi-Fi SINR as Wi-Fi backs off to LTE-U as LTE-U nodes happens to be within -62dBm

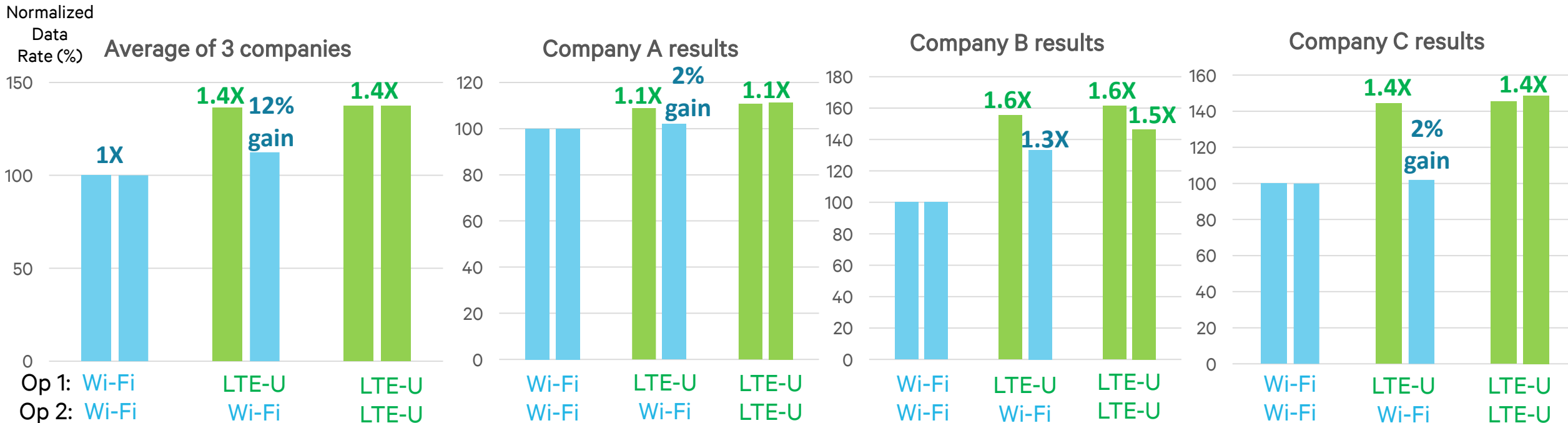


Simulated LTE-U and Wi-Fi Indoor Performance

Medium Density Scenario (SI1-4) from Technical Report

Median DL User Throughput

(2 deployments x 4 indoor small cells + 16 private Wi-Fi APs per building, 10x40MHz unlicensed spectrum)



In this indoor LTE-U/Wi-Fi coex case, Wi-Fi performance is maintained, while LTE-U's average gain is 40%

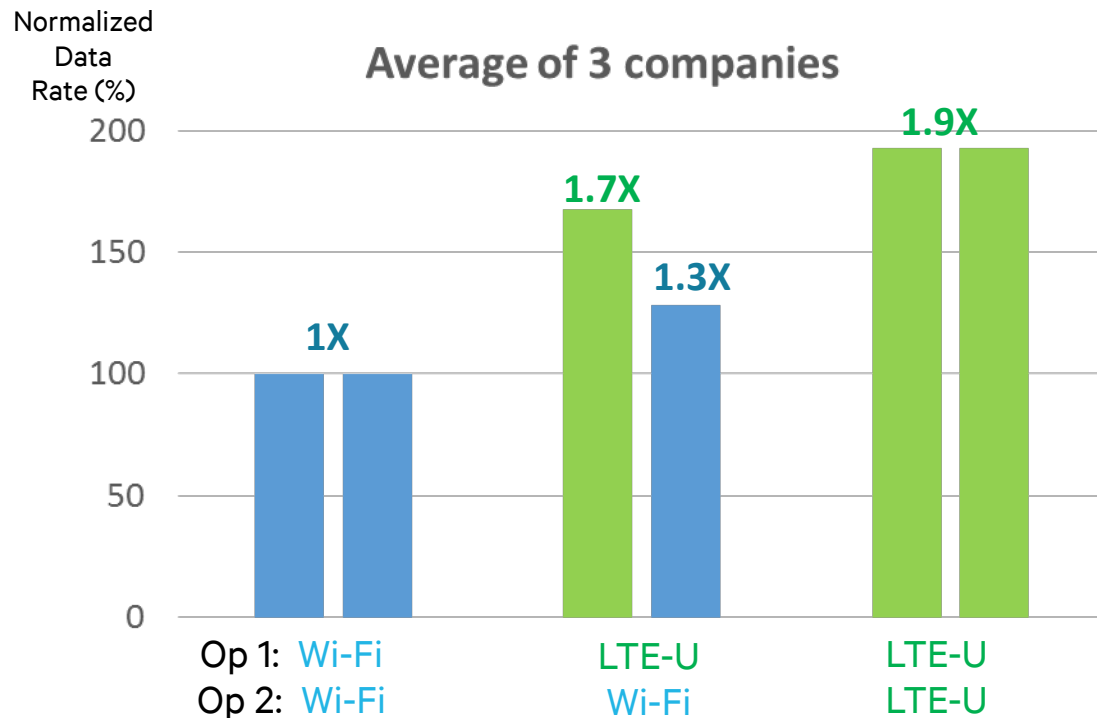
Indoor results from test cases SI1-4: 2 operators with 4 nodes per operator in one building, and 16 private WiFi APs, 10 channels of 40MHz. LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

Simulated LTE-U and Wi-Fi Indoor Performance (Tail Users)

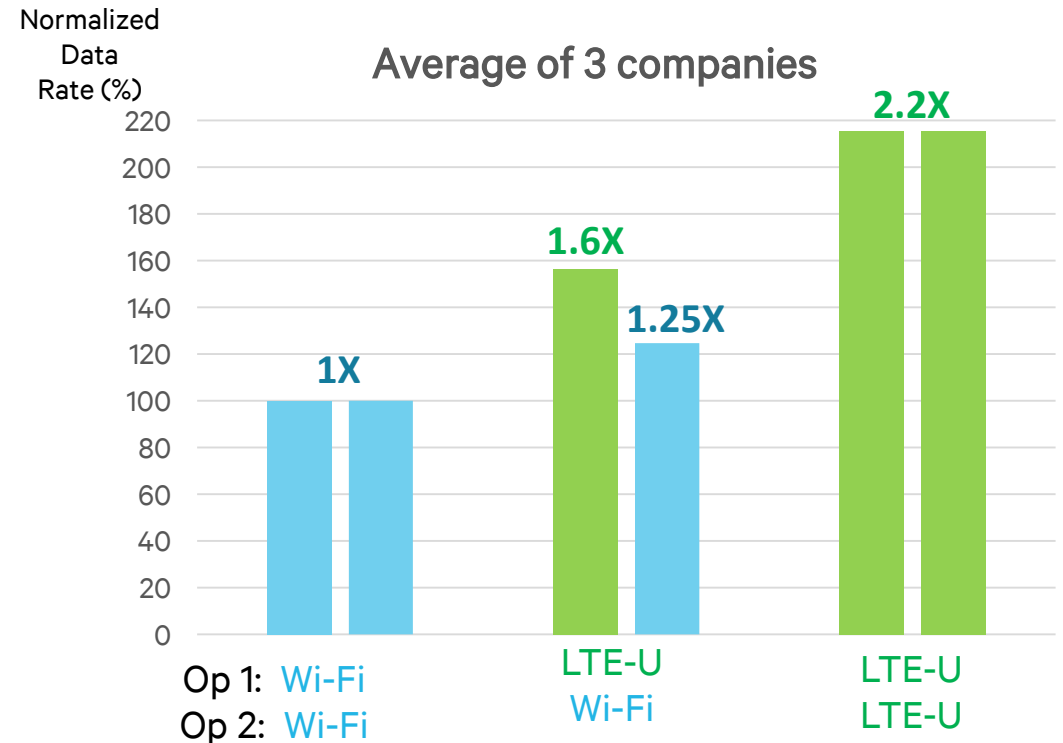
Highlights of the Technical Report

5-percentile Tail DL User Throughput (2 deployments x 4 indoor small cells + 16 private Wi-Fi APs per building)

High Density (SI 5-8, 4x40MHz unlicensed spectrum)



Medium Density (SO 1-4, 10x40MHz unlicensed spectrum)



LTE-U delivers more gains to tail users while maintaining or improving Wi-Fi performance

Indoor results from test cases SI5-8 and SI1-4: 2 operators with 4 nodes per operator in one building, and 16 private WiFi APs, 4(SI5-8) or 10 (SI1-4) channels of 40MHz. LTE-U uses R-10/11 with coexistence techniques. See the Technical Report for more details.

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