Open Standard for
Inter Satellite Link

Final Presentation
QinetiQ/ GES Ltd

8th December 2021

QINETIQ/EMEA/SPACE/PUB2100065

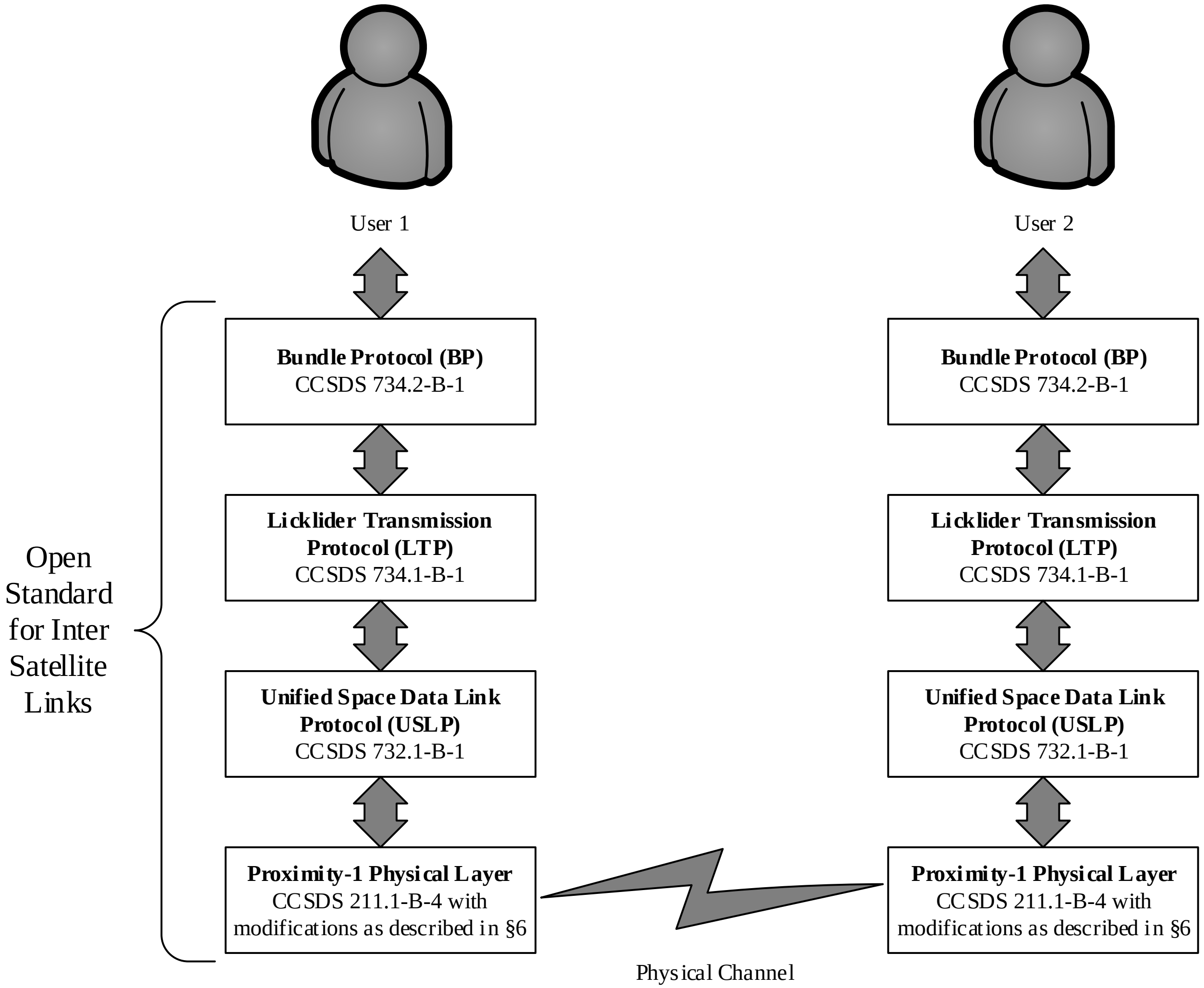
Agenda

- Introduction
- Overview
- Task 1 – Relevant Scenarios and Requirements
- Task 2 – Standard Development
- Task 3 – Test Plan and Software Simulation Implementation
- Software Simulator Demonstration

Standard Overview

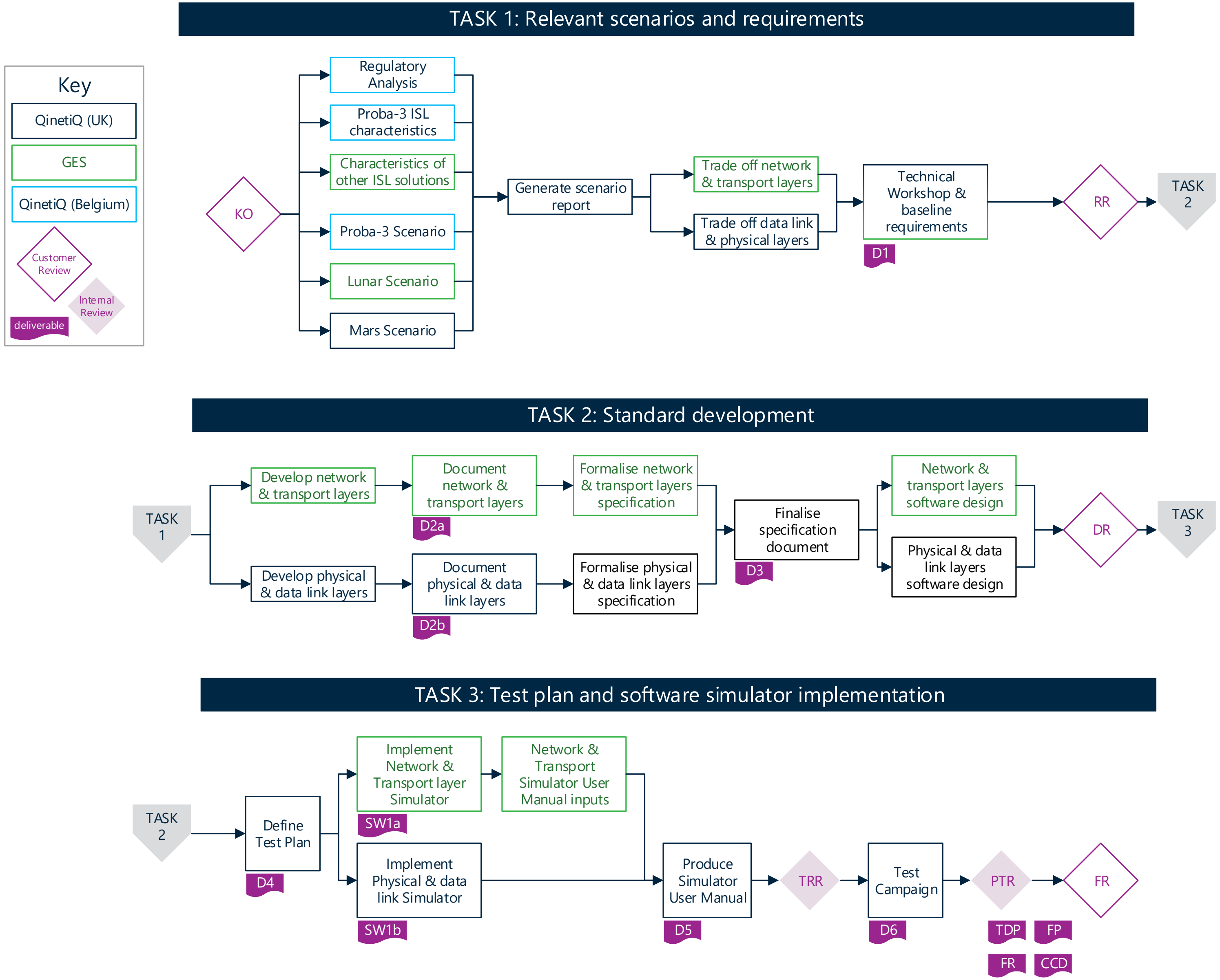
- Overall architecture based on 4 key CCSDS protocols:
  - Bundle Protocol (BP)
  - Licklider Transmission Protocol (LTP)
  - Unified Space Data Link Protocol (USLP)
  - Proximity-1 Physical Layer

The Recommended Practice has been developed following an analysis of current and future inter-satellite link scenarios (including applications around Earth, the moon, Mars and near-Earth asteroids). Key requirements for each scenario have been considered and used to define a common standard, based on trade-offs, to aid implementation and interoperability.



Programme

- The project was led by QinetiQ in the UK with support from the Belgium office, with key tasks and activities performed by Goonhilly Earth Station.
- The project was split into 3 key tasks as shown in the flow chart (right)

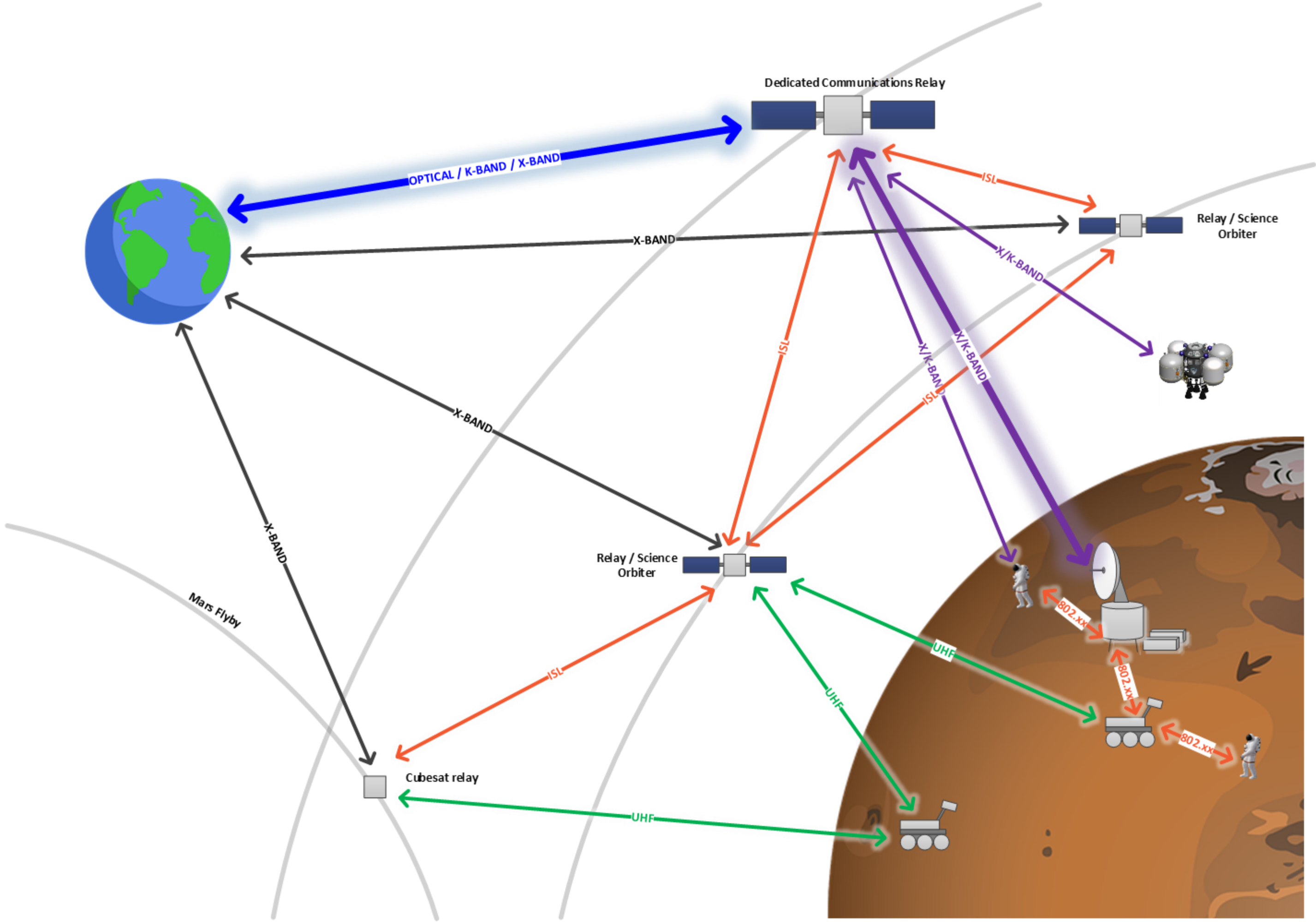


Key Outputs

ID	Title	Document Number	Issue
D1	Draft Specification	QINETIQ/EMEA/SPACE/SPEC2000065	2
-	Scenario Report	QINETIQ/EMEA/SPACE/TR2000051	1
D2	Trade-off and Design Justification Report	QINETIQ/EMEA/SPACE/TR2000060	3
D3	Recommended Practice for Open Standard for Inter Satellite Links (Magenta Book)	QINETIQ/EMEA/AS/SPEC210157	2
SW1	OISL Simulator Software	N/A	-
FR	Final Report (this document)	QINETIQ/EMEA/AS/TR212227	1
D4a	OISL Demonstrator Test Plan	QINETIQ/EMEA/AS/TPN211821	2
D4a D6	Open Inter Satellite Link Demonstrator Software Test Schedule and Results	QINETIQ/EMEA/AS/TP211787	2

Task 1 – Relevant Scenarios and Requirements

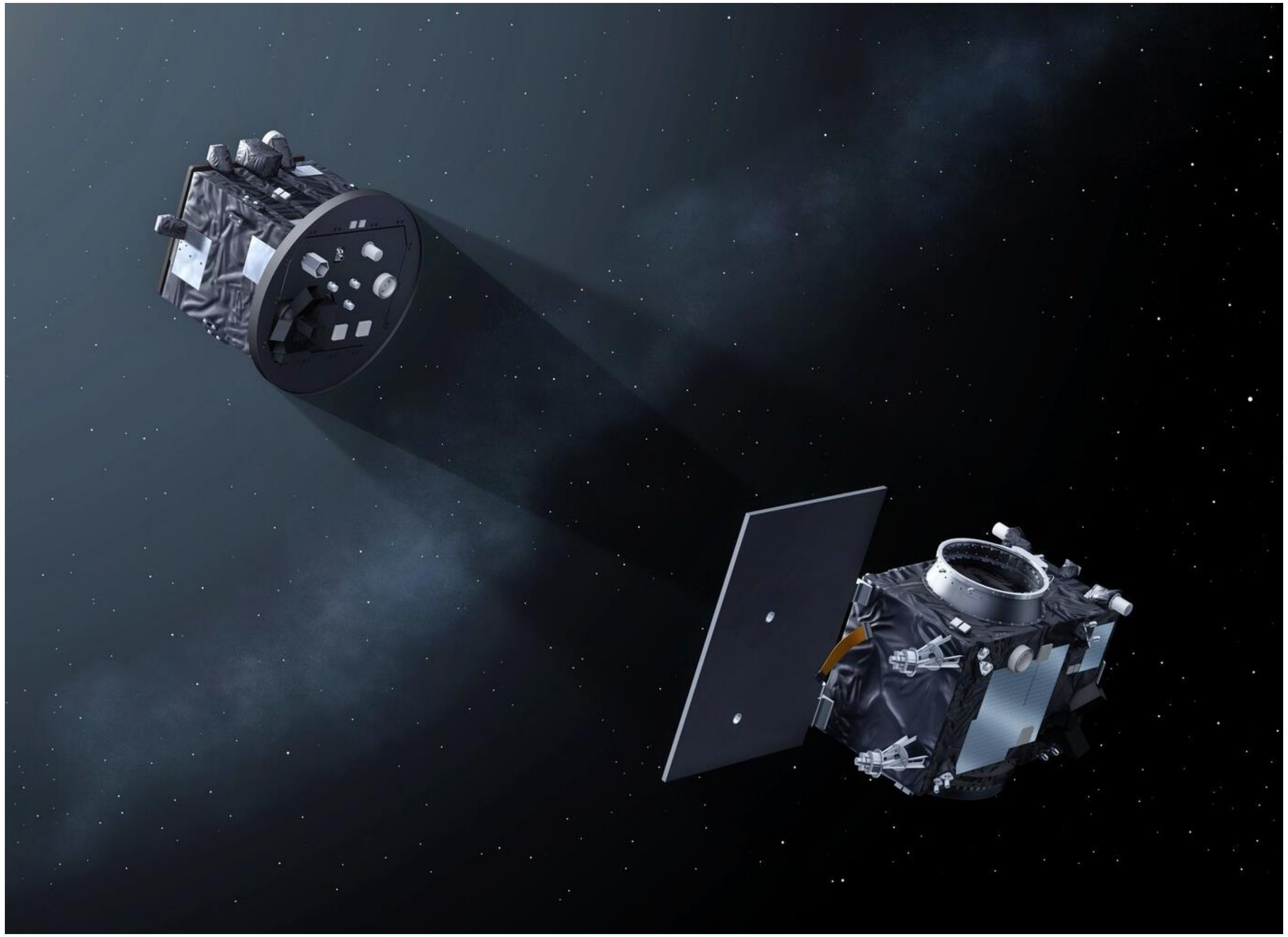
Mars Scenario



- Takes into account NASA's Human Exploration of Mars Design Reference Architecture 5.0

LEO (Proba 3)

- Main functions of the Proba-3 inter-satellite link:
  - Exchange of the formation flying status vector
  - Autonomy demonstration
  - Additional distance measurement and Collision Avoidance Mode (CAM) avoidance function via ranging



Lunar

- The IOAG and CCSDS emphasise the importance of interoperability and cross-support for future missions, therefore the main requirements for Lunar inter-satellite links must reflect this. Interoperability between spacecraft, ground stations, and relay satellites will enable data to be transmitted from the Lunar surface or Lunar orbit to ground stations and mission control centres, even if the mission control centre is not facing the Moon at the time of transmission. The Lunar links must also meet the spectral constraints set out by the Space Frequency Coordination Group (SFCG) and International Telecommunication Union (ITU). The links relevant to relay satellites are proximity links (relay to user vehicle), and cross-links (communications between relay spacecraft). The following characteristics of Lunar cross-links and proximity links were selected to maximise interoperability, particularly with the Lunar Gateway:

Trade-Off – Upper Layers

BP

- The DTN architecture implements store-and-forward message switching by overlaying the Bundle Protocol (BP) on top of lower layer protocols. The BP can interface with lower layer protocols (usually the Transport Layer) through convergence layer adapters (CLAs). The BP sits on top of the CLA protocol stack which then supports bundle exchanges.

LTP

- LTP is the convergence layer of choice for space networks. Advantages over TCP include:
  - Rate-based transmission speed to reduce interaction;
  - No connection establishment, to reduce interaction;
  - Unidirectional data flow to cope with possible channel asymmetry;
  - Acknowledgements are sent back only in response to confirmation requests

Alessi et al, 2019

Trade-off - Data Link Layer

#	Factor	Proximity 1	USLP	DVB-S2	Wi-Fi (IEEE 802.11)	Gamalink
1	Addressing	15	25	5	20	5
2	Adoption	15	12	9	9	3
3	Coding schemes	12	15	9	6	3
4	Flexibility	9	12	3	6	3
5	Flow control	15	15	5	25	5
6	Implementation complexity and cost	12	6	9	9	3
7	Interoperability	10	25	5	20	15
8	Low power consumption features	9	9	3	12	6
9	Precise time transfer features	10	20	10	15	15
10	Segmentation and acknowledgement features	3	4	3	2	1
11	Support of multiple access	15	25	5	20	15
12	Security	3	12	6	9	6
13	Service data units (SDU)	3	4	2	4	2
14	Heritage	5	3	2	2	3
15	Backwards compatibility	15	12	3	3	6
16	Data rates	10	25	20	20	5
	TOTALS	**161**	**224**	**99**	**182**	**96**

Trade-Off – Physical Layer

Name	Proximity-1 (CCSDS)	802.11	GSM	UMTS / IS-95 / CDMA-2000	Wi-max / LTE
Application	Space, autonomous proximity communications	Terrestrial wireless communications	Mobile communications	Mobile communications	Mobile communications
Frequency/ band	UHF	2.4 / 5 GHz	~900 MHz	Various 0.7 – 2.1 GHz	2.5/3.5/5.8 1.25/2.5/5/10/20 GHz
Range	Long (up to >10,000 km)	Short 80 – 150m	< 30km	~ km	1 – 5 km
Bandwidth	30 MHz (Tx+RX bands)	~20 MHz – 80 MHz	50 MHz (up and down)	1.23/ 5 MHz (channel)	3.5/ 7/ 10 MHz
Modulation **Coding**	PSK, Optional convolutional, LDPC	BPSK, QPSK ,CCK, QAM16/64	GMSK	BPSK/QPSK	QPSK/ 16QAM/ 64QAM
Data / symbol rate(s) **Adaptive?**	1-4096 ksps , Yes - ADR	1/ 2 Mbps, <11 Mbps, <54 Mbps	9.6 / <14.4 kbps	9.6 kbps <144 kbps	<75 Mbps <50, 100 Mbps
Low power?	Yes	Power save mode	Sleep / idle mode ?	Sleep / idle mode ?	Sleep / idle mode ?
MA method	FDMA (Multiple frequency channels)	CSMA, DSSS, FHSS, OFDM	TDMA FDMA	CDMA	TDM/ OFDM
Synchronisation?	Yes. Time transfer / correlation service	Timing synch function	Yes	Yes	Yes
Localisation? **Range / range rate?**	Radiometric observable via closed-loop Doppler and/or open loop sampling. Accuracies to ~10m possible	Possibly e.g. via ToA (Time of Arrival) or RSSI (Received Signal Strength Indication)	e.g. via RSSI/ multilateration	e.g. via RSSI/ multilateration	e.g. via RSSI/ multilateration
Flight heritage	Extensive				
Comment		Multiple standards		Multiple standards	Multiple standards

Task 2 – Standard Development

Standard Development

- The standard was developed based on the layout and style of a CCSDS Magenta book, with the rationale that this format would be most suitable for adoption (and therefore greater impact) by a standards agency, nominally assumed to be CCSDS.
- Where possible, references were made to existing standards to ensure maintainability and updateability of the standard, and to allow as much re-use as possible of existing implementations and technology.


QINETIQ

GOONHILLY EARTH STATION

Recommendation for Space Data System Practices

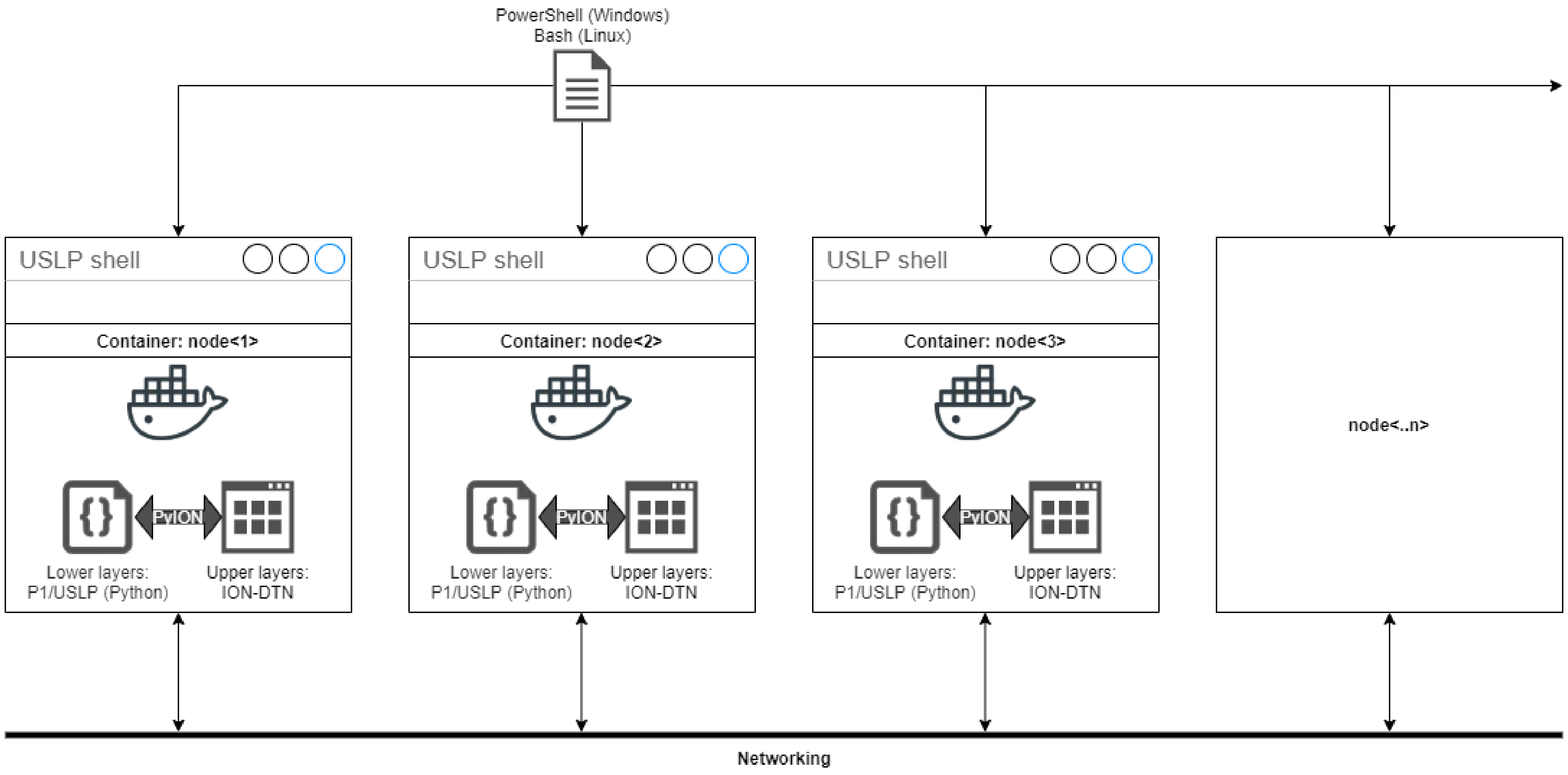
OPEN STANDARD FOR INTER SATELLITE LINK

QINETIQ/EMEA/AS/SPEC210157

PROVISIONAL MAGENTA BOOK

December 2021

Simulator Design

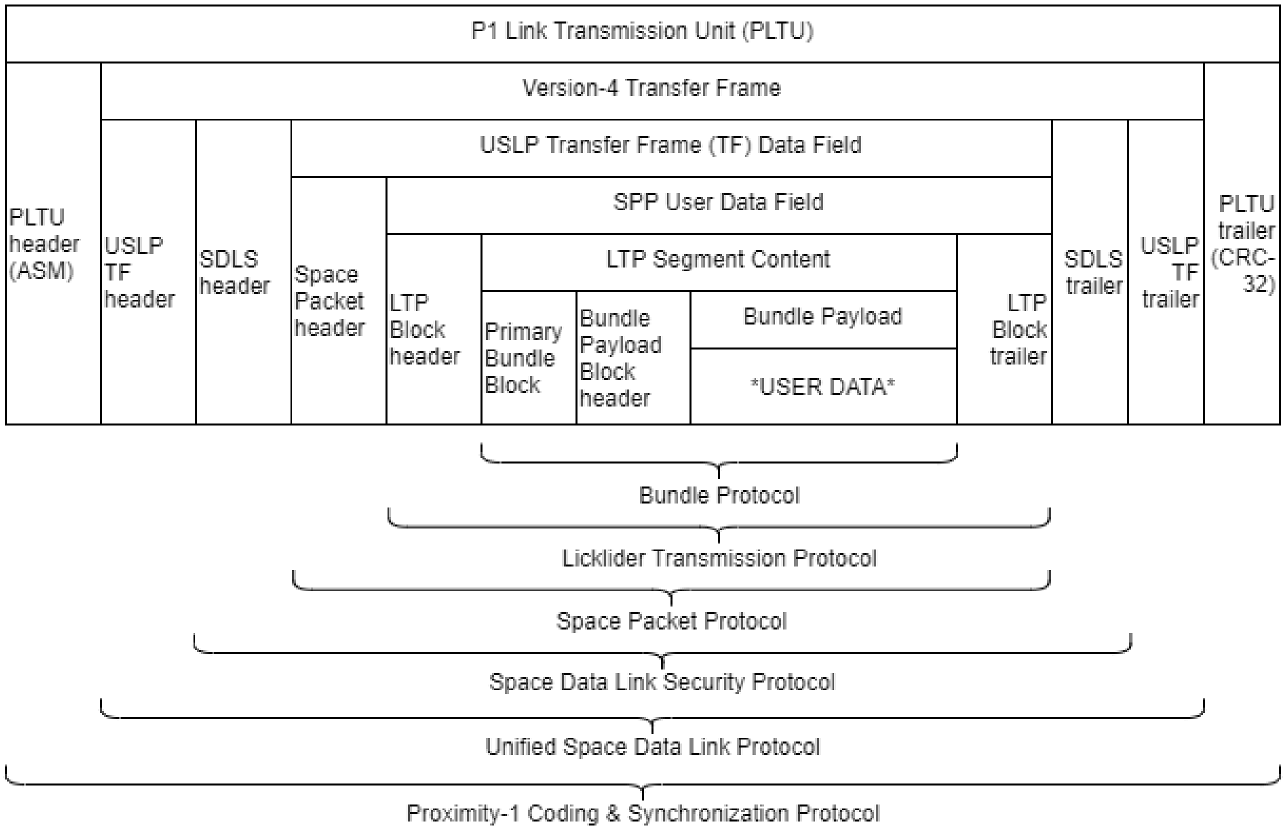


- The simulator comprises two core components:
  - The Python-based prototype software implementation of the following lower layer (i.e. Open Systems Interconnection (OSI) model layers 1-2) Consultative Committee for Space Data Systems (CCSDS) protocols:
  - The National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL) implementation of Delay Tolerant Networking (DTN), the Interplanetary Overlay Network (ION) software

Task 3 – Test Plan and Software Simulation Implementation

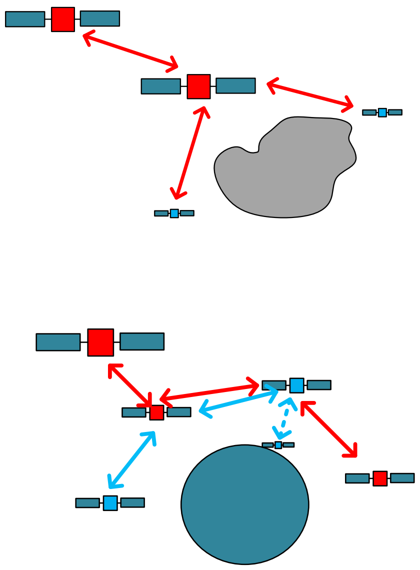
Simulator Implementation

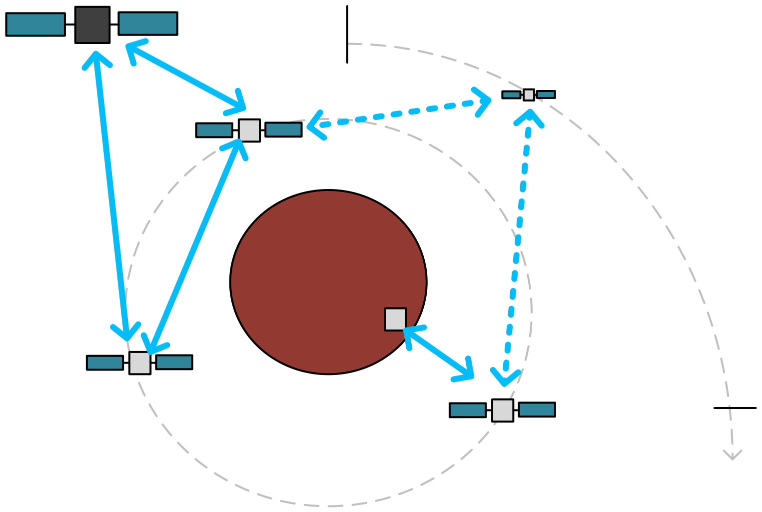
- The simulator is comprised of a number of Python source code files (.py), which implement the lower layers of the OSI model, in addition to Docker (.dockerfile) and Docker-compose (.yml) configuration files for building a Unix environment where the lower and upper layer implementations are executed.
- A number of example configuration files (.ini) are provided for the lower layer implementation as well as PyION configuration files for a 2-node network.
- Additional configuration files are automatically generated (with default parameter values) when new nodes are instantiated.



Simulator Test

- Test Categories
  - Modular tests for individual functions of the various implemented protocols (test cases 1-23)
  - Link efficiency tests (test case 24)
  - System level tests which represent realistic ISL scenarios (test case 25)





- Scenarios representative of potential Mars, Low Earth Orbit (LEO) and Near Earth Asteroid (NEA) Inter Satellite Links (ISL) are described and illustrated in the test plan.
  - The Mars scenario demonstrates a range of links of varying quality, i.e. persistent links, intermittent links, and non-links where a given pair of nodes are not within range at all.
  - The LEO scenario adds the complexity of nodes with differing levels of capability, i.e. full capability versus minimal capability. Both encoding/decoding and encryption/decryption can be resource-intensive activities, therefore a minimal capability node may not be capable of decoding or decrypting received data.
  - The NEA scenario does not differ significantly from the prior two scenarios in terms of features demonstrated, so instead one of the multiple access scenarios is demonstrated – one-to-many. The lower layers broadcast over the Docker subnet with the USLP Source-or-Destination flag set to Source in order to send either time synchronization data or transmitter/receiver parameters data to contactable nodes.

Proposed Future Work

- **Implementation of Bundle Protocol Security (BPSec)**
  - The current software implementation includes security implemented at the link layer (Space Data Link Security, SDLS), however it has been identified that an end to end security implementation would be useful for several applications. This has been identified in the standard, but has not been implemented due to the function not being available in the ION distributable.
- **Implementation on representative hardware**
  - Implementation of the standard on representative hardware (e.g. an engineering model of a space-qualified communications system) would allow additional performance data to be recorded.
- **Interoperability with independent implementation**
  - Although this project has demonstrated that the implementation is self-compatible, value would be added by an independent third party implementing the protocol based on the published standard and successfully interoperated with the QinetiQ / GES implementation.
  - This is widely used, and indeed is required prior to publication of CCSDS standards.
- **Adoption by standards authority**
  - To ensure the standard is adopted and used as widely as possible, work should be undertaken to allow the standard to be adopted by an authority, e.g. CCSDS.

Software Simulator Demonstration

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