TELECOM INFRA PROJECT

Learnings from virtualized RAN technology trials over non-ideal fronthaul

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Executive Summary

The vRAN Fronthaul project group has completed Phase 1 testing in 4 TIP Community Labs hosted by Airtel, BT, CableLabs, and TIM Italy. This work has provided the technical foundation to show that lower layer split virtualized RAN (vRAN) over non-ideal transport network is possible with a multi-vendor solution.

The testing effort has also identified some key findings that must be considered when deploying vRAN over non-ideal transport types.

These key findings include:

- Constrained fronthaul throughput, below a certain threshold, will constrain air interface user plane throughput. The exact threshold can depend on the implementation and may be different for each data direction (i.e. uplink versus downlink).
- Throughput can degrade gracefully, approximately linearly, as fronthaul throughput is constrained.
- A UE can attach at latency up to around 30ms depending on configuration and implementation, even if an attached UE could sustain throughput at higher latency.
- High latency fronthaul can limit the UE attach rate (i.e. UE that can attach per second) to <25 UEs per second.
- Systems maintain near full throughput with high packet loss (up to 1%), though throughput begins to slightly degrade when packet loss exceeds 0.1%.
- Significant jitter can be tolerated with very little effect on air interface throughput.

While all the above points have been observed, they were not all observed in a single implementation. Each multi-vendor implementation tested has areas of stronger performance and areas where further development was needed. The goal of the project was to validate multi-vendor solutions in each Community Lab, and so far, the tested solutions include 4 Remote Radio Unit (RRU) products, 2 fronthaul protocol implementations, and 3 virtual Baseband Units (BBU).

In addition to varied performance, the implementations tested exhibit several gaps between the current state of the technology and what would be required for field and later market trials. Addressing the gaps will likely require product system integrators to create a product roadmap and coordinate the development and integration of the commercial solution.

Introduction to vRAN Fronthaul Project

The TIP vRAN Fronthaul project is helping to create the ecosystem for multi-vendor vRAN solutions with a focus on non-ideal transport/fronthaul. To speed up the availability of carrier-grade solution, TIP Community Labs have developed solution against a common high-level design which can be deployed in a wide range of use cases.

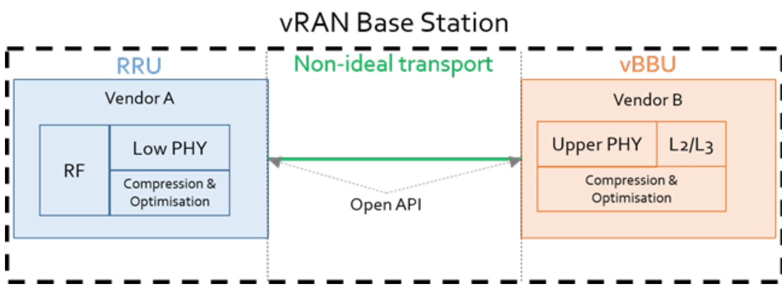

Figure 1 - The 3 key components of the vRAN solution. The RRU, vBBU and Non-ideal transport

Virtualization of the RAN on general purpose processing platforms offers many benefits for future RAN deployments. This includes more flexibility, faster upgrade cycles, resource pooling gains, and centralized scheduling.

As a general rule, the more radio processing that is centralized, the tougher the transport requirements. The TIP vRAN Fronthaul project has chosen a functional split that allows to maximize the centralization gains, relying on existing wired and wireless transport network assets such as GPON, DOCSIS® networks, G.Fast, Ethernet, and Microwave. Using existing transport medium benefits the business case for the vRAN solution to be widely adopted. It also decouples vRAN deployment from transport upgrades, which can help achieve a solution that can be adopted in more regions and hit higher volumes.

A multi-vendor ecosystem is an important requirement for the vRAN solution; it ensures vRAN solutions can be deployed at scale and can benefit from greater competition and expertise from a wider range of technology companies.

Most importantly, virtualization enables network operators and vendors to quickly add the best innovations to future networks, while encouraging the continued flow of innovations that are anticipated.

1.1 Project scope

The project assessed one of the RAN functional splits, Option 7 using the 3GPP split naming conventions[1].

Topics in the scope of evaluation and study include:

- Define the interface/reference implementation RRU vendors to build upon.
- Develop proof of concept with at least two RRU vendors, and at least one vendor of the vBBU.
- Develop a more carrier-grade demonstration for solution-specific scenarios.
- Look at low and high-power solutions for different scenarios (e.g. low power for high density small cells, high power rural access, typical macro and HetNet deployment scenarios for urban and dense urban area)
- Assess solution applicability and performance over different fronthaul options/configurations such as Ethernet (reference), G.Fast, Microwave, PON, and DOCSIS 3.x networks
- Demonstrate the remote reconfiguration capability across various use cases (e.g. multi-operator, multi-frequency)

1.2 The functional split

The TIP vRAN architecture and the tested implementations were based on split Option 7-2 for both the downlink and uplink directions. The split 7 variants are further explained in [2].

These split options were chosen because in general the 7-x family of splits offers the most support for advanced RAN features (e.g. all CoMP variants, ICIC) while maximizing total cost of ownership (TCO) gains from reduction in radio complexity and increased ability for resource pooling and load balancing [3]. In addition, it is worth to mention that according to a study published in [4], the 7-x functional split is the most popular of functional splits and is also adopted by other industry groups like the O-RAN Alliance.

[1] 3GPP TR 38.801 Radio Access Architecture and Interfaces Release 14

The primary area for innovation in lower layer stack splits for non-ideal transport links is latency; transport latency over 250μs breaks the LTE synchronous HARQ timeline. This is true for any split in which the MAC layer is in the centralized unit i.e. Option 6 or Option 7.

When evaluating these two split options, Option 6 MAC/PHY split does not support some of the CoMP variants, but still requires solutions to account for the HARQ timeline being broken to support non-ideal transport links [3]. Therefore, Option 7 was chosen as it provides the maximum functionality gain once the latency issue is addressed.

In addition to latency, significant bandwidth compression is desired relative to legacy fronthaul protocols like CPRI. Option 7 splits enable roughly 10x bandwidth compression at peak rate relative to Option 8 with CPRI. Further, option 7 splits allow fronthaul bandwidth to vary with the user plane traffic load which offers significantly more compression relative to Option 8 (which is constant bit rate) when cell load is less than peak.

1.3 The non-ideal transport

3GPP defines "non-ideal" backhaul in TR 36.932 [5] which covers various transport types with latency between 2ms to 60ms and throughput ranging from 10 Mbps to 10 Gbps.

Backhaul Technology	Latency (One way)	Throughput	Priority (1 is the highest)
Fiber Access 1	10-30ms	10M-10Gbps	1
Fiber Access 2	5-10ms	100-1000Mbps	2
Fiber Access 3	2-5ms	50M-10Gbps	1
DSL Access	15-60ms	10-100 Mbps	1
Cable	25-35ms	10-100 Mbps	2
Wireless Backhaul	5-35ms	10Mbps – 100Mbps typical, maybe up to Gbps range	1

Table 1: Categorization of non-ideal backhaul (ref: Table 6.1-1 from 3GPP TR 36.932 v15.0.0)

1.4 Enabling features

As non-ideal transport can cover a range of different impairment characteristics, that can each vary over several orders of magnitude, a number of features could be used to help overcome these various impairments. Here we describe a few of the key features implemented by some of the vendors in our TIP lab activities. These features enable the vRAN solution to operate in the presence of non-ideal transport characteristics.

HARQ prediction

For synchronous uplink HARQ, the standard requires that HARQ feedback be received 4 subframes after the associated downlink frame. In ideal fronthaul systems this means the fronthaul round trip latency budget is less than 1ms. Some non-ideal fronthaul transport links have latency that is greater than 1ms which breaks the traditional HARQ processing timeline.

A primary project goal in the TIP vRAN Fronthaul project was to validate that peak cell performance is achievable over non-ideal fronthaul links despite the HARQ timeline being broken.

To address this in a 3GPP compliant way, multiple options exist. One solution, already familiar to the industry, is HARQ interleaving. This simply increases the duration of the feedback look for HARQ feedback. While this doesn't impact cell capacity, it does prevent a single user from achieving peak cell performance.

The option chosen by this project is HARQ prediction. Figure 2 shows how HARQ prediction complies with the required timeline even over non-ideal fronthaul.

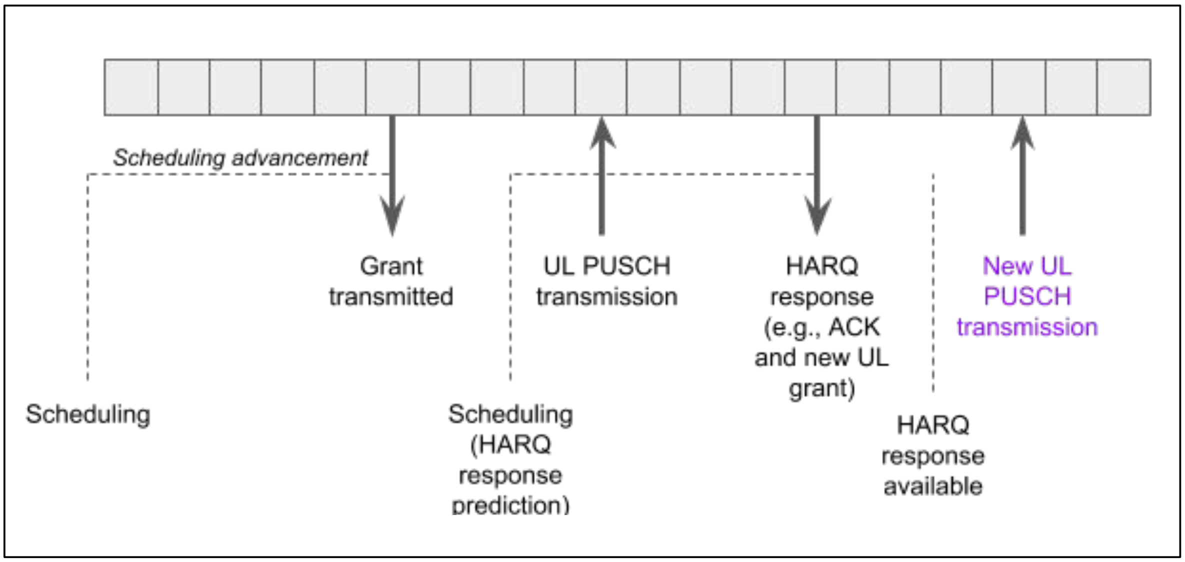

Figure 2 – HARQ prediction over non-ideal fronthaul

Using HARQ prediction, each UE can still achieve peak rate throughput. Peak rate throughput occurs when CQI values are high. When CQI values are high, a prediction of ACK becomes more likely to be correct. In the event that the prediction algorithm predicts incorrectly, this appears to LTE stacks as a bit flipped in the channel, and it is handled by RLC AM or upper layer protocols.

RACH process

When a UE attempts to attach to an LTE network, it starts by performing the random access procedure, or RACH process. This procedure is composed of a four-message exchange, where the messages are commonly referred to as Msg1 through Msg4. In LTE, there are configuration parameters, signaled to the UE via SIB messages, which governs the timing of the four-message sequence.

The main configuration parameters are:

```
    ra-ResponseWindowSize              ENUMERATED {
                                         sf2, sf3, sf4, sf5, sf6, sf7,sf8, sf10},
    mac-ContentionResolutionTimer      ENUMERATED {
                                         sf8, sf16, sf24, sf32, sf40, sf48, sf56, sf64}
```

The primary constraint is therefore ra-ResponseWindowSize which allows for a maximum of 10 subframes (i.e. 10ms) period between the first PDCCH opportunity after the RACH preamble transmission (Msg1) and the reception of the random-access response (RAR, Msg2).

Implementations made for non-ideal fronthaul must therefore design solutions to handle Msg2 timing in a 3GPP compliant way. Here we suggest 2 options, though other approaches exist.

OPTION 1

The first option is implementing a scheduler that reserves semi-persistent resources for the time constrained messages for which extra fronthaul latency may break a timeline in the exchange.

This includes:

- PDCCH resources for RAR
- PDSCH resources for RAR
- PUSCH resources for Msg3

In this method, static values are chosen based on configuration and when a randomly selected value for the RACH preamble matches the statically configured values the RACH process is completed, and the UE can attach.

OPTION 2

The second option is to configure the system such that RACH preamble collisions become more likely. For example, a system can limit the number of available preambles for contention-free RACH to 4, thereby increasing the likelihood that a UE randomly chooses the same preamble 2 RACH attempts in a row. When that occurs, the delayed RAR message (Msg2) will contain the "correct" preamble and the RACH process will complete as normal.

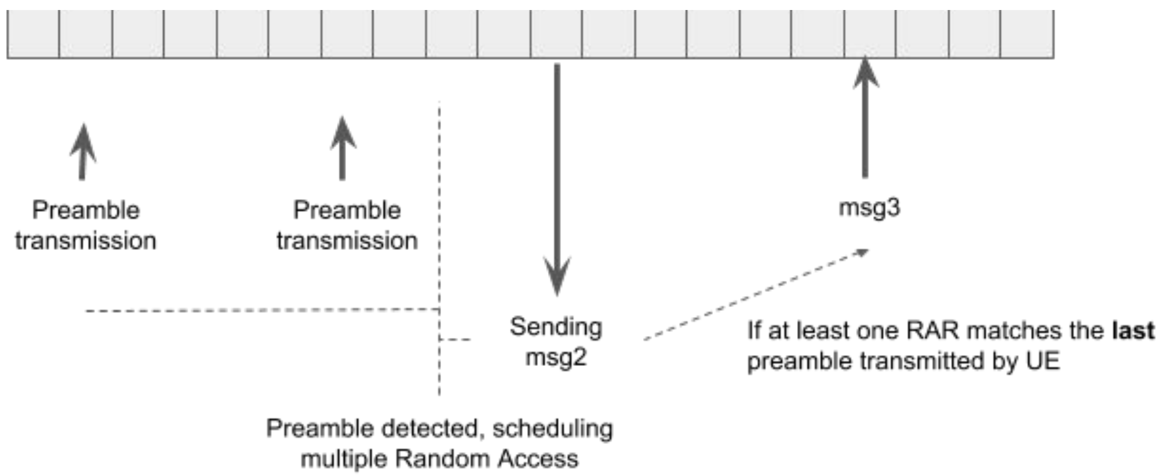

Figure 3 – RACH process

Both of the discussed methods have the effect of limiting UE attach ramp rate. This means that in deployment scenarios where the UE attach ramp rate is a performance metric, there will be system level trade-offs to using non-ideal transport for fronthaul.

Example deployment scenarios which may be impacted include urban macro cells, subway or train station cells, cells serving freeways. By contrast, deployments for which UE ramp rate is not a key performance metric, a limited UE ramp rate will likely go unnoticed. Example deployment scenarios include indoor small cells or pico-cells, fixed wireless access, or outdoor pico-cells in non-urban areas.

1.5 Early adopters

The TIP vRAN Fronthaul project has a large number of operator members, that can all be considered as potential early adopters. In particular four operators who are committed to driving this ecosystem development are currently hosting vRAN Fronthaul projects in their TIP Community Labs and building the solutions around their own use cases.

What is common among all these Community Lab activities, is to build against a common high-level design. However, there are significant differences in the use cases of each operator. Overall this means we have a solution that needs to work over a wide range of non-ideal transport types, for cells of different ranges, and to be deployed in different densities. Through these Community Lab activities, and the trials to follow, we are demonstrating that the developed solution is one that can be deployed at scale.

Use Case	Sponsor	Cell size Density	Transport	Transport Characteristics (Examples)
Small Cell vRAN	CableLabs	High density indoor femto or outdoor small cells	DOCSIS Network	DL < 500 Mb/s UL < 50 Mb/s Packet Loss ~ 0.1% Roundtrip Latency ~10ms
vRAN Cluster in HetNet	TIM	Medium to high density small cells in HetNet	PON/DWDM/ Microwave	1 Gb/s (or higher)
Street Coverage	BT	Medium density pico/macro	G. Fast	200Mb/s-1Gb/s (350m -100m copper line)
Campus	BT	High density micro/femto	Managed Ethernet	1 Gb/s (or higher)
Temporary Coverage	BT	Low density pico	Cellular in-band/ Microwave	1 Gb/s (or higher) (microwave)
Macro Coverage	airtel	Medium/high density macro sites	Microwave	Up to 50Mb/s Packet loss up to 2% Roundtrip latency ~20ms

Table 2: TIP Community Lab Use Case Requirements Summary

Results from TIP Community Labs

When TIP Community Lab activities started, over a year ago, Phase 0 proof of concepts were considered. These were single vendor solutions, using software-defined radios for the RRU. After initial testing of Phase 0 solutions, the project moved onto Phase 1 where solutions that were multi-vendor and commercial form factor RRUs were developed.

Four Community Labs were used for the Phase 1 testing. In each lab there were different combinations for vendors. Each lab validated a solution with one of the three vBBU implementations and one or two of the four RRU products.

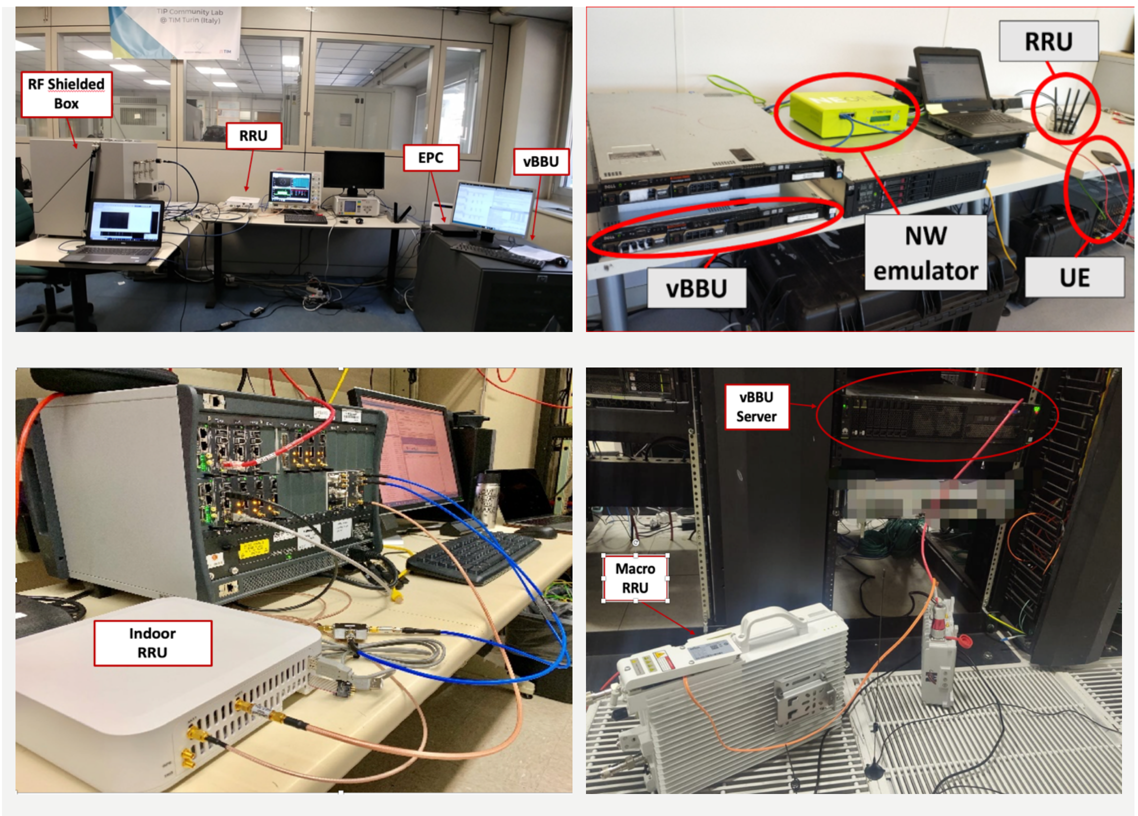

Figure 4 - Phase 1 activities across the 4 TIP Community Labs

This section highlights the key results from these Community Lab activities. From these results it should be possible to understand how the radio performance is impacted by transport impairments.

Across the labs we have tested 2 layer-1 protocols, 3 vBBU implementations, and 4 radio unit implementations. This does not mean that interoperability would be instantly achieved when directly connecting components from different labs. However, the different implementations do not necessitate hardware changes, so it will be possible to adapt the various solutions to achieve interoperability.

These various solutions may exhibit slightly different characteristics to one another. In this paper, rather than comparing these solutions, we have summarized the general characteristics exhibited by most solutions.

2.1 Methodology

Each Community Lab has built its solution(s) for the host operator's use cases. As such, each lab has its own radio configuration (e.g. different channel bandwidths, MIMO options, power capabilities).

The following lab configurations have been used:

	Downlink				Uplink		
Spectrum bandwidth	20 MHz	20 MHz	10 MHz	5 MHz	20 MHz	10 MHz	5 MHz
MIMO config	MIMO (2x2)	SISO	SISO	MIMO (2x2)	SISO	SISO	SISO
Peak radio capacity	150 Mb/s	75 Mb/s	37.5 Mb/s	37.5 Mb/s	50 Mb/s	25 Mb/s	12.5 Mb/s

Table 3 - Radio configurations used, and the peak capacity used for normalizing results

The throughput results (whether referring to radio performance or fronthaul capacity) were normalized by the maximum radio capacity that could be achieved by each lab configuration (Table 3) for a fair comparison.

A generic diagram of the tested solutions is provided in Figure 5. For all of the Phase 1 testing, the RRU and vBBU under test were provided by different vendors. The vRAN solutions were tested to characterize their behavior in the presence of fronthaul impairments (latency, jitter and packet loss) introduced through a network emulator and varying radio conditions. Some testing was done with real UEs (typically placed in a shielded box) and at other times UE emulators were used. Each Community Lab provided its own solution for a test EPC and traffic generation.

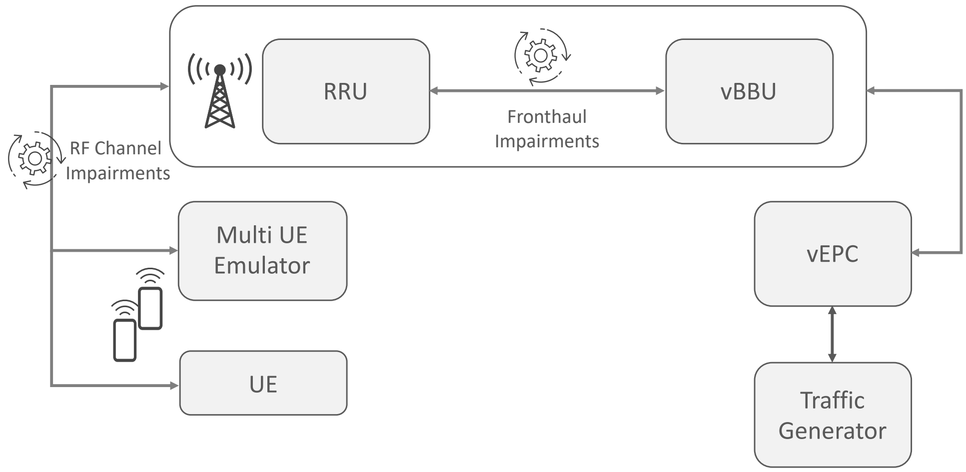

Figure 5 - Generic lab setup

2.2 Key characteristics

All the vRAN solutions tested provided a service that offers close to the maximum radio capacity when the fronthaul bandwidth was not constrained.

When introducing fronthaul impairments (bandwidth congestion, latency, jitter, packet loss), most solutions were able to maintain service. The extent to which the service degrades in response to these impairments does vary with implementation. In general, when talking about fronthaul bandwidth, the fronthaul is considered to be degraded when the bandwidth drop starts impacting the radio interface downlink and uplink throughput.

From the testing, we were able to demonstrate:

- Constrained fronthaul throughput, below a certain threshold, will constrain air interface user plane throughput. The exact threshold can depend on the implementation and may be different for each data direction i.e. UL vs DL.
- Throughput can degrade gracefully, approximately linearly, as fronthaul throughput is constrained.
- A UE can attach at latency up to around 30ms depending on configuration and implementation, even if an attached UE could sustain throughput at higher latency.
- High latency fronthaul can limit the UE attach rate (i.e. UE that can attach per second) to <25 UEs per second.
- Systems maintain near full throughput with high packet loss (up to 1%), though throughput begins to slightly degrade when packet loss exceeds 0.1%.
- Significant jitter can be tolerated with very little effect on air interface throughput.

2.3 Constraining fronthaul throughput

In the testing performed in the 4 Community Labs, a range of behaviors has been observed. Two performance indicators emerged as germane to fronthaul which are the efficiency of the fronthaul compression and the gracefulness of efficiency degradation.

Fronthaul overhead

Fronthaul overhead can be expressed as a ratio of the bits needed on the fronthaul interface over the bits served on the radio air interface. In the ideal scenario (S1 backhaul) this value is close to 1. In an option 8 split (e.g. CPRI) this value can be 2400 or higher.

The ability of a fronthaul system to trend the efficiency metric closer to 1 indicates higher performing compression in the plots below.

Graceful degradation

In the case of graceful degradation, the ideal behavior would be consistent fronthaul overhead, or a vertical line in the plot: this would indicate that 1 bit per second of fronthaul available capacity always caries the same number of bps of LTE traffic. A fronthaul system that exhibits the same overhead at high fronthaul bandwidth as it does at low fronthaul bandwidth is able to degrade air interface throughput gracefully when fronthaul bandwidth is constrained.

A system that exhibits rapid growth in the overhead metric as available bandwidth decreases will exhibit a rapid decrease in the air interface capacity as fronthaul bandwidth is constrained. This is a less desirable behavior. In the graph below, this would be represented as long tail, effectively allowing less and less LTE bps to be transmitted when fronthaul capacity reduces.

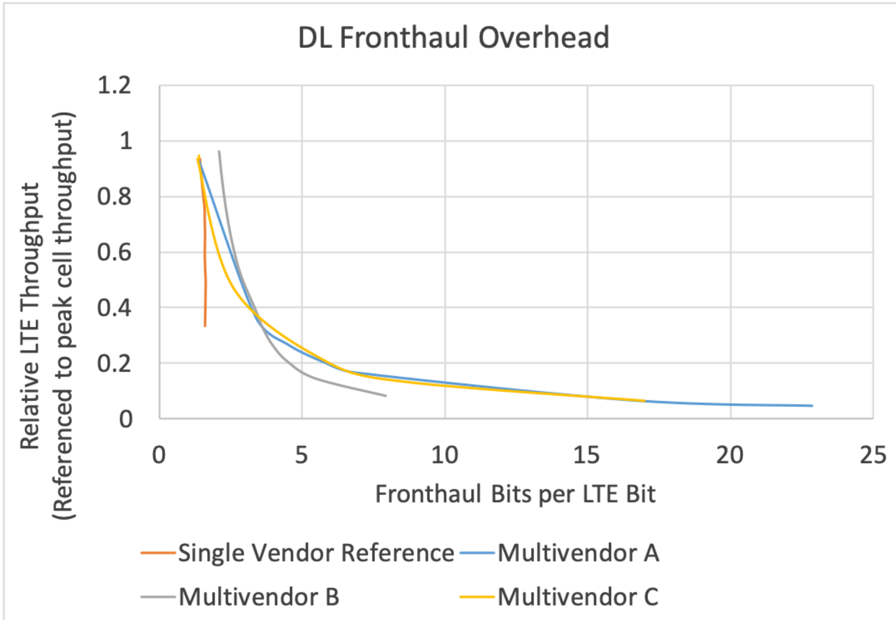

Figure 6 - Downlink Fronthaul Efficiency

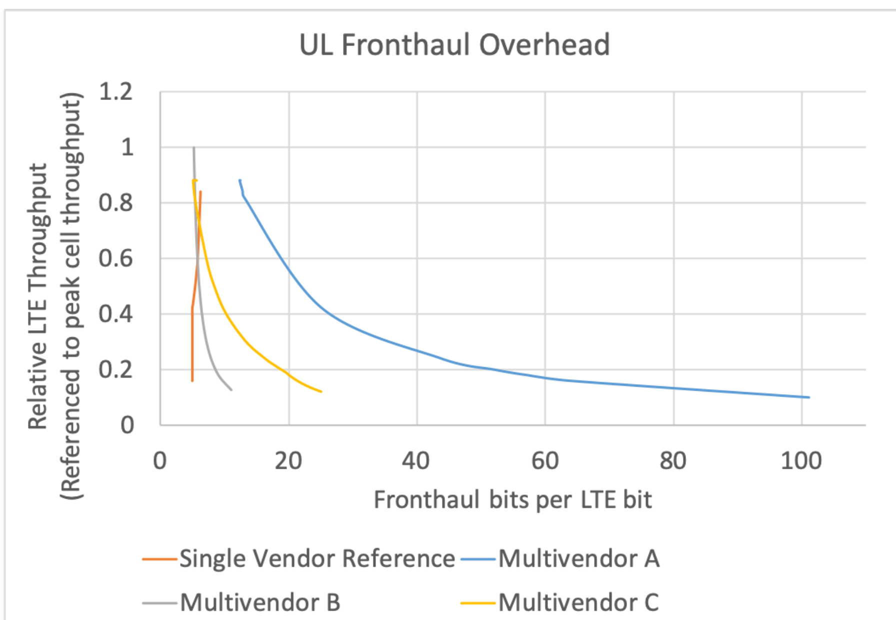

Figure 7 - Uplink Fronthaul Efficiency

As seen in the plots above, the implementations tested have exhibited a range of overhead behaviors. The single vendor reference in both DL and UL provides near ideal behavior with consistent efficiency and the lowest overhead.

In the DL the levels of overhead varied based on vendors compression implementations. In the UL, it can be seen that a wide range of compression approaches (varying from no compression to near ideal) have been implemented in the multivendor solutions.

While none of the multi-vendor solutions matched the performance of the single vendor reference, it is expected that as solutions mature the gap will close significantly.

2.4 Increased fronthaul latency

Results in Figure 9 show the latency performance from one particular multi-vendor solution. In this example we can see that near-maximum throughput is achieved in both uplink and downlink until the round-trip latency is tens of milliseconds. As latency increases beyond the point that radio throughput reduces, there is a gradual degradation in throughput (the exception in this case is uplink TCP, which falls relatively quickly)

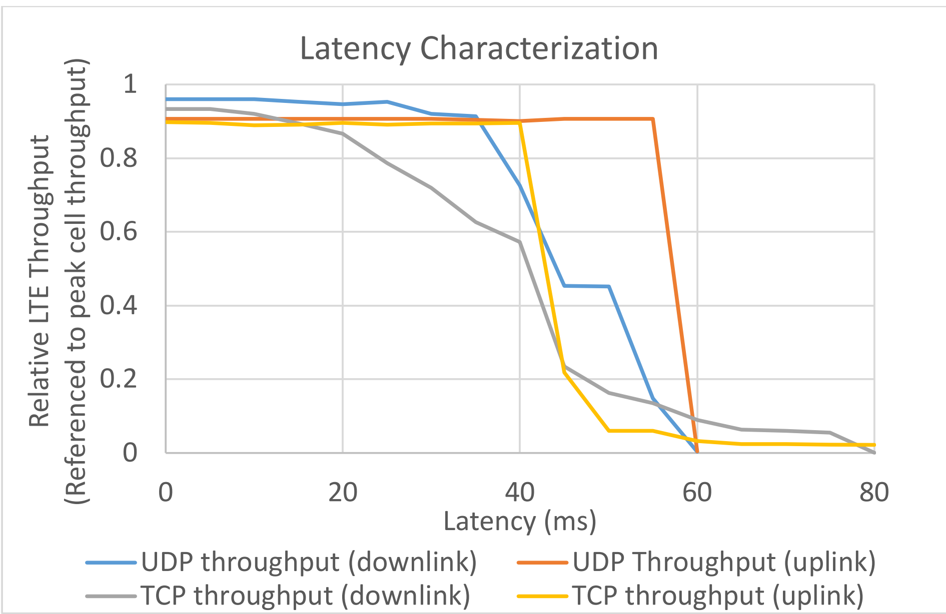

Figure 8: LTE Throughput versus Fronthaul Latency

These latency results shown here are for attached UEs, which can sustain throughput over a wide range of latency values (up to ~60ms). We have discovered different characteristics for UEs that undergo the attach process, which is more sensitive to latency, showing constraints around 30ms depending on configuration and implementation.

High latency fronthaul can limit the UE attach rate (i.e. UE that can attach per second) to <25 UEs per second, which may not be an issue for many scenarios, but will be a limiting factor for others.

2.5 Increased fronthaul packet loss rates

The developed vRAN solution is also tolerant to packet losses on the fronthaul link. Near-maximum radio capacity can be achieved until packet loss rates exceed 0.1%, then we see a noticeable drop in radio throughput. The normalized downlink throughput falls faster than the normalized uplink throughput, indicating that DL is more sensitive to errors compared to UL.

Figure 10 represents a middle ground result. Some solutions tested showed impact to throughput at 0.001% while others did not show throughput impact up to 2% loss. In the latter case some throughput was achievable up to 6% packet loss.

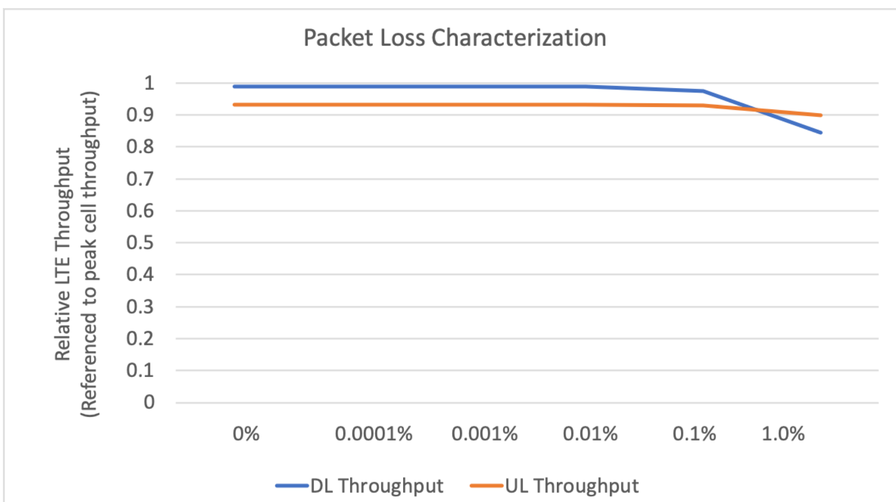

Figure 9: LTE Throughput versus Packet Loss

2.6 Multi-impairment performance

While the above results help demonstrate the vRAN behavior in response to individual transport impairments, it is important to demonstrate that the solution can perform in the presence of a combination of fronthaul impairments.

In addition to controlled lab impairment testing, fronthaul solutions were also tested over various non-ideal network types. Solutions were tested over unmanaged ethernet, DOCSIS networks, and PON networks. These networks introduced combined impairments including constrained bandwidth, increased latency (in the case of the DOCSIS network asymmetrical latency), and peak to peak jitter significantly exceeding 1ms.

In all tested networks, the effects of real-world latency and jitter were negligible, and it was found that when enough fronthaul bandwidth was allocated all solutions could achieve peak cell throughput.

Business case

Mobile data consumption is constantly growing, and mobile network operators are required to build scalable network infrastructure and increase the available capacity to match the user demand. At the same time, mobile operators are looking for ways to drive down network deployment and operational cost and reduce CapEx and OpEx by virtualizing components of the RAN and providing flexible transport options. A disaggregated RAN architecture based on non-ideal fronthaul transport, can help offset the pressures of large capital outlays, provide flexibility over transport and reduce maintenance costs.

The decoupling of hardware and software will enable vRAN (vBBU) to offer significant cost savings. A vBBU applies principles like network functions virtualization (NFV) – moving services to virtual machines and containers. vBBUs will consist of centralized pools of virtualized baseband units as opposed to BBU onsite with RRUs. vRAN can also provide enhanced service provisioning capabilities improving operational efficiencies.

A vRAN architecture based on a BBU/RRU Option 7-2 split like the one tested in the vRAN fronthaul project enables the use of existing non-ideal transport infrastructure with possible moderate upgrades to reduce OpEx that would be spent on dark fiber leases. Signal transport infrastructure is often different all around the world and can result in challenging multi-region deployments. The variation is primarily due to access to certain materials (i.e Copper or dark-fiber) or a preference for an alternative transport method such as Microwave or hybrid fiber-coaxial cable (HFC combines optical fiber and coaxial cable).

vRAN fronthaul non-ideal transport moves away from legacy network architectures, by moving away from fiber centric deployments. Network deployments with vRAN fronthaul are more flexible and cost-effective because they disaggregate the RAN and provide non-ideal fronthaul methods that can be mapped to the solutions validated in TIP Community Labs and described in this paper. For example, when deploying in an emerging market, which is unlikely to have extensive access to ideal fronthaul (i.e. fiber), network operators can purchase fronthaul that can support their use cases and is cost-effective in the deployment zone.

Deploying vRAN with non-ideal fronthaul

The goal for the TIP Community Lab activities was to verify functionality of vRAN components in a controlled environment using non-ideal transport and provide sufficient performance characterization and confidence about the use cases these vRAN solutions can support.

The solutions coming out of the TIP Community Labs should be sufficiently mature that they could become part of field and, later, market trials. The end goal is that this will lead to large-scale commercially deployed vRAN solutions. As the Community Lab activities are in the final stages, our attention is now switching focus towards these next stages.

4.1 Key achievements

The Community Lab activities have successfully enabled us to drive the vRAN ecosystem in the following ways:

- **Multi-vendor vRAN solutions that work** – In each lab we have successfully demonstrated at least one working vRAN solution where the vBBU and RRU come from different technology providers. Thus far 3 vBBU implementations and 4 RRU products have been tested in different permutations across labs.
- **vRAN solutions that work with non-ideal fronthaul** – The results from the TIP Community Labs confirm that the vRAN solutions can operate in the presence of non-ideal fronthaul. We also have some baseline figures of how different impairments will affect radio performance.
- **Separation of software from hardware** – Across the labs we have tested 2 layer-1 protocols. Switching between these protocols does not necessitate any hardware changes. One RRU partner provided the same hardware to two different labs, each using different layer-1 protocols. Furthermore, in all labs, the vBBUs were hosted on Commercial Off-the-Shelf (COTS) servers.
- **Creating a vRAN community** – The project group has 400+ members of which 30+ represent mobile operators. Since the project was formed in 2017, there have been several industry groups that have had similar visions. In order to make vRAN a success we want to agree on common vRAN solutions that can support a wide range of use cases. Alignment with other industry and standards organizations is a focus area for TIP.

- **Vision of how to get to live deployments** – Through the project activities, the group has learned what the current barriers are to get to a commercial deployment and is now making steps to overcome them, as described in the next section.

4.2 Current and future work areas

The TIP Community Labs have shown that disaggregated vRAN solutions can be developed for a wide range of use cases with non-ideal transport. However, there are undoubtably additional work areas before such vRAN solutions can be ready for field trials and deployments at scale.

- **OAM** – A common Operations, Administration, and Maintenance (OAM) design, or as a minimum a standard OAM interface, is a key requirement for multi-vendor vRAN to be a commercial reality. Multi-operator vRAN solutions are also enabled by ensuring this common OAM design, which could allow a neutral host to provide correct access for the operators it supports.
- **Security** – Disaggregating the RAN, does mean that RAN security covers more than just the cell site and S1/X2 interfaces. There are more interfaces and more components to protect. The flexibility of vRAN means that the vBBU could exist in many locations (e.g. on an edge server, in a data center), all of which come with different security considerations.
- **Radio Performance Enhancements** – On-going lab testing in non-ideal fronthaul conditions, such as the boundary conditions of Table 2, is focusing on proving that the solutions maintain acceptable performance, with minimal deviations, in cell edge conditions, multi-user scenarios, user attach latency, and mobility speeds. Additionally, one of the foreseen benefits of centralizing the radio processing, is that cells with overlapping coverage could all share a common vBBU or have co-located vBBUs. This additional coordination can improve interference management, providing higher spectrum efficiency and better cell-edge performance. Future activities need to demonstrate the value of this advantage of vRAN.
- **Virtualization Enhancements** – One of the areas of focus for the group is to understand and validate performance improvements by migrating the multi-vendor implementations from Virtual Machines to Container based solutions.
- **Trials** – Before a commercial launch, field and market trials are needed. In particular we need to demonstrate the stability and scalability of the solution as it matures. The trials will also allow us to understand the full end-to-end solution,

providing the opportunity of systems integrators to show value in driving the adoption of vRAN

- **Interoperability Testing** – Interoperability with commercial grade packet core systems, network management systems, and UEs with high market penetration, along with validation of other mandatory 3GPP features is essential for such disaggregated vRAN solutions to get to commercial readiness. An agreed set of industry test requirements and test cases along with interoperability events such as PlugFests, where the solution providers can test against these requirements, will be very valuable in this respect.
- **5G** – The project has focused on LTE for the TIP Community Lab activities, as this is what the use cases require for early deployment. However, the principles of the LTE solution can be applied to 5G NR and we need to ensure that the next steps of the activity ensure the NR solution is clearly defined.
- **vRAN Systems Integrators –** As there are still many gaps to fill (as identified above) and the vRAN solution could include components from many vendors (RRU, vBBU, compute platform, security functions), systems integrators could play a key role in providing an end-to-end vRAN solution that can be commercially deployed.

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Abbreviations

3GPP	3rd Generation Partnership Project
AM	Acknowledge Mode
BBU	Baseband Unit
CoMP	Coordinated Multi-Point
CPRI	Common Public Radio Interface
CQI	Channel Quality Indicator
DOCSIS	Data Over Cable Service Interface Specification
EPC	Evolved Packet Core
GPON	Gigabit Passive Optical Networks
HARQ	Hybrid Automatic Repeat reQuest
ICIC	Inter Cell Interference Coordination
MAC	Medium Access Control
MIMO	Multi Input Multi Output
NGMN	Next Generation Mobile Networks
NR	New Radio
OAM	Operations Administration and Maintenance
PDDCH	Physical Downlink Control Channel
PDSCH	Physical Downlink Shared Channel
PHY	Physical Layer
PUSCH	Physical Uplink Shared Channel
RACH	Random Access Channel
RLC	Radio Link Control
RRU	Remote Radio Unit
TCO	Total Cost of Ownership
TCP	Transport Control Protocol
TIP	Telecom infra project
UDP	User Data Protocol
UE	User Equipment
vRAN	Virtualized Radio Access Network

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