Long-Haul, High-Capacity 8GHz Terrestrial Microwave Radio Link In-Field Availability Assessment

Network as a Service (NaaS) Solution Group

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Authors

Erik Boch

Meta

eboch@fb.com

Julius Kusuma

Meta

jkusuma@fb.com

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1.0 Executive Summary

The Network-as-a-Service (NaaS) model is particularly well-suited to enable the expansion of mobile connectivity to remote locations that are typically not deemed economically viable using traditional models due to lack of infrastructure, low population density, and high deployment and operational costs. For the purposes of this paper, NaaS is defined as an open access network where a neutral host (NaaSCo) operates a shared Radio Access Network (RAN) that is connected to multiple Mobile Network Operator (MNO) Core Networks.

Microwave backhaul is an important component of the rural NaaS model because it provides lower Capex and faster deployment than fiber, and lower Opex than satellite. However, due to the commercial challenges associated with deploying networks in rural areas and the need to reduce the number of RAN and backhaul sites deployed, microwave backhaul links are often required to be extended to great lengths to make the business case viable, while still maintaining acceptable throughput and availability metrics.

This white paper presents the design and deployment methodologies that were employed in long haul (~50km), high capacity (~1.3 Gbps), high availability (>99.99%), carrier-grade wireless microwave links deployed for mobile site backhaul in Peru, using commercially available equipment and standard design software.

We also present the field measured results gathered over time. The performance of these links was evaluated over a 10-month period, part of which included the rainy season. The results presented in this white paper illustrate that long-haul, high-capacity microwave links can provide connectivity to rural broadband RAN sites while achieving acceptable capacity and availability metrics in a difficult, rain forest environment. The use of standard radio features such as Cross Polarization Interference Canceller (XPIC), Spatial Diversity (SD), Automatic Transmit Power Control (ATPC), and Adaptive Coding and Modulation (ACM) enables this high performance.

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2.0 Introduction

2.1 Background

One of the dominant technologies employed in rural/deep-rural networks is long-haul microwave[1]. Operators have indicated some concerns about the availability-performance of that long-haul, high-capacity microwave that is used to backhaul rural/deep-rural telecom locations.

In order to deploy these microwave links, predictions of availability performance are undertaken, usually using the predictive methodology of ITU-530-13/14. The availability performance of long-haul microwave backhaul is a vital component in the overall operation of a rural site. This is especially important for rural/deep-rural deployment use cases where long-haul, high-capacity backhaul links are needed to optimize the deployment costs of implementing 4G. The obvious main benefit of these long-haul links is the minimization of radio tower infrastructure, which is the largest deployment cost element associated with terrestrial wireless networks.

The goals of this activity were:

- To create carrier-grade backhaul functionality to the settlement of Atalaya, Peru
- Facilitate backhaul for near-future deployment of 3G & 4G RAN sites in the settlement of Atalaya
- Deploy and test high capacity XPIC-capable licensed backhaul solution for long-haul LoS wireless links
- Facilitate the creation of a fanout switching center which can host future wireless spurs out to smaller settlements in the vicinity of Atalaya
- Deploy, and gain an understanding of, greenfield new-tower construction in deep remote areas where physical site access is extremely challenging
- Gather insights into needed technology developments to make deep rural

[1] Ericsson data indicates that > 60% - 70% of mobile sites globally are backhauled using microwave radio link technology

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deployments more cost effective and/or faster

- Gather technical, practical, and deployment-cost inputs to the formulation of a rural playbook to be shared with the Telecom Infra Project (TIP) community.

2.2 Results

The focus of this project is to conduct field verifications of the availability performance of long-haul (> 40 km), high capacity (> 1.3 Gbps in each direction) microwave radio links designed using 60% F1 clear-line-of-sight (CLoS) techniques. ITU-530-13/14 is employed for availability predictions.

The field validations were conducted on two long haul radio links operated by Mayu Telecommunicaciones (Mayutel) in rural Peru. The project involves gathering on-site weather data along with Performance Monitoring (PMON) information over long periods of time. The long-term data gathering was conducted to validate statistical availability performance over a variety of seasonal variations and weather conditions.

The links were deployed in 2018 as part of the Mayutel commercial network, and the full capacity mode of operation and monitoring of the links was brought online in late July 2019. This study has shown & confirmed that long haul, high-capacity radio links can deliver exceptional availability performance. The radio links observed in this study were capable of ~1.3 Gbps throughput in each direction, along with very low latency (on the order of a few hundred microseconds 1-way latency), making them suitable for various long range backhaul applications, including cellular system backhaul.

Overall, during the Nov 1, 2019, to May 31, 2020, test/observation window the availability performance measured (> 99.99%) and exceeded the predicted levels (> 99.95%)[2].

[2] The operator's requirement was a minimum of 99.9% availability.

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2.3 Network Design Overview

At the start of this project in 2017, the settlement of Satipo in Peru had an existing fiber POP. It was desirable to provide a fiber POP extension from Satipo to Atalaya, about 100km from one another.

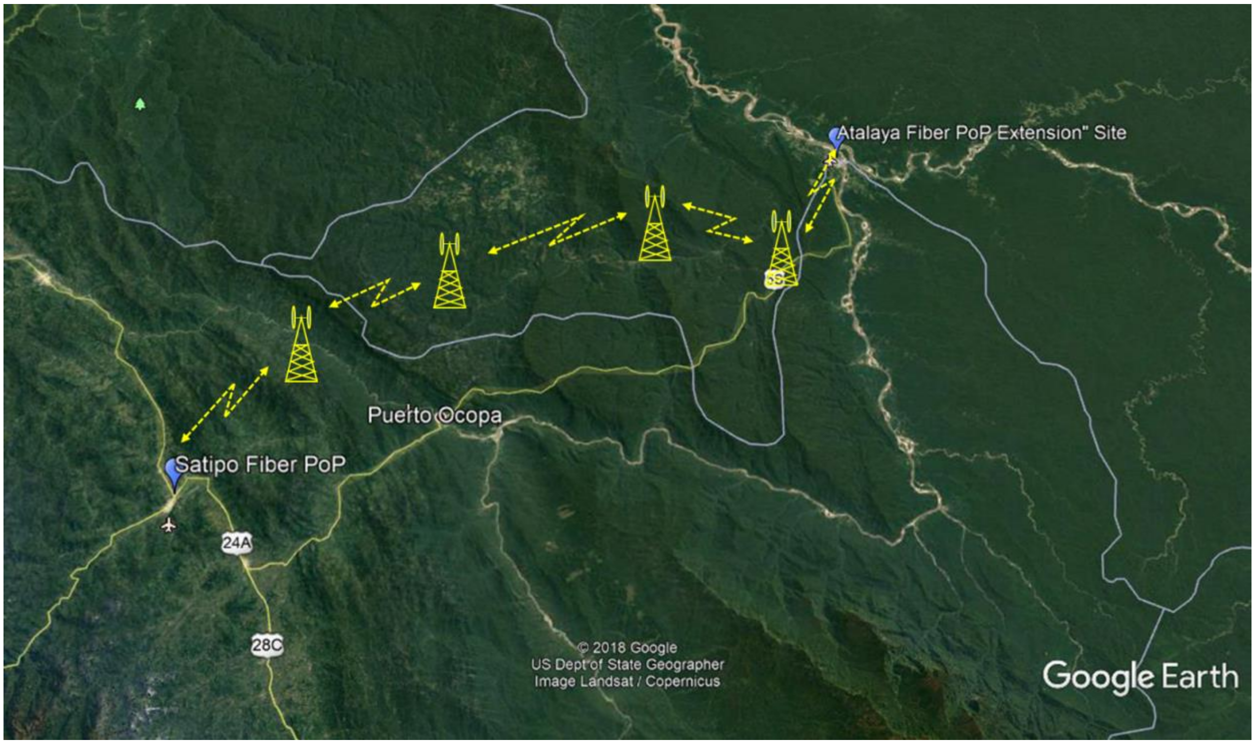

Figure 1 - Overhead map of the Satipo-to-Atalaya service area of interest

The main challenges involved in the backhaul deployment in this pilot revolved around the following:

- Maximizing the capacity of the Atalaya extension-POP
    - Target 1 - 2 Gbps in each direction, full duplex (2 – 4 Gbps aggregate of go + return paths) with a minimum of 500 Mbps in each direction
- Deployment of low-delay functionality consistent with fiber-optic technology
    - < 200us 1-way delay per hop
    - < 1ms 1-way delay for the backhaul route
- Delivery of a carrier-grade backhaul solution
    - Carrier-grade, licensed Common Carrier radio operation, carrier grade Performance Monitoring (PMON)

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- Availability of > 99.95% per backhaul hop

The desire to achieve high availability was challenged by the normal desire to minimize the tower count required to complete the backhaul route. This trade-off drives up the per-hop link distances, which puts pressure on each backhaul link's availability performance.

In the initial design, we followed conventional deployment guidelines defined in collaboration with our operator partners. This includes:

- < 30km hop distance
- < 40m tower heights
- 60% F1 clearance assuming 20m foliage canopy & 5m margin
- 6' maximum antenna size, < 4' desired
- Reuse of existing towers where possible
- New towers (if needed) to be located in road-accessible locations

However, strict adherence to these guidelines resulted in a large number of relay sites, making the network deployment infeasible. In particular, relay sites that don't also provide RAN functionality incur significant infrastructure cost, but don't generate any revenue.

We then revised the guidelines by relaxing the per-hop distance constraint and considering potential relay tower locations away from passable roads. The result of the re-design is shown in Figure 2.

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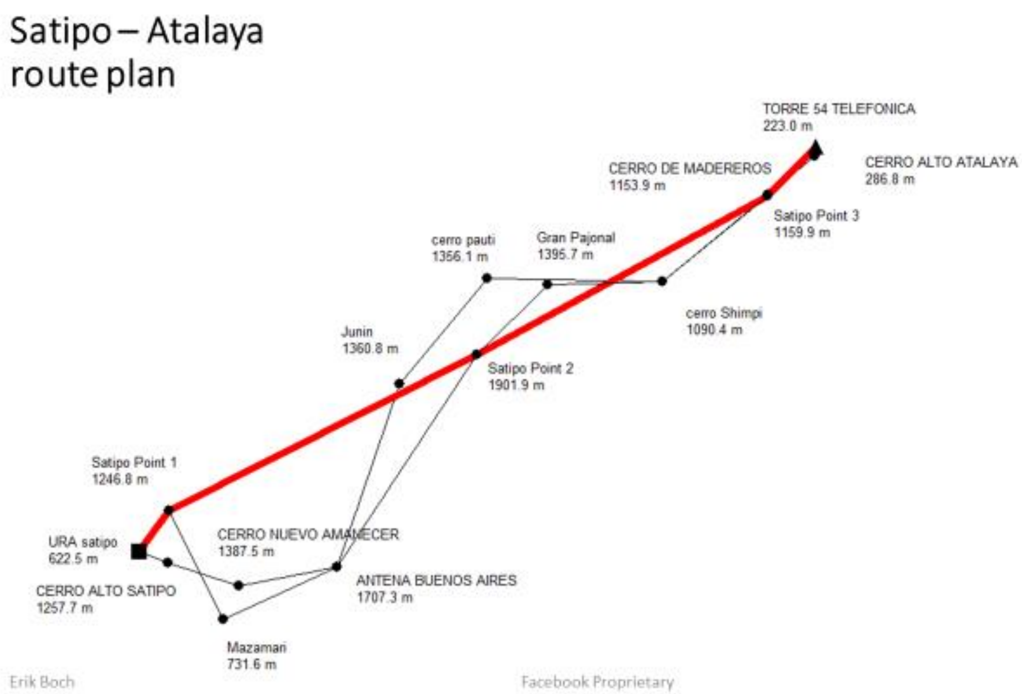

Figure 2 - The finalized Satipo-to-Atalaya microwave route plan

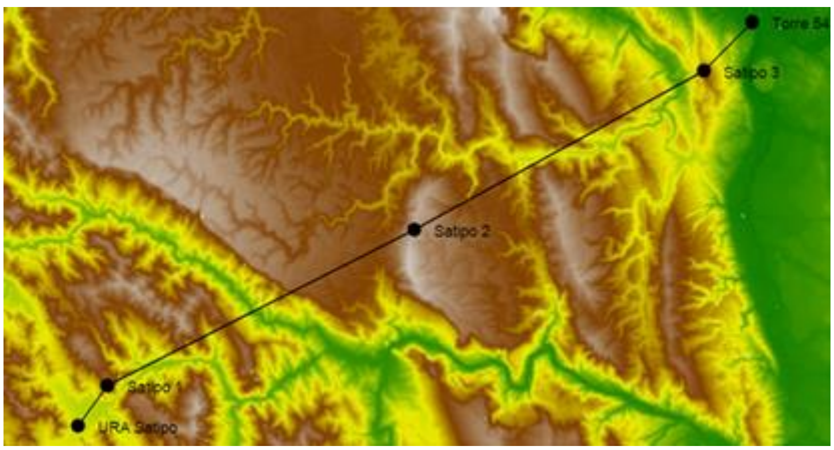

Figure 3 - The finalized Satipo-to-Atalaya microwave route plan overlaid on SRTM topo data

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3.0 Microwave Link Designs

3.1 Microwave Radio Considerations

To achieve high capacity, a solution using Cross Polarization Interference Canceller (XPIC) solution was deployed along with *wide channel* support. XPIC employs co-channel operation such that two orthogonal (isolated) radio channels are created between the endpoints of each link, effectively doubling the capacity of the links.

Analysis of the radio links (particularly the longer links) indicated that Clear-Line-of-Site (CLoS) multipathing represented a significant risk to achieving the desired availability performance targets. To address this, the following de-risking measure were undertaken:

- Radio links are configured for an easy conversion to Spatial Diversity operation by altering the antenna configuration and the radio ODU functional (Software) configuration.
- The radio tower physical configurations were also designed to accommodate the antenna configuration change, should that be required.
- The radio links were analyzed for their performance using Spatial Diversity (SD). SD employs varied radio paths between the link ends to combat dominant multipathing effects

Compared with XPIC, SD's attributes are:

- The same dual-channel radio system operated in SD achieves only half the capacity as an XPIC-configured solution for the same/similar backhaul radio ODU cost
- SD systems require dual antennas which are separated by a prescribed/designed vertical distance on the tower. This increases the required tower height and the wind-loading forces that the tower will be exposed to
- The SD configuration is effective in increasing availability in the presence of multipath.

In conjunction with the operator-partner Mayutel, a decision was taken to deploy an

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XPIC configuration, and to configure the towers so that the radio systems could be reconfigured for SD operation in case the overall backhaul path availability falls below the operator's expectations.

In our design, the long-range links are strung in a line (particularly Satipo 1 – 2 – 3). As such, there is some concern regarding interference along this path. This was assessed in PathLoss using the model shown in Figure 4. With proper consideration for bucking, no consequential interference was predicted by the analysis.

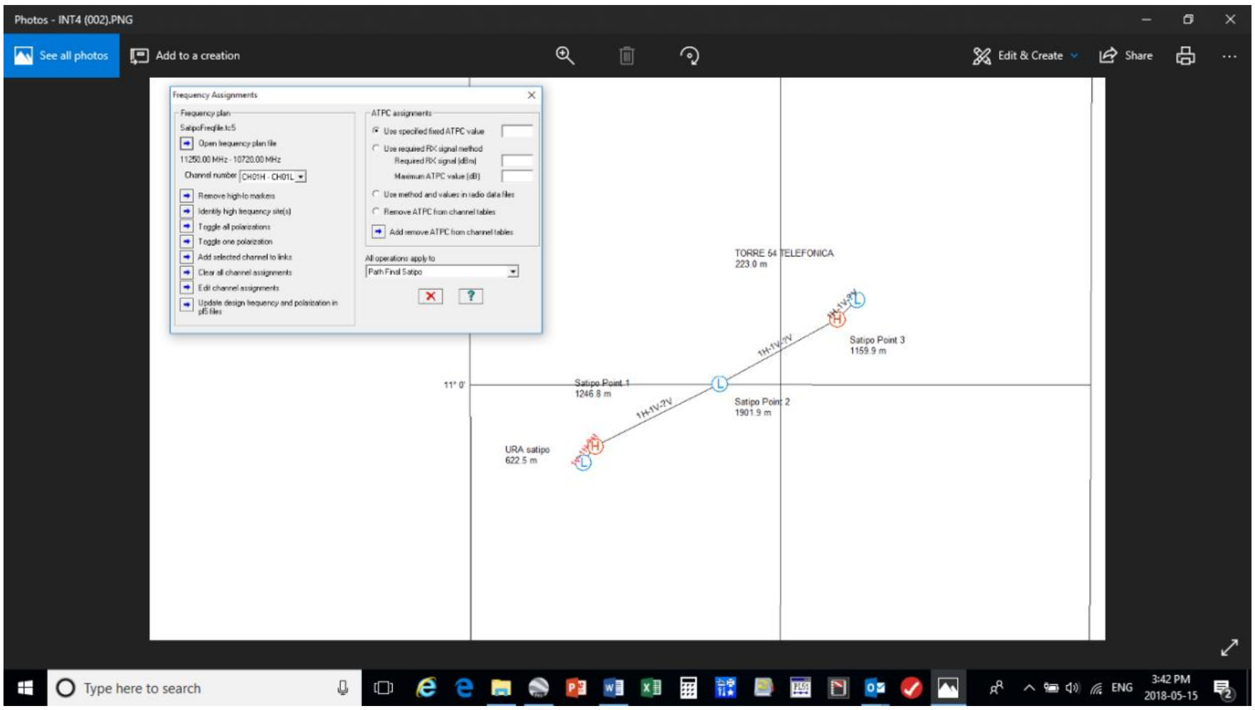

Figure 4 - Frequency and Polarization plan for the Satipo 1-2-3 links

3.2 Link Profiles and Designs

We use Pathloss 5.0™ -- a standard microwave backhaul design software -- with basic SRTM (Shuttle Radar Topography Mission) data to predict and assess the feasibility of the links. We use normal Fresnel clearance requirements and link availability attributes. For Fresnel clearance, the following criteria were applied:

- 8GHz operation in XPIC mode (H polarization used as availability-limiting mode)
- 80MHz (wide channel operation) with ACM-enabled
- 60% F1 clear @ K=1.33 & K = 0.8

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- 20m tree canopy with 5m clearance requirements
- Rain Zone N
- < 6' antennas

In Figure 5, we share the performance predictions of the two long-haul links between Satipo 1, Satipo 2, and Satipo 3. These links provide 1300 Mbps (continuous) in each direction, over 49.16 km and 47.18 km respectively.

Site Information															
Site A	LAT	LONG	Tower Height (m)	Ant Height (m)	Ant Size (m)	Ant Gain (dBi)	Site B	LAT	LONG	Ant Size (m)	Ant Gain (dBi)	Tower Height (m)	Antenna Height (m)	Link Dist (km)
Satipo TEF PoP							Satipo Rooftop	11 14 58.34 S	74 6 10.98 W					~200m, fibered
Satipo Rooftop	11 14 58.34 S	74 6 10.98 W	12+3 (rooftop tripod)	14.5	0.5	35.5	Satipo 1	11 11 45.86 S	74 35 51.21 W	0.5	35.3	35	30	7.14
Satipo 1	11 11 45.86 S	74 35 51.21 W	35	20	1.3	40.6	Satipo 2	10 59 45.82 S	74 11 45.07 W	1.3	40.6	35	20	49.16
Satipo 2	10 59 45.82 S	74 11 45.07 W	35	20	1.3	40.6	Satipo 3	10 47 28.69 S	73 49 2.20 W	1.3	40.6	35	21	47.18
Satipo 3	10 47 28.69 S	73 49 2.20 W	35	25	0.5	35.5	Atalaya 36m	10 44 26.29 S	73 45 20.04 W	0.5	35.3	36	30	8.77

Site Information			Optimal Propagation Conditions								Poor Propagation Conditions							
Site A	Site B	Freq Band (GHz)	PTx	MDS	PRx (clear weather)	RF Chan Size (MHz)	Mod	D/L Thruput (Mbps)	U/L Thruput (Mbps)	Approx Avail	PTx	MDS	PRx (clear weather)	RF Chan Size (MHz)	Mod	D/L Thruput (Mbps)	U/L Thruput (Mbps)	Approx Avail (%)
Satipo TEF PoP	Satipo Rooftop	N/A - fibered																
Satipo Rooftop	Satipo 1	11	24	-58.5	-37	80	1024 QAM	1370	1370	99.994%	28	-82	-33	80	QPSK	244	244	0.0030
Satipo 1	Satipo 2	8	24	-58.5	-41	80	1024 QAM	1370	1370	99.961%	28	-82	-37	80	QPSK	244	244	0.0050
Satipo 2	Satipo 3	8	24	-58.5	-40	80	1024 QAM	1370	1370	99.969%	28	-82	-36	80	QPSK	244	244	0.0040
Satipo 3	Atalaya 36m	11	24	-58.5	-39	80	1024 QAM	1370	1370	99.997%	28	-82	-37	80	QPSK	244	244	0.0020

Figure 5 - High-level overview of the link designs and attributes

Rio Santa to Toncama Link (aka Satipo1 to Satipo2)

This is a 49.16 km link supporting 1300Mbps (continuous) in each of the two link directions.

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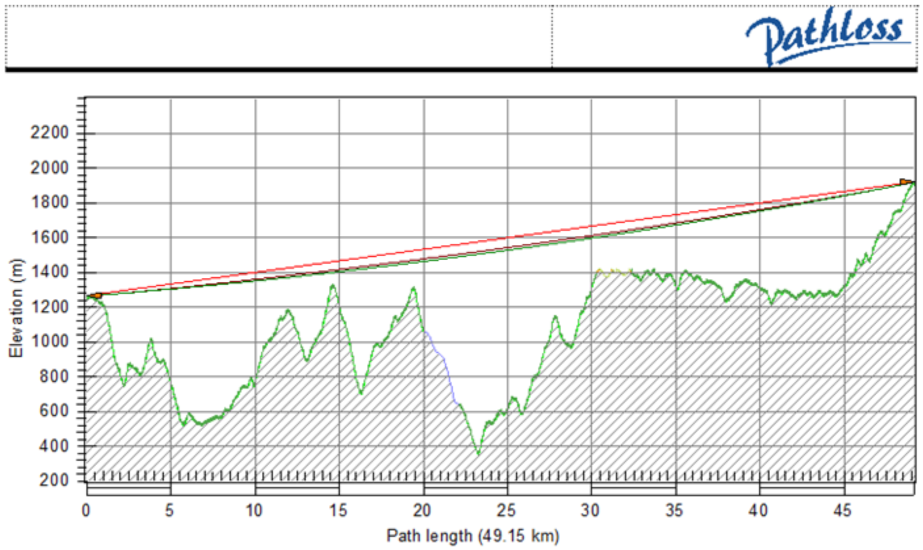

F = 8000.00 MHz K = 1.33 %F1 = 60.0

	Satipo Point 1	Satipo Point 2
Latitude	11 11 45.86 S	10 59 45.82 S
Longitude	074 35 51.21 W	074 11 45.07 W
True azimuth (°)	63.29	243.21
Vertical angle (°)	0.60	-0.93
Elevation (m)	1246.80	1901.88
Tower height (m)	30.00	30.00
Antenna model	VHLPX4-7W (TR)	VHLPX4-7W (TR)
Antenna gain (dBi)	40.60	40.60
Antenna height (m)	20.00	20.00
TX loss (dB)	0.50	0.50
RX loss (dB)	0.50	0.50
Radio model	IP20C-8-80X-A_1501	IP20C-8-80X-A_1501
Polarization	Horizontal	

	TX power (dBm)		RX threshold level (dBm)		EIRP (dBm)		Receive signal (dBm)		Thermal fade margin (dB)		Flat fade margin - multipath (dB)	
1KHQAM 641-784Mbps	**24.00**	**24.00**	**-51.75**	**-51.75**	**64.10**	**64.10**	**-43.68**	**-43.68**	**8.07**	**8.07**	**7.76**	**7.76**
1KLQAM 604-738Mbps	24.00	24.00	-52.75	-52.75	64.10	64.10	-43.68	-43.68	9.07	9.07	8.75	8.75
512QAM 555-679Mbps	24.00	24.00	-55.75	-55.75	64.10	64.10	-43.68	-43.68	12.07	12.07	11.92	11.92
256QAM 505-618Mbps	24.00	24.00	-58.25	-58.25	64.10	64.10	-43.68	-43.68	14.57	14.57	14.37	14.37
128QAM 439-536Mbps	24.00	24.00	-61.25	-61.25	64.10	64.10	-43.68	-43.68	17.57	17.57	17.19	17.19
64QAM 371-454Mbps	24.00	24.00	-64.25	-64.25	64.10	64.10	-43.68	-43.68	20.57	20.57	19.94	19.94
32QAM 304-371Mbps	24.00	24.00	-67.25	-67.25	64.10	64.10	-43.68	-43.68	23.57	23.57	22.35	22.35
16QAM 231-283Mbps	24.00	24.00	-70.75	-70.75	64.10	64.10	-43.68	-43.68	27.07	27.07	24.99	24.99
8PSK 162-198Mbps	24.00	24.00	-72.25	-72.25	64.10	64.10	-43.68	-43.68	28.57	28.57	26.26	26.26
QPSK 114-140Mbps	24.00	24.00	-81.50	-81.50	64.10	64.10	-43.68	-43.68	37.82	37.82	32.66	32.66

	Worst month multipath		Annual multipath		Annual rain		Total annual		Time in mode (%)	
1KHQAM 641-784Mbps	**99.7710**	**99.7710**	**99.9445**	**99.9445**	**99.9657**	**99.9657**	**99.9102**	**99.9102**	**99.9102**	**99.9102**
1KLQAM 604-738Mbps	99.8465	99.8465	99.9628	99.9628	99.9744	99.9744	99.9371	99.9371	0.0269	0.0269
512QAM 555-679Mbps	99.9473	99.9473	99.9872	99.9872	99.9888	99.9888	99.9760	99.9760	0.0389	0.0389
256QAM 505-618Mbps	99.9737	99.9737	99.9936	99.9936	99.9933	99.9933	99.9869	99.9869	0.0109	0.0109
128QAM 439-536Mbps	99.9873	99.9873	99.9969	99.9969	99.9960	99.9960	99.9929	99.9929	0.0060	0.0060
64QAM 371-454Mbps	99.9934	99.9934	99.9984	99.9984	99.9975	99.9975	99.9959	99.9959	0.0030	0.0030
32QAM 304-371Mbps	99.9961	99.9961	99.9991	99.9991	99.9983	99.9983	99.9974	99.9974	0.0015	0.0015
16QAM 231-283Mbps	99.9978	99.9978	99.9995	99.9995	99.9990	99.9990	99.9984	99.9984	0.0010	0.0010
8PSK 162-198Mbps	99.9984	99.9984	99.9996	99.9996	99.9992	99.9992	99.9988	99.9988	0.0003	0.0003
QPSK 114-140Mbps	99.9996	99.9996	99.9999	99.9999	99.9997	99.9997	99.9996	99.9996	0.0009	0.0009

Multipath fading method - Rec. ITU-R P.530-7/ 8
Rain fading method - Rec. ITU-R P.530-7 (R837-5)

Figure 6 - Rio Santa to Toncama (aka Satipo1 to Satipo2) Link Predicted Performance Summary (Pathloss5.0)

As a summary, this link is statistically assessed and predicted to deliver the following:

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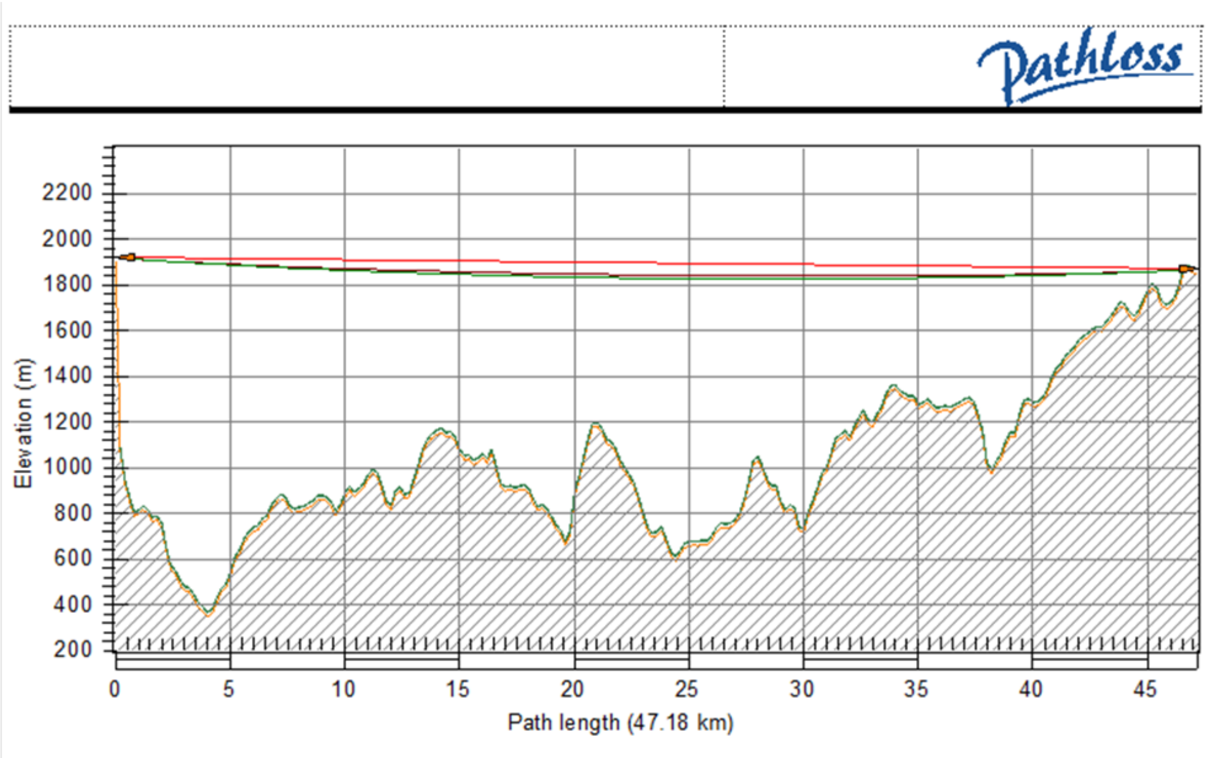
1. Annualized availability is ~ 99.9% in the high-QAM mode (1024QAM). 99.9% represents a 0.001 annualized outage expectancy, or ~ 31,000 seconds (or ~ 8.7 hours annually)
2. Nominal transmit power is configured to be: +24dBm
3. Expected clear-weather receive signal power level expected: -43 to -44 dBm, including an allocation of 3dB for field-factors (thus ~ -40 to -41 dBm without the 3dB field-factor considered)

Toncama to Contreras Link (aka Satipo2 to Satipo3)

This is a 47.18 km link supporting 1300Mbps (continuous) in each of the two link directions.



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F = 8000.00 MHz K = 1.33 %F1 = 60.0

	Satipo Point 2	Satipo Point 3
Latitude	10 59 45.82 S	10 47 28.69 S
Longitude	074 11 45.07 W	073 49 02.20 W
True azimuth (°)	61.35	241.28
Vertical angle (°)	-0.22	-0.10
Elevation (m)	1901.88	1851.00
Tower height (m)	30.00	30.00
Antenna model	VHLPX4-7W (TR)	VHLPX4-7W (TR)
Antenna gain (dBi)	40.60	40.60
Antenna height (m)	20.00	20.00
TX loss (dB)	0.50	0.50
RX loss (dB)	0.50	0.50
Radio model	IP20C-8-80X-A_1501	IP20C-8-80X-A_1501
Polarization	Horizontal	

Pathloss

	TX power (dBm)		RX threshold level (dBm)		EIRP (dBm)		Receive signal (dBm)		Thermal fade margin (dB)		Flat fade margin - multipath (dB)	
512QAM 555-679Mbps	24.00	24.00	-55.75	-55.75	64.10	64.10	-43.30	-43.30	12.45	12.45	12.33	12.33
256QAM 505-618Mbps	24.00	24.00	-58.25	-58.25	64.10	64.10	-43.30	-43.30	14.95	14.95	14.80	14.80
128QAM 439-536Mbps	24.00	24.00	-61.25	-61.25	64.10	64.10	-43.30	-43.30	17.95	17.95	17.70	17.70
64QAM 371-454Mbps	24.00	24.00	-64.25	-64.25	64.10	64.10	-43.30	-43.30	20.95	20.95	20.55	20.55
32QAM 304-371Mbps	24.00	24.00	-67.25	-67.25	64.10	64.10	-43.30	-43.30	23.95	23.95	23.18	23.18
16QAM 231-283Mbps	24.00	24.00	-70.75	-70.75	64.10	64.10	-43.30	-43.30	27.45	27.45	26.12	26.12
8PSK 162-198Mbps	24.00	24.00	-72.25	-72.25	64.10	64.10	-43.30	-43.30	28.95	28.95	27.47	27.47
QPSK 114-140Mbps	24.00	24.00	-81.50	-81.50	64.10	64.10	-43.30	-43.30	38.20	38.20	34.58	34.58

	Worst month multipath		Annual multipath		Annual rain		Total annual		Time in mode (%)	
1KHQAM 641-784Mbps	**98.9598**	**98.9598**	**99.6536**	**99.6536**	**99.9606**	**99.9606**	**99.6142**	**99.6142**	**99.6142**	**99.6142**
1KLQAM 604-738Mbps	99.2051	99.2051	99.7353	99.7353	99.9700	99.9700	99.7053	99.7053	0.0911	0.0911
512QAM 555-679Mbps	99.6198	99.6198	99.8734	99.8734	99.9864	99.9864	99.8598	99.8598	0.1545	0.1545
256QAM 505-618Mbps	99.7751	99.7751	99.9251	99.9251	99.9916	99.9916	99.9167	99.9167	0.0569	0.0569
128QAM 439-536Mbps	99.8763	99.8763	99.9588	99.9588	99.9949	99.9949	99.9537	99.9537	0.0370	0.0370
64QAM 371-454Mbps	99.9312	99.9312	99.9771	99.9771	99.9967	99.9967	99.9738	99.9738	0.0201	0.0201
32QAM 304-371Mbps	99.9602	99.9602	99.9867	99.9867	99.9978	99.9978	99.9845	99.9845	0.0107	0.0107
16QAM 231-283Mbps	99.9783	99.9783	99.9928	99.9928	99.9986	99.9986	99.9914	99.9914	0.0068	0.0068
8PSK 162-198Mbps	99.9841	99.9841	99.9947	99.9947	99.9988	99.9988	99.9936	99.9936	0.0022	0.0022
QPSK 114-140Mbps	99.9969	99.9969	99.9990	99.9990	99.9996	99.9996	99.9986	99.9986	0.0050	0.0050

Multipath fading method - Rec. ITU-R P.530-7/ 8
Rain fading method - Rec. ITU-R P.530-7 (user)

Figure 7 - Toncama to Contreras (aka Satipo2 to Satipo3) Link Predicted Performance Summary (Pathloss5.0)

Multipathing in Hilly, Mountainous Regions

The relatively low operating frequency of the link increases the availability-performance dependency on multi-pathing. However, multi-pathing tends to be more pronounced in flatter regions, or where radio links traverse large patches of open water. These flatter regions generate refractive humidity stratum during the diurnal solar-heating reversals (after sunset, after sunrise). These refractive layers tend to be pronounced in areas where there is also low wind, so the layers can form and remain, rather than be dispersed by wind.

In humid regions where the terrain is hilly, these refractive stratums tend to follow the terrain and therefore, even when they exist, they have less tendency to generate even/flat refractive barriers along the link. This can be more so the case when the terrain involved is flat, for example across open water, across a broad river-delta, or across flat farmers' fields, and so on.

The Pathloss5.0 prediction tool doesn't employ terrain variability in its assessment of multipath availability contributions, so it may provide a more pessimistic analysis

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result.

3.3 Equipment, Hardware, and Site Considerations

Radio equipment

To meet the performance requirements, we use the following guidelines in the selection of the radio equipment:

- All ODU, zero maintenance
- High Tx power capability
- Wide channel operation (80 MHz) at 1024QAM
- < 60W DC consumption
- XPIC, SD and ATPC features available
- 8 or 11 GHz available and certified for operation in Peru

Based on the above guidelines and equipment availability for this deployment, we selected the Ceragon IP-20C HP family.

Cell Site Routing (CSR)

The network design employs daisy chaining where the intermediate node sites are purely relay sites and are not located in areas where RAN equipment will be deployed. As a result, no add-drop traffic is switched out at these sites. The end site in Atalaya employs a carrier-grade routing function so that it can act as an aggregation site, effectively extending the operation of the Satipo fiber PoP.

The central requirements in this pilot were:

- Carrier-grade routing capabilities
- Multi-port GigE port fan out
- Operation in non-air-conditioned environments without fans
- DC powering

In this pilot, the Juniper ACX 1100 series was selected for deployment at both the Satipo PoP location and at the Atalaya PoP Extension site.

Power system

A critical component at each site is the power system. Necessary functionality elements of this system are:

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- Ability to connect to A/C grid, A/C micro-grid or A/C generator facilities
- Ability to connect DC solar generating facilities
    - Sizing of the solar system is determined by the local power draw requirements plus the excess needed to charge the battery backup systems in a timely manner (in < 8 hours)
- Ability to connect to and control battery backup
    - Backup hold up time is defined by the battery solution employed and the charging performance of the power system
- Typical hold-up time requirements are > 24 hours
- Output conditioning and ramp-on/ramp-off control
    - Many electronic components don't operate properly under certain ramp-on or ramp-off conditions, so these need to be programmable in the power supply system
    - Control of max and min DC voltages applied to the electronics is required
- Input and output transient suppression
    - Common and differential mode
- Output lines
    - Resettable Fusing (ideally remotely controllable)
    - Distribution panel for equipment connection
- Remote management interface
    - Ethernet
    - Alarm reporting
    - Remote configuration
    - Remote power cycling of the site
- Dry contact support
    - Connection of site alarms
- Weatherproof, self-contained enclosure with minimal on-site assembly and cabling
- Ability to be physically secured

Guidance from Mayutel was employed to make the selection of the Clear Blue Systems solution based on the fully integrated nature of this product offering, as well as commercial considerations.

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Site considerations

The selected sites were assessed for:

- Mechanical strength (dead weight support)
- Twist & sway limitations
    - Assessed max wind conditions for the area: 60mph was derived based on the average wind for the area being < 5mph
    - Safe limits of the tower mechanical & guying structure
    - Twist limits of antennas: Limit target = ½ 3dB beamwidth of the deployed antennas

Simulations were done using back-to-back pairs of 1.8m (6ft) backhaul antennas to ensure that the tower strengths were sufficient to deal with the possible need to re-configure the sites for Spatial Diversity (SD) operation if multipath performance on the long links proved to be unacceptable.

One particular concern for the sites is the integrity of the lightning control system. Essentially, this system runs a large gauge braided wire the length of the tower connecting the tip-mounted lightning rod and the site (grounding) earthing the blade. Soil assessments are done to define the depth of the earthing blade or pin. The overall impedance of this needs to be as close to 0 ohms as possible (typical is 1 – 3 ohms, no more than 5 ohms as an absolute maximum). It is not good practice to rely on the tower structure itself as the conductor; a separate, continuous stranded copper conductor with very high current-carrying capacity is required.

At the site, all electrically-grounded equipment are carefully bonded to the earthing system. There should only be a single location for the earthing "pit". If multiple sites are used, they need to be bonded together with a large gauge copper conductor to ensure that no ground loops exist.

When specifying equipment for robust operation in the presence of transients associated with lightning, GR 1089 is often specified. It is important to note that older versions of GR 1089 are weak in the area of transient protection. GR 1089 Issue 6 (2012) should ideally be employed when selecting electronic equipment.

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Figure 8 - Picture of construction personnel hand-carrying elements of the radio tower and hardware at the Satipo 1 site

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4.0 Gathered Field KPIs

There were many monitored KPIs from each radio link-end ODU, as well as from weather stations located at the link-end tower sites, and at intermediate locations along the link paths. We present the analysis over two periods:

1. August 2019 - Oct 2019 which saw mostly dry weather with periodic rains.
2. November 2019 – May 2020 which saw the heaviest rain periods, typically in the months between December and March every year.

While the gathered in-field data is extensive, some samples of the data collection results are shown below.

Figure 9 - Rain Events (hourly) During the Observation Interval (Interim, Aug/2019 - Oct 2019)

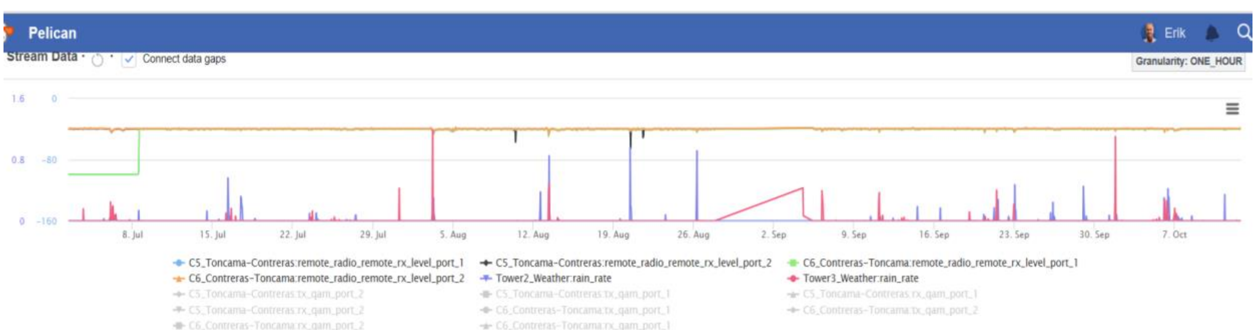

Figure 10 - Receive Signal Level Variations (hourly) during the Observation Interval (Interim, Aug/2019 - Oct 2019)

In the above plot, the nominal receive power level is in the vicinity of -40 to -41 dBm, which is as expected for this [clear-LoS] radio link.

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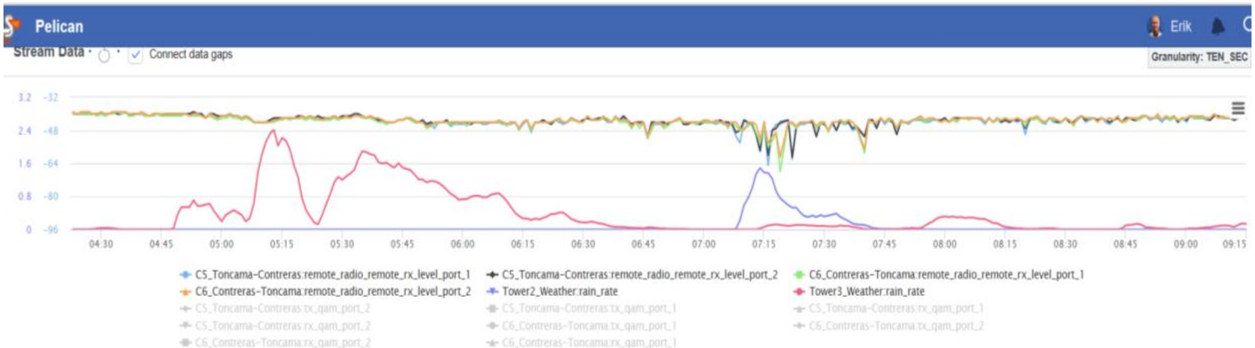

Figure 11 - Zoom-in on Aug 2, 2019, Rain Event Showing Receive Signal Strength Variability During the Event

It is interesting from the above to see the hydrometer responses at either link end showing the rain event occurring at different times across the link. What can be seen is that the rain event probably impacted a larger portion of the link at ~ 07:15, because you can see that only then did the radio signal exhibit fading.

It is also noteworthy to point out that although the rain seems to exhibit a slow, homogeneous presence, the radio receive signal exhibits a rampantly varying response to the propagation channel attributes. This is typical behavior and must be mitigated by ACM and/or ATPC algorithms that are fast enough to counter the channel's highly dynamic radio attributes. Rates in the range of 50 dB/s - 100 dB/s are commonly encountered in practice.

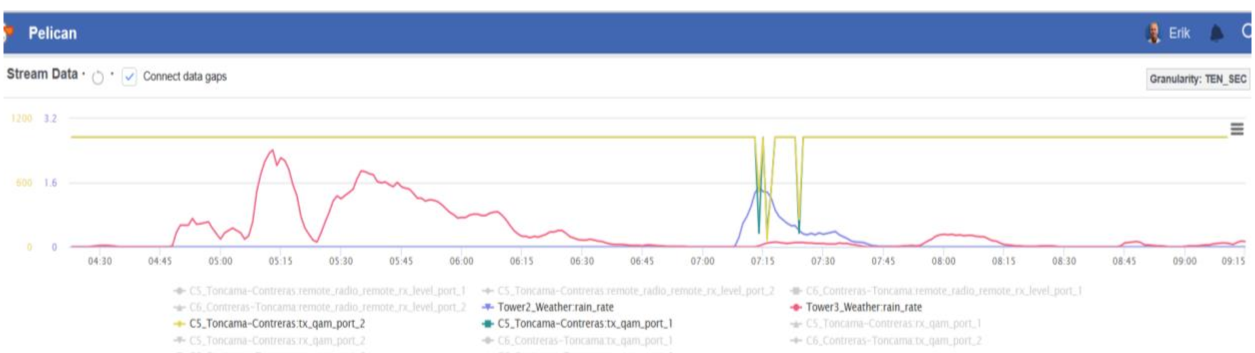

Figure 12 - Zoom-in on Aug 2, 2019, Rain Event Showing ACM Activity During the Event

Another event (on August 13, 2019) shows that the rain events were captured by hydrometers located at both link end sites at similar (but not identical) times. This

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suggests that the rain event impacted both ends (and probably the entire extent of the link) at the same time. This event causes a prolonged receive signal level reduction and a more significant ACM response (i.e., the link reduces its QAM level (and hence capacity) for a longer period whilst the rain event impacts the link.

Figure 13 - Zoom-in on Aug 13, 2019, Rain Event Showing Receive Signal Strength Variability During the Event

In this sample case, the rain event is somewhat present across the link at a point where the Tower2 and Tower3 rain rates cross (~ 0.8 in/hr, or ~ 21 mm/hr). At this point the receive signal fading is ~ 10dB. This compares with a calculated estimate -- based on ITU-838 -- of signal fading at ~ 14dB. The difference is a manifestation of the actual rain rate being experienced across the radio link.

The variability in receive signal levels experienced by the radio link causes expected ACM actions. In periods of fading, the link automatically reduces its modulation complexity to combat the effect of fading, effectively transferring dynamic range from “capacity” to “availability”. In this case a 10 dB fade would be expected to drive the link from the 1024QAM state to the 128QAM state, to recover the 10dB fade experienced at/near the “crossover point). In practice (see below), the link experiences a deeper ACM action just before the “crossover point”, and in fact fades to ~ 64QAM/128QAM suggesting that slightly more than 10dB fading was experienced at that time (i.e., 12 - 13 dB fading was in fact experienced by the link).

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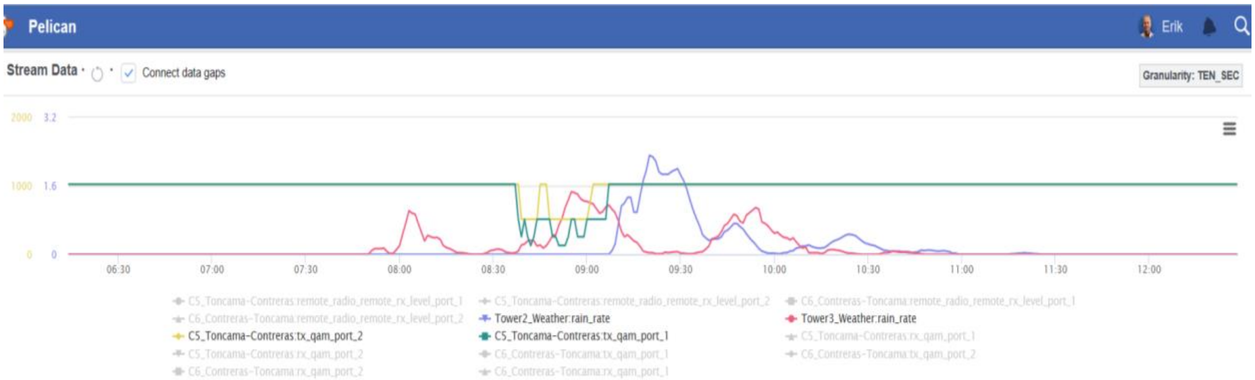

Figure 14 - A closer look on Aug 13, 2019, Rain Event Showing ACM Activity During the Event

In the fall of 2019, Mayutel -- with help from their PtP radio system OEM -- made several improvements and adjustments to the configuration of the radio system to improve overall performance, for example by ensuring that the ATPC is engaged. During the rainy season (approximately December to March) more severe rain events occurred. Some examples are shown below in Figure 15.

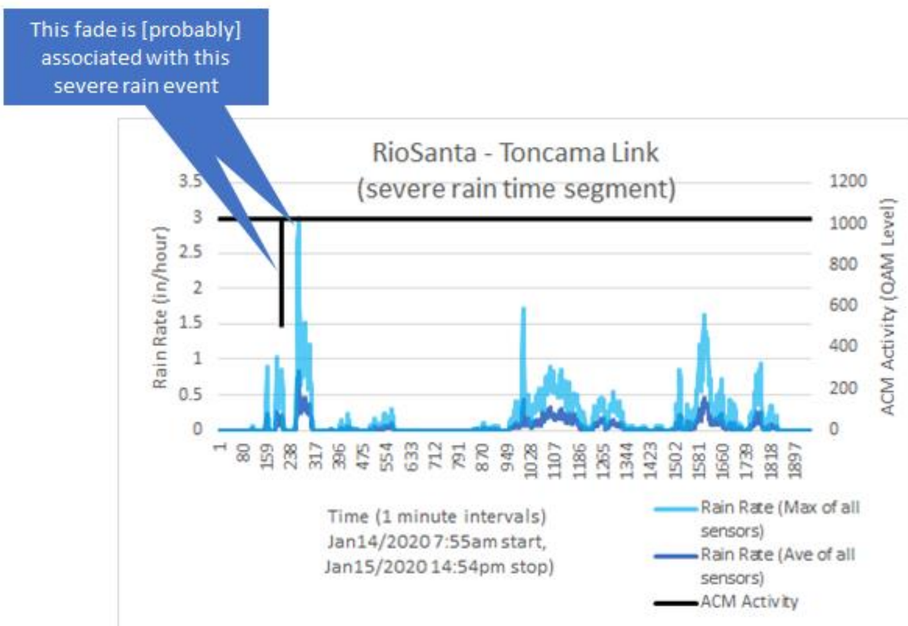

Figure 15 - Severe Weather Time Segment showing the links ACM Performance in the Presence of Heavy

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Rain[3]

At the end of January 2020, Mayutel down speeded the radio links to 128QAM with guidance from the radio system OEM due to an incoming software upgrade. After Jan 30, 2020, the links are set to a maximum modulation of 128QAM which was deemed sufficient by Mayutel. Later, the links were returned to 1024QAM maximum modulation ACM at the end of June 2020.

Operating at 128QAM, the link's link margin is increased substantially. This can be seen in the example below where the link is operating through a 5inches/hour rain event, without incident.

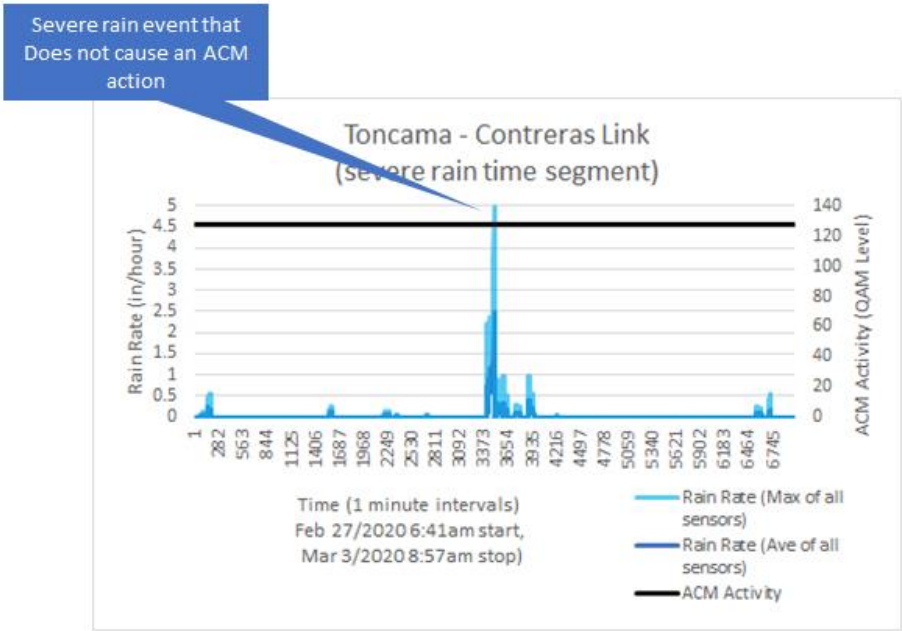

Figure 16 - Severe Weather Time Segment showing the links ACM Performance in the Presence of Heavy Rain

[3] Note that the link's ACM isn't necessarily exactly aligned with the recorded rain event because the weather station(s) aren't necessarily seeing the rain at the same time as the radio path does, since the radio path can be impacted anywhere along it's ~ 50km length.

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4.1 Aug 2019 - Oct 2019 Field Availability Assessment

Interim availability assessments were conducted by reviewing the amount of time (in minutes) that the monitored links spent in the various ACM states. The interim data was collected starting on Aug 1, 2019 @ 12:00:05.858 AM, for a duration of ~ 65 days

The ACM algorithms in the radio link receivers react to link attenuation conditions, and hence can be used to assess time spent in each state.

In this analysis, no data was removed from the field-gathered datasets for this initial reporting period. Therefore, data which might contaminate the dataset may be associated with factors such as:

- Periods of time where power at the site was unavailable
- Periods of time where planned service/maintenance outages were undertaken
- Other periods of time where availability-related data was NOT related to propagation conditions of the link

4.1.1 Rio Santa to Toncama Link, 49.16km (aka Satipo1 to Satipo2)

		Forward link Port 1 - H POL		Reverse link Port 1 - H		Forward Link Port 2 - V		Reverse Link Port 2 - V POL	
QAM level	Operating minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	94190	94042	99.843%	94145	99.952%	93021	98.759%	94157	99.965%
512	94190	51	0.054%	28	0.030%	1073	1.139%	29	0.031%
256	94190	13	0.014%	10	0.011%	29	0.031%	2	0.002%
64	94190	5	0.005%	0	0.000%	3	0.003%	0	0.000%
16	94190	0	0.000%	0	0.000%	0	0.000%	0	0.000%
4	94190	61	0.065%	0	0.000%	62	0.066%	0	0.000%
no link	94190	0	0.000%	0	0.000%	0	0.000%	0	0.000%

Figure 17 - Rio Santa to Toncama Link, 49.16km (aka Satipo1 to Satipo2) Infield Interim Availability Performance Results

From the above results, the link is achieving >99.75% availability in the highest capacity state (1024QAM @ 1300 Mbps throughput). The link has spent 62 minutes in the lowest capacity state (4QAM @ 100Mbps throughput at 0.066% of the time). This is an interesting result because the “V" polarization is expected to be hardier than the “H”

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polarization channel. It is also interesting that although the 'V' suffered slightly less than predicted availability performance, the H polarization-maintained operation at > 99.95% in the 650 Mbps / 1024QAM mode. Therefore, the link was operating at a total of ~ 650Mbps + 100Mbps = 750Mbps during the QPSK events that were encountered on the port 2 - V pol channel.

Expected/predicted availability is > 99.91% in the highest capacity state (1024QAM @ 1300 Mbps throughput) and ~ 0% time spent in the lowest capacity state (4QAM @ 100Mbps throughput).

4.1.2 Toncama to Contreras Link, 47.18 (aka Satipo2 to Satipo3)

		Forward link Port 1 - H		Reverse link Port 1 - H		Forward Link Port 2 - V		Reverse Link Port 2 - V	
QAM level	Operating Minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	94190	94169	99.978%	94167	99.976%	94183	99.993%	94183	99.993%
512	94190	17	0.018%	18	0.019%	4	0.004%	2	0.002%
256	94190	1	0.001%	3	0.003%	2	0.002%	3	0.003%
64	94190	0	0.000%	0	0.000%	1	0.001%	0	0.000%
16	94190	0	0.000%	1	0.001%	0	0.000%	1	0.001%
4	94190	0	0.000%	0	0.000%	0	0.000%	0	0.000%
no link	94190	0	0.000%	0	0.000%	0	0.000%	0	0.000%

Figure 18 - Toncama to Contreras Link, 47.18 (aka Satipo2 to Satipo3) Infield Interim Availability Performance Results

From the above results, the link is achieving >99.97% availability in the highest capacity state (1024QAM @ 1300 Mbps throughput). The link has spent 0 minutes in the lowest capacity state (4QAM @ 100Mbps throughput).

Expected/predicted availability is > 99.61% in the highest capacity state (1024QAM @ 1300 Mbps throughput) and ~ 0% time spent in the lowest capacity state (4QAM @ 100Mbps throughput).

4.2 Nov 2019 - May 2020 Field Availability Assessment

This reporting period bridges the typical rainy season in this region of Peru -- from December to March every year -- where the test links are deployed. During the rainy season, rain events exceeding a few inches/hour of rain are expected.

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It should be noted that unfortunately, there were some periods when some of the weather stations did not report information. In the extended periods where none of the weather stations were reporting, the corresponding KPI data was removed from the analysis. One such period was a 2-week time block in early February, where on one of the links all the weather stations ceased to report. This is believed to be a result of a network configuration change.

4.2.1 Rio Santa to Toncama Link, 49.16km (aka Satipo1 to Satipo2)

KPI data was taken on this link during the Nov 1, 2019, to May 31, 2020, time period. The figure below shows the ACM activity experienced by this radio link[4].

During the reporting period, Mayutel undertook a management action to down speed the link whilst the OEM adjusted the multi-carrier (XPIC) operation of the radio link. The availability figures are therefore computed in two separate sub-cases, the first being <u>before</u> the management event and the second is <u>after</u> the management event.

It is noteworthy that the rain averages amongst the rain sensors is very small compared to the sensor indicating the highest rain event. This suggests that the heavy rain events are small in physical extent, or that they are travelling across the path (as opposed to along its length). As the worst-case rain rate across the long path tends to dominate, we report both the average and worst-case rain rates across all the sensors.

The overall availability performance summaries are shown below in Figure 19.

[4] A large number of various KPIs were gathered, but not shown. Most of these culminate in the ACM actions taken by the link as it tries to compensate for link loss variations due to weather events along the link path

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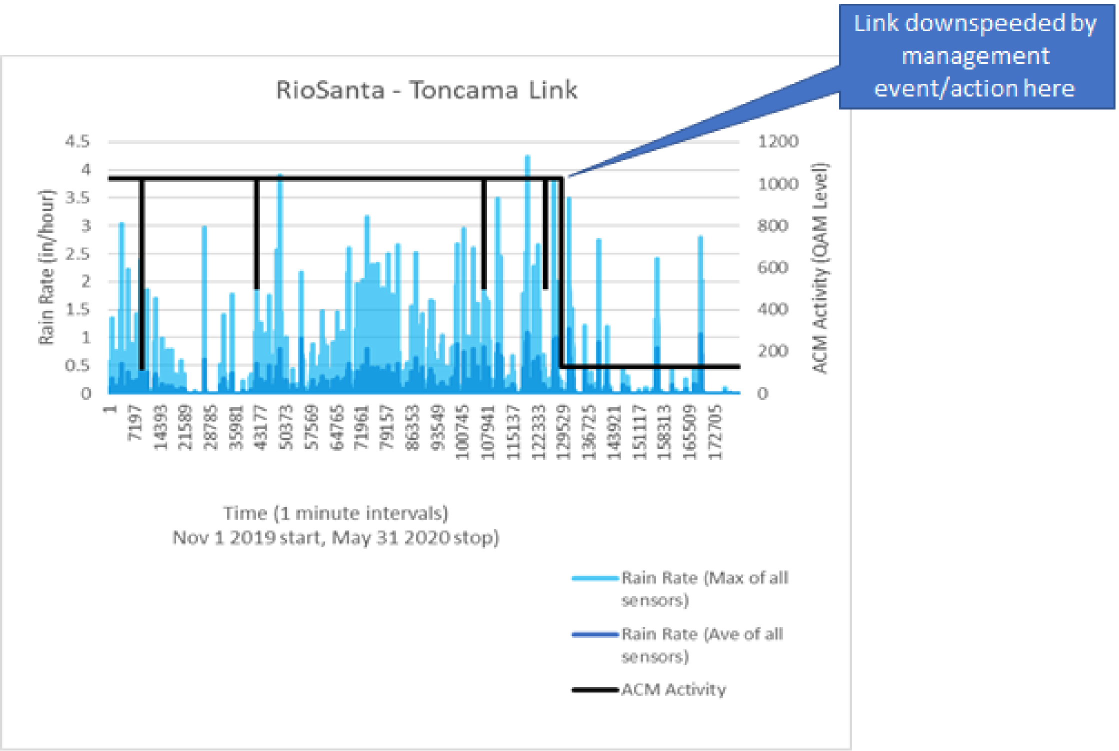

Figure 19 - Nov 1, 2019, to May 31, 2020, Throughput Performance of the Rio Santa to Toncama Link (shown as ACM level) and Rain Events

		Port 1 - H POL		Port 2 - V POL	
QAM level	Operating minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	129247	129230	99.987%	129234	99.990%
512	129247	12	0.009%	8	0.006%
256	129247	0	0.000%	0	0.000%
128	129247	5	0.004%	5	0.004%
64	129247	0	0.000%	0	0.000%
4	129247	0	0.000%	0	0.000%
no link	129247	0	0.000%	0	0.000%

Figure 20 - Availability Performance of the Rio Santa to Toncama Link Before the Management Event (max ACM level allowed to reach 1024 QAM)

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		Port 1 - H POL		Port 2 - V POL	
QAM level	Operating minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	50642	0	0.00%	0	0.00%
512	50642	0	0.00%	0	0.00%
256	50642	0	0.00%	0	0.00%
128	50642	50642	100.00%	50642	100.00%
64	50642	0	0.00%	0	0.00%
4	50642	0	0.00%	0	0.00%
no link	50642	0	0.00%	0	0.00%

Figure 21 - Availability Performance of the Rio Santa to Toncama Link After the Management Event (max ACM level allowed to reach 128 QAM)

4.2.2 Toncama to Contreras Link, 47.18 (aka Satipo2 to Satipo3)

KPI data was taken on this link during the Nov 1, 2019, to May 31, 2020, time period. The figure below shows the ACM activity experienced by this radio link[5].

Similarly, to the previous link, during the reporting period Mayutel undertook a management action to down speed the link whilst the OEM adjusted the multi-carrier (XPIC) operation of the radio link.

The overall availability performance summaries are shown below in Figure 22.

[5] A large number of various KPIs were gathered, but not shown. Most of these culminate in the ACM actions taken by the link as it tries to compensate for link loss variations due to weather events along the link path

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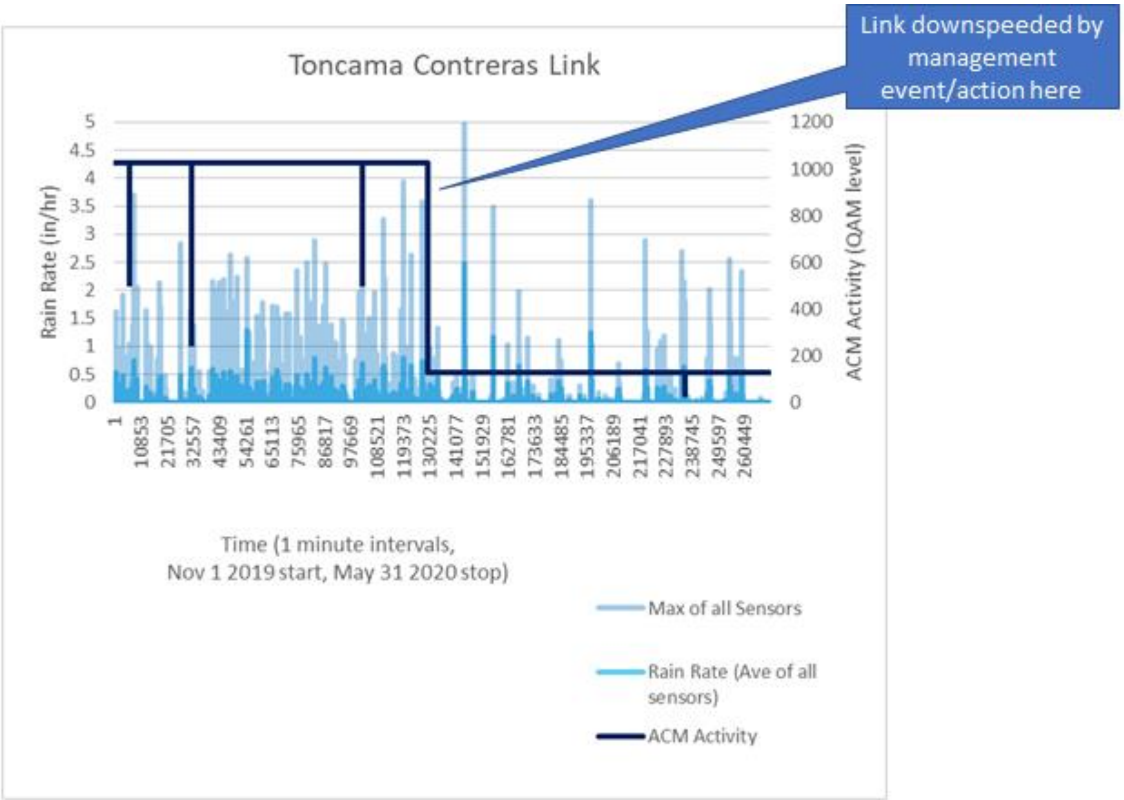

Figure 22 - Nov 1, 2019, to May 31, 2020[6] Throughput Performance of the Toncama to Contreras Link (shown as ACM level) and Rain Events

[6] Note that there were periods of time (i.e., first 14 days of Feb 2020, where the rain/weather meters were not functioning properly, and these periods of time were removed from the analysis

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		Port 1 - H POL		Port 2 - V POL	
QAM level	Operating minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	129504	129501	100.00%	129488	99.99%
512	129504	3	0.00%	15	0.01%
256	129504	0	0.00%	1	0.00%
128	129504	0	0.00%	0	0.00%
64	129504	0	0.00%	0	0.00%
4	129504	0	0.00%	0	0.00%
no link	129504	0	0.00%	0	0.00%

Figure 23 - Availability Performance of the Toncama to Contreras Link Before the Management Event (max ACM level allowed to reach 1024 QAM)

		Port 1 - H POL		Port 2 - V POL	
QAM level	Operating minutes	Minutes in this QAM State	Availability	Minutes in this QAM State	Availability
1024	141796	0	0.00%	0	0.00%
512	141796	0	0.00%	0	0.00%
256	141796	0	0.00%	0	0.00%
128	141796	141796	100.00%	141795	100.00%
64	141796	0	0.00%	0	0.00%
4	141796	0	0.00%	0	0.00%
no link	141796	0	0.00%	1	0.00%

Figure 24 - Availability Performance of the Toncama to Contreras Link After the Management Event (max ACM level allowed to reach 128 QAM)

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5.0 Findings

In the following we summarize the findings from the duration of the pilot project. This study confirms that long haul, high-capacity radio links can deliver exceptional availability performance. The radio links observed in this study were capable of ~ 1.3 Gbps throughput in each direction, along with very low latency (on the order of a few hundred microseconds), making them suitable for various long range backhaul applications, including cellular system backhaul.

Overall, during the Nov 1, 2019, to May 31, 2020, test/observation window -- which includes the heavy rain season in this region of Peru -- the availability performance measured (> 99.99%) exceeded both the predicted levels (> 99.95%)[7] and operator requirement (>99.9%).

5.1 Aug 2019 - Oct 2019

The interim availability data collected on the radio links indicated that the links were performing well. The measured field availability was consistent with predicted availability performance expected, with the exception of a small shortcoming on one of the 8 link channels being monitored. This lower-than-expected-availability-channel seems to be associated with a radio channel that is inclined to operate in 512QAM mode (as opposed to 1024QAM mode). This is very likely an ODU configuration glitch.

5.2 Nov 2019 - May 2020

The final overall availability performance of these radio links has been assessed across significant periods where numerous [heavy] rain events occurred. To some extent, the presence of these events was an expected occurrence because of the normal/annual rainy season which occurs in the deployment area every year.

[7] The operator's requirement was a minimum of 99.9% availability.

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The availability performance indicates that the links are performing above their predicted availability levels. This is largely due to the fact that the long-range nature of the links tends to result in rain events impacting only small segments of the link at any one time. Additionally, not all rainstorm events travel along the length of the link, causing ongoing path loss events. Rather, rainstorm events often cross the links path, impacting it for only short periods of time.

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6.0 Summary

In this document we shared the learnings and findings from the pilot deployment of long-haul microwave backhaul with ~50km links, providing long-range, high capacity (~1.3 Gbps) microwave backhaul links in the Mayutel network between Atalaya and Satipo, Peru. These long-distance links, running over 100km between the two settlements, provide fiber POP extension to a 4G site at high availability (> 99.99%) and low latency (a few hundred microseconds 1-way latency).

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