Title: Africa Nano^3 – Leveraging NANOscience, NANOtechnology and NANOsatellites for Africa-centred connectivity solutions

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☒ **Please keep our idea confidential if we were not selected as finalist/semi-finalist.**

This mission offers continuous connectivity in sub-Saharan Africa and provides a vehicle to leverage the existing African networks of expertise in nanoscience, nanotechnology and nanosatellites. Of the significant value proposition such a mission can have, this proposal focuses on emergency response, increased functionality per unit mass and passive thermal management for improved reliability.

1 Need

- In sub-Saharan Africa, there is dire need for people to be able to request for urgent help for medical and/or safety reasons. This can help manage situations like the recent and on-going Ebola epidemic in West Africa.
- Africa needs a collaborative platform to develop its local space-based technology.
- Given the financial limitations of Africa, it is imperative to increase mission functionality per unit mass of micro- and nanosatellites whilst improving their reliability.

2 Mission Objectives

2.1 Connectivity objectives

- Ensuring that every point in sub-Saharan Africa is always in view of a satellite.
- Ensuring that a message can be relayed from one point to any other point in sub-Saharan Africa. The communications links must be scalable to allow for various message content types, and increased number of users.

2.2 Technology demonstration objectives

- Demonstrate Vanadium Dioxide (VO_2) films in space as 0 Watt input power thermal shields ensuring on board temperatures always remain < 70^0C within a VO_2 coated nanosatellite.
- Demonstrate the use of a camera lens as a high gain patch antenna. This will save the space used for a separate antenna in optical imaging nanosatellite missions.

3 Concept of Operations

Figure 3.1 describes the general mission concept.

3.1 Concept description

A user in need of assistance sends a message (GPS coordinates are part of the message by default) directly to the satellite constellation from a cell phone via a UHF/UHF transceiver module.

High bitrate inter-satellite communications links convey messages from multiple users in real time to ground stations. Messages transmitted to ground stations are sent via GSM networks to emergency care units and SMSes are sent to emergency care practitioners. A reply can be sent to the user in need by responding to an SMS. This reply will be similarly relayed to the user (whose location is now known for physical intervention purposes). Simultaneously, the data from the technology demonstration experiments is downloaded to the ground stations for analysis.

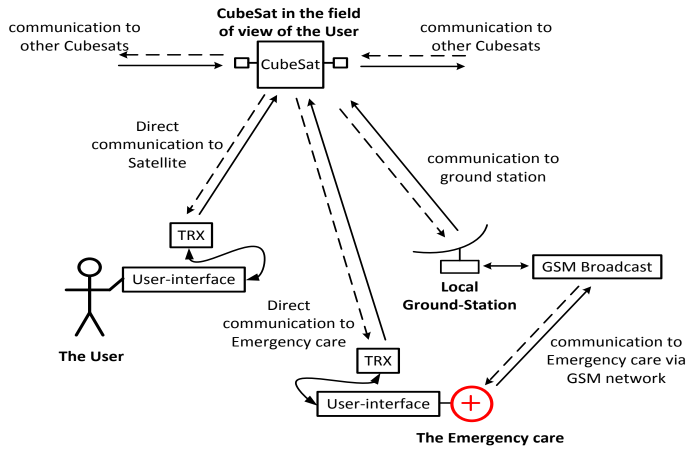

Figure 3.1: Mission Concept

3.2 User segment

3.2.1 Connectivity users

These users include individuals within sub-Saharan Africa who may find themselves in an emergency situation (related to health, safety, assistance of person in need, etc). They should be able to send a distress signal or ask for emergency advice. Users also include emergency care practitioners within Sub-Saharan Africa who may need to send urgent potentially life-saving messages to each other or to users in distress in order to improve medical/emergency care services in remote areas.

3.2.2 Technology demonstration users

These users are African scientific, business and engineering communities. The first users are research fellows from iThemba LABS-National Research Foundation of South Africa, University of South Africa (UNISA), and Cape Peninsula University of Technology (CPUT). Vanadium dioxide (VO_2) produced at iThemba LABS/UNISA [1] is coated on a CPUT designed instrument to measure its thermal shielding capabilities in space (0 W input power, T $\leq$ 70^0C within a VO_2 coated enclosure). An IP pending design by CPUT/UNISA/iThemba LABS converts a camera lens into a possible high gain patch antenna.

3.3 Ground Segment

Cell phones are so prevalent in Africa that they are present even in areas too remote to be part of power grids (and sometimes even out of GSM network range). Users buy a communications (comms) module (portable GSM-enabled UHF transceiver) and a customized SIM card (interface with any cell phone technology). The SIM card is inserted into the user's cell phone, allowing him/her to send a message to the com module. The module in turn relays the message directly to the satellite constellation. The module can also receive a message from the constellation and relay it to the user's cell phone. The ground station in Cape Town will be the one at CPUT. A similar ground station will be built in Buea, Cameroon.

4 Key Performance Parameters

Antennas– High gain antennas are required for the highest possible data rates for inter-satellite communications.

Inter satellite communications– This must be achieved between adjacent satellites in the same orbital plane (3 orbital planes with 8 satellites per plane) to ensure near real time temporal resolution.

ADCS – The satellites should be stabilized nadir pointing with ±5^0 accuracy in all axes. This is critical for inter-satellite communications and the camera lens antenna experiment (among other possible payloads).

5 Space Segment Description

The satellites will be 2U CubeSats except for those which will carry technology demonstration payloads. Those will be 3U satellites with an extra unit for technology demonstration. Figure 5.1 shows an artist impression of what the satellites will look like, and the satellite subsystems.

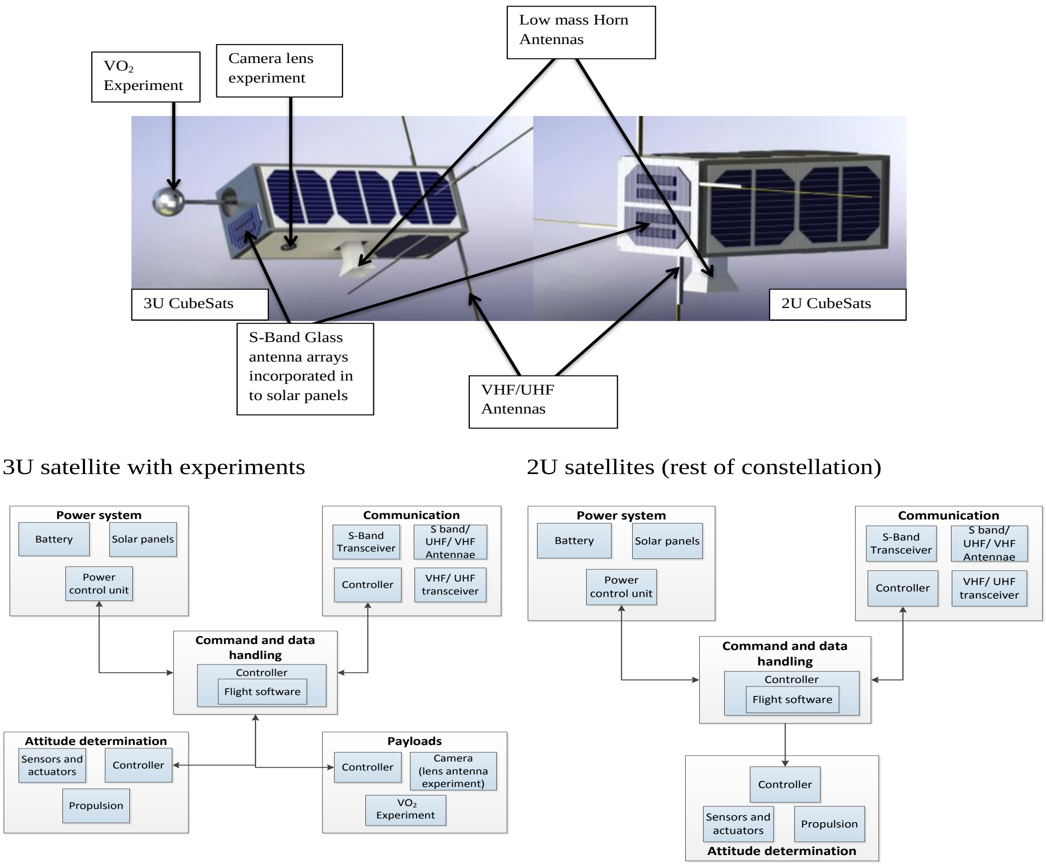

Figure 5.1: 3U and 2U satellite subsystems

5.1 Communication

Table 5.1 shows the mission link budget. Links include ground to satellite communications (foldable UHF and S-band antenna array for users; UHF/VHF and S-band antennas for ground station), satellite to ground communications (ultra-light push-out horn antennas for S-band link), and inter-satellite communications (CPUT designed glass antenna array inserted in solar panels for S-band link). Satellites will have a back-up VHF receiver and antenna as an emergency backdoor.

Table 5.1 Mission link budget

Parameters of the communication system	User to Sat. (UHF UpLink)	Sat. to User (UHF downlink)	GS to Sat. (S-band UpLink)	Sat. to GS (S-band downlink)	Sat. to Sat. (S-band link)
Physical distance between 2 antennas	800 km	800 km	800 km	800 km	5800 km
Transmit power	1 W	1 W	10 W	2 W	2 W
Transmit antenna type	Foldable Dipole	Deployable Diople	Dish	Dual Linear L/S-band Horn Model HCDL14-19-S	Glass antenna arrays
Transmit antenna gain	2 dBi	2 dBi	30 dBi	21 dBi	23 dBi
Transmission frequency	437 MHz	437 MHz	2450 MHz	2450 MHz	2450 MHz
Transmission modulation type	FM + GMSK	FM + GMSK	QPSK	QPSK	QPSK
Transmission data rate	9.6 Kbps	9.6 Kbps	1 Mbps	1 Mbps	1 Mbps
Link margin at 0° elevation	**4.14 dB**	**4.14 dB**	**6.56 dB**	**5.34 dB**	**3.57 dB**
Eb/No	11.67 dB	11.67 dB	10.5 dB	11.40 dB	9.64 dB
Free-space loss	152.73 dB	152.73 dB	167.73 dB	170.57 dB	180.54 dB
Additional loss	5.9 dB	5.9 dB	5.9 dB	5 dB	5 dB

5.2 Power and mass budgets

Tables 5.2 and 5.3 show the power and mass budgets. A margin of 5% is included in the budgets

Table 5.2: Power budget

Satellite Subsystem	3U_Power Usage		2U_Power Usage	
	Power during Sun (mW)	Power During Eclipse (mW)	Power during Sun (mW)	Power During Eclipse (mW)
EPS				
Analogue + digitial Circuitty	264	264	264	264
Battery Heater	0.00	333.35	0.00	333.35
ADCS				
Control Unit + Actuator	300.00	300.00	300.00	300.00
C&DH				
OBC	110.00	110.00	110.00	110.00
UHF/VHF Transceiver				
Tx (15 min max)	1250.00	0.00	1250.00	0.00
S Band Transceiver				
Tx (Active 1W RF Power)	2490.00	2490.00	2490.00	2490.00
Rx (idle)	52.47	52.47	52.47	52.47
Science Payload				
VO2 Module	35.00	35.00		
Imaging	0.00	0.00		
Camera (6.6 min max)	24.75	24.75		
Total Power Required + Design Margin	5940.66	4737.56	5862.24	4659.14

Table 5.3: Mass Budget

Subsystems	Components	Mass in grams (3U)	Mass in grams (2U)
Communications			
	UHF/VHF transceiver	100	100
	UHF/VHF antenna	50	50
	S Band antenna	10	10
	S Band transceiver	100	100
Attitude determination			
	Sensors, actuators and control unit	310	310
Power			
	Solar panels	600	480
	Battery	780	520
	Power Control Unit	90	90
C&DH			
	On Board Computer	100	100
Structure			
	Chassis	600	550
Payloads			
	Camera lens experiment	170	
	Control unit	60	
	VO_2 module	300	
Total		3270	2310

5.3 ADCS

The z+ axis will be nadir pointing and the roll, pitch and yaw stabilized to within $\pm 5^0$. The control modes will include de-tumbling stabilizing and orbit insertion/correction. These modes will be achieved with the ADCS stack (available on cubesatshop.com) developed by the Electronic Systems Laboratory (ESL) in Stellenbosch. Field Emission Electric Propulsion (FEEP) thrusters will be used for orbit insertion/correction.

6 Orbit/Constellation description

Table 6.1 shows the orbital elements used to achieve the mission objectives. Each orbital plane will contain 8 satellites to ensure total and quasi continuous ground coverage of sub-Saharan Africa, with an average revisit time < 3 minute.

To avoid falling to the ISS altitude, orbit correction is used. Delta-V is estimated from

Table 6.1: Orbital elements [3,4]

Orbital plane	Plane 1	Plane 2	Plane 3
Altitude (km)	800	800	800
Inclination (deg)	35	35	35
RAAN (deg)	0	120	240
Overpass time(min)	15.287	15.287	15.287
Ground track velocity (km/s)	6.623	6.623	6.623

$\Delta v_{rev} = \pi \left(\frac{C_D A}{m} \right) a \rho V$ [2,3], achievable with Field Emission Electric Propulsion (FEEP) thruster systems.

7 Implementation plan and risks

7.1 Implementation plan

Each launch will place a group of satellites into their respective orbital planes. The satellite project cycle will commence with the mission concept review, mission and system definition review, mission and system requirements review and the critical design review. System acceptance and flight reviews will follow, after which will be the testing phase. Next are the operation and support phases. Finally, the decommissioning review will ensure that the satellites meet the necessary de-orbit requirement. The deorbit concept is similar to the Terminator Tether deorbit concept [5], where the ADCS unit is separated from the rest of the satellite, leaving a tether between the two parts.

7.2 Risks

- Failure of any of the communications systems will impact the reliability of the emergency response link.
- Failure to establish the necessary collaboration between African governments can impair the mission.
- Failure of a satellite will affect the near real time temporal resolution.

- Failure of the ADCS will compromise pointing accuracy and hence the mission as a whole.

8 Business feasibility

The emergency centres (private and governmentally owned) will be charged a monthly cost for the service and they can in turn act as a reseller to the end-users. Development cost will be reduced through in-house development at Universities and co-funding of capacity building funding platforms. The communications modules will be built and maintained though a collaboration of universities in sub-Saharan Africa. An uptake of 30 medical centres is expected in the first year of operation and afterwards a yearly increase of 10%. Cell phones are the user interface to the com module (seen as an access point), therefore apps can be developed for existing cell phone platforms. Users can adapt quickly to the mission, and this will ensure uptake. From the fourth year (first year after full commissioning), 20% of the total mission cost will be invested to develop and launch 20% of the constellation so that the entire mission is renewed every 5 years onwards. Table 8.1 shows the cash predictions for the first 5 years of the proposed business model.

Yearly cost per medical centre (including maintenance costs): $ 240 000

Launch cost: $ 10 000 / kg (approximately $ 30 000 per satellite)

Satellite cost (including launch cost): $ 130 000 per satellite (due it being constructed by Universities)

Ground station expenditure (GSEX) and operational expenditure (OPEX): M$ 1.5 per year

24 satellites in the constellation (total cost): M$ 3.12

Table 8.1: Cash flow predictions for the proposed business model

Year	GSEX & OPEX ($)	Capital repayment ($)	Further development ($)	Yearly Revenue ($)	Yearly Profit ($)
First	1,000,000	0	0	0	-1,000,000
Second	1,250,000	0	624,000	0	-1,874,000
Third	1,500,000	1,560,000	624,000	7,200,000	3,516,000
Fourth	1,500,000	1,560,000	624,000	7,920,000	4,236,000
Fifth	1,500,000	0	624,000	8,640,000	6,516,000
Cumulative	6,750,000	3,120,000	2,496,000	23,760,000	11,394,000

A source of income not mentioned in the abovementioned predictions is the marketing of the demonstrated developed technology, and the know-how thereof.

9 References

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