A White Paper on

Tight coupling of LTE Wi-Fi Radio Access Networks - A Testbed Evaluation

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ABSTRACT

A tighter coupling of LTE and Wi-Fi interfaces can be achieved by integrating them at the radio protocol stack. LTE and Wi-Fi Radio level Integration with IPsec tunnel (LWIP) is the term coined by 3GPP for one such tighter level of LTE-Wi-Fi interworking at IP layer. This tighter level of interworking replaces the traditional way of cellular-Wi-Fi interworking through a packet gateway, and it can react to the dynamic changes in the wireless link quality. We have developed a variant of LWIP prototype in our laboratory and made commercial UE (Nexus 5) to readily work with the LWIP. The developed LWIP testbed uses OpenAirInterface (OAI) for LTE network and Cisco Access Point/Atheros device with Hostapd as Wi-Fi interface. In this white paper, we present the implementation details and interesting results achieved using IP level integration of LTE and WiFi. We also show the LWIP performance improvement of using UDP transmission over both LTE and Wi-Fi links. Also, the video transmission over LWIP unveils the potential of this link level aggregation.

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Introduction

A forecast on data explosion predicts that the data traffic generated by mobile devices is growing at an exponential rate, than it could ever imagine. As per [1], mobile data traffic will reach an annual run rate of 366.8 Exabytes by 2020, up from 44.2 Exabytes in 2015. Operators look for a best solution to cater this ever increasing demand. LTE-Wi-Fi interworking is one such technology which can serve this high data requirement. The problem which exists with LTE-Wi-Fi (or 3G - Wi-Fi) interworking is their underlying interworking architecture. The interworking from rel. 8 to rel. 11 is completely realized through offloading (i.e., moving a flow completely from LTE interface to Wi-Fi interface and vice-versa). Such flow offloading requires a change in the flow route from the cellular core network to the Wi-Fi network. The flow routing is unnecessary and inefficient in indoor and low mobility scenarios, where the traffic demand is very high. To address this problem, and to serve delay bounded service and increase the flexibility in seamless offloading there is a necessity for these two radios to work closer. Hence, LTE-Wi-Fi Radio Level Integration with IPsec Tunnel (LWIP) has evolved realizing a tighter integration by associating a Wi-Fi radio next to LTE radio which facilitates an enhanced control over both the radios. Also, LWIP binds LTE and Wi-Fi protocol stacks. LWIP realizes the interworking benefit at link level for better quality of service with seamless flow mobility across LTE and Wi-Fi interfaces. LWIP has the following advantages.

1. The LTE core network is unaware of the existence of a Wi-Fi interface.
2. LTE acts as a licensed anchor point for communication.
3. Radio level interworking allows effective utilisation of LTE and Wi-Fi links.

In this white paper, we describe our LWIP testbed, that has been developed using open-source platforms such as OpenAirInterface [2] for LTE module and Cisco AP/Hostapd [3] for Wi-Fi module. OpenAirInterface LTE (OAI-LTE) is used to build this LWIP prototype. LWIP emerges as a competing technology for LTE-U with support for LTE like transmission in unlicensed band. This white paper concentrates on implementation details and best outcomes of LWIP technology. In principle, LWIP could be realized in two ways,

1. Collocated LWIP
2. Non-collocated LWIP

In the collocated LWIP scenario, Small cell evolved-NodeB (SeNB) and Wi-FiAP are located in same device and tightly integrated at Radio Access Network (RAN) which are driven by finer control decision by combined intelligence. Unlike collocated LWIP, a non-collocated LWIP requires an intelligent decision making in steering data because of round trip delay introduced between LTE and Wi-Fi links.

LWIP: Interworking benefits

Architecture proposal and standards

As a part of release 12, 3GPP proposed an interworking architecture for realizing radio level integration called LWIP [4] as given in Figure 1.

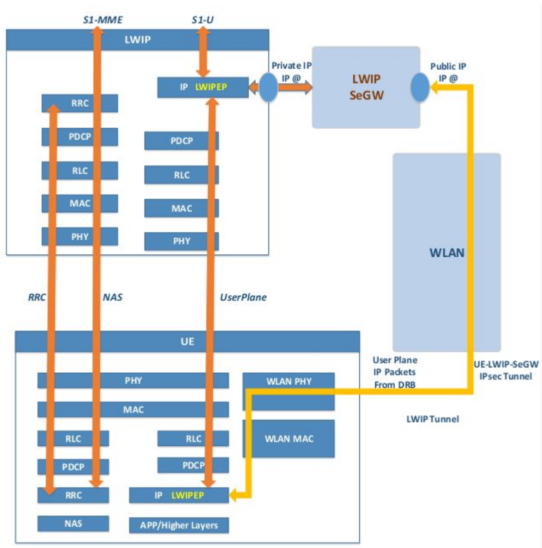


Figure 1: Protocol stack of LWIP proposed by 3GPP

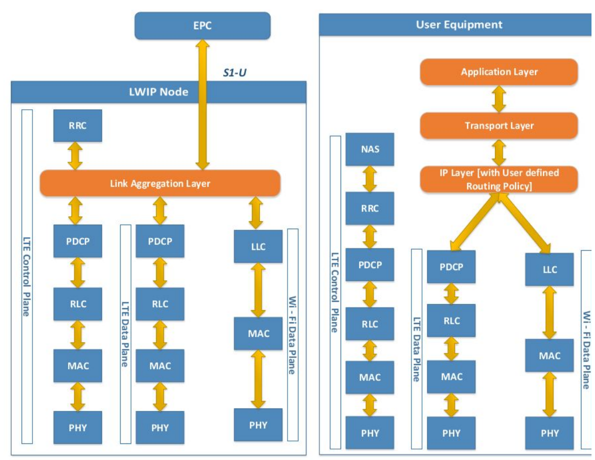


Figure 2: Protocol stack of LWIP proposed by IITH

At IITH, we have implemented a complementing and more tighter level integration at IP layer to perform traffic steering at the granularity of bearer level, flow level, and packet level. This traffic steering is done above the PDCP layer of LTE and the LLC layer of Wi-Fi in their respective protocol stacks as shown in Figure 2. Based on the traffic steering mechanism, the traffic steering layer decides which packets/flows/bearers to be transmitted over LTE and Wi-Fi and sends them over the corresponding radio interface.

LWIP is realized by introducing a Link Aggregation Layer (LAL) in the protocol stack of LWIP node. LAL does not add any new header to the IP data packets received from EPC via the S1-U interface. Packets going through LTE and Wi-Fi interfaces follow regular packet forwarding procedures at their protocol stacks and get delivered directly to IP layer. In LWIP architecture, the traffic split can be realised through flow level split or packet level split or bearer level split.

Advantages of the proposed LWIP architecture

LWIP is leveraged by its ease of implementation to achieve the aggregation benefit. Also, LAL supports collecting various network parameters and actively participates in intelligent decision making for steering IP traffic across LTE and Wi-Fi interfaces in the downlink. The interesting fact is that LWIP readily works with minimalistic changes in commercial UE as demonstrated in our test-bed using Nexus 5.

LWIP testbed using OAI

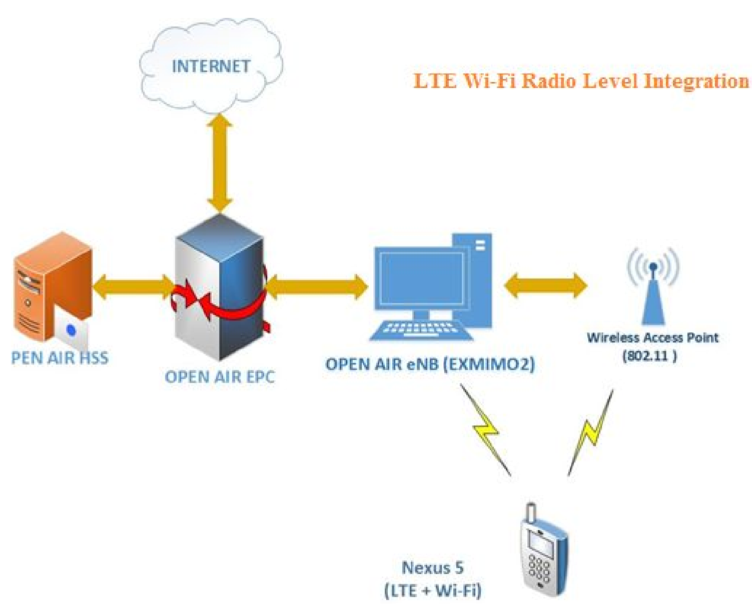


Figure 3(a): LTE Wi-Fi interworking at link level components.

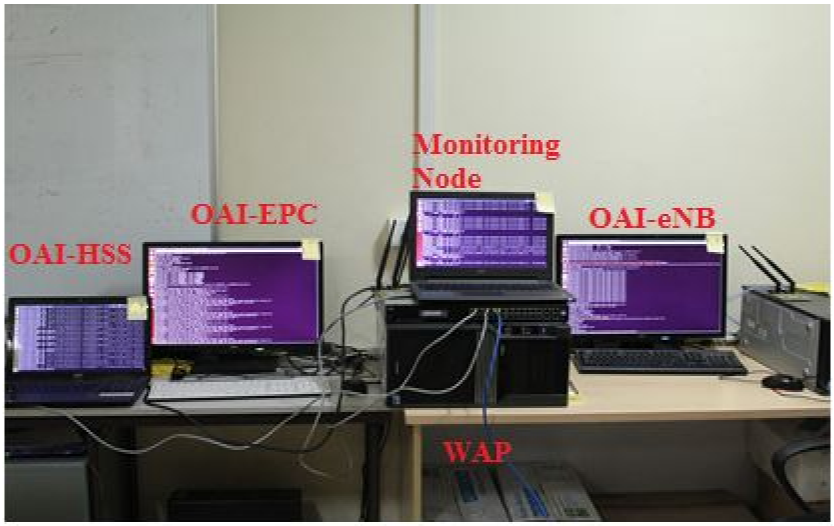


Figure 3(b): LTE Wi-Fi interworking testbed setup.

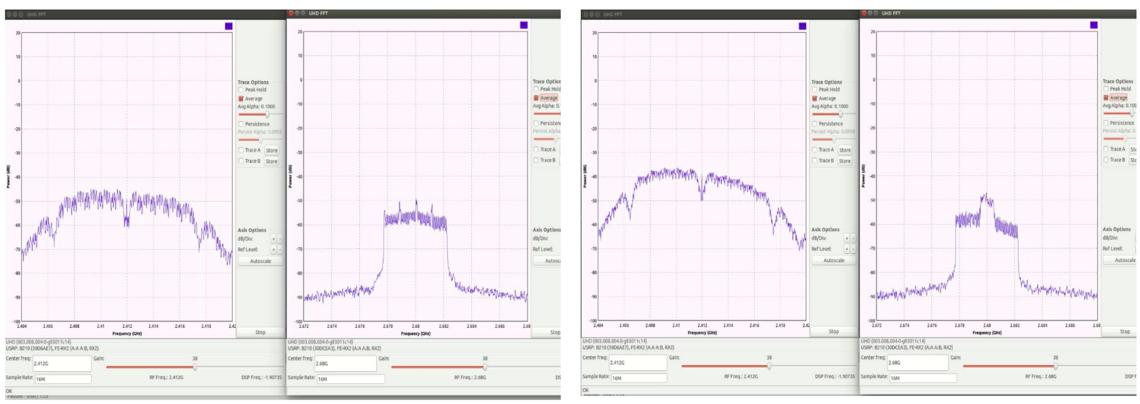
Figure 3a depicts the test setup of our proposed LWIP which encompasses the implementation structure and components of LWIP in a non-collocated fashion. Figure 3b shows the LWIP testbed.

LWIP testbed setup consists of OAI-LTE and Cisco AP connected through an ethernet link as shown in Figure 3. EXMIMO2 (SDR) boards are used as radio front end for LTE. This board is connected in a Linux machine using PCI express. The Linux machine is in turn connected to the OAI core network (openair-cn) running on a high-end server through gigabit ethernet. OAI core network comprises of MME, S-GW, P-GW, and HSS. For the UE, a commercial android phone (Nexus 5) is used.

The working procedure includes, running an Android application (developed in-house) in Nexus 5 which enables both LTE and Wi-Fi interfaces simultaneously to send and receive data through both interfaces at the same time. The link-aggregation layer located in LWIP device runs a redirection module which does traffic steering between LTE and Wi-Fi interfaces. It supports steering at packet level, flow level, and bearer level. The system is tested to steer traffic at all granularities. The implementation supports dynamic flow movement across LTE and Wi-Fi interfaces.

Performance Evaluation

A simple experiment of demonstrating the power on the LTE and Wi-Fi channel while downloading a file simultaneously through LTE and Wi-Fi interface using the proposed LWIP architecture is shown in Figure 4.. Figure 4 (a) shows the initial power in the channel which is very low in both LTE and WiFi channel. In Figure 4 (b), a file download is started which leads to an increase in the power level of LTE and Wi-Fi channels simultaneously. The complete working of the system is available online [7].



(a) Power level of Wi-Fi (left side) and LTE (right side) before any transmission

(b) A file is simultaneously downloaded through Wi-Fi (left side) and LTE (right side) interfaces

Figure 4: Power level of the channel before and during LWIP operation.

Figure 5, shows the developed Android application which aids in measuring the LWIP performance. Also, we have enhanced the open-source Android application "HIPRI KEEPER"[6] which can enable both LTE and WiFi interfaces at the same time to test the LWIP operation. The performance of LTE-Wi-Fi integration is studied with UDP iperf [5]. From a remote server iperf sends data to the UE (Nexus 5) to check the downlink performance in the following cases.

1. iperf using UDP - LTE only, Wi-Fi only, LWIP.
2. Quality of a video transmission - LTE only, Wi-Fi only, LWIP.

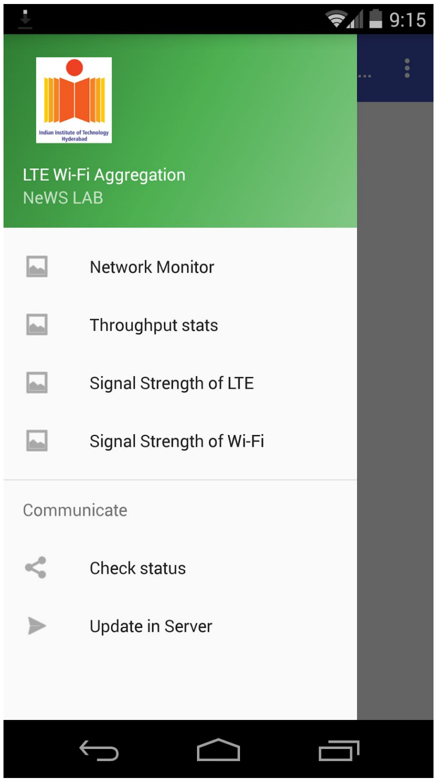


Figure 5: Android app for measuring network performance.

Parameters	Values
LTE Bandwidth	5 MHz
Wi-Fi Bandwidth	20 MHz
Wi-Fi network Delay	40 msec
LTE network Delay	10 msec
Wi-Fi Standard	IEEE 802.11b

Table 1: LWIP experimental parameters.

UDP Test using iPerf

A simple UDP iPerf test is conducted from a server in local network to the UE (Nexus 5). Figure 6 shows the throughput observed during the iPerf test in our experimental test-bed. It is very clear from the results that by using LWIP, an UE can achieve a sum of combined throughput of LTE and Wi-Fi links. This is achieved by doing a packet level routing between LTE and Wi-Fi links. This finer level of integration is possible only because of tight coupling of the LTE and Wi-Fi links.

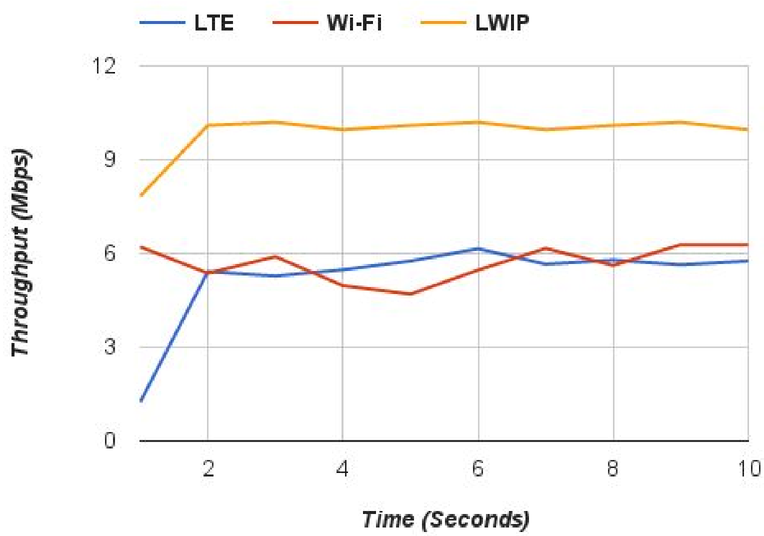


Figure 6: Throughput in iPerf test using UDP (in downlink).

Video Streaming over LWIP

To see the performance of a video streaming, a sample video is streamed to Nexus 5 which is located at the coverage edge and its quality is checked using all three cases (LTE only, WiFi only, and LWIP. The delay through Wi-Fi and LTE networks are comparable to the delay for a locally cached data or a data center next to the Gateway of LTE and Wi-Fi networks. A screenshot in each case is as shown in Figure 7. It is very evident from the figures that, the LWIP is making a best utilization of both LTE and Wi-Fi links and able to achieve a higher video quality as compared to standalone LTE and Wi-Fi links.

Streaming over LTE

Streaming over Wi-Fi

Streaming over LWIP

Figure 7: A Video streaming over LWIP.

Conclusions

This white paper has demonstrated the feasibility of LTE-Wi-Fi Radio Level integration (LWIP) using OAI LTE and commercial UE. There are numerous research challenges in a practical environment pertaining to real-time LWIP on flow and packet level routing which can be well studied using this testbed. A quick decision making solution with rich traffic steering algorithms can enhance the interworking benefit and make its performance as competing to LTE-U. We focus on implementing a Hetnet-Cloud using the developed LWIP system.

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