The Sky is the Limit: Evaluating the Argos Satellite Constellation Coverage in Different Terrain Types

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***Abstract*—Satellite communication has seen significant adoption in recent years, particularly for remote data gathering and telemetry. With the reduced cost of utilizing satellite communication and its wide terrestrial coverage in areas with insufficient or no alternative communication infrastructure, satellite communication is an attractive option. The Argos satellite constellation, consisting of 10 satellites in Low Earth Orbit (LEO), is dedicated to the global collection of environmental data and conservation efforts, globally. The transmission success rate is evaluated across different types of terrestrial types of terrain. The coverage of the Argos constellation is assessed across various horizon profiles, including mountainous, urban, and open. The findings in this paper indicate that the transmission success rate is influenced substantially by the terrain profile, with elevated horizons reducing satellite visibility. Throughout the study, the highest success rate is observed when satellites are above 20° elevation, but it is noted that more than half the satellites passes are below 10° elevation.**

I. INTRODUCTION

Significant effort is being made in the conservation field to understand the environmental factors that influence the behaviour and movement of wild animals. This information can help resolve animal-human conflicts, control the spread of animal-borne diseases, prevent animal poaching, and satisfy scientific curiosity.

Biotelemetry is an important tool for acquiring animal behavioural data. Tracking collars, with some form of communication for data retrieval, have been used for many years. However, the terrestrial communication environment often presents significant challenges in terms of reliability and feasibility. Power constraints are an additional severely limiting factor. Satellite data links often seem to present an obvious alternative and a perfect solution. However, this is not always the case, as demonstrated by the findings documented in this paper.

A. Terrestrial and Satellite Networks

There are many established ways of remotely collecting data from animals in the field. One technique is to log data on a device worn by the animal and then retrieve the device to collect the data at the end of a study. Some more advanced tracking devices can send data to nearby radio infrastructure using radio transmitters, such as cellular, LoRaWAN, Sigfox and NBIoT. In cases where the terrestrial network infrastructure is not in place, IoT-over-satellite networks is an emerging alternative. Satellite connectivity makes it possible for animals to be tracked over wide areas and across country borders, which is often necessary in conservation research such as those involving migrating species. Figure 1 illustrates the communication channels typically used by animal tracking devices.

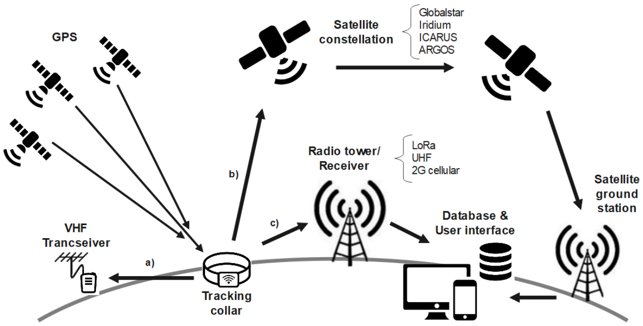


Fig. 1. An illustration of the communication channels typically used by tracking collars. Traditional tracking is done by a) VHF transceiver to triangulate the VHF "ping" collar. Modern telemetry allows for data to be sent via b) satellite networks or c) terrestrial networks that store and process the data on remote servers accessed through a user interface or API.

B. Conservation and IoT-over-Satellite

Satellite technology can improve the impact of much conservation work significantly. Information about movement ecology can address challenges, such as how to monitor animal-borne disease spread, animal communication, land use, climate change, and biodiversity loss [1].

The satellite Internet of Things (IoT) is on the verge of becoming very popular due to its ability to connect sensors and devices across the globe. While satellite connectivity has traditionally been an expensive and exclusive technology reserved for military and space observation applications, it has also been utilised for conservation research since the early 1960s. The performance and cost of this technology has improved significantly and enabled the modules to be reduced in size and weight. This has resulted in ability to study smaller animals using satellite data links.

The ICARUS project, for example, is using satellite technology to track small animals and birds using ultra-small and low-power transmitters [2].

Johnson et al. [3] made use of Argos Satellite transmitters to track the paths of migrating animals, while Dujon et al. [4] used similar technology to track marine life. These studies were previously not possible due to the lack of terrestrial communication infrastructure over these vast and remote areas.

C. Effect of the Terrain on Radio Communication

The quality and reliability of radio communication is heavily influenced by the propagation path between the transmitting and receiving antennas. Radio waves are electromagnetic signals that propagate through space, and can be absorbed and reflected by obstacles such as trees, mountains, and even the atmosphere. Reflection occurs when the propagating radio wave encounters an object that is large in comparison with its wavelength. Due to a mismatch in impedance between the air in which the wave has been propagating and the foreign object, some energy is absorbed by the object and the remaining energy is reflected. Radio waves with shorter wavelengths are scattered by smaller objects and edges in a process referred to as diffraction, which enables these signals to better propagate around and between objects. Topography becomes an important factor to consider at frequencies above approximately 30 MHz because mountains and tall buildings are larger than the wavelength (less than. 10m) leading to "radio shadows" or an echoing effect as shown by Bertoni [5].

D. Research Objective

To minimize energy consumption in wildlife tracking collars, it is crucial to enhance transmission efficiency. Given the significant impact of terrain on satellite availability, our objective is to gather data using the Argos system to develop a better understanding of this relationship.

II. LITERATURE REVIEW

Lu et. al. [6] considered non-specular scattering due to hilly or mountainous terrain. This work showed that these scattered paths can contribute substantially to the received signals, compared to the direct signals, in sufficiently rugged terrain. Whitteker et. al. [7] analysed the propagation behaviour at two distinct frequencies, 700 MHz and 2.4 GHz, in environments cluttered with foliage and vegetation. In communication with satellites, the distance that the signal travels through vegetation depends on the satellite's elevation angle. The authors concluded that such ground clutter significantly influences radio wave propagation.

Mehmood et. al. [8] investigated channel modelling for land mobile satellite communication links and pointed out that the performance of these systems depend on various factors, including elevation angles, radio frequency, climate and geographic location. Pollock [9] devised a model to forecast diffraction attenuation caused by signal propagation over terrain in Low Earth Orbit (LEO) satellite systems. He found that constellations with a higher number of in-view satellites and more frequent observations of higher elevation satellites achieve higher access availability.

III. HARDWARE AND INFRASTRUCTURE

A. Argos Satellites

The Argos satellite constellation is a system of satellites dedicated to the collection of environmental data and support of conservation efforts. The constellation consists of 10 satellites in Low Earth Orbit (LEO) and provides global coverage. An additional 25 Kinéis nanosatellites are scheduled for launch in June of 2024 to expand the coverage and capabilities of the Argos constellation. The operational Argos satellites are listed in Table I.

The Argos satellites are equipped with the Argos Data Collection System (DCS) which is a satellite-based system used for environmental monitoring, wildlife tracking, and other applications. The data is transmitted to the satellites using small, lightweight transmitters attached to the platforms, or animals being monitored. The data is then relayed to the network of ground stations for processing and analysis. The Argos DCS can also determine the transmitter's location using the Doppler effect. This technique allows for very energy efficient localisation, but only achieves a location accuracy of between 150m and 1km. This location data is also not available to the transmitter for onboard processing.

Three of the legacy satellites and the new Kinéis satellites are capable of downlink. The downlink capability allows for the transmitters to detect when there are satellites in view to avoid transmissions when the satellites are out of range. Since not all satellites have this capability, a strategy is required that does not rely on this feature.

B. Satellite orbits

The Argos satellites are in a sun-synchronous polar orbit, which means that they cover the entire Earth's surface, passing over the same location periodically. The orbital period of the satellites is around 100 minutes with a repeat cycle varying between 2 and 35 days. The orbital parameters are described by its two-line-elements, which are used to get its position and predict its future path. Figure 2 shows the predicted times that each Argos satellite will pass over Stellenbosch each day in January 2024. Since the orbits are deterministic, this information can be accurately computed and used to know when the satellite will be overhead and in view of the transmitter. ArgosWeb is a web-based tool, maintained by CLS, that can be used to obtain these pass predictions for a given location. This is useful for planning the transmission schedule to achieve better transmission success, since the satellites are not in view all the time. Unfortunately, due to remnant atmosphere, solar radiation, and other external factors, the satellites drift from their calculated path, making these predictions only accurate for up to three months.

TABLE I
OPERATIONAL LEGACY ARGOS SATELLITES (JUNE 2024)

Satellite	NORAD ID	Argos instrument	Altitude	Orbit period (minutes)	Repeat cycle (days)	Mission period	High data rate and Downlink Capable
ANGELS[a] (A1)	44876	A-DCS4	490	94.4	-	2019 - 2026[b]	X
SARAL (SR)	39086	A-DCS3	800	100.6	35	2013 - 2024[b]	X
CS-HoPS (CS)	54023	A-DCS4	750	99.9	-	2022 - 2027[b]	X
OCEANSAT-3 (O3)	54361	A-DCS4	723	99.3	2	2022 - 2027	X
NOAA-15 (NK)	25338	A-DCS3	813	102.9	-	1998 - 2024[b]	
NOAA-18 (NN)	28654	A-DCS3	870	101.9	-	2005 - 2024[b]	
NOAA-19 (NP)	33591	A-DCS3	870	101.9	-	2009 - 2024[b]	
MATOP-A[c] (MA)	29499	A-DCS3	827	98.0	29	2006 - 2021	X
METOP-B (MB)	38771	A-DCS3	830	101.3	29	2012 - 2026	
METOP-C (MC)	43689	A-DCS3	827	101.3	29	2018 - 2027	

The information in this table was collected from OSCAR (Observing Systems Capability Analysis and Review Tool) web tool in March 2024 [10]. OSCAR, produced by World Meteorological Organisation (WMO).

[a] There is currently one prototype ANGELS (Argos Neo on a Generic, Economical and Light Satellite) satellite to prepare for the planned 25 nanosatellite fleet.

[b] The estimated End of Life (EOL) might extend past this date.

[c] The METOP-A mission has reached end of life.

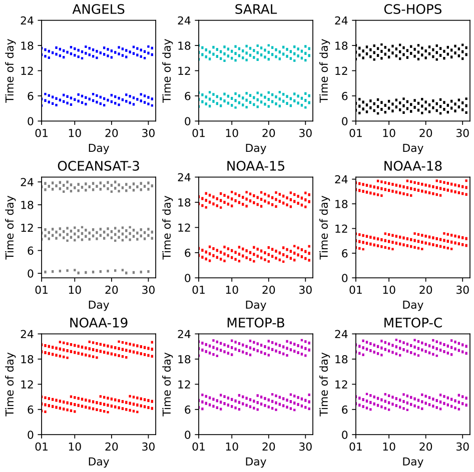


Fig. 2. The calculated times that each of the active Argos satellites pass Stellenbosch, South Africa in January 2024. The satellite pass times were generated using ArgosWeb.

The altitude of the satellites is around 800km, which is therefore the minimum possible transmission distance. The maximum visible distance, however, is encountered when the satellite is on the horizon, a distance of over 3000km from the transmitter. The new Kinéis nanosatellites will be in a slightly lower orbit (650km), which will reduce the satellite pass duration, as well as the transmission distance. This will give an opportunity to reduce the transmission power in low power applications, at the cost of a reduced transmission window.

C. Argos Transmitter

The Argos transmitters have been used in various applications, including wildlife tracking, weather monitoring, and oceanography. Devices such as the Linkit Core and the Kim1 module make use of the ARTIC (Argos Receiver Transmitter with Integrated Control) integrated circuit to transmit low power radio signals to Argos satellites.

The Linkit Core is a GPS sensor device featuring open-source hardware and software for quick configuration and deployment. The Kim1 modules can be used for quick integration into more specialised designs using a UART as a command interface and a GPIO pin to disable the module for better power management.

The Kim1 Shield is used in this project to test the Argos transmitter. A Raspberry Pi was used to configure and periodically send messages via the Kim1 Shield. The Raspberry Pi relies on an external real-time clock to maintain time when it is powered off. Each instruction and configuration of the Kim1 Shield is time-stamped and logged on the Raspberry Pi. This setup allows for a comparison between the messages received from the Argos network with the ground truth messages stored locally on the Raspberry Pi. Figure 3 shows the physical setup used in the experiments.

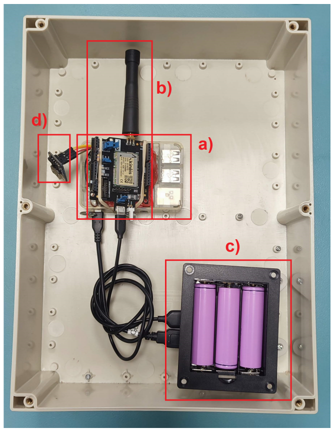


Fig. 3. The Argos transmitter box showing the a) Raspberry Pi, b) Kim1 Shield, c) battery, and d) external real-time clock as indicated.

IV. EXPERIMENTAL SETUP

In order to gain a better understanding of the behaviour of the Argos Satellites, the orbital information and calculated pass times over the Western Cape of Southern Africa were investigated. A preliminary evaluation of the predicted pass times revealed that the satellites predominantly pass over the Western Cape in two groups each day, one in the morning and one in the afternoon. Figure 4 shows the average hourly distribution of satellite passes over Stellenbosch in April 2024.

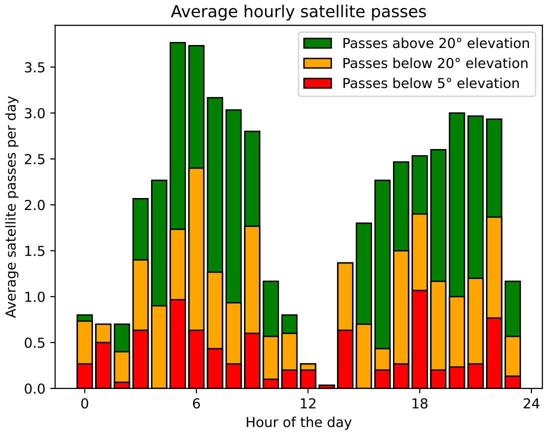
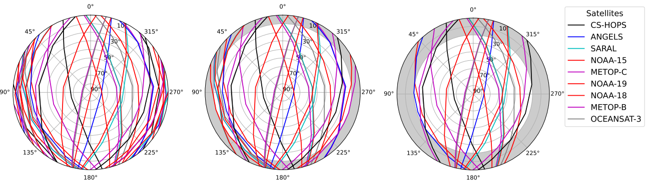


Fig. 4. The hourly distribution of satellite passes over Stellenbosch in April 2024. Each bar shows the total number of satellites reaching a maximum elevation of less than 5°, less than 20° and above 20°.

When considering the elevation of the anticipated passes, it is noted that satellites often reach a maximum elevation that is lower than the geographical horizon of the transmitter. Figure 5 shows the possible impact of a raised geographical horizon, as may for example be raised by mountainous or hilly terrain. Due to the shadowing caused by the geographical horizon, transmissions are less likely to be received when the satellites are at a low elevation.



(a) 0° elevation (b) 10° elevation (c) 20° elevation

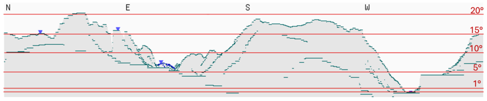
Fig. 5. Argos satellites passing above Stellenbosch in one day in 2023, filtered by the maximum elevation of each pass. a) 48 passes at 0° elevation, b) 32 passes at 10° elevation, c) 21 passes at 20° elevation.

For this reason, the experimental transmissions were performed in their different terrains: mountainous, urban, and open area. These three types of terrain were chosen to represent the different environments in which the Argos transmitters might be applied for animal tracking. The mountainous area in question is the middle of the Jonkershoek valley in, Stellenbosch. The mountains surrounding this location rise to about 1250m above the transmitter in places, obscuring up to 20 degrees above the celestial horizon, and leaving only the north-west side without mountains on the visible horizon.

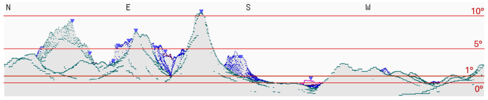
The urban area transmission tests were performed from the rooftop of a 5-story building in the town of Stellenbosch. This was considered to represent a typical location in which to place a stationary transmitter in an urban area. Although there are almost no other buildings obscuring the geographical horizon, there are mountains to the west of the town with elevations between 5 and 10 degrees.

The open area transmissions were done in Langebaan, on the west coast of the Western Cape, 120km from Stellenbosch. The transmitter was placed in an open field with only a few trees and fynbos vegetation in the vicinity. The area has no significant hills or geographical obstructions that could limit the view of the sky.

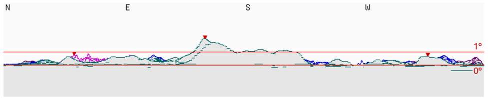
The geographical horizon profiles were calculated by obtaining elevation data of the surrounding terrain and performing a viewshed analysis [11] from the location of the transmitter. This was achieved using the online tool, heywhatsthat.com [12]. These profiles are depicted in Figures 6a, 6b, and 6c respectively.



(a) The mountainous area, Jonkershoek, Stellenbosch.



(b) The urban area, Central Stellenbosch.



(c) The open area in Langebaan, Western Cape.

Fig. 6. Geographical horizon profiles of the three locations used for the experiments. The red horizontal lines indicate angular altitudes. The images were generated using the tool [12].

The transmitter was placed on the ground in both the mountainous and open areas, and on a rooftop in the urban area. The omni-directional antenna was positioned upright for all the experiments to avoid inconsistent data due to changing antenna gain and directionality.

A. Data Collection

The Kim1 Shield was set up to transmit Argos messages, which were subsequently recorded upon successful reception by satellites. Each message contained a 32-bit timestamp indicating the sending time. The transmitter was configured to send messages every 5 minutes over periods lasting 21 to 23 hours. This process was repeated across varying transmission powers (100mW, 250mW, 500mW, 750mW, and 1000mW) and in the three distinct terrain types.

When a message is received by a satellite, the time, RSSI, and the name of the satellite is recorded along with the original message. This data was retrieved from the ArgosWeb portal. Pass predictions were then used to estimate the elevation and azimuth of the receiving satellite at the recorded time of the transmission. The logs maintained by the transmitter were utilized to determine the positions of visible satellites for cases in which the messages were not received. The results of these tests are presented in the next section.

V. RESULTS

A. *Success Rate*

The results or our experiments are summarized in Table II. The table shows that the success rate of the transmissions is higher in the open and urban areas than it is in the mountainous area. It is also noted that many transmissions occurred at times at which no satellites are above the celestial horizon. This indicates the need for a more efficient transmission strategy. Satellite presence is referred to as the time at which a satellite is above the celestial horizon. In order to verify whether the captured data can be considered a fair representation of the norm, the percentage of satellite presence in our data was compared to the calculated satellite presence over a 1-month period. The measured average of 34.09% was found to be close to the calculated figure of 32.99%.

TABLE II
TRANSMISSION TEST RESULTS IN 3 DISTINCT TERRAIN TYPES.

Area	**TX Power (mW)**	**Number of TXs**	**Number of TXs with Sats**[a]	**Number of RXs**	**RX/TX (%)**	**RX/TX with Sats (%)** [a]
Mountainous						
	100	265	102	17	6.42	16.67
	250	261	128	41	15.71	32.03
	500	304	130	47	15.46	36.15
	750	253	131	31	12.25	23.66
	1000	300	101	33	11.00	32.67
Urban						
	100	301	165	52	17.28	31.52
	250	283	204	78	27.56	38.24
	500	302	165	43	14.24	26.06
	750	281	188	59	21.00	31.38
	1000	290	156	51	17.59	32.69
Open						
	100	245	147	58	23.67	39.46
	250	284	164	66	23.24	40.24
	500	282	169	60	21.28	35.50
	750	286	171	62	21.68	36.26
	1000	303	178	67	22.11	37.64

[a] *with Sats* identifies the transmissions that occurred while satellites were above the celestial horizon.

B. *Elevation Analysis*

Transmissions to satellites with elevations below 20° proved to be very inefficient. However, satellite elevations are below 10° more than half the time. Radio transmissions become more successful with increased satellite elevation, but it was also observed that the success rate decreases again above 60°. This is likely due to the gain pattern of the omni-directional antenna which has a null at 90°. This is illustrated in Figure 7, which presents the transmission data grouped by satellite elevation at the time of message transmission.

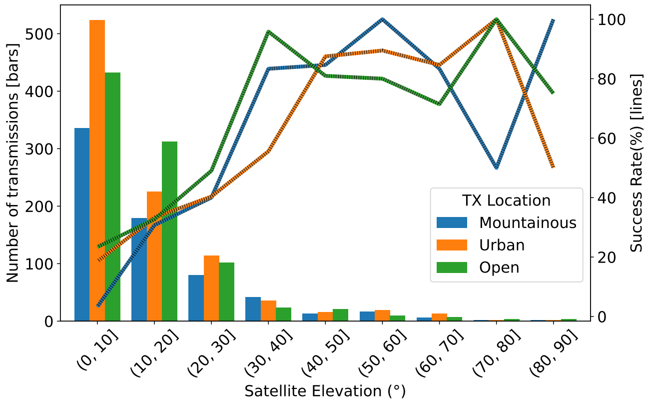
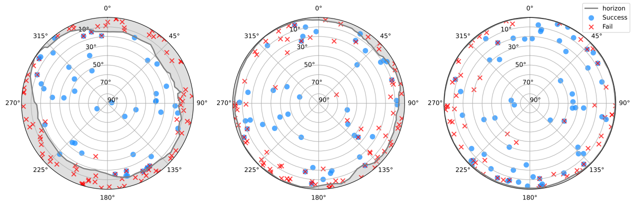


Fig. 7. Considering only transmissions where a satellite was above the celestial horizon, the line graph shows the number of transmissions as a function of the satellite's elevation at the time of transmission. The bar graph displays the mean communication success rate as a function of the elevation angle of the visible satellite. The data is presented separately for each of the three terrain types: mountainous, urban, and open area.

C. *Shadowing Effect*

Figure 7 also shows that the mountainous area has a much lower success rate at elevations below 20° than the urban and open areas. This is due to the mountains obscuring the line of sight of the satellites.

The radar plots in Figure 8 clearly indicate that transmissions below the geographical horizon were not successful due to the shadowing effect. A clear divide between the transmissions that were received and not received in terms of the geographical horizon is observed. This is more prominent in the mountainous area, where the mountains obstruct the view of the satellites.



(a) Mountainous Area (b) Urban Area (c) Open Area

Fig. 8. Radar plots of successful (blue dots) and unsuccessful (red crosses) transmissions in (a) the mountanous area, (b) the urban area and (c) the open area.

D. *RSSI Analysis*

The Received Signal Strength Indicator (RSSI) can be used to determine the quality of a received signal. The signal strength is greatly influenced by the distance between the transmitter and the receiver, which is a function of the elevation of the satellites. Figure 9 indicates that the average

RSSI increases with the elevation angle of the satellites, as might be expected.

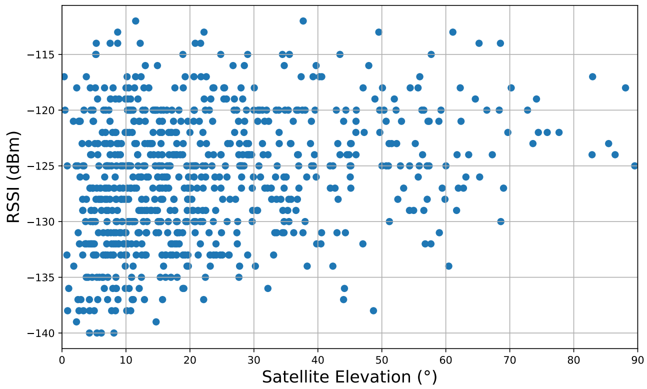


Fig. 9. RSSI of the received signals as a function of the elevation angle of the satellites. Only data for 500mW (27dBm) transmissions are shown.

E. Transmission Power

The transmission powers used by the Kim1 Shield during measurements were 100mW, 250mW, 500mW, 750mW and 1000mW, corresponding to levels between 20dBm to 30dBm, respectively. Figure 10 illustrates that there is no clear trend in the success rate of the transmissions with increase in transmission power. However, the average RSSI of the received signals shows an increase with higher transmission power. This is expected, as signal strength is directly proportional to transmission power.

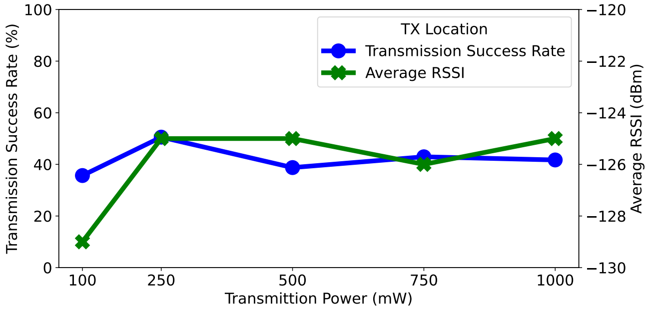


Fig. 10. Transmission success rate and average RSSI of the received signals for transmission powers of 100mW, 250mW, 500mW, 750mW and 1000mW. The plots show averages over all the tests in the three terrains. Only messages that were received by a satellite are considered.

VI. CONCLUSION

In this study, the impact of geographical horizon profiles on the success rate of IoT-over-Satellite radio transmissions using the Argos satellite network was investigated. The pass predictions and behaviour of the Argos legacy satellites were analysed, revealing that they pass over the Western Cape of South Africa in two groups each day. Experiments were conducted in mountainous, urban, and open areas to evaluate the practical performance of transmissions in these different types of terrain. The results showed that, as the geographical horizon elevation increases, the effective satellite transmission window decreases due to the shadowing effect. By varying the transmission power, and it was found that the success rate of transmissions was not affected substantially by the transmission power. However, the average RSSI of the received signals did show an increase with higher transmission power. The findings demonstrate that the geographical horizon profile greatly influences the effective satellite transmission window. This information can be used to optimize the transmission strategy of IoT-over-Satellite devices to improve the success rate of transmissions and limit power usage. Such optimization could be valuable in conservation efforts, where effective, low-energy transmission is essential.

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