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ESA Statement of Work

Application of a BitTorrent-like data distribution model to Mission Operations

Reference	**GSP-SOW-11-169**
Issue	**1**
Revision	**1**
Date of Issue	**06/02/2013**
Status	**Approved/Applicable**
Document Type	**SOW**
Distribution	**Open**

European Space Agency
Agence spatiale européenne

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1 INTRODUCTION

1.1 Scope of the Document

This Statement of Work (SOW) describes the activity to be executed and the deliverables required by the European Space Agency (referred to as “ESA” or “the Agency”) in relation to the “Application of a BitTorrent-like data distribution model to Mission Operations” study. It will become part of the contract (Appendix 2) and shall serve as an applicable document throughout the execution of the work.

1.2 The General Studies Programme

ESA’s General Studies Programme (GSP) (www.esa.int/gsp) interfaces in different ways with all of ESA’s programmes, but its main role is to carry out preparatory analysis and act as a “think tank”, laying the groundwork for the Agency’s future activities.

The objectives of the general studies programme are to:

- Contribute to the formulation of the overall ESA strategy
- Study feasibility for selection of new mission concepts
- Prepare/demonstrate the case for approval and funding of new optional projects/programmes
- Support the evolution of ESA by analysing and testing new working methodologies

A diversity of topics is investigated via GSP undertakings, running across the entire spectrum of the Agency’s activities. In average, each study lasts one to two years, sufficient time for in-depth exploration of each subject.

The assessment studies undertaken by the GSP provide ESA and its member states with the necessary information on which to base their decisions about the implementation of new programmes and the future direction of space activities.

1.3 Background for the activity

With the move towards extending IP networks into space, there is now the opportunity to consider the use of well-established and mature internet communication models for use in space missions. One of the most attractive of these models, particularly in terms of distributed and resilient data delivery, is a 'torrent'.

ESOC has recently taken final delivery of a complete implementation of the CCSDS File Delivery Protocol [AD1] and, although it does not rely on IP networks (indeed, it is independent of underlying communication technologies), it does provide a set of services that could be used to implement a torrent-like distribution model.

1.3.1 The "BitTorrent Network"

The proposed network is an adaptation for LEO mission operations of the well-known internet data distribution model using the CCSDS File Delivery Protocol [AD1]. It is characterised by a high density VPN of mini/small (inexpensive) antennas on ground that act as peers in a network sharing data with the spacecraft, mission control centres and data subscribers, and spacecraft that downlink over geographical regions rather than particular ground stations, see Figure 1**Error! Reference source not found.** below.

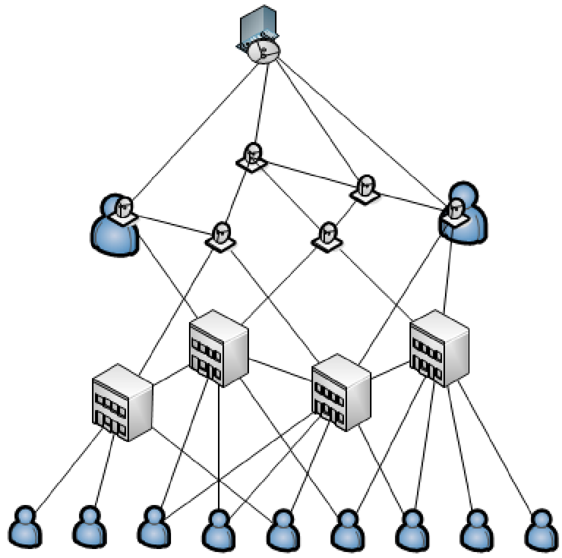

Figure 1 Bit Torrent-like data distribution model applied to space missions

To aide in the understanding of this concept, here is a use case that takes advantage of it:

- The **Environment Monitoring System** is a constellation of micro/mini satellites in multiple low-to-mid Earth orbits providing real-time monitoring and information delivery on a global scale: like a GPS network but providing environmental data. Following the principle of "whatever is received is useful and the more timely the better," the data can be used by emergency services on ground when dealing with large scale natural disasters such as forest fires and tsunamis.

The space-ground and ground-ground communication model is currently envisaged as follows:

- A high density of small antennas on ground. For the greatest geographic distribution, for example, they could be positioned on the roofs of embassy buildings, universities, hospitals etc. all around the world.

- The antennas shall be simple, robust and inexpensive such as small but steerable COTS terminals for use in remote areas and simple hemispherical antennas for use in dense coverage zones. More unconventional solutions could also be considered such as an array of fixed antennas, back-to-back in a circle, which provide 360deg azimuth coverage e.g. 6x70deg beam-width.
- For data downlink (TM and other file-based payload data), the spacecraft broadcasts continuously over the area beneath it rather than pointing and radiating towards a particular ground station. This results in a 'torrent' of CFDP File Segments being received by one or more ground stations and, potentially, no one ground station seeing all parts of the same file. The files are then accordingly reconstructed within the network on ground.
    - As the intention is to allow the data to be concurrently distributed to multiple users, there shall be a subscription service to which the consumers of the data can subscribe via application specific clients optionally using a push or pull model.
        - Note that the subscription services could be categorised in terms of spacecraft, type of data, region of Earth or a mixture of these and other categories. The Destination ID of the CFDP Protocol Data Unit (PDU) could be segmented to represent the different classes of categories possible or be, simply, an index number.
    - Selected nodes in the network shall host a given subscription service (of one or more subscription types) and have the responsibility of collecting applicable file segments, reconstructing the files (depending on the implementation), cataloguing and archiving them whilst super nodes act as subscription brokers/handlers in a similar way to the way torrent trackers work (or rather RSS feed proxies, depending on the implementation).
        - This layering of the network allows a separation between the highly variable (and potentially high-traffic) end-user subscriptions service and the core space-ground communications segment whilst still enabling direct access to instantaneous file segments for users in view of the spacecraft who, with suitable authentication, can also become ad hoc members of the core, ground receiving network. This is reflected in Figure 1 above.
    - It shall be the responsibility of the end-user application that is ultimately responsible for the data and/or spacecraft in question to ensure data completeness by requesting any missing CFDP file segments from the spacecraft.
- For data uplink (TCs and other file-based interactions), only one of the ground station antennas in view of the spacecraft at any one time is designated (with one or more back-ups) as the uplink terminal for that period. This is to avoid the risk of interference at the receiving spacecraft from overlapping beam patterns.

- The core network shall be a secure VPN (using IPsec, for example) using standard internet connections to which all ground terminals and ad hoc data receivers must connect. It could be that remote ground terminals have to use VSAT links to route via Geo-Comm satellites.

There are no restrictions on which CFDP Class to use, it shall be part of this study to explore these options. Likewise, the option of having CFDP installed at the ground stations (with perhaps a switch-over to the true BitTorrent protocol) versus having it only at the Subscription nodes and using SLE between them and the ground stations shall also be considered.

1.4 Applicable Documents (ADs) and Reference Documents (RDs)

The following documents shall be consulted by the Contractor as they contain relevant information to prepare the offer:

N	Reference	Title	Author	date
AD1	CCSDS 727.0-B-4	CCSDS File Delivery Protocol (CFDP) http://public.ccsds.org/publications/archive/727x0b4.pdf	CCSDS	January 2007

The following documents can be consulted by the Contractor as they contain relevant background information:

ESA Statement of Work	Reference	Title	Author	date
RD1		http://www.agi.com/products/by-product-type/applications/stk/		
RD2		QualNet Developer v5.1 http://www.antycipsimulation.com/solutions/communications-modelling-simulation		
RD3	CCSDS 720.1-G-3	CCSDS File Delivery Protocol – Introduction and Overview http://public.ccsds.org/publications/archive/720x1g3.pdf	CCSDS	April 2007
RD4	CCSDS 910-G-2	Space Link Extension Services – Executive Summary http://public.ccsds.org/publications/archive/910x0g2.pdf	CCSDS	March 2006
RD5		http://www.esa.int/esaCP/SEMQD49U7TG_index_0.html		

1.5 Acronyms and abbreviations

AD	Applicable Documents
BP/LTP	Bundle Protocol / Licklider Transmission Protocol
CCSDS	Consultative Committee for Space Data Systems
CFDP	CCSDS File Delivery Protocol
COTS	Consumer Of The Shelf
EDRS	European Data Relay System
ESA	European Space Agency
EO	Earth Observation
GPS	Global Positioning System
GSP	General Studies Programme
ID	IDentifier
IP	Internet Protocol
IPsec	Internet Protocol Security
KO	Kick off meeting
KPI	Key Performance Indicator
LEO	Low Earth Orbit
PDU	Protocol Data Unit
RD	Reference document
RSS	Really Simple Syndication
SLE	Space Link Extension
SOW	Statement of work
STK	Satellite Tool Kit
WP	Work package
TBD	To Be Determined
TCP	Transmission Control Protocol
TDRSS	Tracking and Data Relay Satellite System
TM	TeleMetry

UDP	User Datagram Packet
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal

2 OBJECTIVES OF THE ACTIVITY

The objective of the study is to assess the technical feasibility, capacity of data transfer possible and true compatibility with CFDP services of the space-ground and ground-ground communications of the network model presented in section 1.3.1.

The study should in particular:

- Analyse the proposed concept and evolve its definition as required,
- Define a reference scenario and KPIs against which the model can be assessed,
- Specify the technical components of such a network,
- Perform dynamic simulations to assess the effectiveness of the model.

3 WORK TO BE PERFORMED

3.1 Work Logic

The contractor is first expected to demonstrate an understanding of the proposed concept and the CCSDS CFDP and SLE protocols before proceeding to empirically evaluate the network's potential.

3.2 Task Description

3.2.1 Task 1: Feasibility assessment of the proposed approach

- **Input**

This SOW and contract.

- **Task description**

The contractor shall analyse and, if relevant, propose modifications of the concept described in section 1.3.1 in order to ensure that the objectives of the study are met. The contractor shall consider different system options including, but not limited to a) the choice of CFDP classes, b) the location of CFDP entities on ground and c) the option of transitioning to the true BitTorrent protocol once on-ground.

A reference scenario shall be defined to allow the comparison of this concept against a classical data return model (prime ground station with data dumps once per orbit) and one that uses a data relay satellite (e.g. [RD5]). KPIs shall be defined to baseline the different concepts against which the comparisons shall be later made

- **Output**

Documents D1 and D2 as defined in section 4.3.

3.2.2 Task 2: Technical Definition of the Network Characteristics

- **Input**

Results from Task 1.

- **Task description**

The BitTorrent Network does not have a static definition as in the case of a classical ground segment. Thus, the contractor shall define the network characteristics and constituent elements that can be used as modular building blocks for the construction of a network. There shall be a trade-off of applicable hardware components and a technical definition of the required network characteristics and their compatibility with the CFDP standard identifying any inconsistencies and proposing solutions.

- **Output**

Documents D3 and D4 as defined in section 4.3.

3.2.3 Task 3: Technical analysis and comparison

- **Input**

Results from Task 2.

- **Task description**

The contractor shall demonstrate the performance (good or bad) of the BitTorrent network against the classical and EDRS alternatives. This shall be done by way of dynamic simulations that combine extensive mission modelling with in-depth network and node data traffic analysis. The requirement here, then, is to develop such a dynamic model for evaluation at the System Engineering level.

A high-level specification of the required features is defined in Appendix A. As a large part of these features are readily available in STK Pro [RD1] with the Analyzer, Communications, Coverage and Integration modules, for which ESOC already has a network licence, the contractor is required to use STK as the simulator baseline complemented with a respected and widely supported network modelling and analysis product. Any software licences required to practically use this product shall be delivered along with the STK scenarios.

- **Output**

Documents D5 and D6 as defined in section 4.3, the STK/network scenarios, the components of the modelling environment installed and demonstrated at ESOC (on the day of the Final Presentation), plus any software licences required for the practical and continued use of the environment.

4 REQUIREMENTS FOR MANAGEMENT, REPORTING, MEETINGS AND DELIVERABLES

The standard requirements for Management, Reporting, Meetings and Deliverables (Appendix 3 to the Contract) shall apply, taking account of the following specific requirements for the present activity, which shall prevail in case of conflict.

4.1 Reporting

There are no rigid reporting requirements. The Agency expects, however, to be kept involved in the concept evolution process and requires visibility of Task 3 activities allowing the possibility to provide regular feedback.

4.2 Meetings

The list of major meetings is as follows:

KO meeting to be held at ESOC.

Fortnightly progress meetings to be held via Webex with a brief status report emailed at least one day in advance. (In person meetings will be called if the Agency's Technical Officer is concerned about the progress of the study.)

Final Presentation to be held at ESOC.

4.3 Deliverables

4.3.1 Documentation

The contractor shall deliver the documents indicated in the table below. Electronic documents shall be delivered in both, searchable PDF and native format.

Document identifier	Title	Milestone	Number of paper copies
D1	Feasibility assessment report with CFDP compatibility analysis (Task 1)		None
D2	Baseline concept definition, reference scenario for the comparison of BT vs EDRS vs classic data delivery models, and KPIs (Task 1)		None
D3	Technical specification of network building blocks (Task 2)		None

D4	Trade-off of hardware elements leading to recommendations (Task 2)		None
D5	Simulation test plan and results (Task 3)		None
D6	Installation and User documentation for the delivered test environment		None
D7	Final Report and Executive Summary ▪ An electronic copy of the Final Report (as approved by the Technical Officer) shall be sent to the following e-mail address: documentation.gsp@esa.int ▪ The Executive Summary shall also be provided in searchable PDF format suitable for publishing on the Agency's Web Page. Both documents shall be free of all commercial/confidential information, which should be provided under separate cover if necessary. No copyright nor dissemination restrictions shall be indicated.		None

4.3.2 Software and Licences

Relating to the outputs of Task 3, the contractor shall deliver any software licences required for the practical and continued use of the STK/network scenarios developed for the simulations (bearing in mind that ESOC already has a suitable STK licence). The installation and liability for the simulator at ESOC shall be limited to the day of the Final Presentation.

4.4 Commercial Evaluation

Does not apply.

5 SCHEDULE AND MILESTONES

5.1 Project Milestones

The following project milestones are applicable to this study:

Milestone	Description	Events Timeline
K/O	Kick-Off	T_0
M1	D1, D2 (draft delivery of the concept as it is expected that it may have to evolve during the activity)	T_0 + 2 months
M2	D3, D4 (again, draft versions of both documents)	T_0 + 3 months
M3	D2, D3, D4, D5: final deliveries of these products plus the STK scenarios and any relevant software licences	T_0 + 5 months
FP	D6 and Final Presentation	T_0 + 6 months

All documents shall be reviewed following delivery and comments provided within 2 weeks of official reception.

5.2 Duration

The duration of the work shall not exceed 6 months from kick-off to end of the activity.

APPENDIX A SIMULATOR REQUIREMENTS

The test environment shall enable the System Engineer to demonstrate in a rapid prototyping manner the rate and volume of data return achievable in order to quickly assess the basic validity of the new architecture before looking at the cost, complexity and other factors of its implementation.

User configurable items

- Network definition
    - Density and positioning of ground antennas
        - Automated positioning based on uniform distribution
        - Manual positioning based on geographic co-ordinates
        - Manual positioning of ground antennas based on Points Of Interest such as cities and types of buildings (embassies, consulates, universities, hospitals, etc.).
    - Size and type of ground antennas (definable per location)
    - On-ground link capacities (definable per link)
    - Data Relay Satellites (definition per satellite)
        - Orbital location
        - Number of data relay channels on the satellite, e.g. the EDRS as proposed, [RD5], has 64 channels (the same number as the TDRSS satellites)
        - Their own ground station as part of the overall ground network
    - Network protocol
        - Choice between TCP, UDP, CFDP, BP/LTP, user-definable, etc.
        - Note, that whilst this is not intended to be a design environment for new protocols, it shall have a flexible programming interface that allows the simulation of protocol features.
    - Network configuration
    - Control centres in the network (that want to communicate with their spacecraft)
- Mission/spacecraft definition
    - Number and type of on-board antennas
    - Spacecraft data generation rate (Mbits per orbit assuming a uniform generation rate)
    - Spacecraft commanding requirement (kbits per orbit, transmission as and when possible)
    - Orbit
    - Mission control centre
- Multiple mission definitions

Architecture evaluation features

- Link budget analysis.
- Network performance measurements allowing data capacity, packet loss and data timeliness predictions.

- Complexity rating.

Test harness

A simulator test harness for automating the test runs and optimising the configuration against user defined targets, e.g. rate and volume of data return, maximum number of deployed units, etc.