A Real-Time Performance Evaluation of Tightly Coupled LTE–Wi-Fi Radio Access Networks

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Outline

Need and development of LTE Wi-Fi Aggregation

- Mobile data traffic will grow 7x by 2021 compared to that in 2016 [1].
- Spectrum crunch, high cost of licensed spectrum burdens operator.
- Rel.8 - PMIP based mobility and ANDSF, Rel.9 - eANDSF, Rel.10 - IP Flow mobility, Rel.11 - location based selection of gateway for WLAN and Rel.12 - WLAN network selection, Multiple PDN connections, and IP preservation.

Advantage of LTE Wi-Fi Radio Level Integration Architecture

- EPC need not manage Wi-Fi separately and it is controlled directly by the LTE small cell (SeNB) inside LWA node.
- Radio level integration allows effective radio resource management across Wi-Fi and LTE links.
- LTE acts as the licensed-anchor point for UEs communication with network.

Radio Level Integration Architectures

1. LTE Wi-Fi integration at IP Layer
   - Realizes the integration at IP layer of LTE eNB protocol stack
   - An IPSec Tunnel is established between eNB and UE through WLAN termination
   - Flow offloading is recommended, packet level steering has challenges
2. LTE Wi-Fi integration at PDCP layer
   - Traffic Steering is employed at PDCP layer of LTE eNB
   - Reorders the packet received at the destination using DC reordering procedure
   - Packet level steering is feasible
3. LTE Wi-Fi integration at RLC layer
   - Traffic Steering is employed at RLC layer of LTE eNB
   - Traffic steering can be done at byte level
   - High Reliability and minimized out-of-order delivery

Architecture

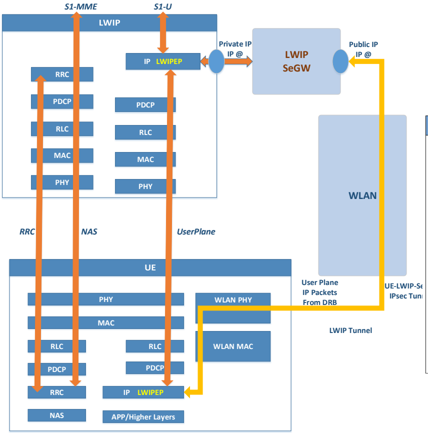


Figure 1 : 3GPP Architecture for non-collocated LWIP.

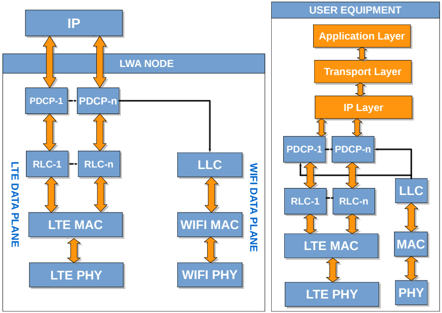


Figure 2 : LTE Wi-Fi Aggregation.

Protocol Implementation Structure of LWIP Prototype

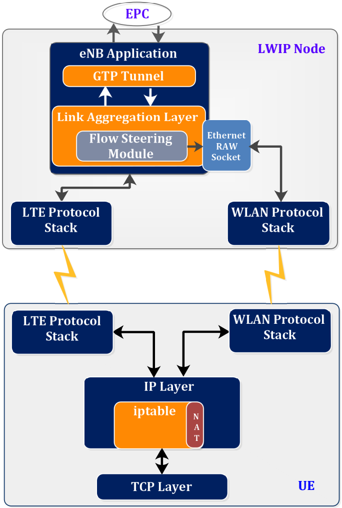


Figure 3 : LWIP Prototype

Realization of LWIP Testbed using OAI

Procedures

- A socket connection with the destination should be done with LTE interface IP at UE.
- The Wi-Fi interface details of UE has to be informed to LTE SeNB.
- A packet from LTE core network has to be re-routed to Wi-Fi network.
- An unmodified connection between LTE-SeNB and UE through Wi-Fi interface has to be maintained.

Parameters For Evaluation

Setup Parameters For LWIP

Parameter	**Value**
LTE - Mode	FDD
LTE - Bandwidth	5 MHz
LTE - Operating Frequency	Band 7 (2600 MHz)
Wi-Fi - Standard	IEEE 802.11 g
Wi-Fi - Bandwidth	20 MHz
Wi-Fi - Operating Frequency	Channel 1 (2412 MHz)

Experiment Configurations

Setup Configuration

Parameter	Value
OAI LTE eNB Hardware Config	ExMIMO2, Intel Xeon 8 core, 12GB DDR, Gigabit Ethernet 1 Gb/s
OAI LTE eNB Software Config	Ubuntu 14.04, Low Latency Kernel 3.19
OAI EPC Hardware Config	Intel Xeon Server 24 core, 64GB DDR, Gigabit Ethernet 10 Gb/s
OAI EPC Software Config	Ubuntu 14.04, Kernel 3.19 generic
Remote Server Harware Config	Intel Xeon 8 core, 32GB DDR, Gigabit Ethernet 1 Gb/s
Remote Server Software Config	Ubuntu 14.04, Kernel 3.2 Apache 2 Webserver, TCP - High Speed
User Equipment	Nexus 5 - hammerhead, Android 4.4.4 (KitKat)

Outline

Experiment Setup [2]

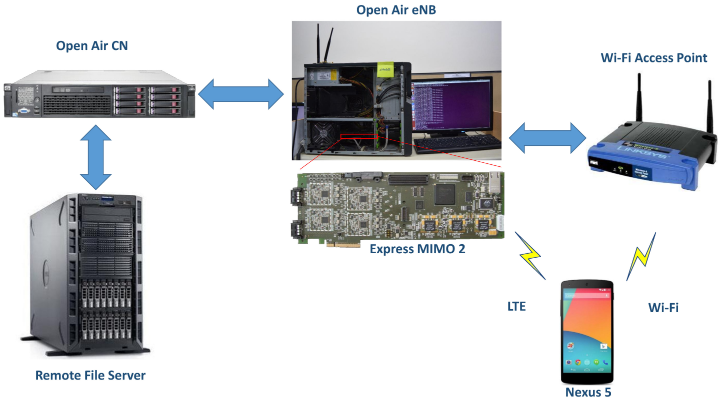


Figure 4 : Experiment Setup

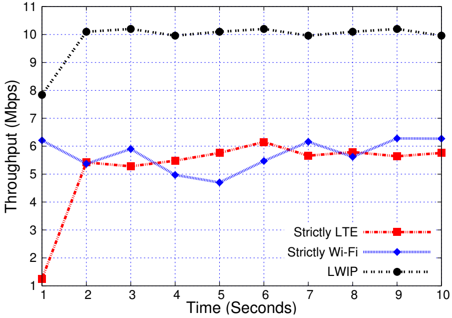


Figure 5 : Throughput in iPerf test using UDP (in downlink - 802.11 b)

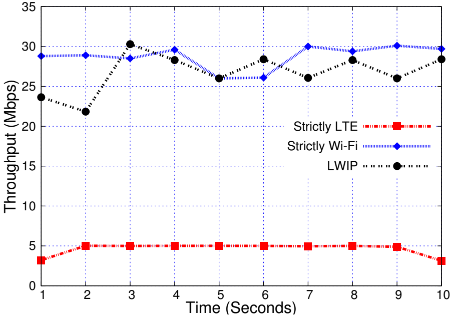


Figure 6 : Throughput in iPerf test using UDP (in downlink - 802.11 g)

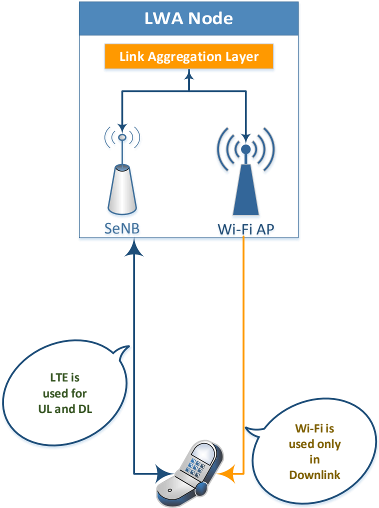
Outline

Link Aggregation Strategies (LAS)

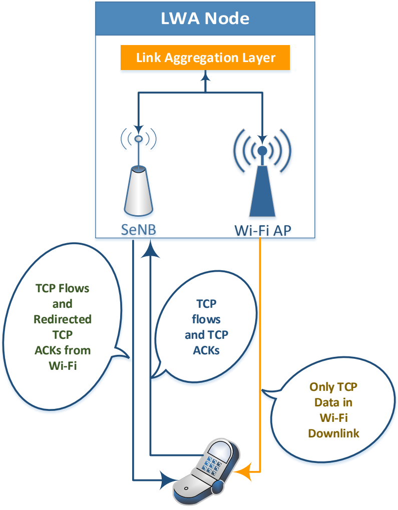
Types

- **LTE NoLAS:** Two flows are simultaneously downloaded through LTE.
- **Wi-Fi NoLAS:** Two flows are simultaneously downloaded through Wi-Fi.
- **FS-LAS:** Flow split enables one flow to be downloaded through LTE and other through Wi-Fi.
- **WoD-LAS:** WiFi only in Downlink enables both the flows to use Wi-Fi for downlink and the corresponding TCP ACKs are sent through LTE in uplink.

Link Aggregation Strategies



WoD-LAS



TWoD-LAS

TCP File Download - User Throughput

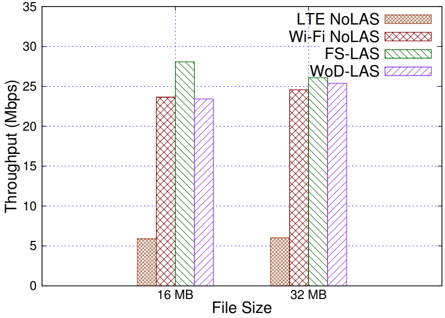


Figure 7 : Throughput with Low Contention

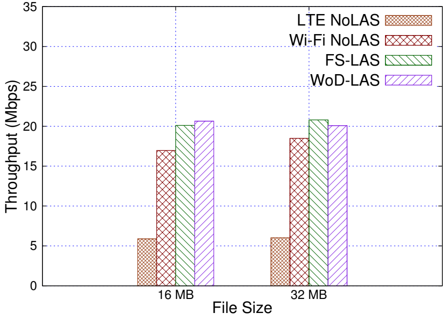


Figure 8 : Throughput with High Contention

TCP File Download - Wi-Fi Throughput

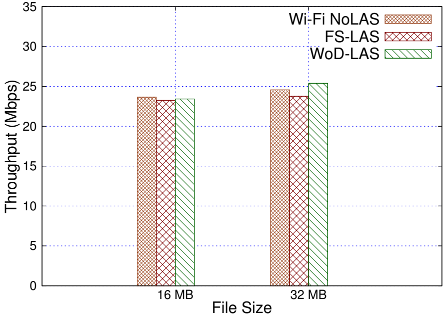


Figure 9 : Throughput of Wi-Fi with Low Contention

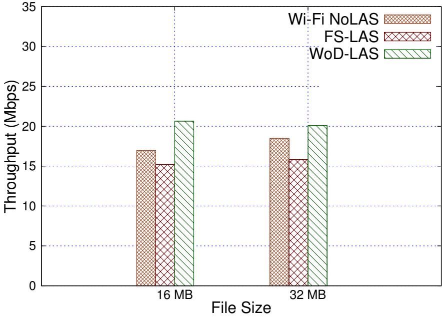


Figure 10 : Throughput of Wi-Fi with High Contention

TCP File Download Time

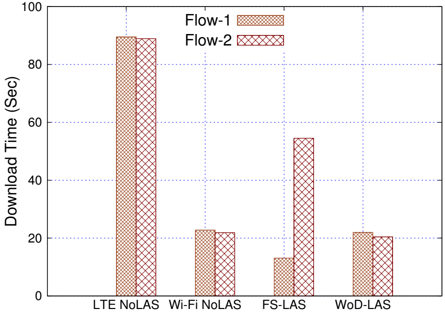


Figure 11 : Time to download a 32 MB file with low contention.

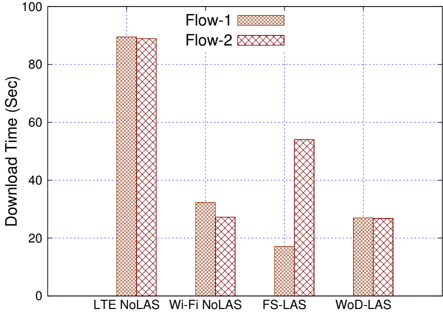


Figure 12 : Time to download a 32 MB file with high contention.

Conclusions and Future Work

1. Performance of LWIP is studied using OAI LTE, Cisco AP, and commercial UE.
2. The developed prototype does not require any modifications to the protocol stack of the UE.
3. Different link aggregation strategies exhibits varied performance in LWIP prototype.
4. WoD-LAS has improved sum of flow throughputs by 28% as compared to FS-LAS, when the contention in Wi-Fi channel is high.
5. Efficient packet level steering solutions across LTE and Wi-Fi links in real time is required to improve TCP performance.

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- OAI : OpenAirInterface, "EURECOM", http://www.openairinterface.org/.
- HostAPD : For Linux Wireless AP, http://w1.fi/hostapd/.
- 3GPP TS 36300 : *E-UTRAN; Overall description*, Stage 2.
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