



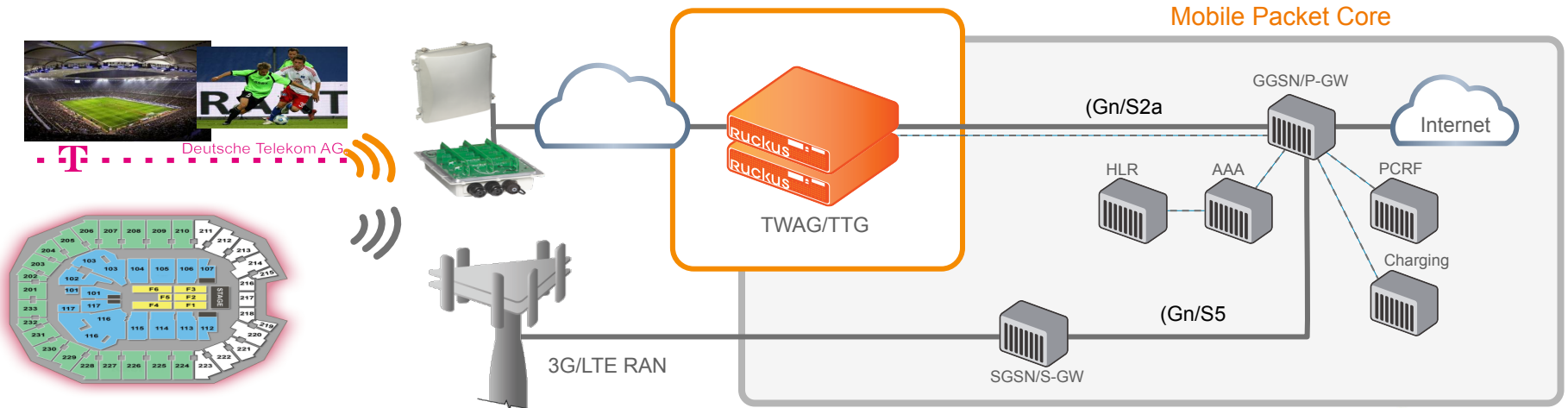
Proposals for LTE Operation In Unlicensed Spectrum

Dave Wright + Kevin Francis

Ruckus Wireless

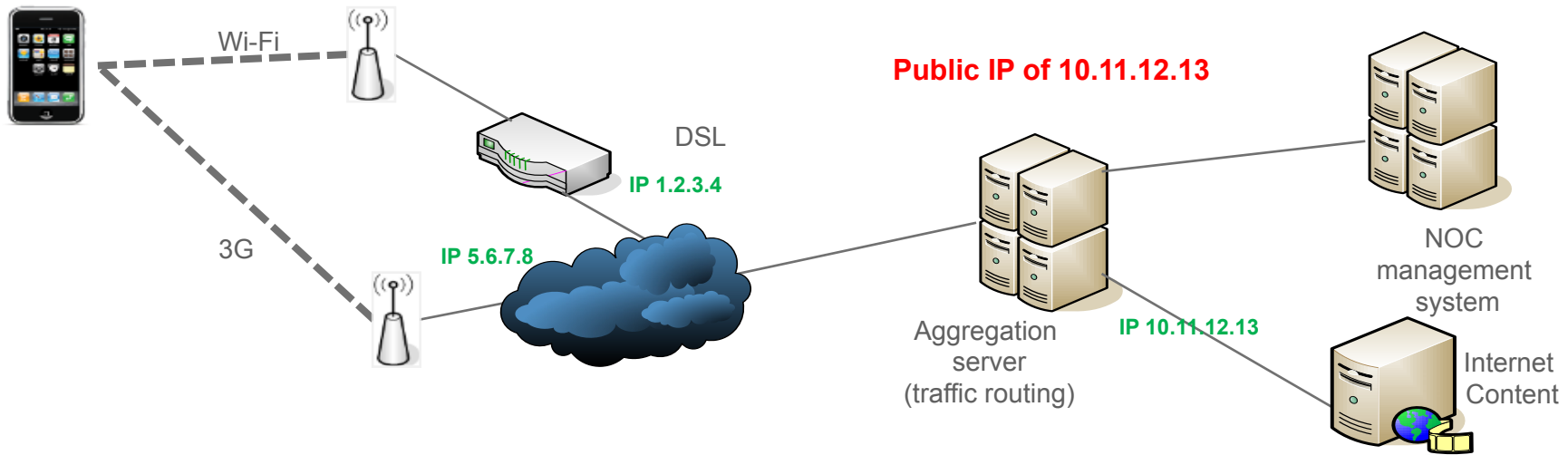
Network-based 3GPP SaMOG

- Mobile packet core integration via the SCG 200
- Supports 3GPP SaMOG (TS 23.402) standard
- Sessions always remain anchored to the same P-GW



Client-based Multi-Path TCP

- Can load balance across cellular and Wi-Fi connections
- If Wi-Fi or cellular slows down under load, traffic is just moved to the other link
- Supported on mobile devices like the iPhone



The Value of Unlicensed Spectrum

- **Wi-Fi has seen unprecedented success**
 - Simple integration – over 10 Billion Wi-Fi enabled devices
 - Widespread adoption across virtually every market segment
 - Massive scale with ~\$140B/year economic impact in US
- **LTE is jumping into 5 GHz spectrum**
 - LTE-U, LAA-LTE, LWA
- **Fair sharing is the future**

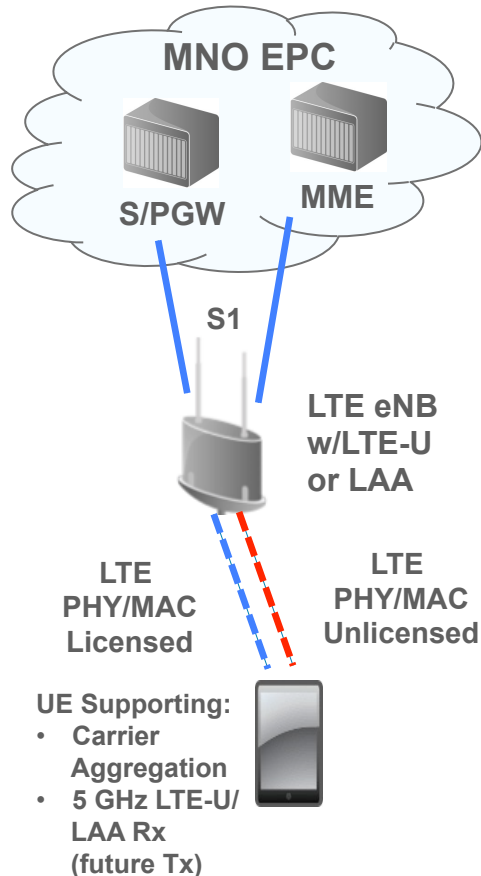


LTE in Unlicensed Spectrum

- **Fair Access is critical to protecting Wi-Fi users and services**
 - Listen before talk (LBT) is not supported in pre-standard **LTE-U** proposals
 - CSAT is an optional best effort technique
 - LBT must be mandatory to ensure fair sharing for **LTE-LAA**
 - Wi-Fi community will lobby for LBT as part of 3GPP standard
 - **LWA** utilizes 802.11 CSMA/CA for medium access



LTE-U and LAA-LTE



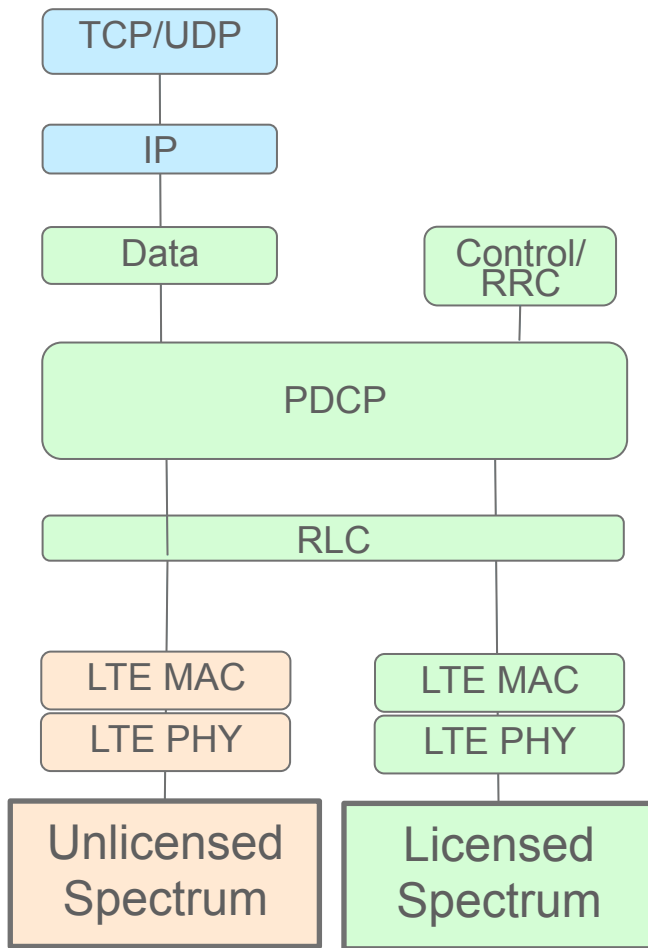
What are they?

- Require a licensed band 'anchor'
- Unlicensed for opportunistic data boost
- Linked to Small Cell architectures
- Initially downlink only, uplink to follow
- LTE-U w/o LBT, CSAT type access (pre-standard)
- LAA w LBT (Rel 13 proposed standard)

What are the expected benefits?

- Native Integration to Mobile Core
- Improvements in user experience*
- No additional spectrum cost

LAA-LTE Protocol Stack



Unlicensed used for SDL*:

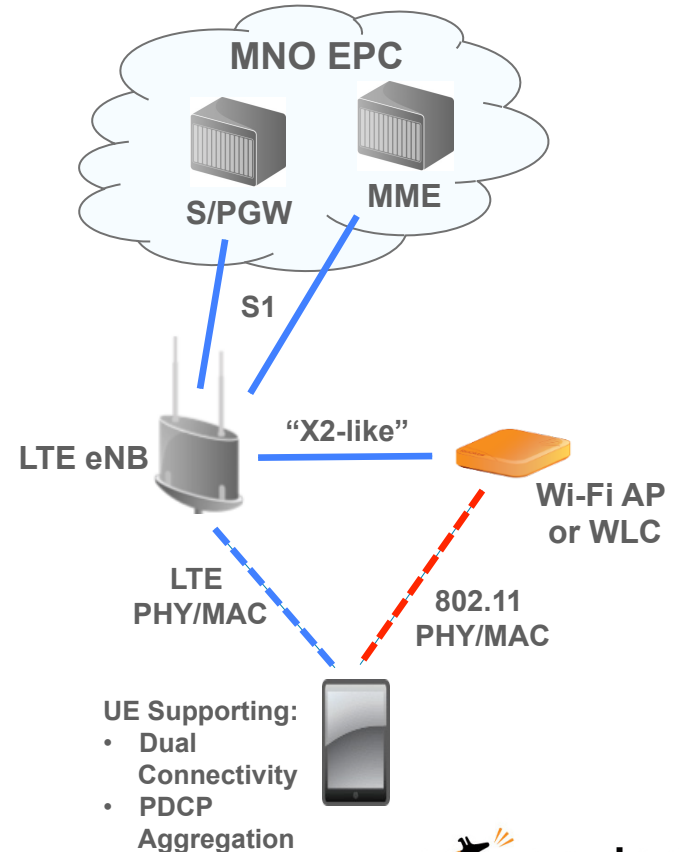
- Primary data channel (P-Cell, not shown in stack diagram) is in licensed spectrum
- Control channel for the Secondary Unlicensed data channel (S-Cell) is operated over licensed spectrum

*Follow on implementations after Release 13 may support uplink operation in TDD mode.

LWA (LTE – Wi-Fi Link Aggregation)

LTE in Unlicensed Spectrum using 802.11

- Based on PDCP splitting/combining capabilities in LTE eNB and UE modem
- eNB and AP enhanced to support “X2-like” interface for both control and data plane forwarding
- AP also provides Unlicensed Environment information to eNB as traffic balancing metric
- AP encapsulates LTE PDCP datagrams in 802.11 MAC frames for transmission over the air
- Wi-Fi coexistence via 802.11(CSMA/CA?)
- 3GPP Release 13 Study Item



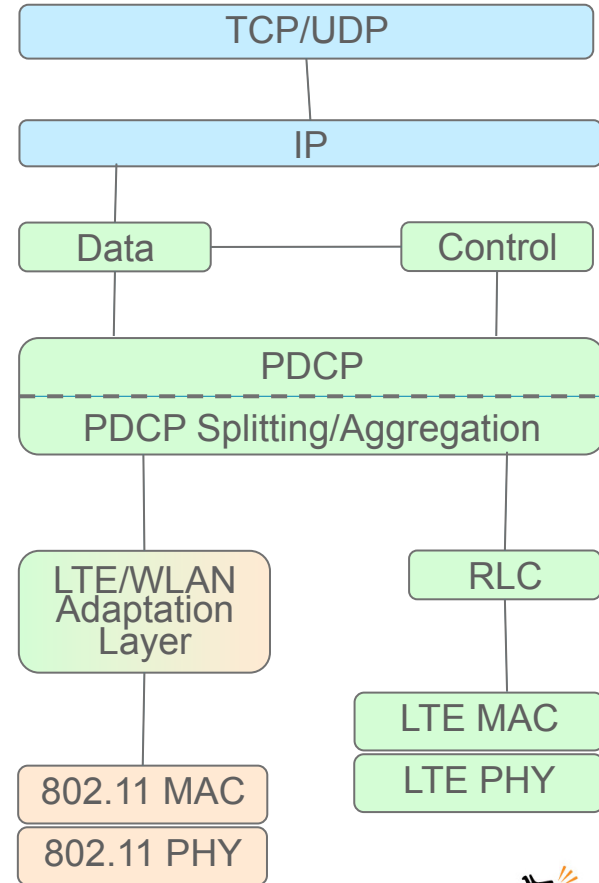
LWA Protocol Stack

Modification to:

- LTE RRC to support data plane option via 802.11 “path”
- PDCP to support splitting/aggregation to/from 802.11 and LTE “paths”
- WLAN MAC to support PDCP EtherType

Addition of:

- LTE/WLAN Adaptation Layer to support mapping of Bearer and QoS information between the LTE and 802.11 environments

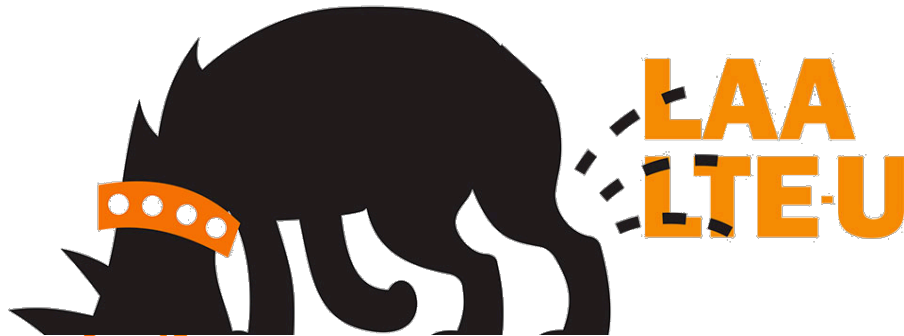


Digging Deeper

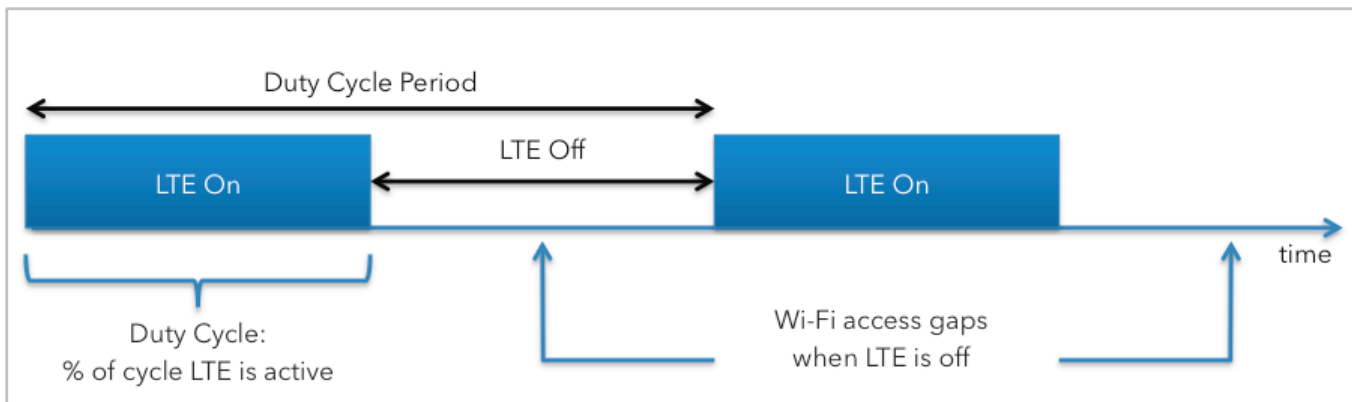
OPTION	Layer 2 Transport	Wi-Fi Coexistence	Unlicensed Bands	Standards Body	Unlicensed Data Boost	Unlicensed RAN Node
LTE-U	LTE E-UTRA	Duty Cycle (e.g. CSAT)	5 GHz 3.5 GHz?	None	Downlink (SDL)	LTE-U Capable eNB
LAA-LTE	LTE E-UTRA	LBT (specifics TBD)	5 GHz 3.5 GHz?	3GPP (Rel 13 SI)	Rel13 Downlink Future +Uplink	LAA Capable eNB
LWA	802.11	802.11 (CSMA-CA?)	5 GHz 2.4 GHz*	3GPP (Rel 13 SI)	Downlink and Uplink	Wi-Fi AP with LWA

Common Characteristics

- A Licensed Spectrum “Anchor”
- Unlicensed/Licensed integration is at the RAN, standard EPC interfaces



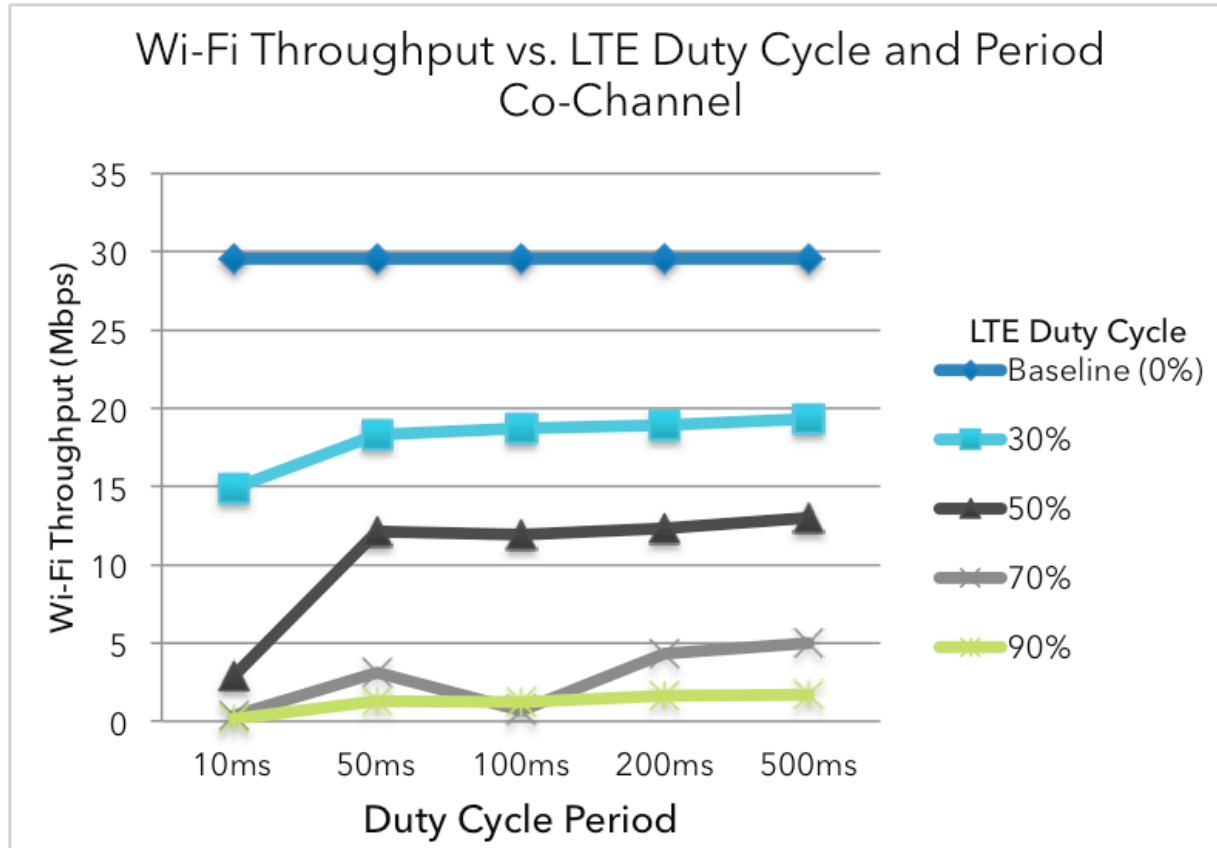
Carrier Sense Adaptive Transmission (CSAT) (src-CableLabs)



- CSAT perform clear channel selection
- Duty Cycle is a repeating on/off pattern
- Duty Cycle Period defines how often the pattern repeats (usually in milliseconds for our discussion)
- Duty Cycle Percentage is the fraction of the period that LTE is turned on.

Wi-Fi Throughput

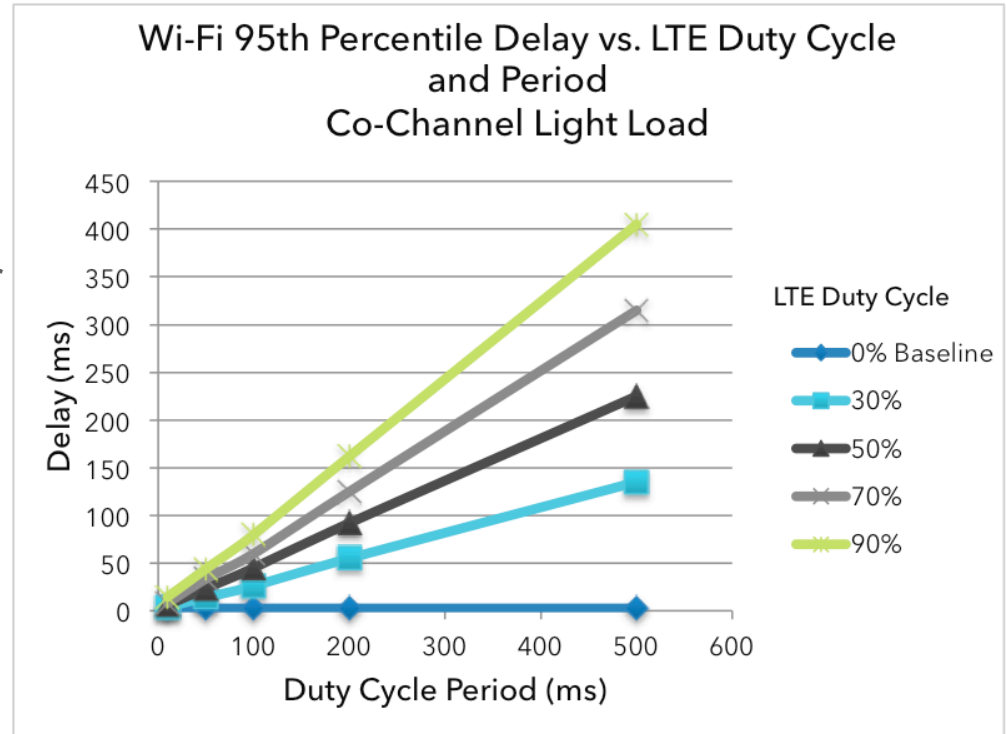
(src CableLabs)



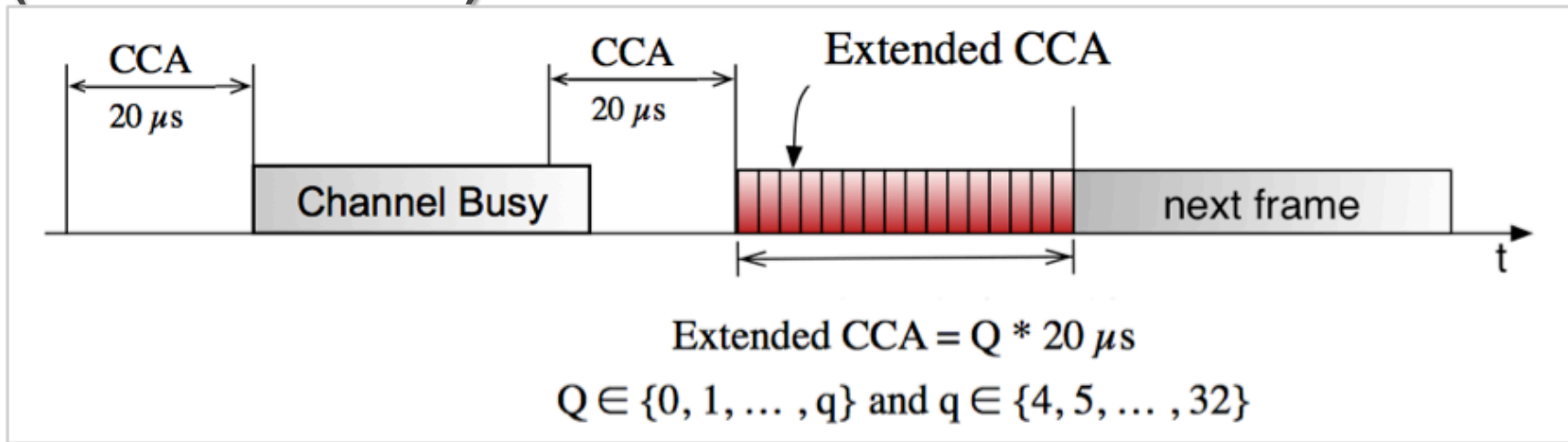
Wi-Fi Latency

(src CableLabs)

If the duty cycle period is configured as too low, the throughput of a Wi-Fi network sharing the channel will be negatively impacted. On the other hand, if the duty cycle period is too high, the latency of a Wi-Fi network sharing the same channel will be negatively impacted.

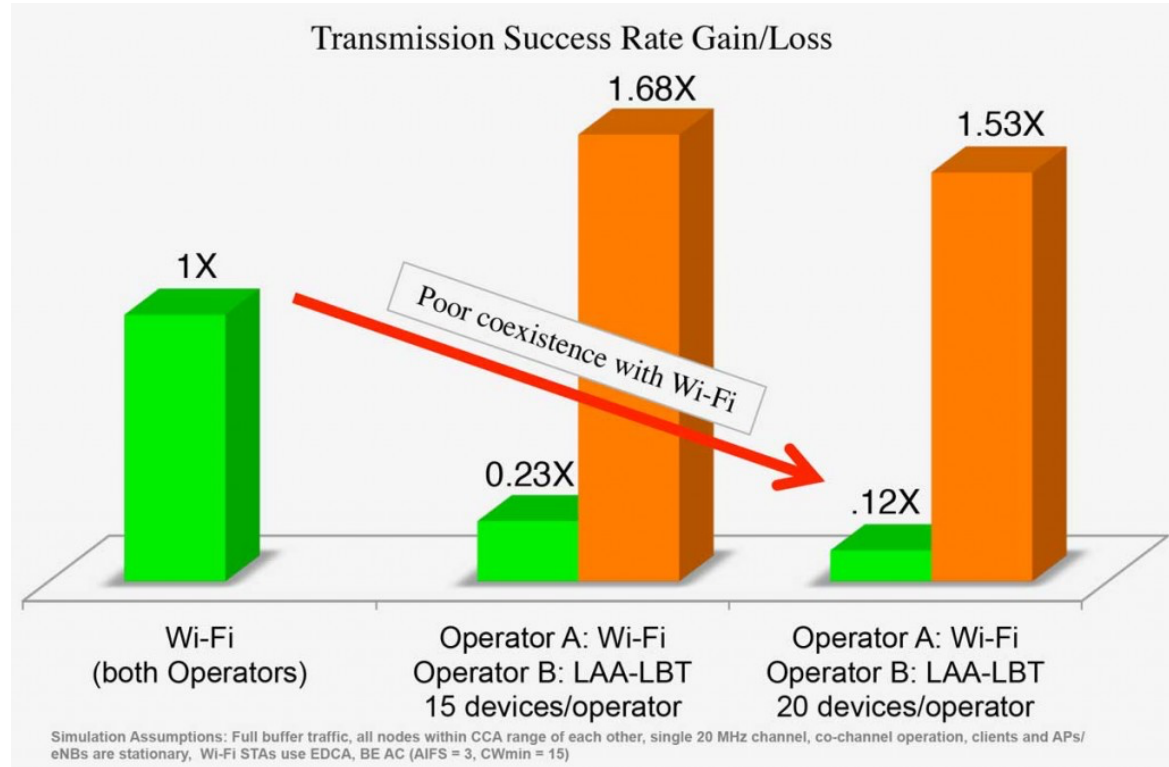


Listen Before Talk – EU Load Base Equipment Scheme (src - CableLabs)



- Wi-Fi uses $9 \mu s$ slots and a Clear Channel Assessment (CCA) with exponential backoff.
- EU-LBE uses Extended CCA. EU-LBE uses a static range from 0 to q slots, where each slot is $20 \mu s$. The value q is fixed for a given product, i.e., the extended CCA range is always the same size.

*With 4 or fewer devices per operator, there does appear to be good coexistence; both Wi-Fi and LAA clients see improvement over the Wi-Fi to Wi-Fi case.



The Future of Spectrum

- **Spectrum Sharing highly favored by regulatory agencies**
- **Sharing regimes can provide:**
 - Access Flexibility: e.g. 3.5 GHz Incumbent, priority, and general authorized
 - Frequency Flexibility: e.g. Priority access to 10 MHz paired in various areas
 - Time Flexibility: e.g. Long-term, short-term, or on-demand
- **Sharing regimes require careful coordination**
- **3.5 GHz is a high priority for shared access, dense deployments**



Parting Thoughts

- LBT/CSAT needs careful thought and tuning to achieve fairness – exponential backoff?
- Stand-alone option – Control Plane runs over unlicensed radio
- Hair-Pin – latency requirement between the unlicensed radio and the licensed macro
- Neutral host support
- Device support a must – what will Apple support?