# Architectural Challenges and Solutions for Collocated LWIP - A Network Layer Perspective

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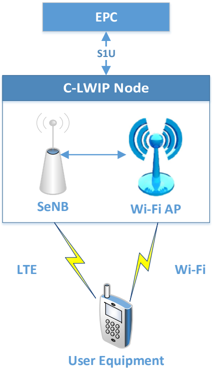
# Outline

# Introduction

- Mobile data traffic growth is exploding and it will reach 30.6 Exabytes per month by 2020
- Telco providers/operators face challenges in order to improve their network capacities

- Utilizing unlicensed band efficiently has gained operator interest for the increasing their bandwidth
- LTE-U, LAA, LWIP, LWA are the different ways of realizing the efficient utilization of unlicensed band.
- We focus on LWIP for harvesting the benefits of unlicensed band



## Tightly coupled LTE Wi-Fi interworking - LWIP

- Multihomed host realizes aggregation of multiple interface benefits at application layer (eg., Samsung boost), Transport layer (eg., MPTCP) and the most recent is LWIP.
- LWIP allows the interworking benefits at IP layer and it is standardised as a part of Rel 13
- LWIP has following benefits
    - Wi-Fi operations are controlled directly via LTE base station (eNB) and therefore LTE core network (i.e., Evolved Packet Core (EPC)) need not manage Wi-Fi separately.
    - Radio level integration allows effective radio resource management across Wi-Fi and LTE links.
    - LTE acts as the licensed-anchor point for any UE, providing unified connection management with the network.
- LWIP has finer level of control on radio interfaces, for making efficient steering decision

# LWIP Architectures

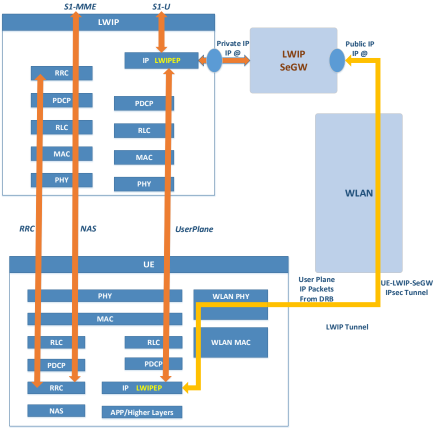



Figure : 3GPP LWIP Architecture

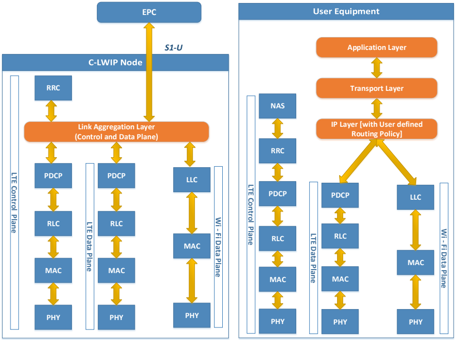
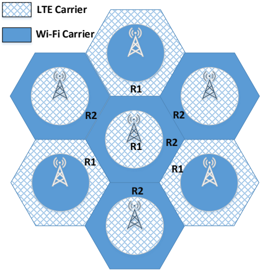



Figure : Proposed C-LWIP Architecture

## Architecture Comparison - Physical Layer

- C-LWIP provides flexibility in adapting fractional frequency reuse technique for mitigating inter-cell interference.
- In dense urban scenarios, C-LWIP mitigates interference among neighbouring C-LWIP nodes by assigning non-overlapping LTE and Wi-Fi bands.
- In 3GPP architecture, interference mitigation could not be done effectively as LTE radio has no control over Wi-Fi radio.



## Architecture Comparison - Network Layer I

1. IPSec tunnel in 3GPP architecture involves encryption of packets at IP layer and link level encryption of WLAN.
2. C-LWIP architecture reduces the overhead of double encryption (i.e., at IP and Layer 2 of WLAN) by using Wi-Fi key per client derived from existing eNB key $K_{eNB}$.
3. 3GPP architecture required each packet sent through IPSec tunnel to get added with the tunnel endpoint header, which adds to inefficient use of resources over the wireless channel.

# Architecture Comparison - Network Layer II

4. C-LWIP architecture does not require any additional headers.
5. 3GPP architecture decision for traffic offloading is simplified at a coarse level of granularity e.g., observed throughput and delay over an interface can be the determining factor for taking the offloading decision.
6. C-LWIP architecture supports decision making for offloading at a very fine granularity of information i.e., channel load, received SNR of Wi-Fi and channel characteristics such as loss and fading.
7. Both the architectures can supports existing UEs to readily work with the LWIP nodes.

# Implementation of C-LWIP in NS-3

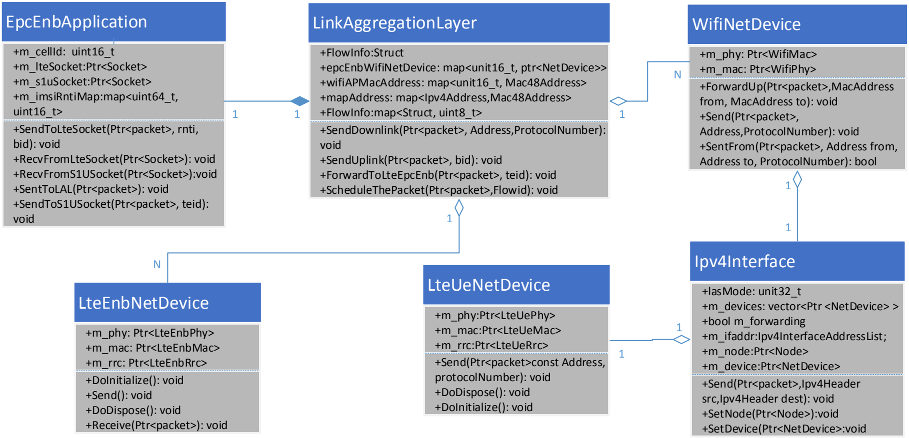
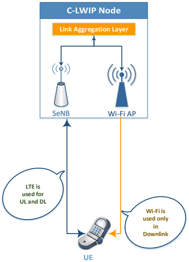



Figure : Class Diagram for C-LWIP implementation in NS3

# Link Aggregation Techniques

- **Naive LAS or N-LAS:** LTE and Wi-Fi links are simultaneously used for sending uplink and downlink IP data traffic.
  1. Packet Split N-LAS
  2. Flow Split N-LAS
- **Wi-Fi only on Downlink LAS or WoD-LAS:** Wi-Fi is used for transmitting downlink traffic while LTE is used for transmitting both uplink and downlink traffic.



## Experiment Configurations

| Parameter | Value |
|---|---|
| Number of C-LWIP Nodes | 1 and 10 |
| LTE Configuration | 10MHz, 50 RBs, FDD |
| Wi-Fi Configuration | IEEE 802.11a, 20 MHz |
| Traffic Type | Mixed (voice, video, web, FTP) |
| Distance b/w UE & C-LWIP node | 5 to 25 Meters |
| Distance b/w two C-LWIP node | 40 Meters |
| Simulation Time | 100 Seconds |
| Error Rate Model | NIST Error Rate Model |
| Mobility Model | Static |
| Wi-Fi Rate Control Algorithm | Adaptive Auto Rate Fallback |
| LTE MAC Scheduler | Proportional Fair Scheduler |
| Number of seeds | 5 |
| Wi-Fi Queue size | 400 packets |
| backhaul Delay | 40 ms |

## Evaluation Scenario

- Experiment 1: UDP test with one user
- Experiment 2: UDP test with multiple users
- Experiment 3: UDP heavy traffic in home scenario
- Experiment 4: TCP heavy traffic in home scenario
- Experiment 5: Mixed traffic in an indoor stadium

| Traffic Class | Nature | Expt #3 | Expt #4 | Expt #5 |
|---|---|---|---|---|
| Voice | UDP | 20% | 20% | 40% |
| FTP | TCP | 20% | 60% | 50% |
| Video | UDP | 60% | 20% | 30% |
| Web | TCP | 20% | 40% | 60% |

# Performance of UDP flows

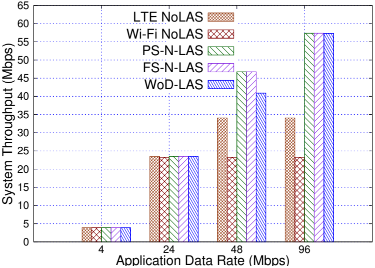



Figure : UDP Network Throughput : One UE

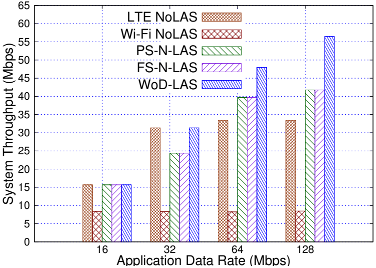



Figure : UDP Network Throughput : Four UE

## Performance of C-LWIP in Home Scenario

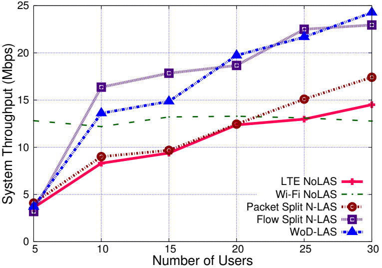



Figure : Home Scenario with one C-LWIP Node, Mixed Traffic, UDP Heavy

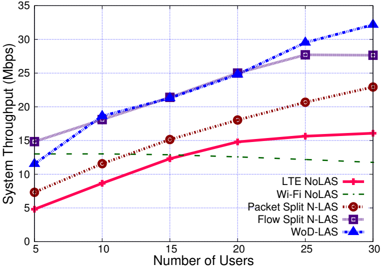



Figure : Home Scenario with one C-LWIP Node, Mixed Traffic, TCP Heavy

# Performance of C-LWIP in Indoor Stadium Scenario

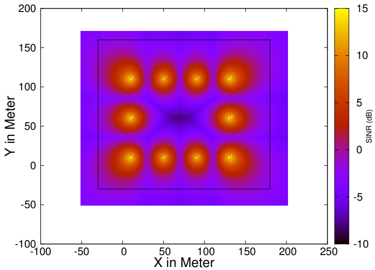



Figure : REM Plot for Indoor Stadium layout with 10 C-LWIP Nodes

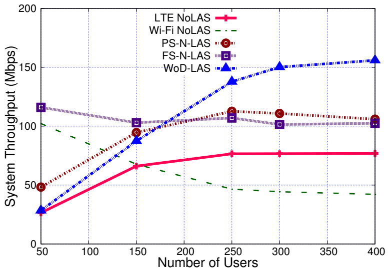



Figure : Indoor Stadium with 10 C-LWIP Nodes, Mixed Traffic

# Performance of C-LWIP in Indoor Stadium Scenario (contd.)

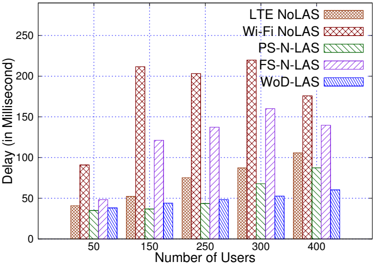



Figure : Delay of Voice Traffic in Indoor Stadium with 10 C-LWIP Nodes

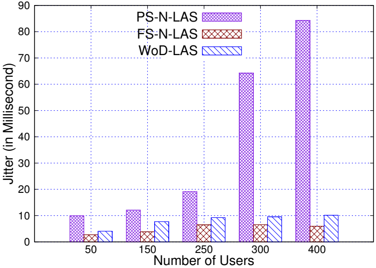



Figure : Jitter of Voice Traffic in Indoor Stadium with 10 C-LWIP Nodes

## Conclusions and Future Directions

- Proposed a C-LWIP architecture and enumerated its benefits over 3GPP LWIP architecture.
- Proposed C-LWIP architecture does not impose any protocol level modification at UE side and makes the existing commercial UE to readily work with C-LWIP.
- C-LWIP module is developed in NS-3 simulator which serves as an experimental platform
- The simulation workbench supports various existing traffic steering schemes and capable of handling the design of intelligent traffic steering algorithms.
- 50% improvement in system throughput is observed for WoD-LAS, as compared to N-LAS in an indoor stadium environment.

## Acknowledgements

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