A Packet Level Steering Solution for Tightly Coupled LWIP Networks

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Radio Level Interworking Architecture - LWIP

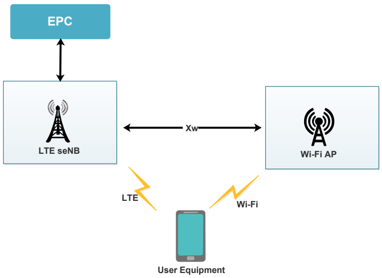


Figure: 3GPP LWIP Architecture

- Existence of Wi-Fi AP is not known to EPC, *i.e,* Wi-Fi AP is controlled directly by the LTE small cell (SeNB).
- Enables effective radio resource management across Wi-Fi and LTE links.
- LTE acts as the licensed-anchor point for UE's communication with the network.

Challenges with LWIP

- Tighter LTE and Wi-Fi interworking architectures can harvest maximum benefit of link aggregation with packet level steering
- Packet level steering may lead to Out-of-Order (OOO) delivery of packets at the receiver due to link heterogeneity
- TCP receiver generates DUPlicate ACKnowledgements (DUP-ACK) for OOO packets received
- The unnecessary DUP-ACKs adversely affect the TCP congestion window growth and then lead to poor TCP performance
- Efficient packet level steering and avoiding OOO delivery are necessary to reap in full benefits of LWIP

Out of Order Delivery Problem

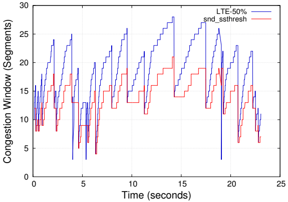


Figure: CW for split ratio of 50% across LTE and Wi-Fi with 100 msec RTT for a 16MB file download.

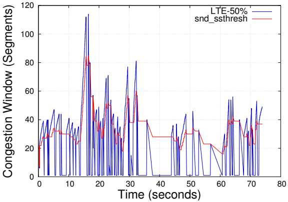


Figure: CW for split ratio of 50% across LTE and Wi-Fi with 20 msec RTT for a 32MB file download.

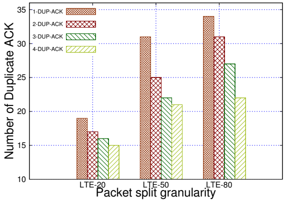


Figure: Out Of Order packet delivery for packet split ratio of 20%, 50%, and 80% for 100 msec RTT.

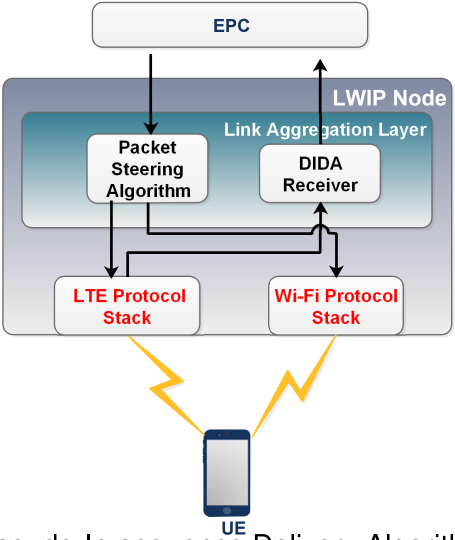
Literature Review

1. Delayed ACK [4] introduces a waiting time before the receiver generates a DUP-ACK
2. Delay in ACK generation provides opportunity for the receiver to minimize the necessity for generating DUP-ACK
3. Delaying ACK in slow start phase will negatively affect TCP growth
4. MPTCP [7] enables multiple TCP sub-flow to be sent over different interfaces. But it is inefficient to make quick decisions to steer the packets across different subflows.
5. MPTCP takes steering decision at the sender so it cannot react for the fluctuations on the wireless channel quickly.
6. In LWIP, the packet level steering introduces OOO packet delivery at the last hop, which is not addressed earlier.

Objectives

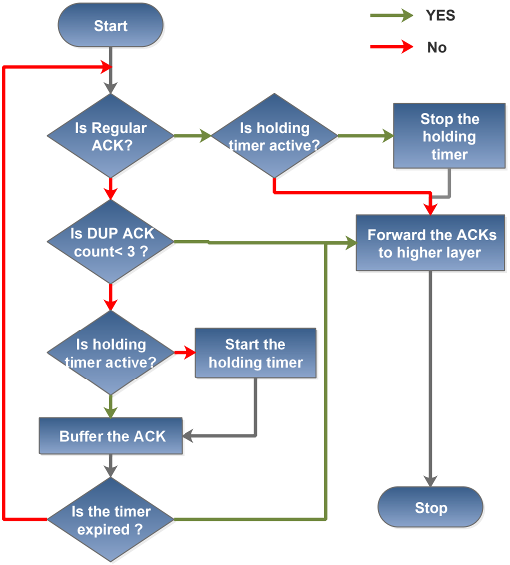
1. Does not affect the growth of TCP congestion window
2. Reduces the triple DUP-ACK delivery to TCP sender
3. Combination of packet steering technique and reordering technique to achieve higher throughputs
4. No change to the TCP semantics
5. No split in TCP session, i.e., a single congestion window at the TCP sender

Components of the Proposed Solution - DIDA



DIDA: Dynamic pseudo-In-sequence Delivery Algorithm

Working Procedure of DIDA



Optimal Holding time

Optimal holding time can be given as t_{opt}

$$t_{opt} = \frac{1}{2Ae^{-1}}\Bigg((2Ae^{-1} \times RTT + B(1-e^{-1})) + \sqrt{(2Ae^{-1} \times RTT + B(1-e^{-1}))^2 + 4Ae^{-1}(e^{-1} \times B \times RTT - Ae^{-1}RTT^2)}\Bigg)$$

where

$$A = \delta_{buff} \times w \times (1 - \beta(w))$$

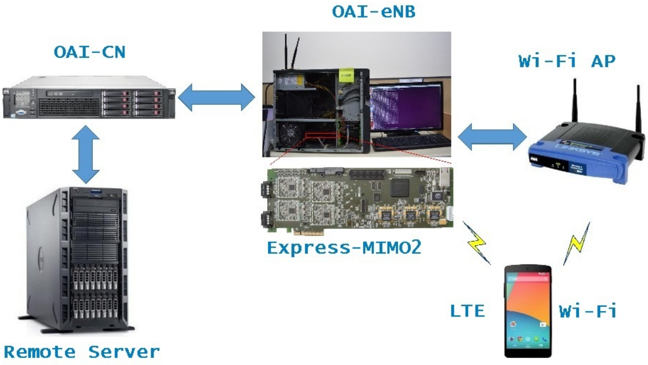
$$B = \delta_{buff} \times \alpha(w) \times T_E$$

operating range can be defined as

$$LB = t_{opt} - \frac{R}{S_1 \times \theta}$$

$$UB = t_{opt} + \frac{R}{S_2 \times \theta}$$

Realization of LWIP Testbed



Testbed Configurations

Parameter	Value
OAI LTE eNB Hardware Config	ExMIMO2/USRP-B210, Intel Xeon 8 core, 12GB DDR, Gigabit Ethernet 1 Gbps
OAI LTE eNB Software Config	Ubuntu 14.04, Low Latency Kernel 3.19 Ubuntu 14.04, Kernel 3.4.60-mptcp
OAI EPC Hardware Config	Intel Xeon Server 24 core, 64GB DDR, Gigabit Ethernet 10 Gbps
OAI EPC Software Config	Ubuntu 14.04, Kernel 3.19 generic
Remote Server Harware Config	Intel Xeon 8 core, 32GB DDR, Gigabit Ethernet 1 Gbps
Remote Server Software Config	Ubuntu 14.04, Kernel 3.2 Apache 2 Web server
User Equipment	Nexus 5 - hammerhead, Android 4.4.4 (kitkat)
LTE eNB bandwidth	5 MHz
Number of resource blocks	25
Wi-Fi transmit power	20 dbm
LTE MAC scheduler	Round Robin
Wi-Fi frequency, bandwidth	2.4 GHz, 20 MHz
Wi-Fi standard	IEEE 802.11 g, n

Throughput observed for different packet split ratios with DIDA

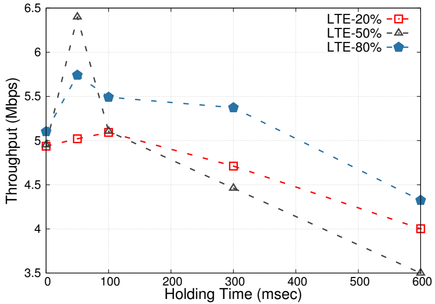


Figure: Throughput for RTT 100 ms.

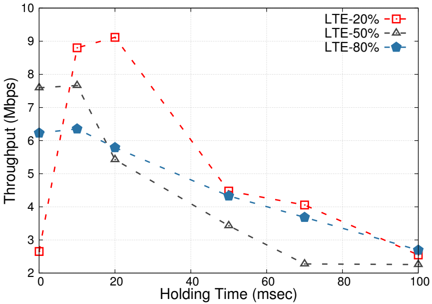


Figure: Throughput for RTT 20 ms.

Performance Study of DIDA Algorithm

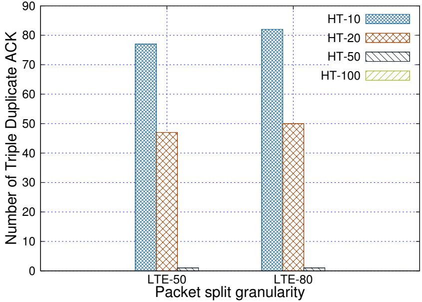


Figure: Triple DUP-ACKs observed for different packet split ratios.

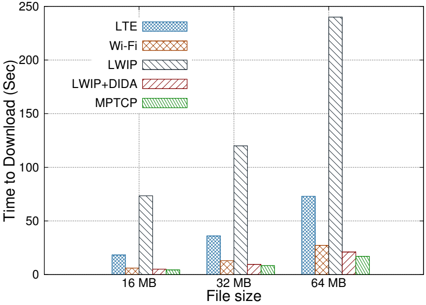


Figure: Download time observed for LWIP, LWIP with DIDA, and MPTCP.

Performance comparison with MPTCP

1. Various congestion control algorithms of MPTCP viz., Coupled, Uncoupled and Link Increase Algorithm (LIA) are considered.
2. When LTE and Wi-Fi link rates are incomparable, then MPTCP suffers from "the speed of the slowest link" problem and hence fails to achieve the aggregated throughput.
3. LWIP+DIDA has improved the throughput due to its efficient holding mechanism
4. When IEEE 802.11g is used (here LTE and Wi-Fi link rates are comparable), then MPTCP gets the full aggregation benefit
5. LWIP+DIDA achieves comparable performance with MPTCP. It has improved the system throughput by 2X compared to native LWIP.

Conclusions

- Proposed DIDA efficiently reduces the OOO packet delivery problem in the context of TCP.
- DIDA didnot allow any change to the TCP sematic and hence can be adopted widely.
- Operating DIDA with optimal holding time saves 20% of DUP-ACKs on average, which might have caused TCP congestion window to drop.
- DIDA doubles the throughput achieved as compared to native LWIP.

Acknowledgements

This work was supported by the project "Low LatencyNetwork Architecture and Protocols for 5G Systems and IoT"

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