TELECOM INFRA PROJECT

Smart Off-Grid Power for Rural Connectivity

Results of a field study examining the application of Smart Off-Grid power to provide cost-effective, reliable telecommunications services in rural regions of Peru

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META RESEARCH, MAYU TELECOMUNICACIONES, CLEAR BLUE TECHNOLOGIES

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Supporters

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Reducing Rural Telecom Power Cost through Smart Off-Grid Technology

Abstract

This paper provides the outcome of a field study that evaluated the value of Smart Off-Grid as the power solution to confirm how it can make rural telecom more viable. In this field study, two adjacent solar-powered off-grid mobile telecom sites were constructed in rural Peru and monitored over a period. These sites provide coverage over two similarly sized settlements and use the same RAN and backhaul equipment. One site was sized and operated as a baseline conventional site, and the other was sized and operated as a Smart Off-Grid site. This allows us to compare the performance of the two sites directly.

In a world dependent on technology, universal access to connectivity is necessary to achieve the UN Sustainability Development Goals. However, a substantial rural digital divide remains that can only be bridged through low-cost telecommunications infrastructure. This begins with the power solution, as the power system typically accounts for 25% or more of a telecom site's total cost.

The project validated that Smart Off-Grid power provides a compelling 40% cost advantage over the conventional off-grid solution while meeting the operators' performance, with no impact on data usage.

The paper outlines the purpose, plan and results of a field trial launched by Meta Research in collaboration with Mayu Telecomunicaciones and Aviat Networks and supported by Clear Blue Technologies.

By conducting a side-by-side test comparing a conventional site and a smart site, the field trial demonstrated that Smart Off-Grid power can reduce power system requirement without compromising performance requirements including availability.

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1.0 Introduction

1.1 The Challenge of Rural Connectivity

According to the GSMA's 2021 Report on the State of Mobile Connectivity, 450 million people live in areas not covered by mobile broadband networks, while 3.4 billion people still do not use the internet, including those living in a region with mobile coverage. Simultaneously, the COVID-19 pandemic has pushed more aspects of our global economy onto virtual platforms, increasing the need for widespread access to mobile connectivity.

The overwhelming majority of those in the coverage gap live in rural or remote areas in low-income countries. There is a meaningful digital divide between urban and rural communities, with many rural communities lacking access to connectivity. Establishing lasting connectivity in rural regions is a significant challenge. To help close this gap, telecommunications providers need to build new telecom sites and links or upgrade existing ones. However, many rural areas lack access to an electrical grid. This presents a significant challenge, as telecom sites and networks consume considerable power, which is expected to rise even further. Essentially, the inadequacy of existing power infrastructure has impeded the development of reliable mobile broadband coverage in remote rural areas. In addition, rural connectivity is not economically viable for service providers because of high infrastructure costs and low subscriber density and, thus, low revenues.

In places with no reliable electricity grid, reliance on off-grid power solutions supplied by solar, diesel or hydro is necessary. Each has its challenges, including but not limited to costs, logistics, technology development, transportation and maintenance, presenting a barrier to providing connectivity in remote areas. Ultimately, cost challenges inhibit connectivity in rural areas, and innovation is the only way to overcome such obstacles.

It is increasingly important to bridge the significant division despite these challenges, because access to basic mobile connectivity is becoming a basic need. By bridging this divide, we can help spur substantial socioeconomic progress for these rural communities in low-income countries and bring millions of people into the international economy.

Ultimately, to help remove these barriers and help make rural connectivity more accessible, a significant focus on developing technologies and partnerships amongst industry leaders is critical. This has become increasingly more important as the need for coverage in all parts of the world increases. Innovations like Smart Off-Grid power (referred to as "SmartPower" during this trial) can enable companies to build and operate telecom sites more efficiently, reducing cost barriers, and by collaborating with others in the industry — including telecom operators, community leaders, technology developers and researchers — companies can find solutions that enable scalable and sustainable connectivity for everyone.

In 2021, Meta Research, supported by key strategic partners Mayu Telecomunicaciones ("Mayutel"), Clear Blue Technologies, Aviat Networks and others, embarked on a field study to identify a solution to these challenges. Called "Project SEISMIC" (Smart Energy Infrastructure for Mobile Internet Connectivity), the project aimed to test a solution to smartly manage the power and functionality of telecom sites.

1.2 Economically Viable & Sustainable Telecommunication

To connect the under-connected in rural areas, a low-cost infrastructure solution is an essential component. Reliable power infrastructure is extremely costly to implement in deep-rural communities, which is why bridging the connectivity divide has been so challenging. A reliable, efficient and low-cost power solution is the only way to make mobile connectivity a reality for the millions of unconnected people in remote regions. Telecom sites can be designed and operated more efficiently and cost-effectively by implementing smart power management. For example, we can reduce the capacity and transmission power of the site during less busy periods. By doing so, we want to better design and operate off-grid sites to reduce costs and improve their sustainability.

SmartPower offers several benefits to network operators:

- It reduces the initial site construction cost by using the same RAN and backhaul equipment but fewer batteries and solar panels, with a low-friction upgrade path as future demand and usage increases.
- By using SmartPower on conventionally sized sites, battery performance and lifespan can be increased.
- It opens the potential of re-sizing diesel or hybrid sites into solar-powered sites, which means the operator no longer has to re-supply diesel fuel to those sites.

1.3 The Implementation of Smart Off-Grid Power to Solve the Problem

Project SEISMIC, also referred to as the SmartPower Research Project, set out to address two key hypotheses within this field experiment:

- Firstly, to determine if elements of a telecom power system can be remotely controlled to provide the right functionality and adjustability without sacrificing key telecom performance indicators such as uptime or power availability.
- Secondly, to see if SmartPower telecom sites can provide the right telecom performance without compromising user expectations and experience while meeting operators' objectives, including subscribership and revenue.

Clear Blue's Smart Off-Grid power technology was the ideal solution for powering rural connectivity with its remotely manageable functionality. By drastically reducing power system costs, this technology allows mobile broadband service providers to offer a commercially viable and scalable rural telecom solution.

2.0 Smart Off-Grid Power Field Trial

2.1 Field Trial Purpose

To prove that Smart Off-Grid power ("SmartPower") is a viable and cost-reducing solution to telecommunications in rural areas, Project SEISMIC (Smart Energy Infrastructure for Mobile Internet Connectivity) was launched as an initiative between Meta Research and Mayutel, along with BaiCells, Aviat Networks and Clear Blue Technologies, that aimed to help accelerate rural telecom infrastructure through innovations in power management. By collecting real-world field study data, the project aimed to validate whether telecom sites powered by Smart Off-Grid power technology could achieve significantly lower capital expenditures, reduce site power consumption, minimize operating costs and optimize service levels.

This project, now called the SmartPower Research Project, deployed two sites in Mayutel's area of operations in deep-rural Peru: a baseline site and a SmartPower site on two settlements of similar profiles near one another. In undertaking the field study, the participating companies expected to show that SmartPower, based on Clear Blue's technology, could reduce energy consumption, installation costs and operating expenses for telecom operators while not compromising network service.

When looking at a real-world telecommunications application, deploying power systems for telecom sites is extremely costly, accounting for about 25% of total site cost. For providers like Mayutel, whose business target is to deploy 4G services in rural and deep-rural regions of Peru, this can be both costly and challenging. Rural operators often must deploy sites in areas with poor- or no-grid power conditions and poor infrastructure, including a lack of adequate roads. Therefore, every site element, including the power system, needs to be transported, installed, secured and maintained. Hence, this field trial set out to assess the need for a low-cost power solution.

Network operators must meet availability targets — in most cases between 98% and 99.999% in deep-rural areas — against all expected conditions. In off-grid and poor-grid regions with periods of poor or extreme weather, this often means that a large number of solar panels and batteries have to be provisioned to meet the availability target because the worst-case weather conditions dictate the sizing of the power system. Ultimately, this leads to high costs for mobile operators such as Mayutel. However, with Smart Off-Grid power technology from Clear Blue Technologies, power is remotely managed. Power systems are reduced in size by 40-70% and overall power system costs by 40% without sacrificing uptime, thus allowing Mayutel to successfully meet its availability targets within a viable business case.

In addition to productization challenges, SmartPower must answer several key questions:

1. Can elements of a telecom site be controlled and provide the right functionality and adjustability without sacrificing availability?

2. Can SmartPower sites support telecom service without compromising user expectations and experience and operators' objectives, including subscribership and revenue?

To answer these questions, the SmartPower Research Project team embarked on lab and field testing, as explained further below.

2.2 Field Trial Overview & Plan

Meta formed a collaborative project with Clear Blue, Mayutel, BaiCells and Aviat Networks to deploy a SmartPower field trial. Two settlements of similar size in close geographic vicinity were served by mobile-telecom sites with the same equipment configurations, except for the power systems. The objective of this trial was to answer the two key questions above relating to the value of SmartPower.

The trial consisted of two similarly configured mobile network sites near one another. The sites will be referred to as:

1. "Baseline site" (no SmartPower), located in Shambo, Peru
2. "SmartPower test site," located in Naranjal, Peru

The field trial involved two sites located in Mayutel's Peru network, which serves settlement populations and RAN coverage areas similar in size.[1] The sites are close to each other and are subject to similar:

- Weather conditions
- Solar generation conditions
- Mobile-user demand
- Mobile-user behaviour

However, no two settlements are exactly alike. Naranjal — where the SmartPower test site is located — is more connected and has terrestrial (road) access and other villages in the proximity, and some people of this village have access to the service; people have higher incomes (many of them work for a palm plantation). Shambo — the baseline site — is more isolated due to the geography, and people have other economic activities and lower incomes. Therefore, we expected more traffic and users in the Naranjal site compared to the Shambo site.

Exposure to similar climatic conditions allowed the sites to experience similar solar-generating performance and weather-related radio performance impacts, allowing the gathered KPIs to be compared to accurately determine the performance implications of the SmartPower concept. The assessment of the impacts of SmartPower's dynamic control of RAN and microwave backhaul systems on the various RAN end user performance KPIs is the key focus of the overall field trial.

[1] Mayutel (Mayu Telecomunicaciones) is a rural mobile network operator in Peru.

Conventional telecom sites are designed and operated with few to no adjustments during operation. This means that availability requirements are derived from peak power consumption. With SmartPower, we believed that we could design a telecom site that requires fewer solar panels, batteries and other power system elements, which would drive down cost and improve sustainability.

The baseline site located in Shambo, Peru, was equipped with a conventional solar battery system sized to deliver a 2% unavailability performance with the telecom equipment operating “normally” (i.e., constant full-power consumption). At the SmartPower test site in Naranjal, the power system was sized to deliver a 2% unavailability performance under SmartPower proactive/predictive control algorithms, which resulted in a 40-70% power system size reduction and 10% less total site CapEx.[2]

Using a live in-network rural deployment, a six-month field trial was undertaken to understand better how the SmartPower concept impacts the trade-offs between:

1. Solar battery system sizing, performance and cost
2. RAN telecom system key performance KPIs

SmartPower essentially dynamically controls the RAN and microwave backhaul systems to deliver the desired availability performance. There is a potential impact on the RAN and microwave system performance and service delivery resulting from managing power with SmartPower functionality; however, these are known planned impacts and thus avoid unexpected disruptions. These potential impacts on telecom performance could include:

- RAN session connection success and failure rates
- Dropped active sessions in the RAN
- Reduced throughput performance in the RAN

[2] The proactive/predictive control algorithms were provided by Clear Blue Technologies Inc (Toronto, Canada) using their cloud-based control solution.

- Reduced throughput performance in the microwave backhaul
- Customer quality of experience degradation

These performance challenges could then potentially impact customer satisfaction, subscribership and revenue.

However, at the SmartPower test site, the dynamic control never jeopardized connectivity, and performance impacts were planned, known to providers and customers, and temporary (off-hour scheduled maintenance). When power is reduced, 4G connectivity is reduced, and 2G service was used in non-peak hours. Therefore, although there were specific times when service was reduced, Smart Off-Grid power management ensured that connectivity was never lost.

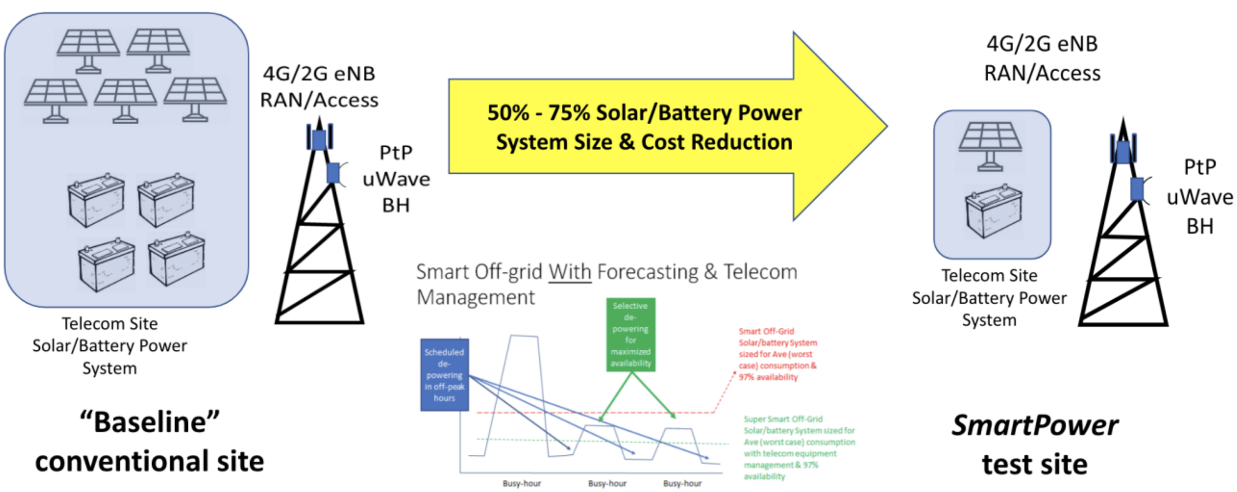


Figure 1 - SmartPower field trial basic information

Field Trial Site Locations & Tower Heights

	Site name	Latitude	Longitude	Call sign	Station code	Elevation (m)	Tower height (m)
3	Esperanza de Aguaytia ("test" site)	08 08 21.89 S	074 49 17.78 W			146.4	21.0
4	Shambo Provenir ("baseline" site)	08 07 11.60 S	074 46 27.48 W			149.6	80.0

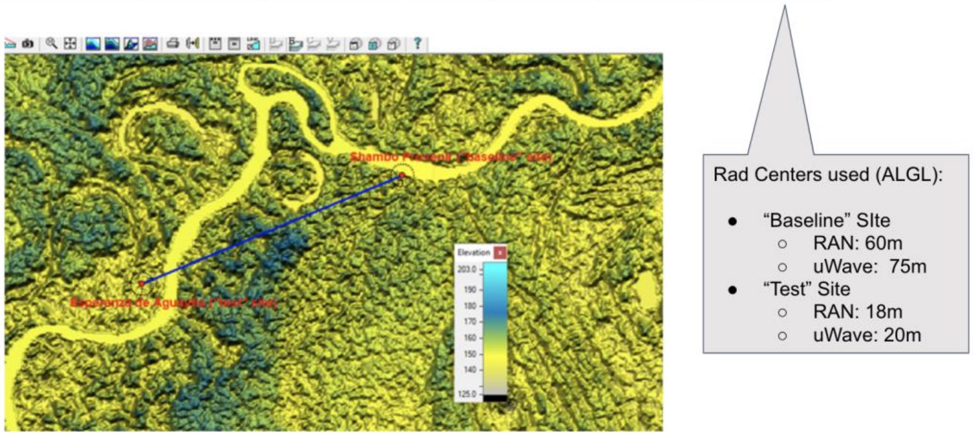


Figure 2 - SmartPower field trial site information and local topography. The image is generated using Pathloss™ software, using SRTM30 data source.

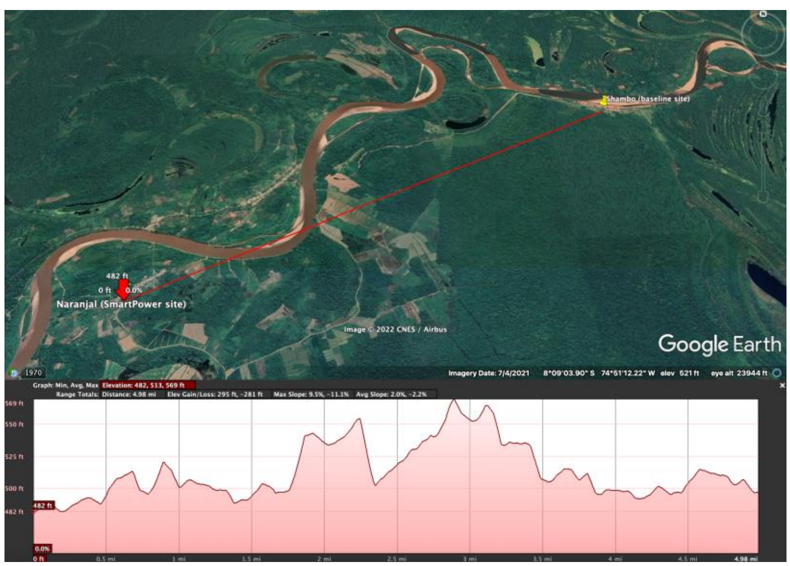


Figure 3 – Google Earth view of SmartPower sites and the path profile between the two sites, approximately 7.9km from each other.

2.3 Field Trial Power System Configuration

To evaluate the efficacy of SmartPower to maintain telecom site performance while delivering lower costs and higher revenues for providers, these sites had to be similarly equipped and subject to similar conditions. The following telecom equipment was deployed.

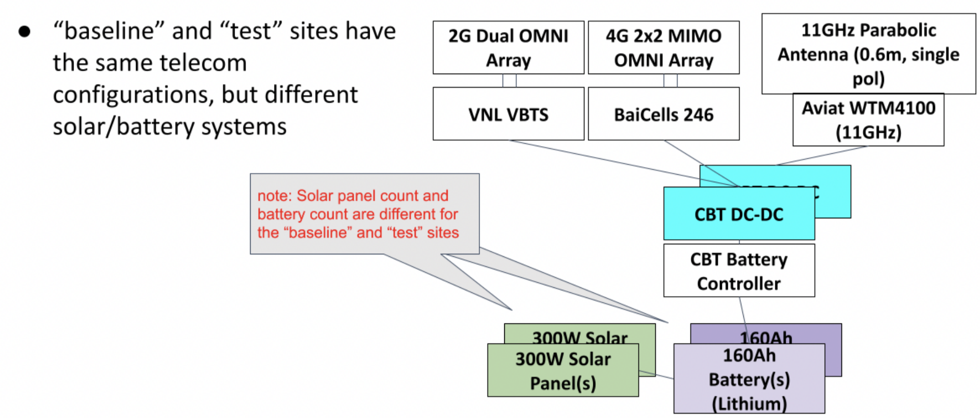


Figure 4 – Field trial telecom configurations for baseline and SmartPower sites

Both the baseline and SmartPower test sites have the same telecom configurations but were set up with different solar panel and battery systems. The baseline site's system was equipped with several more solar panels and batteries to ensure availability. In contrast, the SmartPower test site's system was much smaller, intending to proactively manage power to maintain availability. Through this methodology, this field trial effectively isolated the effect of Smart Off-Grid power technology on cost, system size and telecom performance.

Full Power ("Baseline" test Site)

No Dimming		
Power system Config	300W Solar Panels Req'd	13
	160Ah Batteries	4
	Unmet Load Time (annualized)	2.00%

Major "Dimming" Available (SmartPower test Site)

Major Dimming		
Power system Config	300W Solar Panels Req'd	5
	160Ah Batteries	2
	Unmet Load Time (annualized)	1.30%

Figure 5 – Power profile comparison between the baseline and the major dimming modes

3.0 The Role of Smart Off-Grid Power in Rural Connectivity

3.1 Smart Off-Grid Power Overview

The SmartPower concept proposes to use smart, adaptive system management on off-grid power systems to allow operators to adjust the functionality, performance and power usage of a telecom site. This is done by considering future weather conditions, expected power supply, battery levels and user requirements, which allows operators to deploy a smaller solar battery power system — using fewer solar panels and batteries — while maintaining the acceptable overall performance of the telecom site, including power availability. As a result, site CapEx, physical footprint and transportation costs are lower. Design studies using Smart Off-Grid power technology suggest that achieving 40-70% power system size reduction and 10% less total site CapEx (including RAN, backhaul, civil, tower and power) can be achieved while meeting the 98% availability target. The field trial confirmed these predictions.

SmartPower achieves this performance through the innovative use of scheduled, reactive, proactive and predictive management of the telecom site's power loads. The predictive aspect of the SmartPower system is based on weather forecasting combined with knowledge of the site's power system condition and health ascertained by historical monitoring data of system performance.

3.2 Smart Off-Grid Power Energy & Weather Forecasting

SmartPower begins with an energy forecasting and management program to determine how to manage energy to maximize uptime performance. Modeling the performance of the solar battery system availability is undertaken using 30-year historical climate data. Using this data, a statistical view of the solar power system's performance can be assessed for its ability to power the site and generate excess power needed to charge the battery system for overnight and poor-weather conditions.

For telecom sites without SmartPower functionality, such as the baseline site in Shambo, the configuration of solar panels and batteries needs to be much larger. The baseline site's solar battery system is sized to deal with statistical weather patterns such that it can meet the 2% unavailability criteria.

3.3 Dynamic Dimming for SmartPower Management

SmartPower dynamically controls the site's telecom equipment power consumption by altering the operating configuration of the telecom equipment (primarily the RAN system and the microwave backhaul system). SmartPower enables scheduled power system reductions in non-peak hours to optimize telecom performance when user demand is highest. Power can also be reduced, or "dimmed," strategically to conserve power when it is not needed.

At the outset of the project, Clear Blue Technologies developed a plan to dynamically manage the power system to ensure that Mayutel would meet its availability targets. Clear Blue's plan entailed managing power by 'dimming' or reducing power to five different levels based on five unique scenarios.

Figure 6 below summarizes the various planned "dimming" control modes, the associated RAN or backhaul system configuration state, and the resulting power consumption. Using these dimming modes, SmartPower can reduce the site's power consumption by up to 83%.

Site "dimming mode" (under power mgmt control)	RAN Consumption (W)	BH Consumption (W)	Smart Off-grid Controller	Site Consumption (W, without DC-DC ineff)	% Reduction from Full Power State	Power Consumption Compared to Full Power	Notes
1- full power	249	60	8	317	0%	100%	- Full Power, no poweer reductions applied - RAN: 2x2 MIMO, 30W/ant 4G, 10W/ant 2G - BH: +27dBm PTx, dual carrier
2	190	56	8	254	20%	80%	- RAN: 2x2 MIMO, 20W/ant 4G, 10W/ant 2G - BH: +27dBm PTx, single carrier (50% capacity)
3	148	50	8	206	35%	65%	- RAN: 2x2 MIMO, 10W/ant 4G, 5W/ant 2G - BH: +21.5dBm PTx, single carrier (some further capacity reduction in poor propagation conditions)
4	65	48	8	121	62%	38%	- RAN: 2x2 MIMO, 4G off, 5W/ant 2G - BH: +15.5dBm PTx, single carrier (some further capacity reduction in poor propagation conditions)
5 (sleep with NMS wakeup)	0	46	8	54	83%	17%	-RAN: sleep mode, no hosted Ues - BH: operating at +15.5 dBm PTx to retain site connectivity for "wake up"
6 (sleep with scheduled wake up)	0	46	8	54	83%	17%	RAN & BH: full sleep, scheduled wake only, no wake during sleep

Figure 6 – Site telecom equipment power consumption under various SmartPower "dimming" or power reduction modes. DC-DC efficiency of 91% is added to site comsumption figures to calculate power system load.

"Dimming" script #	Power Reduction ("Dimming") script functional descriptions
1	- Full Power, no power reductions applied - RAN: 2x2 MIMO <u>20W/ant 4G</u>, 5W/ 2G - BH: +27dBm PTx, dual carrier
2	- RAN: 2x2 MIMO <u>10W/ant 4G</u>, 5W 2G - BH: +27dBm PTx, single carrier (50% capacity)
3	- RAN: 2x2 MIMO <u>5W/ant 4G</u>, 5W 2G - BH: <u>+21.5dBm PTx</u>, single carrier (some further capacity reduction in poor propagation conditions)
4	- RAN: <u>4G off</u>, 5W 2G - BH: <u>+15.5dBm PTx,</u> single carrier (some further capacity reduction in poor propagation conditions)
5	- RAN: <u>sleep mode,</u> no hosted UEs - BH: operating at +15.5 dBm PTx to retain site connectivity for "wake up"

Figure 7 – Summary of SmartPower "dimming" modes planned for the field trial

The SmartPower test site's power consumption can be dynamically controlled. In the worst-case scenario, the system is driven to the primary dimming levels (i.e., dimming mode/script #4) to allow the telecom site to maintain its availability performance. The solar battery system is therefore sized to support this worst-case scenario.

Based on additional considerations from Mayutel, the implemented scenarios differed slightly from the above plan. In this field trial case, the mobile operator (Mayutel) is unable to place the system into mode 5 (sleep) during off-hour periods (i.e., 12 am to 6 am) due to regulatory limits. These limits required the 2G service to be maintained 24 hours a day. This requirement meant that for the Naranjal SmartPower test site, only the 4G service could be adjusted. In the field trial, only dimming modes 1 through 4 were utilized in three combined scenarios. The RAN 2G never experienced a scheduled power disconnect, as it was maintained with 5W transmitting power for 24 hours per day.

4.0 Site Deployment and Implementation

4.1 Site Deployment

During the site deployments, in the spring of 2021, the rainy season hit and the expected river flooding in the lowlands near the river was present. During this part of the season, the rain was frequently present. This season is the key time when the long-term performance of the SmartPower system needs to be evaluated.

4.2 Baseline Site Management

To assess the SmartPower system during the trial, the normalized performance of the RAN system needed to be established so that, over time, it would be possible to evaluate the impacts of SmartPower dimming actions. This was performed by running the baseline site and through the supply of reliable and established RAN services provided by Mayutel.

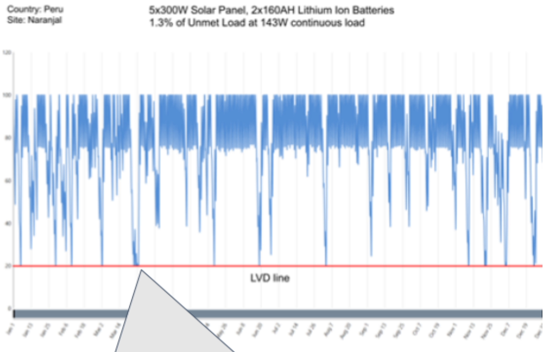
4.3 Clear Blue's Power Management for the Naranjal Site

The SmartPower test site would be managed with the three revised dimming modes previously described. Because of the SmartPower functionality to efficiently manage power, the SmartPower test site required a much smaller system to meet the operators' availability targets. By managing the power system according to these three dimming modes, with the SmartPower functionality, Clear Blue could successfully maintain power availability with a system 40-70% smaller. As a result, the entire site CapEx (not just the power CapEx) was lowered by 10% without compromising power availability.

Analysis Using Historical [2019] Weather Patterns - "major" dimming applied at SmartPower Test Site

- Using 2020 weather patterns, solar charging performance is analyzed to determine the required solar/battery system sizing needed to achieve < 2% (max) unmet load conditions
- this is a prediction for the worst case at the "test" site
- **results:**
  - **300W solar panels req'd: 5**
  - **160Ah batteries req'd: 2**
  - **Unmet Load Condition: ~ 1.3%**

Data Protected by NDA



Notes
- **batteries more/frequently reach LV**
- **when the system is operating in the 60+% range, less dimming will be employed**
- **when the system is at/near 100%, no dimming will be applied**

Full Power ("Baseline" test Site)

No Dimming		
Power system Config	300W Solar Panels Req'd	13
	160Ah Batteries	4
	Unmet Load Time (annualized)	2.00%

Major "Dimming" Available (SmartPower test Site)

Major Dimming		
Power system Config	300W Solar Panels Req'd	5
	160Ah Batteries	2
	Unmet Load Time (annualized)	1.30%

Figure 8 - Solar battery system sizing comparison summary: Baseline site vs. SmartPower site

The power system at the Naranjal site was actively managed by Clear Blue's expert service team through its online cloud-based software platform Illumience.

The implementation of the three dimming mode scenarios was based on the energy and weather forecasting within the SmartPower system. Below is an example of how Clear Blue actively managed power to ensure uptime availability under various circumstances at the Naranjal site; however, the weather forecasts are not from the Naranjal SmartPower test site but are examples of how this site would be managed under various weather conditions.

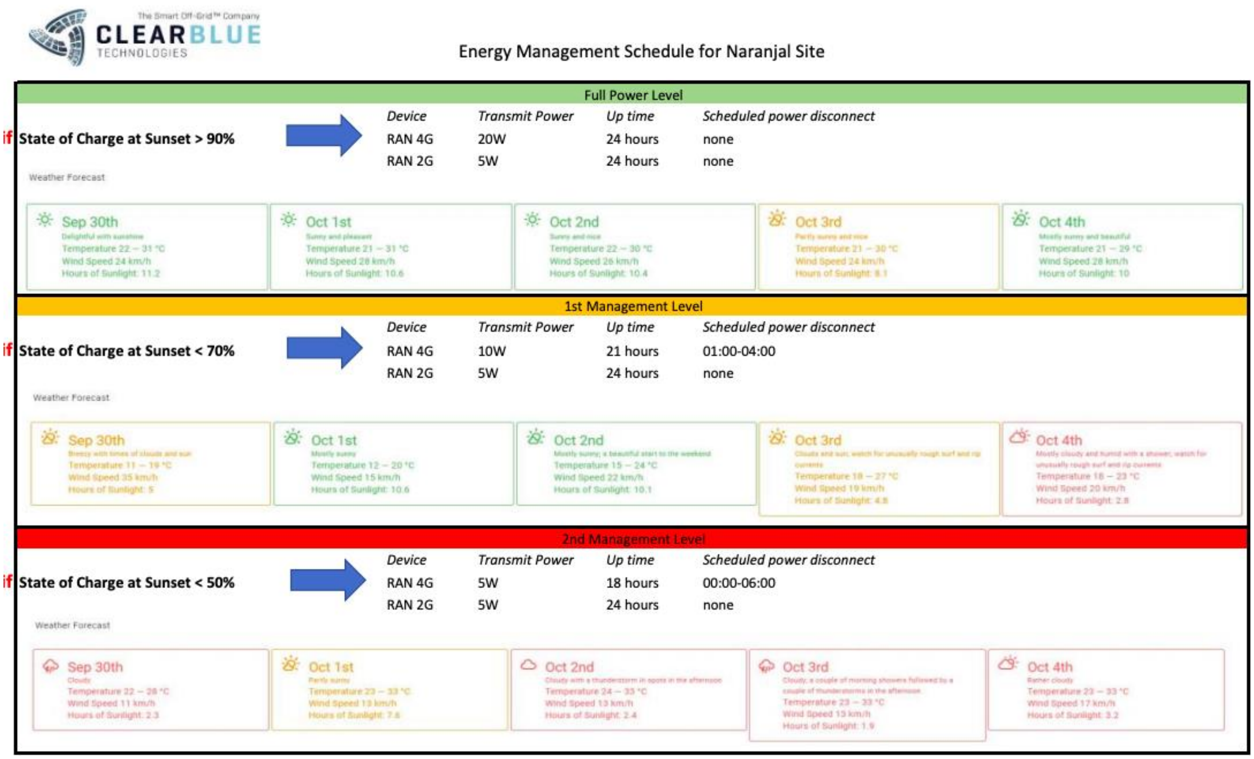


Figure 9 – Energy management schedule generated by Clear Blue's management system

The resulting solar battery power system sizing can be compared for the baseline and SmartPower test sites.

5.0 Smart Off-Grid Power & Telecom Performance Findings

5.1 Dynamic "Dimming" Impact on Telecom Performance

SmartPower enables smaller solar battery power systems through the dynamic control of the SmartPower site's power consumption performance. The main performance attributes that are potentially impacted by SmartPower dynamic control are:

1. Changes to the transmit power of the microwave backhaul link

   This reduces the throughput of the radio link under certain weather conditions where poor weather conditions burden the radio link's fade margin at the same time as the SmartPower action is occurring.

2. Changes to the transmit power of the 4G RAN

   This reduces the RF power density in some portions of the cell's coverage area, which can cause either a reduced speed connection to user equipment (UE) in those areas or a lack of coverage in those areas. When there is a coverage failure, it is expected that the call-setup failure rate may increase or the dropped-call rate may increase.

3. Reduction in RAN service from 4G+2G to 2G-only.

   This effectively will cause the cell to revert to a voice+text only service. When the 4G service is turned off through a SmartPower action, the active 4G sessions will get dropped, which should be visible as an abrupt increase in 4G dropped-call rate.

5.2 Impact on Microwave Backhaul

The SmartPower test site's microwave backhaul system employs a link design with embedded rain-fade and multipath-fade margin. During normal operating conditions, the margin can be consumed by transmit power reductions (via SmartPower) with little or no impact on the backhaul link's performance. If the transmit power is reduced simultaneously as poor-weather propagation conditions exist, the backhaul link may experience a downspeed (due to an ACM action). The statistical occurrence of this downspeeding is shown below.

A. Expected backhaul link availability: 99.879%
B. Expected downspeeded backhaul link availability: 99.7%

Note that condition "B" above would statistically occur if the radio link were operated continuously at the lowest transmit power. This isn't the case under SmartPower control, which will be a highly infrequent occurrence. A goal of the field trial project is to try to quantize this relationship.

5.3 Impact on RAN Performance

The SmartPower test site's RAN system employs two RAN units:

1. 4G 2x2 MIMO (BaiCells)
2. 2G dual antenna (VNL)

The SmartPower dimming control impacts the transmit power of the 4G system. To reduce power consumption, SmartPower reduces the transmit power in steps. The lowest step entails completely turning off the 4G RAN, leaving the RAN to operate in 2G mode only. Although numerous RAN-related KPIs get impacted by reducing the RF power, the first-order impact is in coverage performance and power density. These impact the capacity of UE connections in some regions of the cell's coverage (or cause UE sessions to drop).

The first-order predictions indicate that during major dimming events, the SmartPower test site's RAN cell coverage will be impacted:

1. 4G RAN at full power, PTx = 2 x 20W
   - Overall service coverage with a 10km radius cell: ~80%
   - Percent of the cell able to support 64QAM DL UE sessions: ~7%
2. 4G in major dimming mode, PTx = 2 x 5W
   - Overall service coverage with a 10km radius cell: ~70%
   - Percent of the cell able to support 64QAM DL UE sessions: 4%

Figure 10 – Shambo (baseline) site deployment.
All deployment site photos from Peru were taken by our partners at Mayu Telecomunicaciones and are used here with permission. To request permission to use the photos, contact **servicios@mayutel.com**.

Figure 11 – Shambo (baseline) site deployment.
All deployment site photos from Peru were taken by our partners at Mayu Telecomunicaciones and are used here with permission. To request permission to use the photos, contact **servicios@mayutel.com**.

6.0 Findings

6.1 Findings Summary

In this collaborative project, a field trial was launched to examine the value of Smart Off-Grid power as a low-cost solution for rural telecom. The rural telecom market crucially depends on low-cost infrastructure to establish connectivity. As the power system accounts for about 25% of the telecom site's costs, a low-cost power solution is imperative to make rural telephony economically viable for mobile network operators and end users.

The trial determined whether Smart Off-Grid power could provide a cost-effective solution without compromising power availability and jeopardizing the operators' service requirements. To answer this question, two telecom sites were deployed (one with a conventional off-grid power system capable of meeting the targeted availability without power management services and one with a Smart Off-Grid power system) and monitored over six months. This trial showed that Smart Off-Grid power ("SmartPower") reduced power system costs by 40% and overall site CapEx by 10% without compromising uptime performance or power availability.

Through the period spanning from late May 2021 to early December 2021, the Shambo baseline site and Naranjal SmartPower test site were operated, and performance monitoring was undertaken continuously in 15-minute intervals. The 15-minute intervals were reduced to hourly readings by averaging the 15-minute intervals. Although many performance monitor (PMON) KPIs were recorded, only a subset of them was analyzed at the end of the observation period and reported on in this report.

The PMON KPIs deemed to be of most interest were:

1. Backhaul transmit power
2. RAN transmit power
3. RAN UE connections
4. RAN downlink throughput delivered

5. Local weather conditions
    a. Rain rate (mm/hr, maximum observed in the observation window time)
    b. Cloud cover (percent of visible sky)

The basic SmartPower concept is to essentially adjust the site's power consumption by proactively controlling the backhaul and RAN transmit power levels. Because the deployed equipment used in the trial exhibits a strong power-consumption dependence on these parameters, the site's power consumption can be controlled to a large degree. Predictive weather patterns are used as the basis of these proactive power adjustments. Making these adjustments is the key enabler in allowing the smaller, less costly solar battery system to be deployed.

This field trial attempts to gain insight and understand how these power consumption manipulations impact the telecom performance of the network. Therefore, the leading KPI indicators of interest are:

- Site availability
- RAN capacity impacts

6.2 Backhaul Transmit Power

The backhaul system connects the Shambo baseline site and Naranjal SmartPower test site to the rest of the network.

The Shambo site's backhaul power PMON is shown below. The figure shows that the site's backhaul power is statically configured at +27dBm. There are a few points where the RF transmit power drops to "0" in this figure. These indicate instances where the network was disconnected from the site, and the PMON readings (SNMP "gets") failed to return readings. In the case of this study, these are associated with two types of events:

- Rain-related fading of the microwave link, causing the site to be unreachable[3]

[3] For the purposes of this study, it is assumed that the former is not a significant contributor to overall site availability.

- Site power system outages where the solar battery system was unable to maintain the operation of the site due to its capacity or weather (solar charging) conditions

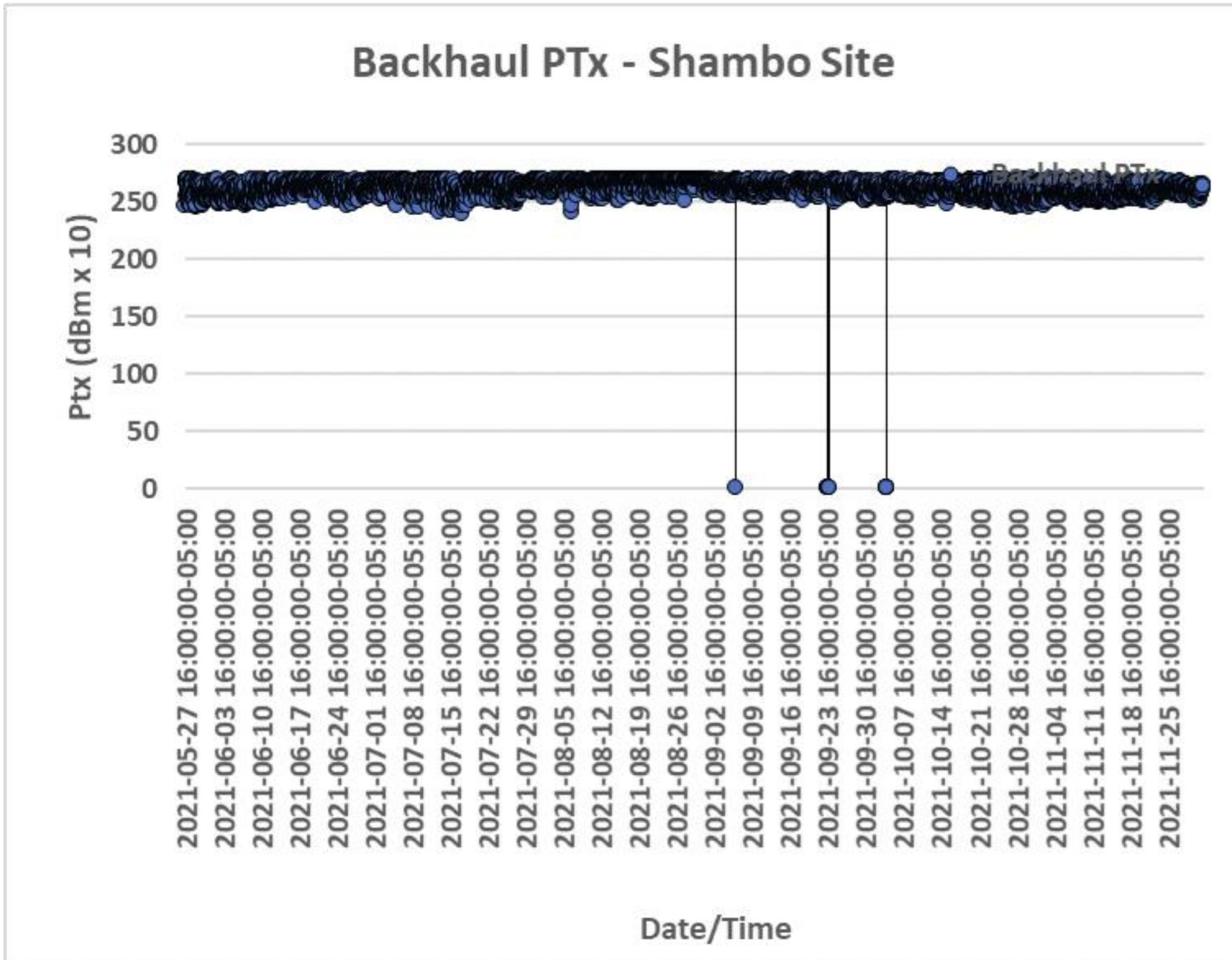


Figure 12 - Shambo baseline site backhaul transmit power PMON results

The Naranjal SmartPower site's backhaul transmission power is controlled via the SmartPower 4, 5 predictive algorithms. The PMON associated with this KPI is shown below. As noted in the figure, there are changes made to the backhaul transmit power throughout the trial duration. These are the result of bold predictions made by the SmartPower algorithms. Because the backhaul systems' impact on overall power consumption is small (compared with the RAN), infrequent changes are applied by the SmartPower algorithms.

Also, in this figure, there are a few points where the RF transmit power drops to "0." These indicate instances where the network was disconnected from the site, and the PMON readings (SNMP "gets") failed to return readings. In the case of this study, these are associated with the same two types of events as for the Shambo readings described previously.

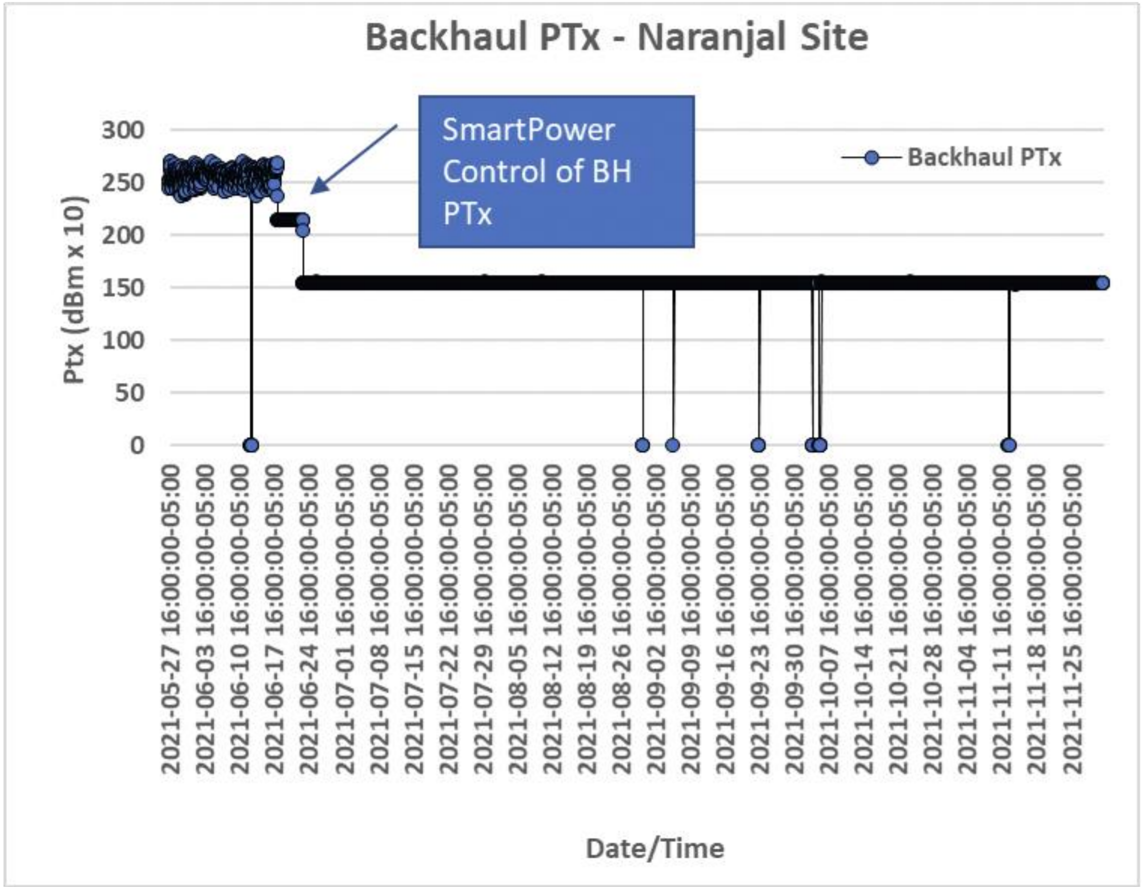


Figure 13 - Naranjal SmartPower test site backhaul transmit power PMON results

6.3 RAN Transmit Power

RAN transmit significantly impacts a site's overall power consumption performance.

As shown in the figure below, the Shambo site's RAN transmit power is configured statically at its maximum level (+43dBm per antenna). Also, in this figure, there are a few points where the RF transmit power drops to "0." These indicate instances where the network was disconnected from the site, and the PMON readings (SNMP "gets") failed to return readings. In the case of this study, these are associated with two types of events:

- Rain-related fading of the microwave link, causing the site to be unreachable.[4]
- Site power system outages where the solar battery system was unable to maintain the operation of the site due to its capacity or weather (solar charging) conditions.

[4] For the purposes of this study, it is assumed that the former is not a significant contributor to overall site availability.

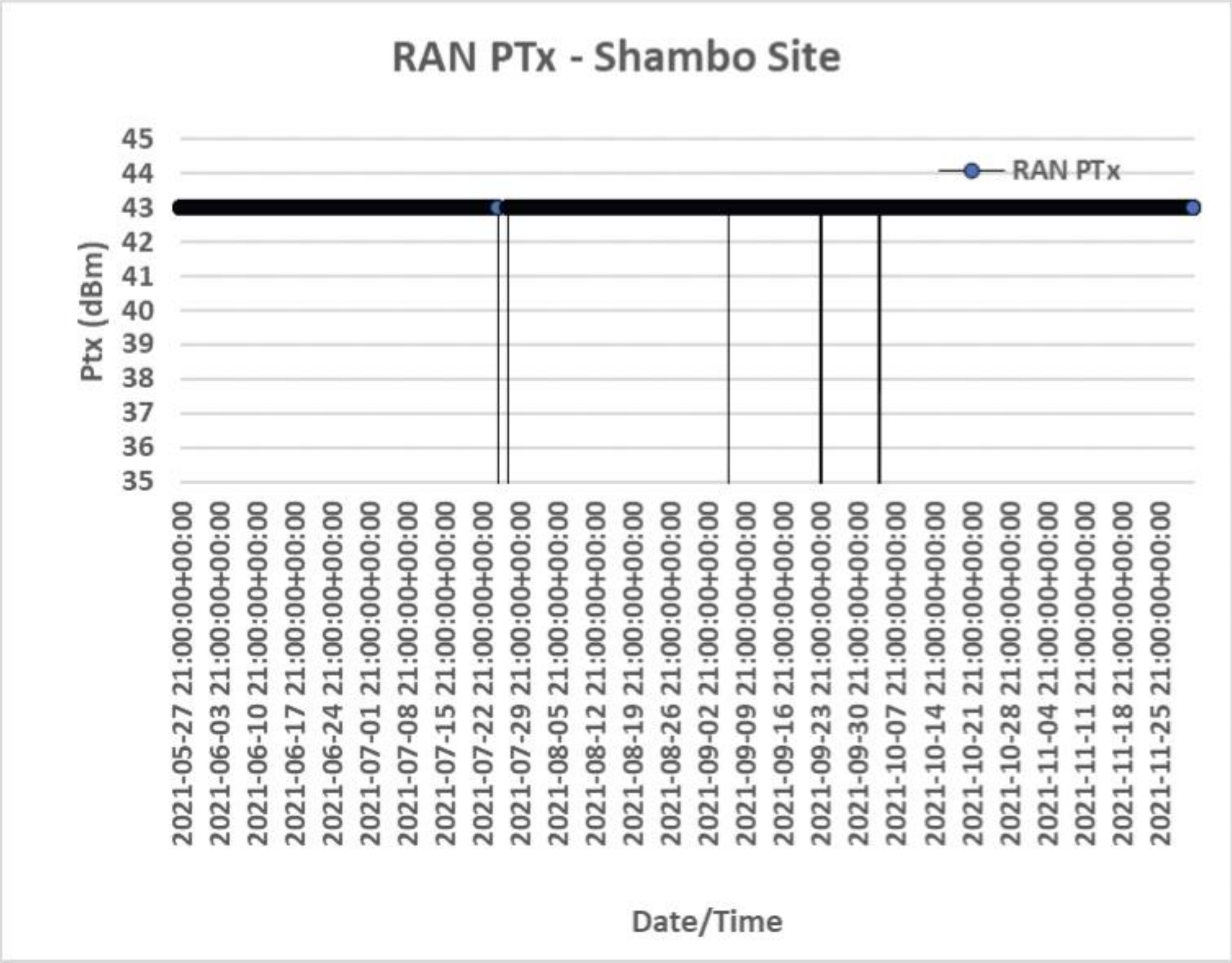


Figure 14 - Shambo baseline site RAN transmit power PMON

The Naranjal SmartPower site's RAN transmit power PMON is shown in the figure below.

There are a few noteworthy observations:

1. The maximum levels are altered between +43dBm per antenna and +36dBm per antenna. These are SmartPower algorithm-driven changes to the site's configuration. In the six months, there are approximately 13 changes, or approximately two per month. This is an important factor, as it provides insight into how often the site needs to be adjusted.

2. The power frequently drops to 0 dBm. Although some of these events are the result of the site's power system unavailability, most of these events are related to proactive shutdowns ("muting") of the 4G RAN in the 1 am to 3 am or 4 am time window, when user traffic drops to zero within the RAN service area.

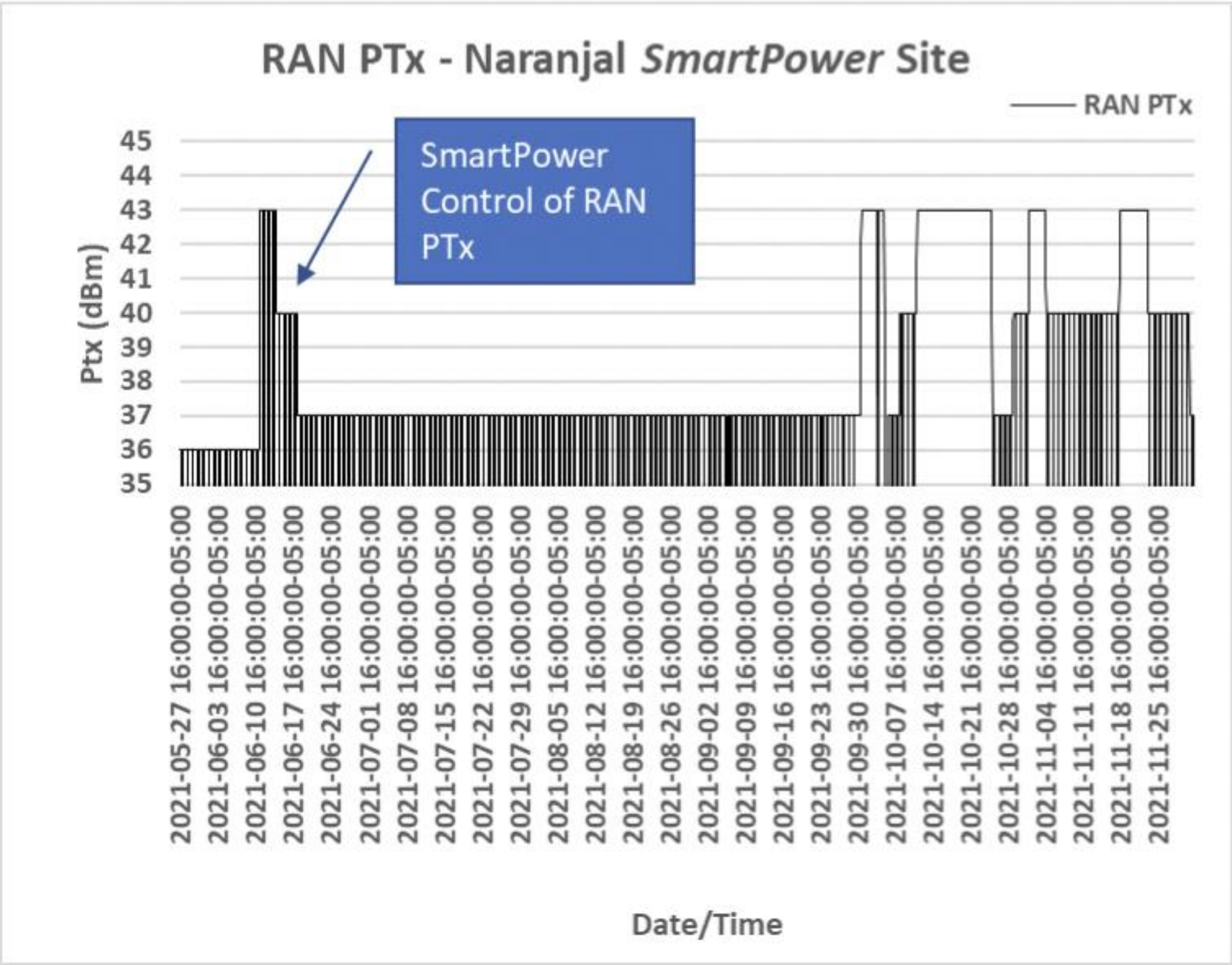


Figure 15 - Naranjal SmartPower test site RAN transmit power PMON

To examine the RAN transmit power PMON in somewhat more detail, the figure below shows the Naranjal SmartPower site's PMON. The backhaul transmit power is held steady at +27dBm during this observation window, while the RAN transmit power is reduced regularly (muted to 0dBm) during the time periods between 1 am to 3 am or 4 am when RAN user traffic drops off and the RAN isn't needed.

It should be noted that the service provider is required by law to keep at least 2G services operating 24 hours a day, so only the 4G system is manipulated during this field trial.

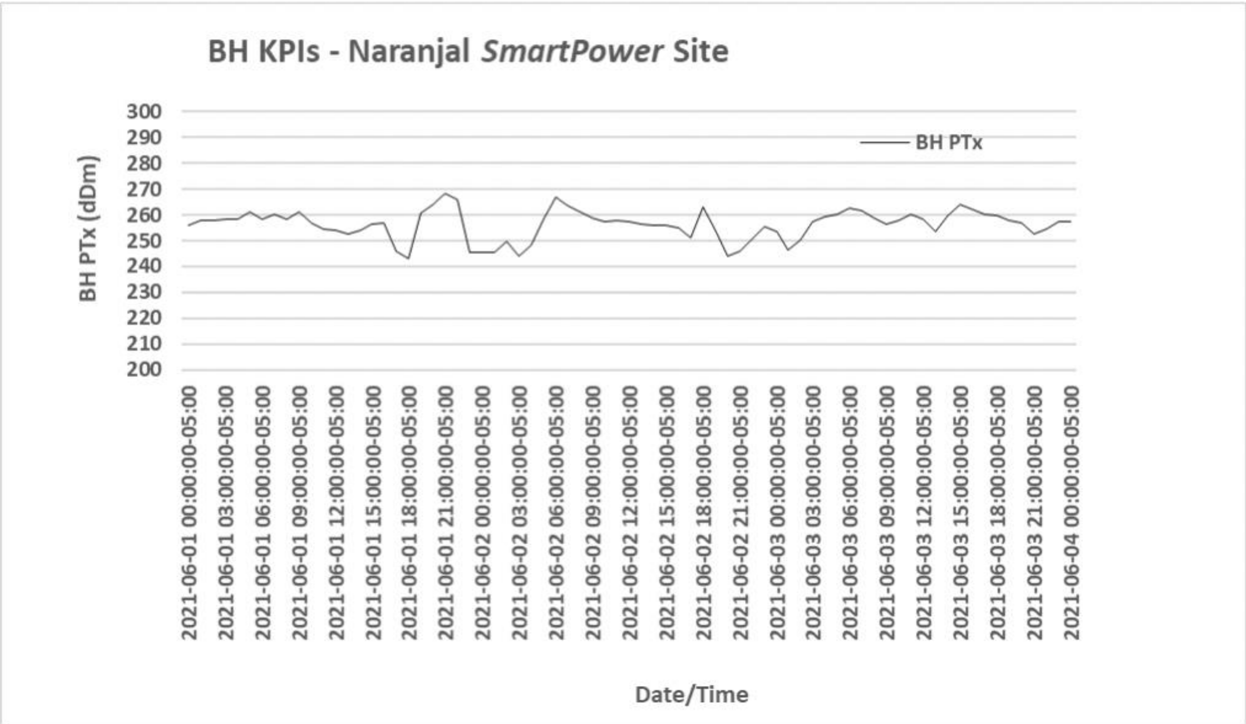


Figure 16 - Naranjal SmartPower test site backhaul transmit PMON (detailed)

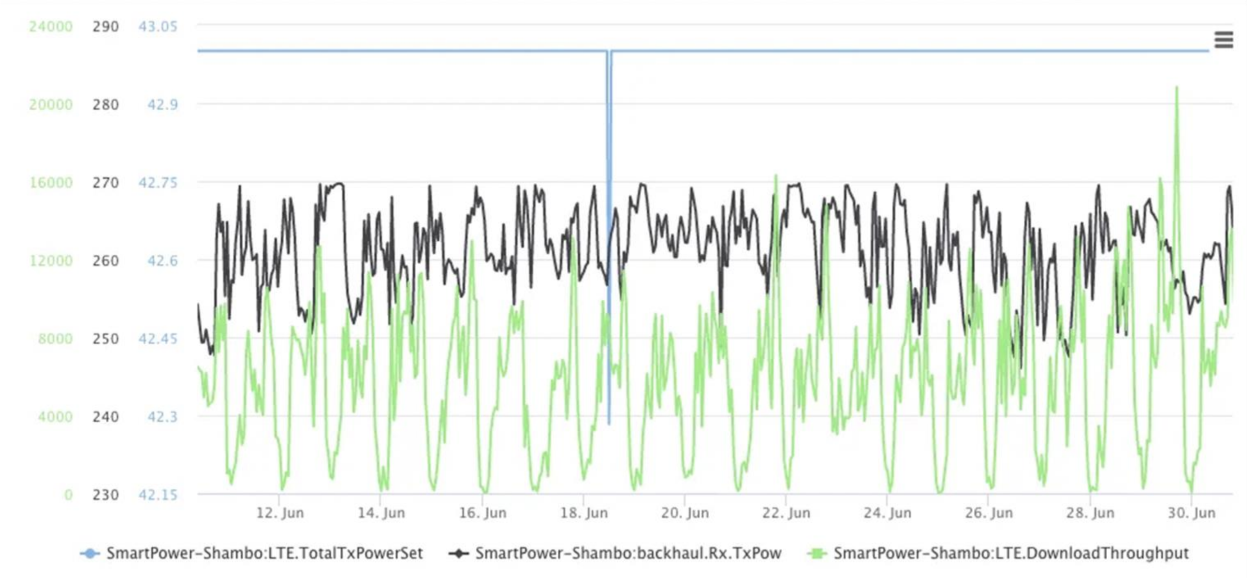


Figure 17 - Shambo baseline site initial installation performance showing ~12Mbps peak RAN throughput (as a reference)

This value of capacity is steadily maintained across the field trial timeline, with perhaps a slight increase over time, as shown in the figure above. The RAN site hosted ~12-15Mbps during peak periods, with the odd spike above that level. Busy-hour UE sessions being hosted were:

- At the beginning of the trial: 20-30 sessions
- Toward the end of the trial: 30-40 sessions

The figure below shows the RAN throughput PMON at the Naranjal SmartPower test site at the beginning of the trial. During busy hours, the traffic was ~30-35Mbps, with a few spikes going beyond that level.

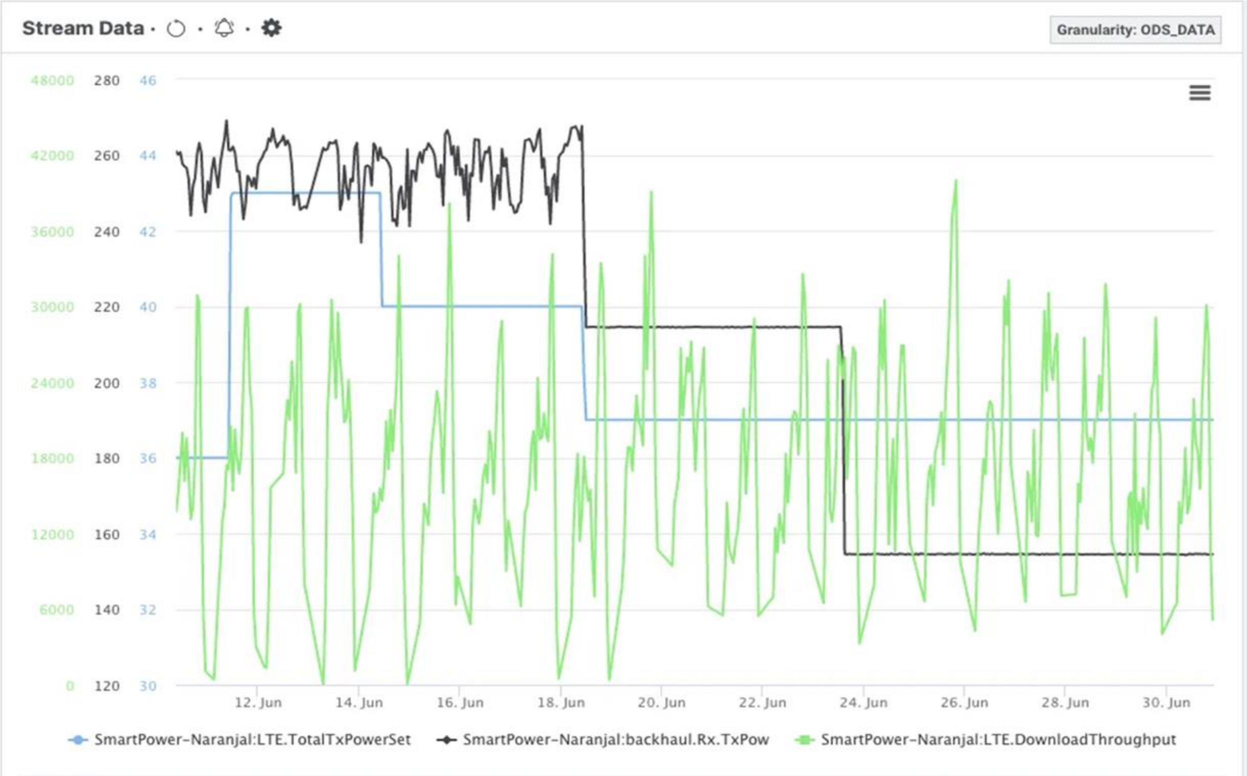


Figure 18 - Naranjal SmartPower test site initial installation performance showing ~30-35Mbps peak RAN throughput (as a reference)

The Naranjal SmartPower test site's RAN performance across the duration of the field trial is shown in the figure below. The RAN capacity is reasonably steady across the field trial period (30-35Mbps peak) and the active UE sessions are about 50-60 during peak hours.

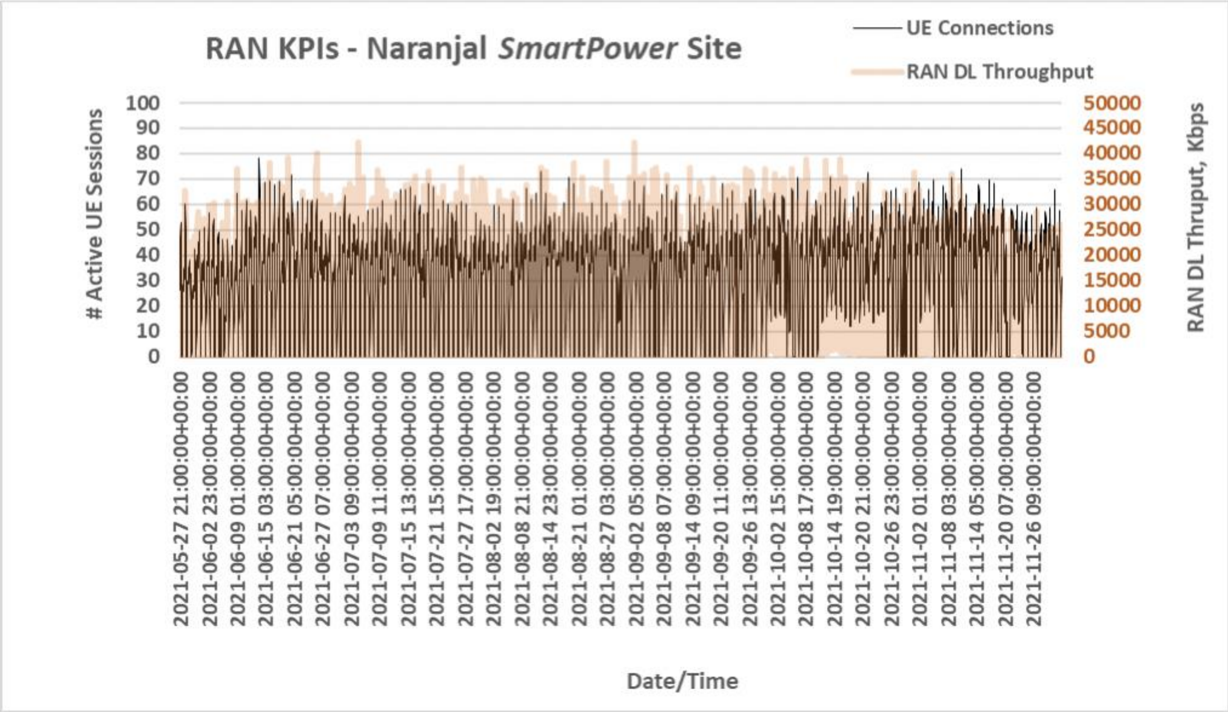


Figure 19 - Naranjal SmartPower test site RAN performance PMON gathered over the field trial

In the figure below, a closer look at a select time period (72 hours) shows the Naranjal SmartPower test site's RAN PMON. Of note is that the site's 4G RAN was turned off from 1 am to 3 or 4 am on a reasonably regular basis due to near-zero UE connection (and throughput) demands.

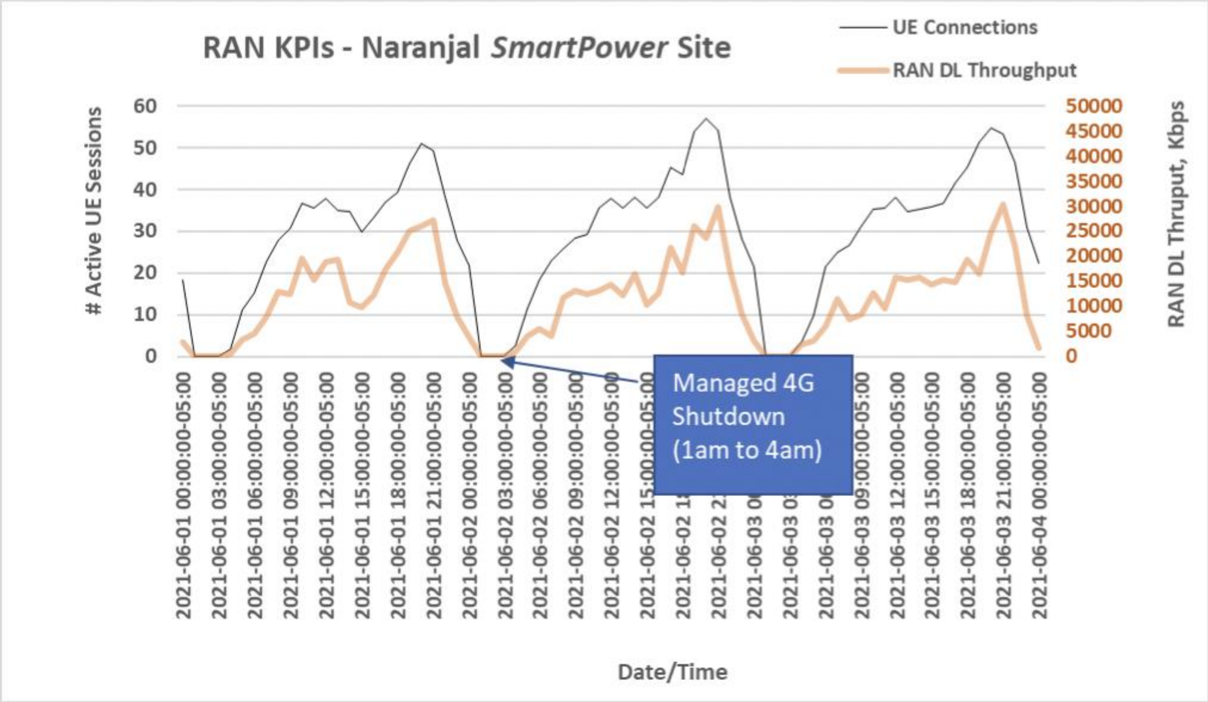


Figure 20 - Naranjal SmartPower test site RAN performance PMON gathered over a 72-hour time window

6.4 Weather Relationships

A key dependency of the SmartPower concept is its relationship to the weather and predictions of weather conditions. Weather affects several things:

1. Solar charging performance (cloud cover and rain impair this)

2. Backhaul radio availability performance (rain impairs this)

The SmartPower solution focuses on deploying smaller, lower-cost power systems to reduce costs in rural and deep-rural network deployments. To understand the context or assess availability associated with the solar battery power system, we need to be convinced that the backhaul connection is not a major contributor to site outages during the trial period.

Rain and multipathing are the two main contributors to backhaul radio link availability. The design of the backhaul radio deployed in this trial is a short-haul (< 8km), low-frequency link (11GHz link with an availability target of 99.7% annually, when operating at its minimum PTx). The figure below shows that the field trial time period spans a reasonably dry period of the year in the deployment location. There were only a few rain event occurrences. They were small (1.2mm/hr rain rate or less), suggesting that the backhaul radio link's availability should be relatively high (compared to the predicted power system availability).

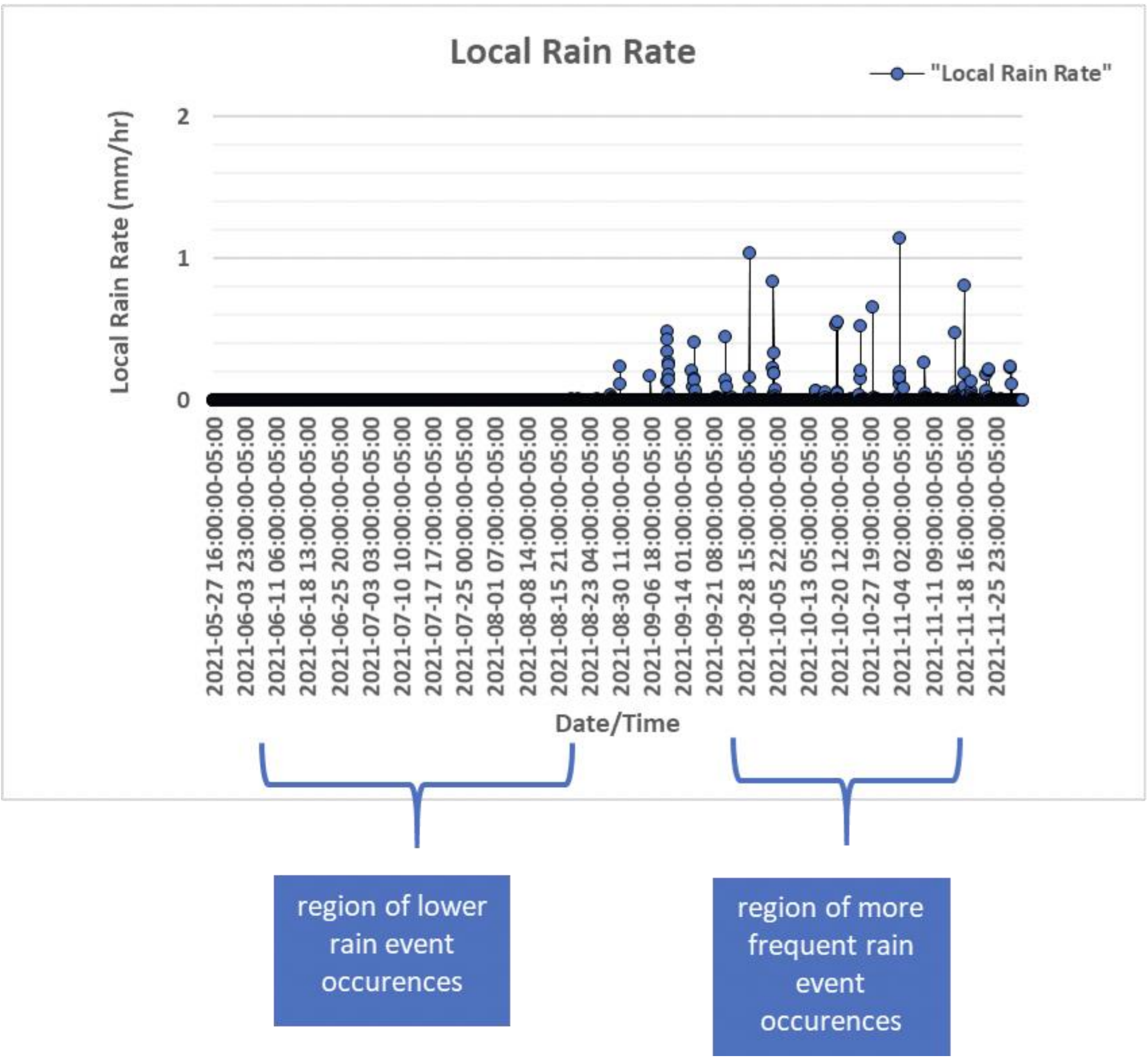


Figure 21 - Measured rain rate PMON across the field trial timespan

The solar battery system is in part sized by analyzing historical weather patterns, since solar power generation performance is also impacted by cloud cover. The weather patterns are also used in part to assess required battery system sizing. The figure below shows the cloud cover percentage PMON gathered during the field trial. Although cloud cover varies randomly, it can be observed that the amount of variation appears to be increased in the last 30% of the trial period. This aligns with periods of higher rates of power adjustment of the Naranjal SmartPower site, illustrating the relationship between cloud cover and SmartPower site adjustment activity.

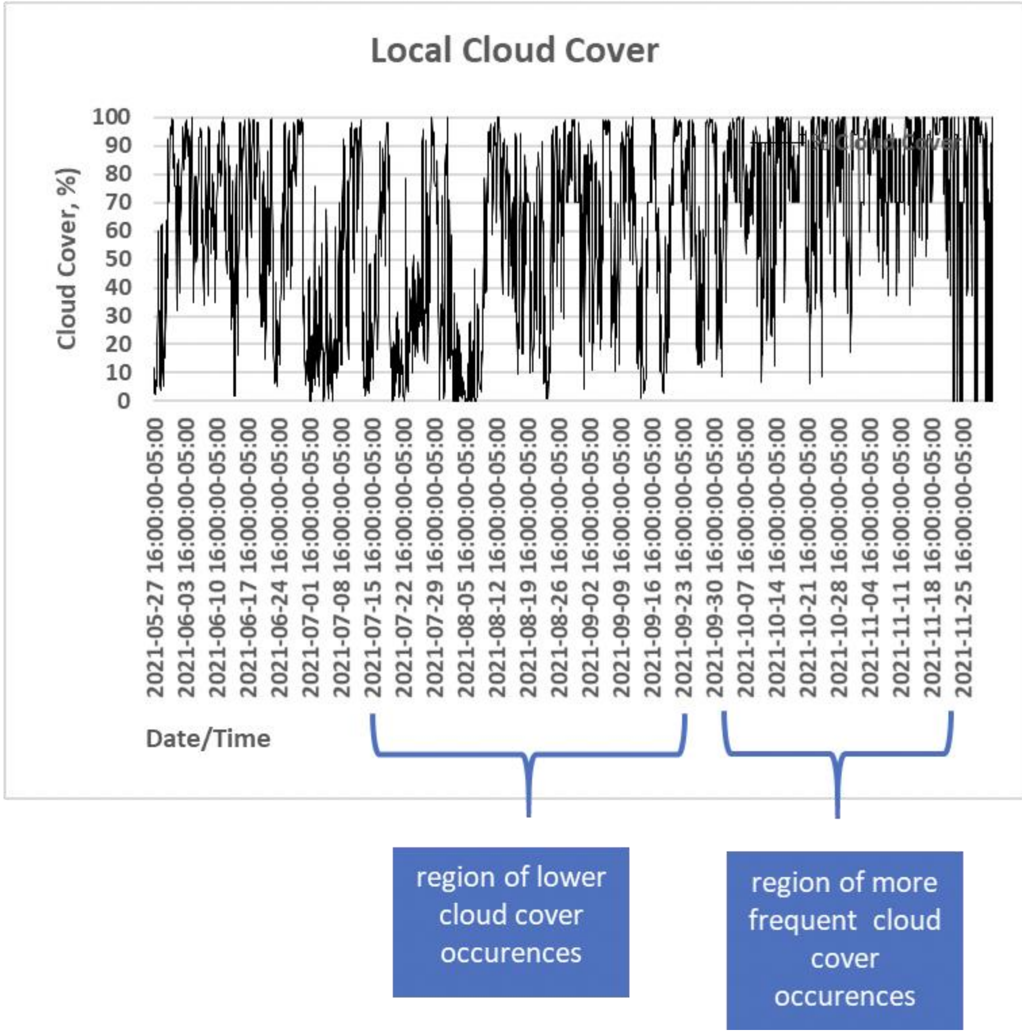


Figure 22 - Measured cloud cover PMON across the field trial time span

6.5 Download Speeds & User Connections

During the trial, we logged download (DL) and upload (UL) speeds and UE connections at both sites. Below, we show the recorded DL, UL and UE numbers, averaged daily, over the test period.

Naranjal — where the SmartPower test site is located — is more connected and has terrestrial (road) access and are other villages in the proximity, and some people of this village have access to the service; people have higher incomes (many of them work for a palm plantation).

Shambo — the baseline site — is more isolated due to the geography, and people have other economic activities and lower revenues.

As described in the field trial overview, we expect more traffic and users in the Naranjal site compared to the Shambo site.

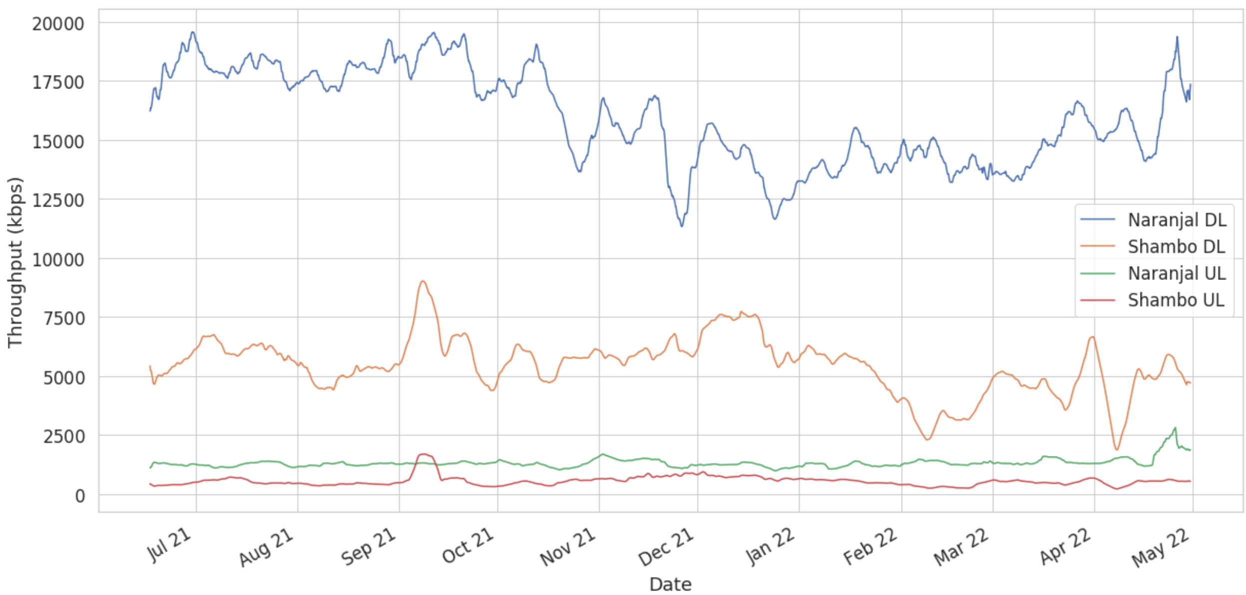


Figure 23 – Download (DL) and upload (UL) throughput, averaged daily, over the test period

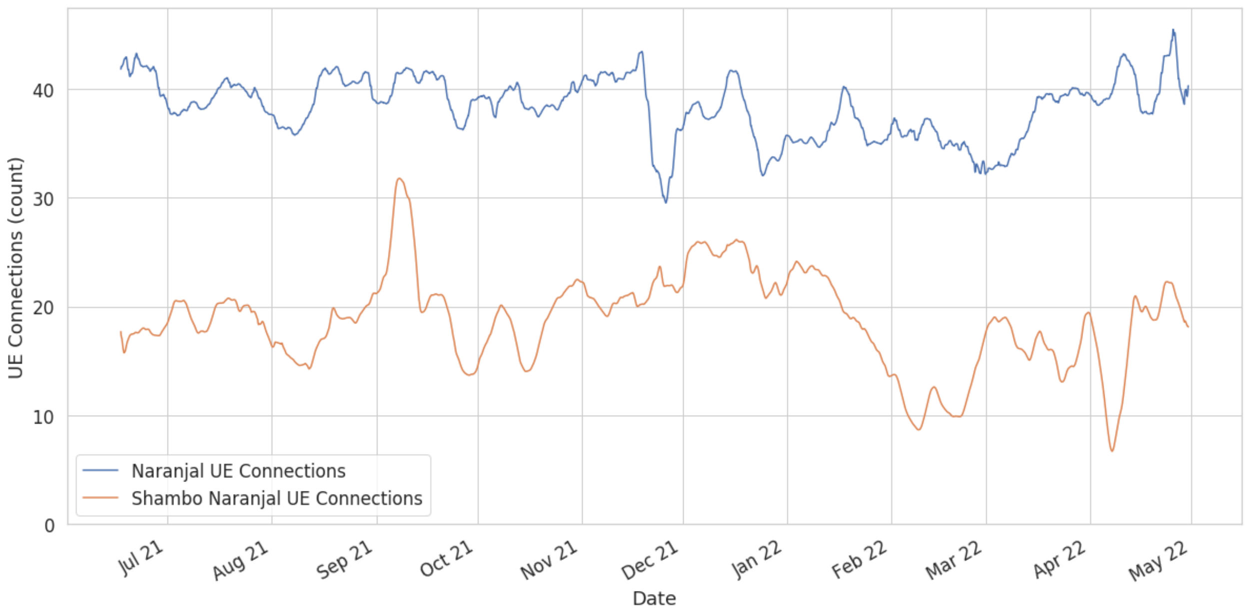


Figure 24 – Number of UE connections, averaged daily, over the test period.

6.6 Results and Discussion

The above findings demonstrate the actual value of Smart Off-Grid power technology. The SmartPower Research Project set out to evaluate the effect of Smart Off-Grid power on overall telecom site costs and performance. A conventional power system is sized with enough solar panels and batteries to provide sufficient power in the worst of weather conditions. Smart Off-Grid power systems can be much smaller because the power is actively managed to an extremely high degree.

In this trial, power was dynamically controlled by the Clear Blue Technologies service team to ensure the success of the field trial. Such power management led to a reduction in power system cost by 40% and a reduction in total site CapEx by 10%. In a market that heavily depends on reliable, low-cost infrastructure, a Smart Off-Grid power solution with a significant impact will help bring connectivity to millions of people.

The field trial shows that the smaller size of Clear Blue's Smart Off-Grid power system and active management of dimming modes exceeded the desired uptime availability requirements with planned and managed adjustments in telecom service performance. Unexpected blackouts did not occur, and there weren't any significant impacts on telecom service performance.

When it comes to off-grid solutions, it is often thought that there is a trade-off between affordability (smaller system size) and telecom performance. However, this field trial disproved that such a trade-off exists. With Smart Off-Grid power, you can achieve the same performance and availability targets as conventional off-grid systems with far greater cost efficiency. In fact, both sites provided nearly identical power availability, allowing Mayutel to reach its availability requirements.

7.0 Conclusions

Overall, the project found that Smart Off-Grid Power reduced power system costs by 40% and total site CapEx by 10%. In the rural telecom market, a 10% site CapEx reduction is highly significant, and Smart Off-Grid power makes an enormous difference in reducing power system costs. The technology provides a clear cost advantage over alternative power solutions. In this market, a low-cost power infrastructure solution is game-changing, making rural connectivity possible and scalable.

Smart Off-Grid power enables service providers such as Mayutel to provide reliable connectivity through manageable RAN reductions while maintaining uptime availability targets. This can provide connectivity to millions of people who were previously unreachable due to the fundamental challenges of rural telecom. Establishing lasting connectivity in these deep-rural communities will provide previously unattainable opportunities for socioeconomic progress. This collaborative project clarifies that Smart Off-Grid power is the solution for rural connectivity and shows how collaboration and innovation can make a tangible difference.

The implications of this field trial are undoubtedly groundbreaking. The study substantially proves the value of Smart Off-Grid power as a solution for rural telecom, and Clear Blue's Smart Off-Grid technology is the power solution that makes rural telecom scalable to bridge the digital divide. This field trial is a starting point for changing the nature of rural connectivity. These sites will continue to run, and over the next few years, Clear Blue expects to see that the Smart Off-Grid power test site also provides a significant advantage regarding the long-term operating costs. Due to the ability to remotely and proactively maintain power systems, the Smart Off-Grid site will require fewer maintenance site visits; issues can be anticipated, and 70% of them are managed remotely. This will lead to a greater return on investment for telecom operators in the long run.

As the system accumulates more data, power management can be further automated, enabling AI-driven power management and scalability to larger networks. The value that active management and control of off-grid power can play in providing reliable connectivity at a lower cost will help make connectivity in deep-rural, off-grid locations more feasible.

TELECOM INFRA PROJECT