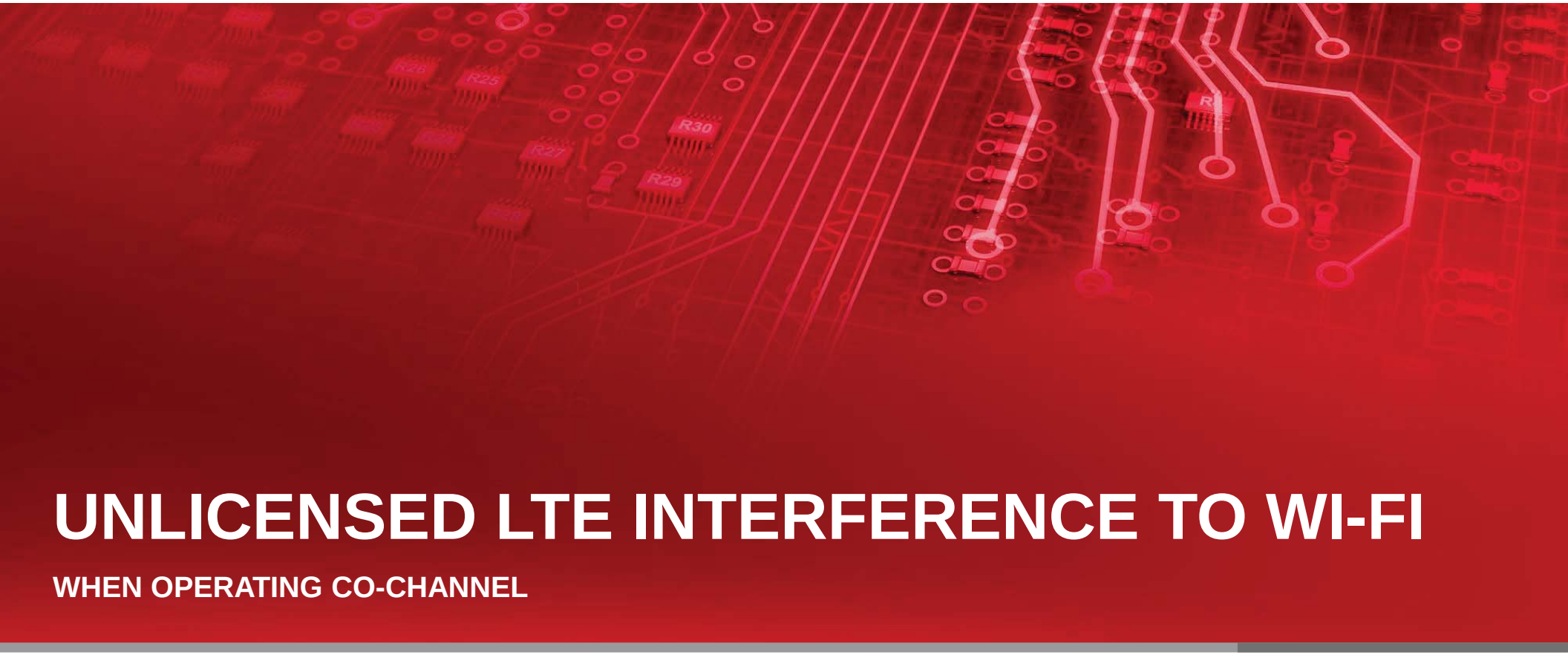

UNLICENSED LTE INTERFERENCE TO WI-FI

WHEN OPERATING CO-CHANNEL

Christopher Szymanski

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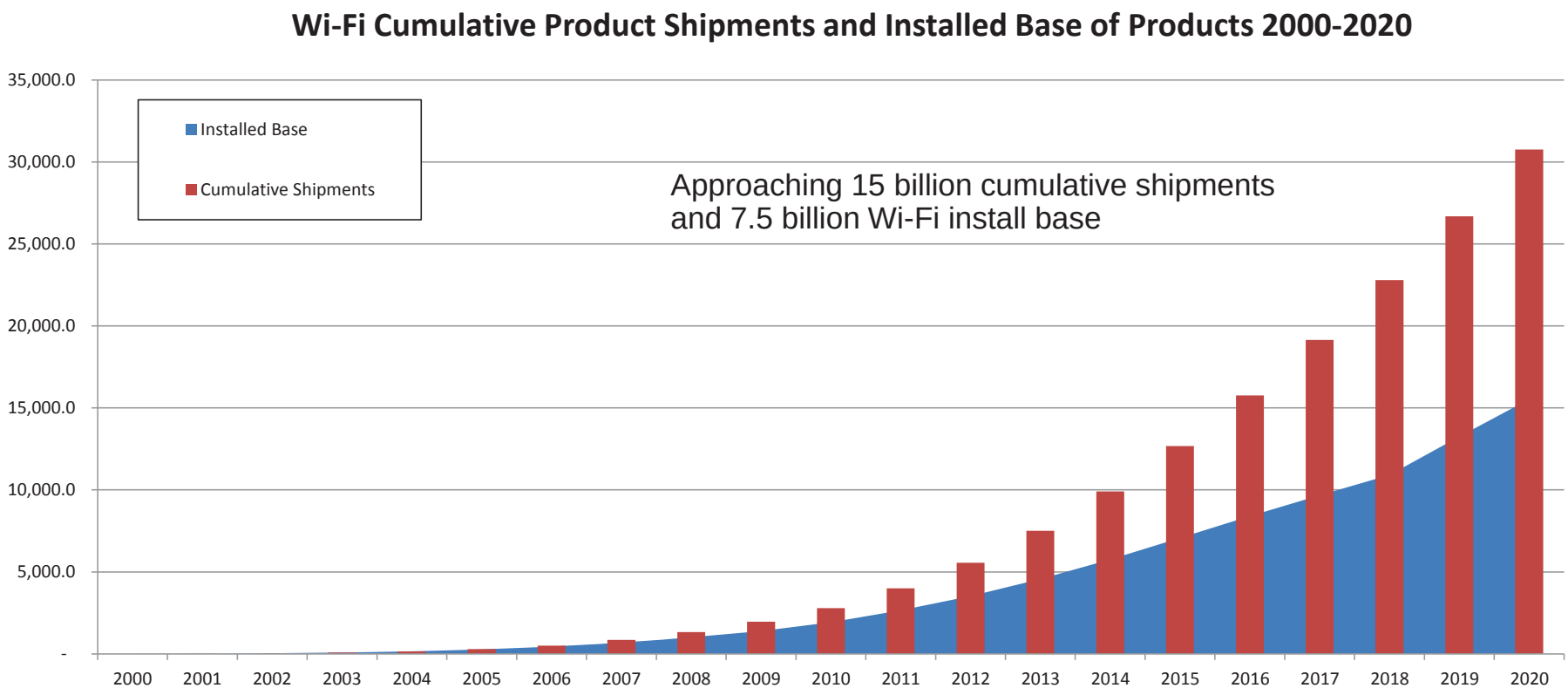
WI-FI DEMAND EVER-INCREASING



Source: ABI Research: Cumulative Wi-Fi-enabled Product Shipments and Installed Base of Wi-Fi-enabled Products World Market, Forecast: 2000 to 2020.

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WI-FI IS PREDOMINATE WAY FOR PEOPLE TO ACCESS INTERNET; IN SOME INSTANCES THE ONLY WAY

- **Cisco:** Mobile data traffic increased 74% in 2015, reaching 3.7 exabytes per month [1]
- **Over 80% of mobile data traffic goes over Wi-Fi**
  - **Strategy Analytics' Telemetry Intelligence Platform**: From 2H13 to 1H15 Wi-Fi traffic grew at over 2X the rate of cellular traffic, accounting for ~83% of wireless traffic [2]
  - **Analysys Mason**: 81% of smart phone traffic is carried over Wi-Fi [3]
  - **Mobidia**: "Wi-Fi dominating monthly data usage" [4]
    - iOS users consume 82% of wireless data over Wi-Fi
    - Android users consume 78% of wireless data over Wi-Fi
- **Pew Internet Research**: In-home Broadband access decreasing, increasing number of "smartphone-only" adults (13% of Americans are smartphone-only, and shift most pronounced among lower income households) [5]
- **Public Libraries and the Internet**: 90.5% of public libraries offer Wi-Fi Internet access, and bandwidth capacity of libraries becomes an increasingly significant issue [6]

[1] http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/mobile-white-paper-c11-520862.pdf; [2] http://www.wirelessweek.com/news/2015/08/study-cellular-wi-fi-data-usage-among-smartphone-users-tripled-under-two-years; [3] Research Report: Consumer smartphone usage 2014: mobile data usage *April 2015*; [4] http://www.mobidia.com/insights/topic/whitepapers; [5] http://www.pewinternet.org/2015/12/21/home-broadband-2015/; [6] http://www.plinternetsurvey.org/analysis/public-libraries-and-broadband

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LTE-U/LAA MUST BE FAIR TO TYPICAL WI-FI DEPLOYMENTS

“Fair coexistence between LTE and other technologies such as Wi-Fi as well as between LTE operators is seen necessary.”

”However, it is not enough to minimize interference simply for regulatory aspects. It is also essential to insure that a deployed system will operate as a ‘good neighbor’, and not significantly impact legacy systems.”

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CO-CHANNEL LTE INTERFERES WITH WI-FI

- Based on a variety of tests & simulations, Broadcom and many other industry leaders believe that Wi-Fi links will be severely degraded by interference from neighboring co-channel LTE-U based networks
- The most harmful impact to the user experience will be on Wi-Fi signal strengths below -62 dBm (802.11 “below ED”)
  - In-the-field measurements for enterprise and outdoor deployments have demonstrated that:
    - ~90% of Wi-Fi links are below -62 dBm
    - ~50% of Wi-Fi links are below -80 dBm
- Effects on user experience
  - Greatly reduced Wi-Fi AP coverage areas
  - Poor performance because of reduced throughput and increased latency
- LTE-U impact to lower level Wi-Fi links is likely to apply to any co-channel LTE, unless politeness mechanisms are specifically designed to protect low level signals
  - LAA incorporates various technologies to improve coexistence fairness/politeness with WiFi, but if LAA is unable to detect Wi-Fi traffic, then LAA’s protection mechanisms are irrelevant

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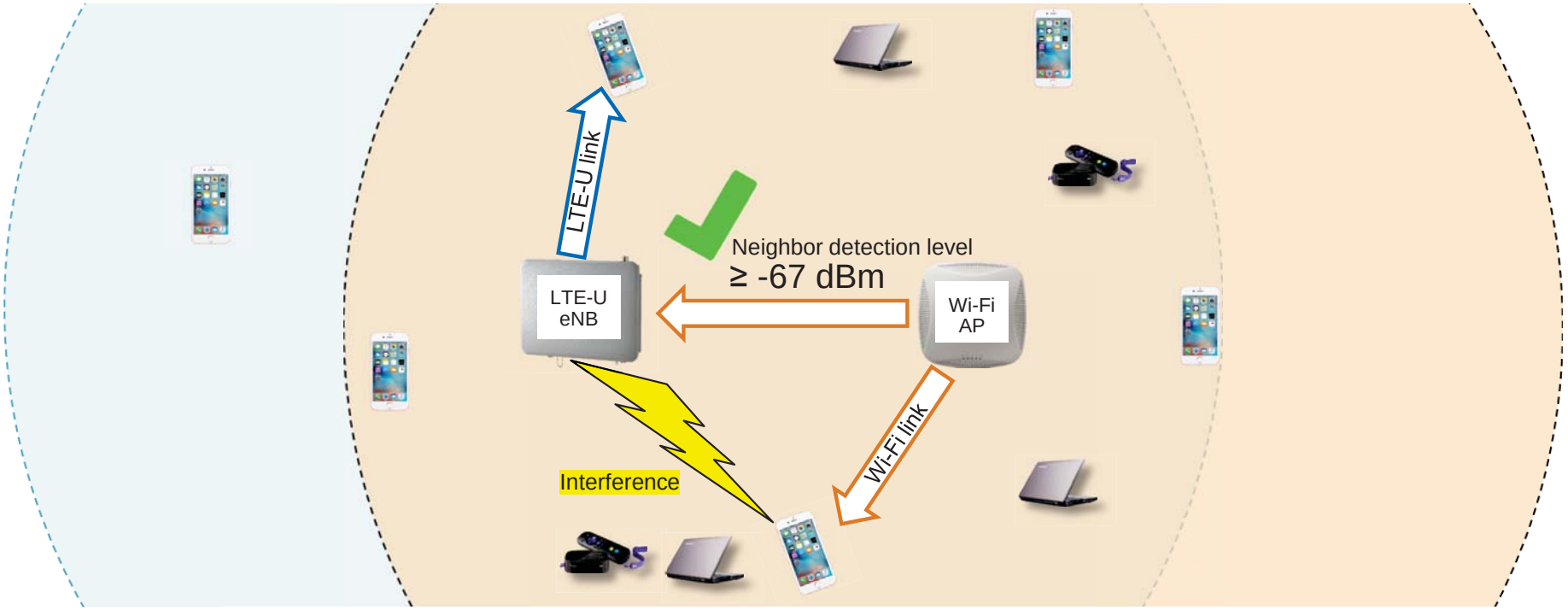
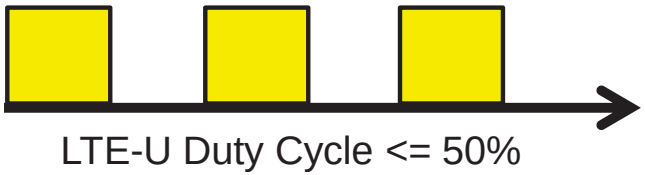
LTE-U CHANNEL SHARING: NEIGHBOR DETECTION





- LTE-U eNB must be able to detect the Wi-Fi signal in order to adapt its duty cycle or make a clear channel assessment

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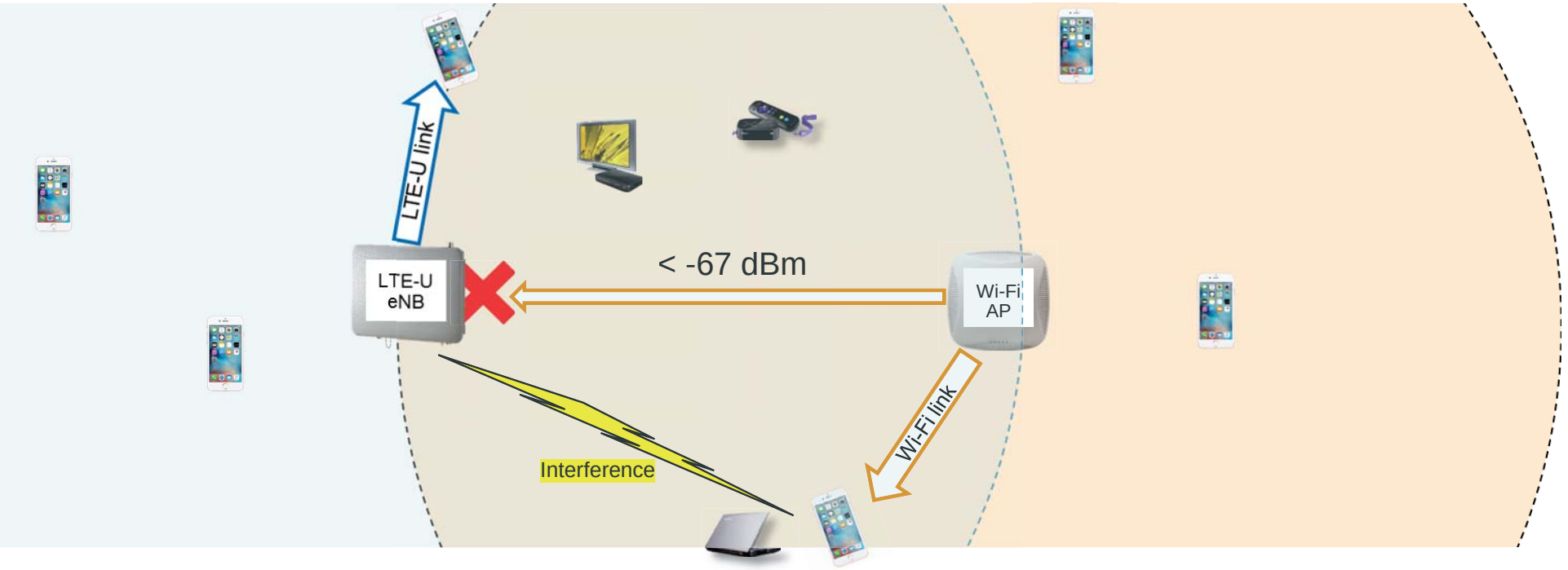
LTE-U CHANNEL SHARING: NEIGHBOR DETECTION FAILURE



LTE-U Duty Cycle = 90% +

- eNBs will likely be unable to hear neighboring median strength Wi-Fi signals
- eNB interferes with Wi-Fi nearly all the time

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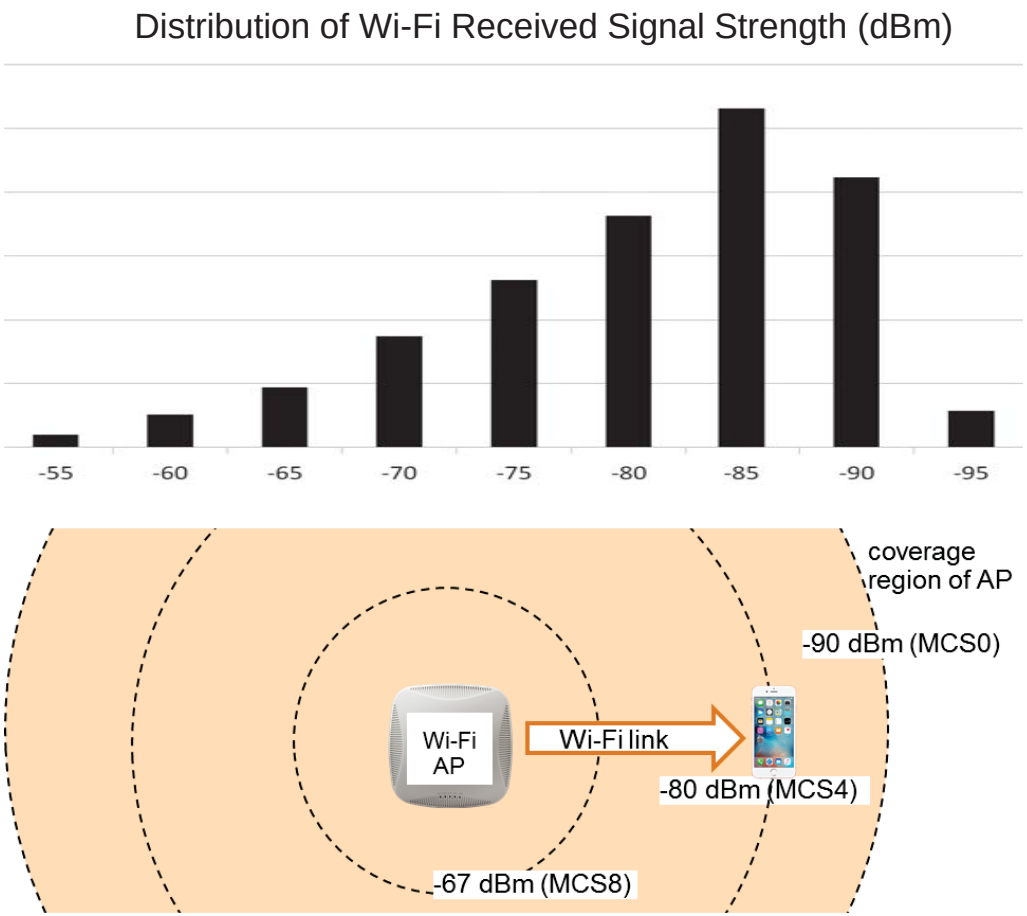
INTERFERENCE IMPACT ON TYPICAL WI-FI LINK SIGNAL STRENGTHS



- For average Wi-Fi link signal strengths, even low levels of interference from neighboring networks can massively degrade link quality
- In-field measurements show that Wi-Fi link signal strengths in the range -80 to -85 dBm are typical
  - Sufficient throughput for good user experience (e.g., HD video)
- To ensure fairness to deployed Wi-Fi, we recommend mandatory neighbor detection at level of at least -82 dBm
  - Consistent with Wi-Fi preamble detect levels

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LTE-U AND WI-FI COEXISTENCE TEST CONFIGURATION

- Broadcom conducted laboratory tests based on the **draft** WFA Test Plan v0.8[3]
  - Test Case 4.10 “LTE-U Node Impact on Wi-Fi Throughput Performance Test”
- Scenario
  - 2 networks, downlink full buffer UDP, coexisting on same 20 MHz channel, quasi Line-of-Sight
  - Interference levels: [a] -60 dBm [b] -65 dBm (~”WFA Test Level 2”) [c] -75 dBm (~”Optional WFA Test Level 3”) [d] -90 dBm
- Wi-Fi network setup:
  - 1 AP + 1 STA (both BCM4366 4x4 chipset, 11ac LDPC)
  - Wi-Fi link signal strength (AP heard by STA): -80 dBm (per **draft** WFA Test Plan)
- LTE-U network setup:
  - 1 eNB based on Broadcom LTE Small-Cell platform
    - Varying LTE-U duty cycles (ON period of 20 ms, compliant with LTE-U Forum spec[4])
    - “Phase 1” (eNB full buffer load)

[3] “Coexistence Test Plan, DRAFT v0.8”, Wi-Fi Alliance
[4] “LTE-U SDL CSAT Procedure Technical Specification v1.0, LTE-U Forum

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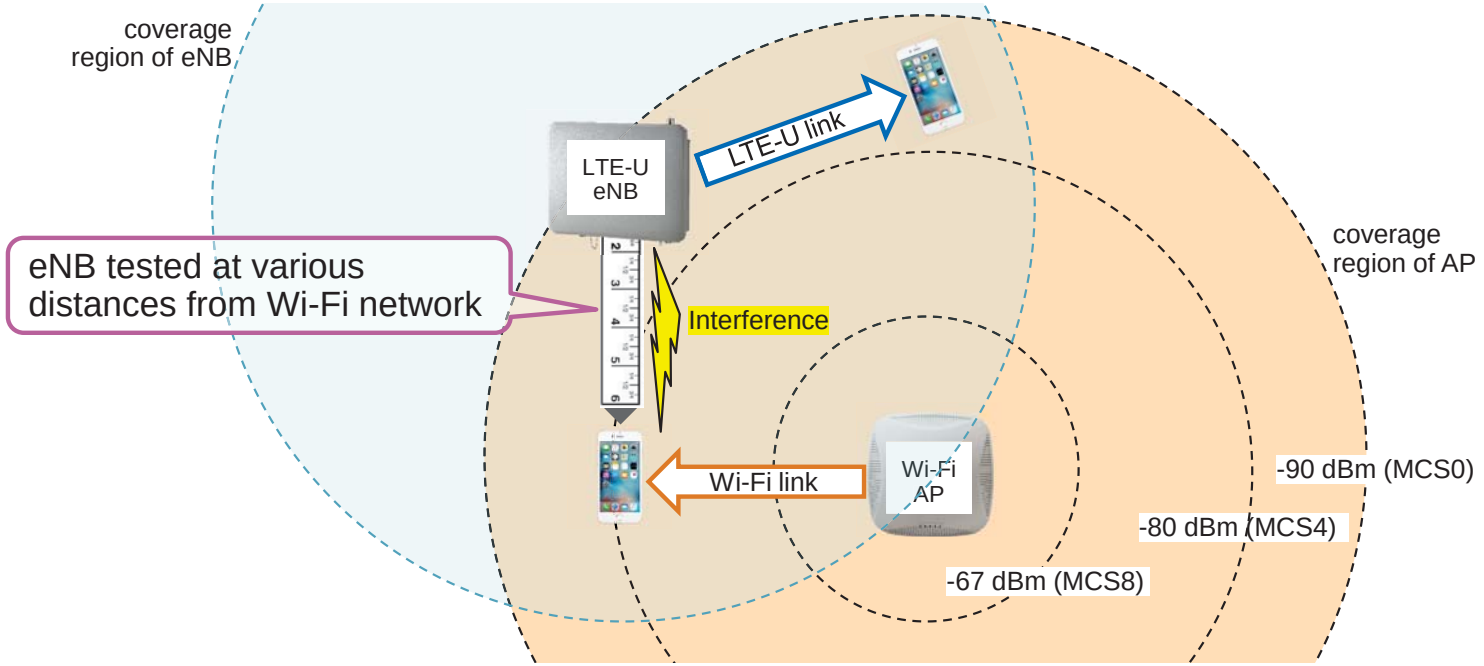
LTE-U AND WI-FI COEXISTENCE TEST SCENARIO



- Demonstrate impact of LTE-U interference on Wi-Fi throughput
  - When eNB is at various distances from the Wi-Fi network

MCS indications are guidelines based on 20 MHz, LDPC, Nss=4, AWGN

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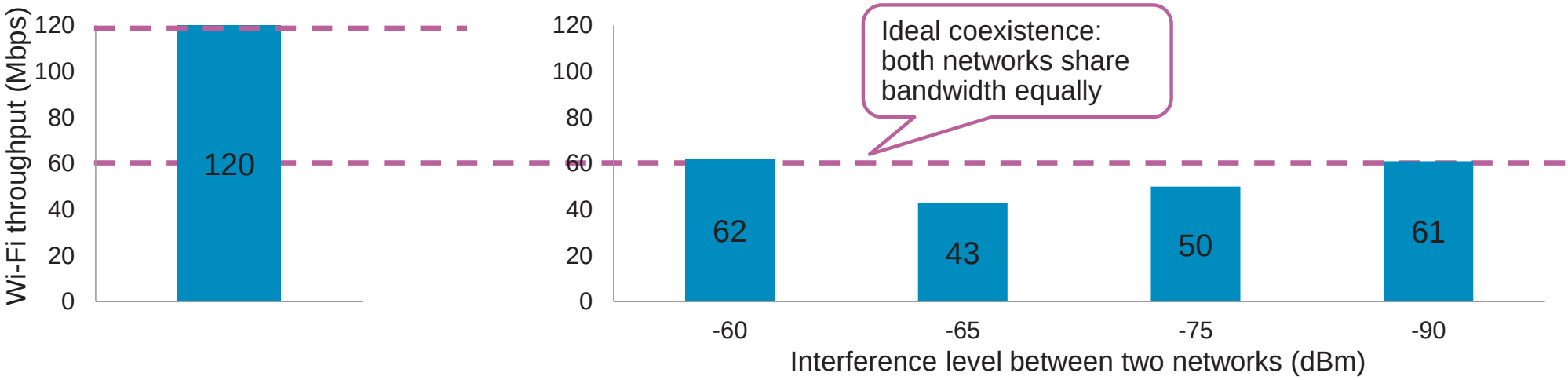
BASELINE: WI-FI + WI-FI



1 Wi-Fi network

2 Wi-Fi networks coexisting

- Wi-Fi + Wi-Fi coexistence is basically robust over a wide range of interference levels
- The two networks defer to each other and share the available airtime and bandwidth
  - At -60 dBm interference, OBSS frame detection is accurate and collisions are very rare
  - At -65 and -75 dBm interference, occasional OBSS frame misdetection causes collisions that modestly reduce throughput
  - At -90 dBm interference, some OBSS misdetections occur but lower interference means some collisions can still be decoded

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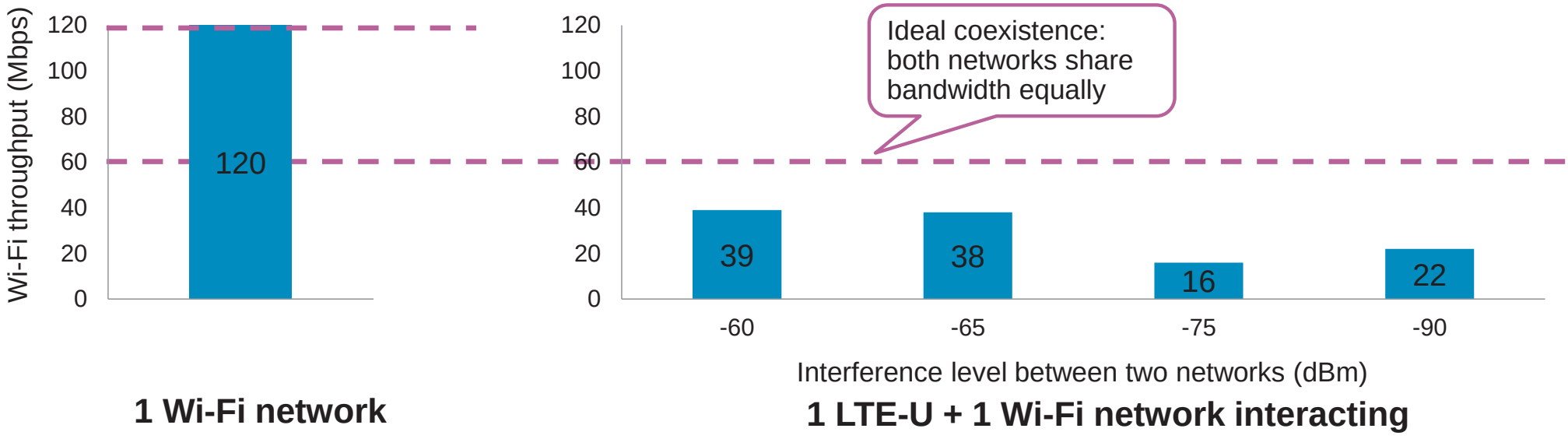
WI-FI + LTE-U 50% DUTY CYCLE (NEIGHBOR DETECTION)



1 Wi-Fi network

1 LTE-U + 1 Wi-Fi network interacting

- Even when LTE-U detects Wi-Fi neighbor and limits its duty cycle to 50%, throughput of the Wi-Fi network is substantially degraded compared to Wi-Fi + Wi-Fi case
  - At all interference levels, LTE-U ON cycles interrupt Wi-Fi transmissions and cause retransmits, with a knock-on effect on Wi-Fi rate adaptation implementations in response to unexpected interference
  - At -75 dBm interference, degradation is worst since LTE-U interference is low enough that Wi-Fi cannot always detect it and back-off its own transmissions, yet high enough that the SINR of the resulting collisions is very poor

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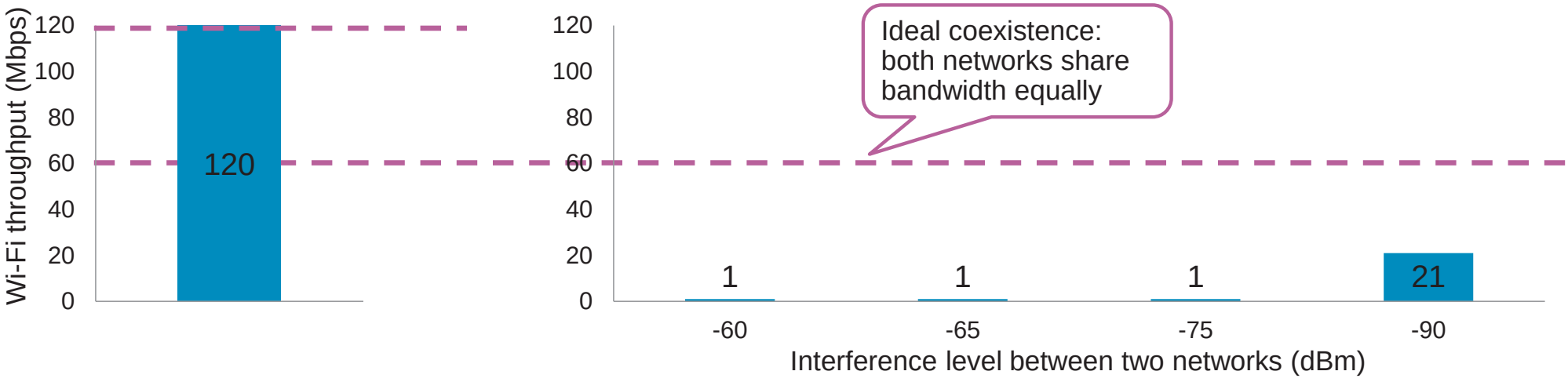
WI-FI + LTE-U 90% DUTY CYCLE (FAILED NEIGHBOR DETECTION)



1 Wi-Fi network

1 LTE-U + 1 Wi-Fi network interacting

- If LTE-U doesn't detect Wi-Fi neighbor and raises its duty cycle to 90%, the impact on the Wi-Fi throughput is catastrophic
  - Still substantial degradation even when the interference level is as low as -90 dBm

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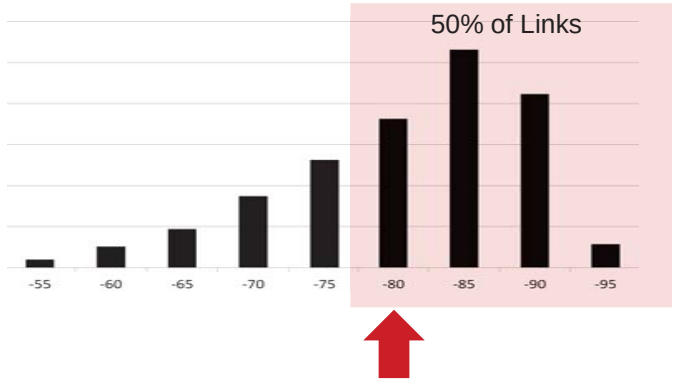
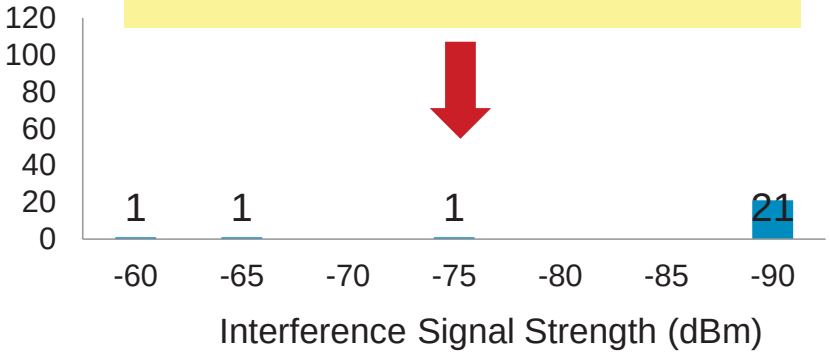
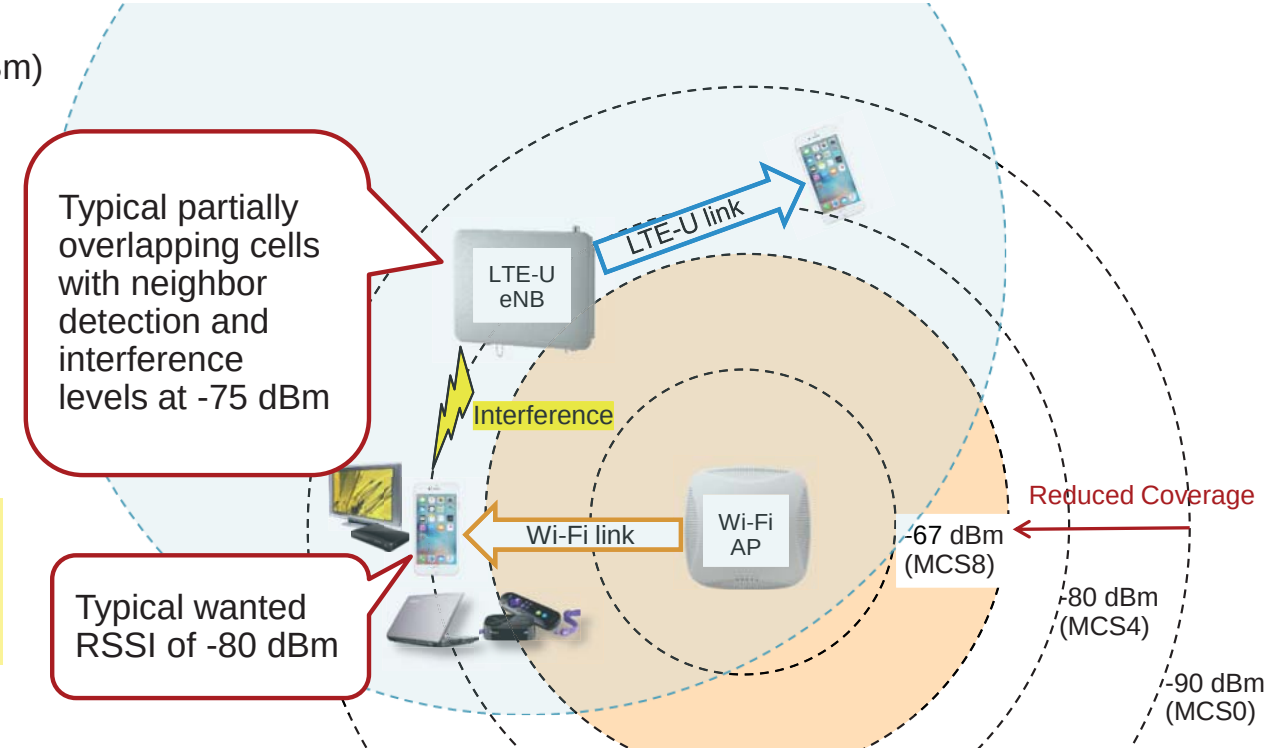
IMPACT OF LTE-U INTERFERENCE ON TYPICAL WI-FI LINKS

Distribution of Wi-Fi Received Signal Strength (dBm)



In this very typical coexistence scenario…





Wi-Fi throughput may fall to <u>almost zero</u>; Is there anything to prevent shrunken Wi-Fi coverage area in current LAA specification?

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CONCLUSIONS

- The issue is being framed as a technology vs technology or cable vs carrier dispute, but poor coexistence will be felt by the users
- There are hundreds of millions of Wi-Fi devices installed in the US today, many of which provide the sole means of broadband access to part of the population
- Coexistence fairness should be based on how deployed LTE-U devices would impact the typical Wi-Fi user in real world deployments
  - Coexistence fairness must not be based on edge cases
- LTE-U as currently contemplated would be a disaster for Wi-Fi, and any type of co-channel LTE (e.g., LAA) is likely to significantly reduce Wi-Fi coverage area unless specific coexistence mechanisms are adopted
  - Additional LTE-U and LAA coexistence work remains critical prior to mass deployment

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