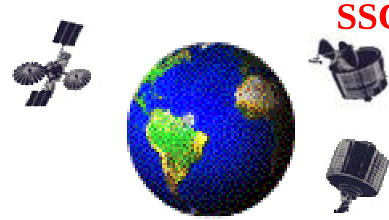
SATELLITE AND SPACE COMMUNICATIONS **SSC**
http://committees.comsoc.org/ssc/

IEEE COMMUNICATIONS SOCIETY



SSC Newsletter **Vol. 30, No. 1, June 2020**

CONTENTS

The Satellite and Space Communications (SSC) Committee is a volunteer group actively involved in advancing satellite and space communication technologies within the IEEE. This committee is approved by the IEEE Communications Society and is governed by the constitution and bylaws of the IEEE as well as the other twenty-three Technical Committees in the Society. The committee belongs to the Technical Committee Clusters of Communication/Signal Processing (C/SP).

SATELLITE & SPACE

- JOIN US –

All conference attendees are welcome to join us in the SSC Committee meeting.

ONLINE MEETING URL:
https://ieeemeetings.webex.com/ieeemeetings/j.php?MTID=mcd4cf54218f279bc9a28b51efef34b71

Meeting number: 592 898 734
Attendee code: FFnKM24Yvv3
Time: 6:00 AM (EST) 15 June 2020

Future SSC Meetings
December 2020, Taipei, Taiwan
June 2020, Montreal, Canada

ICC 2020 SSC Committee Activities:

Symposium on Selected Areas in Communications:

Monday, June 8, 8:00 – 09:50 Dublin, Ireland Time Zone
SAC-SSC1

Monday, June 8, 10:00 – 11:50 Dublin, Ireland Time Zone
SAC-SSC2

Monday, June 8, 12:00 – 13:50 Dublin, Ireland Time Zone
SAC-SSC3

HOW TO JOIN SSC COMMITTEE AND MAILING LIST

If you like to join SSC Technical Committee: Please send your name and e-mail address to the SSC Secretary, optionally include your mail address, telephone and fax numbers.
If you like to join SSC Mailing List: Instructions on how to subscribe/unsubscribe are available at https://comsoc-listserv.ieee.org/cgi-bin/wa?A0=ssc.

SSC COMMITTEE OFFICERS

CHAIR
Dr. Tomaso de Cola
German Aerospace Center (DLR)
Munchenerstr. 20,
Oberpfaffenhofen, 82234
Wessling, Germany
Tel: +49-8153-28-2156
Fax: +49-8153-28-2844
E-mail:
tomaso.decola@dlr.de

VICE CHAIR / EDITOR
Prof. Song Guo
Department of Computing
The Hong Kong Polytechnic University
Hung Hom, Kowloon
Hong Kong
Tel: +852-2766-7259
Fax: +852-2774-0842
Email:
song.guo@polyu.edu.hk

SECRETARY
Prof. Mianxiong Dong
Muroran Institute of Technology
27-1 Mizumoto-cho, Muroran,
Hokkaido, 050-8585, Japan
Tel: +81-143-46-5473
Fax: +81-143-46-5409
Email:
mx.dong@csse.muroran-it.ac.jp

PAST CHAIR
Dr. Igor Bisio
Department of Telecommunication, Electronic, Electrical Engineering and Naval Architecture,
University of Genoa
Via Opera Pia 13, 16145,
Genova, Italy
Tel: +39 010 353 2806
Fax: +39 010 353 2154
Email: igor@dist.unige.it

COMMITTEE HISTORIAN
Mr. Louis Pollack
c/o Pollack Associates
15321 Delphinium Lane
Rockville, MD, USA 20853
Tel: +1 301 929 1295

COMMITTEE ADVISOR
Prof. Desmond P. Taylor
Dept. of Electrical & Electronic Engineering
University of Canterbury
Private Bag 4800
Christchurch, New Zealand
Tel: +64 3 364 2213
Fax: +64 3 364 2761
e-mail:
taylor@elec.canterbury.ac.nz

MESSAGE FROM THE CHAIR

Dr. Tomaso de Cola

As my terms of SSC chair is completing end of June, this is my last message. I've been serving the TC as chair for two consecutive terms and I've to report important results collected so far, mostly in terms of increased participation to the meetings and in general to the daily business of the TC. Moreover, important editorial initiatives have been promoted by the TC in this time frame. I'm certainly happy to report important special issues appeared on IEEE JSAC, Network, Wireless Comm. Magazine. Moreover a second special issue on JSAC was proposed, which although received good reviews was not approved. As a result, other initiatives were started on other journals in order to take advantage of the very good moment for satellite communications.

In general leading the technical committee has been a great challenge given the high expectation on the activity of the TC and the will to further improve the level and quality of 3ffectties here conducted. In this respect, I can certainly report the satisfaction of the TC members as confirmed by the increased number and the growing interest in our tasks. Achieving these important results has certainly required important effort and I'm happy to share the satisfactory results with the other officers of the TC who have continuously helped me and supported in all planned activities. As such, I'm very confident that the new officers will receive the TC in a very healthy and stable situation and will be able to keep up with the results trends observed so far. This said, I can only wish the best to the new chair for achieving even more important results and still attain very high promotion and visibility levels within ComSoc.

Election of the new TC officers. The election of the new terms officers (i.e. from July 2020 till June 2022) has been started in May for the selection of the vice-chair for which three candidates were provided, whereas no election was initially run for the positions of chair and secretary as only candidate was identified. Later on, the TC Board Director (Dr. Stefano Galli) reminded that also those positions should be subject to an election process independently of the number of candidates for compliancy to the ComSoc bylaws. As such, a new election round has been just started and we are confident to close the process by the end of June (including the approval from the TC Board director and ComSoc-VP), so that the new officers will be able to start their term on July 1st as stated by the P&P.

Participation to TC Meetings. The SSC TC last meetings have been showing a continuously good trend in the number of attendees, confirming the number already recorded in the previous meetings held in 2018. In particular, the trend is to always have about 30-40 attendees participating to the SSC meeting, hence testifying the increasing interest in the TC activities and also confirming the stability of our TC. Moreover, additional new members interested in the SSC activities are directly contacting the SSC officers to get involved in the committee activities hence showing specific interest in the conducted activities. Nevertheless, we have to continue to publicize our meeting and to invite members, past and new, to attend.

Operative Policies and Procedures (OP&P). Upon discussion during the last meeting, the charter is expected to be update so as to include also topics related to UAV and more in general new space, which are going to become more and more important in the context of SatCom in a broad sense. A new version of the charter will be likely submitted to the TC board for validation and approval in the second half of 2020.

Membership Management. The approach started a few years ago to continuously attract more people is achieving quite good results, also in relation to the large audience of each SSC meeting. Moreover, the editorial initiatives around SatCom have increased the worldwide visibility of SSC hence possibly increasing the attention towards the TC and eventually getting new members.

Extended Cooperation. It consists of strict cooperation with Industries, research institutes, standardization institutes (e.g., CCSDS, ETSI, DVB), and space agencies of several countries (e.g., NASA, JAXA, ESA, DLR). The success of this task is further strengthened by the presence of industry and academia in many of the editorial initiatives promoted by the TC, counting on satellite operators and vendors. Moreover, most of the last perspective articles present in the newsletter are coming from industry-driven projects, hence showing the great interest from industry and space agencies about the work being done in the TC.

SSC Website and Mailing List. Maintenance and periodic update of mailinglist and website are performed by the committee secretary, in order to guarantee up-to-date material and possibly attract new members interested in SatCom-related topics.

Current Journals/Magazines. A new special issue about satellite communications as support of IoT services has been proposed for the IEEE IoT journal. The proposal has been submitted early May and feedbacks are supposed to be received within June.

Conference Activities (ICC/GC and others). In ICC/GC is consolidated the SSC Track. In the recent years the SSC track has been quite successful. The SSC track of past GC editions and the current ICC'19 showed a very good number of submissions, being approximately 70 and 60 respectively. The present edition of GC'19 also maintains this trend with a considerable number of accepted paper, though slightly less than the previous editions. ICC' 20 has confirmed this trend with a good number of submissions, eventually resulting in 18 accepted papers. Concerning other conferences, the SSC TC has endorsed SPECTS, WiSee, and ASMS/SPSC for year 2020 (third quarter).

Standardization Activities. Since the meeting in Atlanta (IEEE GC'13), we have appointed the Standard Liaison, Dr. Henry Suthon, Principal Senior Engineer at Boeing (h.suthon@ieee.org), who has recently confirmed his commitment in this role. Additionally, a dedicated board (formerly conceived as WG) is being under formation so as to put even more effort and visibility on the standardization activities performed around satellite and space communications. In this respect, it is worth noting that the contribution of this group to the standardization context is also confirmed the perspective article present at the end of this newsletter, where the effort paid by the satellite community in 3GPP to promote the inclusion of non-terrestrial networks (including SatCom) is highlighted. Moreover, liaison with IEEE standardization groups are being formed in the exercise of providing inputs to the IEEE 5G initiative where the dedicated SatCom WG has already compiled a report about the technology roadmap until 2030.

Dr. Tomaso de Cola, Chair
Satellite and Space Communications TC

SCANNING THE WORLD

Song Guo

From January to June in 2020, there have been 32 space launches including 4 failures so far. The first half of 2020 has witnessed a lot of news on satellite technologies and space communication activities. Some representative news is summarized below.

On January 7, Space X conducted the first rocket flight of 2020s by using its Falcon 9 to deliver the newest batch of 60 operational Starlink satellites into orbit. With this launch, SpaceX becomes the largest satellite operator by "active" satellite measurement, surpassing PlanetLabs by roughly 30 satellites. Different from previous operational Starlink flight, the deployment orbit is approximately 10 km higher and one of the Starlink satellites will test a new "experimental darkening treatment" to reduce its visibility from the ground. SpaceX says 24 launches are needed to provide global broadband service through the Starlink service. But the company could provide an interim level of service over parts of the Earth later this year, once SpaceX has launched around 720 satellites on 12 Falcon 9 flights.

On January 16, Arianespace launched two telecommunications satellites – Eutelsat KONNECT and GSAT-30 – on an Ariane 5 launch vehicle. The first spacecraft deployed during the launch sequence was Eutelsat KONNECT, a spacecraft developed by Thales Alenia Space and operated by Paris-based Eutelsat. It can offer a total capacity of 75 gigabits per second (Gbps) and will allow Eutelsat to provide Internet access for companies and individuals at 100 megabits per second (Mbps). Another spacecraft was GSAT-30, a telecommunications satellite developed and manufactured by the Indian Space and Research Organization (ISRO). This spacecraft will be stationed at the 83-degree East longitude position once in orbit and will provide high-quality television and communications services to the Indian mainland. GSAT-30 is expected to replace the INSAT-4A spacecraft in orbit, which was launched on an Ariane 5 in December 2005.

On February 6, the European launch services provider Arianespace — in conjunction with the European-Russian Starsem company launched a Soyuz 2.1b/Fregat-M rocket from Baikonur Cosmodrome in Kazakhstan with 34 OneWeb space-based internet satellites. This launch was the first of up to 10 OneWeb mission this year. OneWeb aims to have at least 648 satellites in orbit, the company plans to begin providing global Internet service next year. OneWeb's satellites will relay broadband signals through powerful ground stations, or gateways to provide low-latency broadband networks. Once deployed, the OneWeb constellation will enable user terminals capable of offering 3G, LTE, 5G and Wi-Fi coverage, providing high-speed access around the world by air, sea and land. On March 21, they launched the second 34 satellites to orbit.

On May 12, A Chinese Kuaizhou 1A rocket launched the first two spacecraft for China's planned 80-satellite Xingyun communications and data relay constellation. As an important part of the "Five Clouds and One Vehicle" project led by China Aerospace Science and Industry Corporation, this project aims to build a space-based Internet of Things through the construction of China's first low-orbit narrowband communication satellite constellation to achieve the real-time transmission and 5 ffecttive connection of intelligent terminal data such as various information nodes and sensors around the world.

Prof. Song Guo, Vice Chair
Satellite and Space Communications TC

FORTHCOMING GLOBECOM AND ICC CONFERENCES

GLOBECOM 2020

December 7-11, 2020, Taipei City, Taiwan
http://globecom2020.ieee-globecom.org/
IEEE GLOBECOM 2020 – IEEE Global Communications Conference (GLOBECOM) is one of the IEEE Communications Society's two flagship conferences dedicated to driving innovation in nearly every aspect of communications. Each year, more than 2,900 scientific researchers and their management submit proposals for program sessions to be held at the annual conference. After extensive peer review, the best of the proposals are selected for the conference program, which includes technical papers, tutorials, workshops and industry sessions designed specifically to advance technologies, systems and infrastructure that are continuing to reshape the world and provide all users with access to an unprecedented spectrum of high-speed, seamless and cost-effective global telecommunications services.

COSPONSORING / RELATED CONFERENCES AND WORKSHOPS

ICC 2021

June 14-18, 2021, Montreal, Canada
http://icc2021.ieee-icc.org/
The International Conference on Communications (ICC) is one of the two flagship conferences of the IEEE Communications Society, together with IEEE GLOBECOM. Each year the ICC conference attracts about 2-3000 submitted scientific papers, a technical program committee involving about 1500 experts provides more than 10000 reviews, the conference being finally attended by 1500 – 2000 professionals from all around the world. IEEE ICC is therefore one of the most significant scientific events of the networking and communications community, a must-attend forum for both industrials and academics working in this area. IEEE ICC 2021 – Featuring the latest developments in telecommunications from a technical perspective. Subjects include Communications Theory, Wireless Communications, Wireless Networking, Optical Networking, Next Generation Networks for Universal Services, Multimedia Communication and Home Networking, Signal Processing for Communications, Communications QoS, Reliability and Performance Modeling.

CONFERENCES CALENDAR

CONFERENCE	DATE & LOCATION	INFORMATION
SPECTS 2020 International Symposium on Performance Evaluation of Computer and Telecommunication Systems	July 20-22, 2020 Madrid, Spain	http://atc.udg.edu/SPECTS2020/
ASMS/SPSC 2020 Advanced Satellite Multimedia Systems Conference (ASMS) and Signal Processing for Space Communications Workshop (SPSC)	October 20-21, 2020 Online	https://www.asmsconference.org
ITC 2020 32rd International Teletraffic Congress	22-24 September 2020 Osaka, Japan	http://itc32.org/
ICTS 2020 International Conference on Computer, Information and Telecommunication Systems	5-7 October 2020 Hangzhou, China	http://atc.udg.edu/CITS2020/
ICL-GNSS 2020 International Conference on Localization and GNSS	2-4 June 2020 Tampere, Finland	http://www.icl-gnss.org/2020/
PIMRC 2020 IEEE International Symposium on Personal, Indoor and Mobile Radio Communications	31 August - 3 September 2020 London, UK	http://pimrc2020.ieee-pimrc.org/
VTC-Fall 2020 2020 IEEE Vehicular Technology Conference (VTC-Fall)	October 4 - 7, 2020, Victoria, Canada	http://www.ieeevtc.org/vtc2020fall/

To all SSC members: If your postal address, telephone or fax numbers have changed, please update them with the committee secretary. You can review our current records on our web page at http://committees.comsoc.org/ssc/.

PERSPECTIVE ARTICLE June 2020

DTN research for Space Communications

Nicola Alessi, Andrea Bisacchi, Carlo Caini, Gian Marco De Cola, Lorenzo Persampieri
ARCES/DEI University of Bologna, carlo.caini@unibo.it

***Abstract* — This paper presents a brief overview of Delay-/Disruption Tolerant Networking research when applied to Space Communications. After an historical introduction, the paper focuses on two research topics, Transport protocols and routing, investigated at University of Bologna in recent years in cooperation with some space agencies' researchers. For each topic, the challenges to be overcome are shown, before examining both state-of-the-art solutions and current research proposals.**

INTRODUCTION

Delay-/Disruption-Tolerant networking (DTN) originates from the early research on Interplanetary Networking (IPN) started at NASA-JPL in the late `90s by a small group of renowned researchers, including the co-author of TCP/IP protocols Vinton Cerf. The name DTN was assumed when it was realized that challenges to be tackled in space were also present in a few terrestrial "challenged networks", which demanded a common solution. The DTN architecture extends the TCP/IP architecture by inserting the new Bundle Layer between Application and (usually) Transport on a few selected nodes. The new layer acts as an overlay, with its own addressing and routing. Both the architecture [1] and the Bundle Protocol (BP) [2] were defined by IRTF (Internet Research Task Force) in 2007. Current research is carried out in parallel by IETF (Internet Engineering Task Force) and CCSDS (Consultative Committee for Space Data System). DTN protocols are at present being used experimentally on the ISS (International Space Station) [3] and will likely be used in future NASA missions.

The DTN architecture has many novel aspects. Two, however, are paramount [4]. First, DTN redefines the Transport layer scope, no longer end-to-end but restricted to one DTN hop; this is instrumental in enabling the use of different transport protocols on different segments of the network, as dictated by the various challenges to be tackled. Second, bundles (BP packets) can be stored for long periods on intermediate DTN nodes, essential to enabling transmission in the presence of disruptions and link intermittency.

In the rest of this paper, we will focus on two important research topics of DTN in space, Transport protocols for space and DTN routing.

TRANSPORT LAYER IN SPACE

A. Challenges

Let us start from the shortest space links, i.e. those with LEO satellites. Here, the main challenge is due to link intermittency caused by the relative motion of the satellite and Earth. Opportunity for transmissions, or, "contacts", are short and few, in contrast to Internet links which are usually available continuously. This impairs the use of standard transport protocols, such as TCP. Moving to GEO satellites, the ground-satellite-ground propagation delay (about 250-300ms) becomes a challenge, which may add to link intermittency in the presence of mobile terminals [4]. On longer distances, e.g. Earth-to-Moon, the increased delay (about 1.3s) prevents an efficient use of TCP. The problem is exacerbated when we consider interplanatery links, whose distances and delays are literally astronomical. For example, the one way Earth-to-Mars delay is in the range of [3, 21] minutes, depending on the relative positions of planets. The Round Trip Time (RTT), an essential parameter for all reliable transport protocols, is twice, rocketing to 42 minutes in the worst case. In interplanatery networks this challenge always adds to scheduled intermittent connectivity due to the deterministic motion of planets and space assets. The two challenges, delay and intermittency, are actually combined. In fact, strange as it may appear to our "terrestrial-used" minds, a Transmission (Tx) window of a contact is not the same as the corresponding Receiving (Rx) window, the latter being shifted forward by the propagation delay, an effect that is totally negligible in terrestrial and satellite networks, but not on interplanatery distances.

B. State of the art solutions

To cope with both scheduled intermittent connectivity and long delays, the Licklider Transmission Protocol, called after the Internet pioneer Joseph Licklider, is the designed solution. The differences from TCP are clearly dictated by the different space challenges [5],[6]. LTP is contact aware, i.e. it stops and resumes Tx and Rx activity in accordance with time intervals declared in contact plan (a collection of contacts, calculated and distributed in advance to all DTN nodes). Moreover, by contrast to TCP, whose Tx rate is window based, depending on acknowledgement reception, LTP is rate based, i.e. it transmits at the rate declared in the contact plan. This is necessary when considering interplanetary links, for which any feedback based Tx rate control would be impractical because of the duration of the control loop (the RTT). As an essential side effect of this design choice, LTP loss recovery, when present (in "red" block parts [6]), is completely decoupled from Tx rate, by contrast to TCP. To better understand the LTP recovery mechanism, we must consider that one or more bundles may be aggregated in an LTP block, which is an autonomous entity, independently transmitted. As data bundles are usually much larger than Internet packets (e.g. one bundle for one file, such as a photo), the LTP block may in turn be quite large as well. Thus, it usually needs to be divided into multiple LTP segments, manageable by lower protocols (UDP or specialized space protocols). Lost red LTP segments are then recovered by means of an ARQ mechanism, which would be quite usual, but for the fact that its clever design allows for multiple recoveries in the same retransmission cycle. This is essential to limit the additional recovery delay in cases of single or multiple losses to one RTT (best case).

LTP has been widely studied in the literature. At the University of Bologna we contributed both to the performance analysis and to the development of some enhancements, in collaboration with DLR and NASA researchers [7]. These enhancements are at present available on the LTP version contained in ION, the DTN suite developed by NASA-JPL [8].

C. Further studies and prospective solutions

The main problem of LTP, when applied on Interplanetary links, is that the error recovery is based on ARQ, as in terrestrial solutions, but ARQ can become extremely costly in space. In more detail, although the additional delay due to ARQ recovery is limited to one RTT (best case), one RTT means 42 minutes on Earth-to-Mars links in the worst case, vs. a few tens of ms on Earth. Thus, while LTP alone can cope well with both LEO and Earth-to-Moon challenges, it may suffer on longer interplanetary distances. A simple solution could be to try hard to limit losses by acting at physical layers only to make losses very rare. In practice, however, losses cannot be eradicated. Moreover, various services must be provided at upper layers, some requiring reliability, others not, and physical layer only solutions do not provide great flexibility in this perspective.

Luckily, an alternative to ARQ exists, called Packet Layer Forward Erasure Correcting coding (PL-FEC) 错误!未找到引用源。. The same kind of FEC codes that are used at physical layer, (namely, Reed Solomon, LDPC, etc.) can be used to protect information packets instead of information bits. The advantage of this technique on ARQ is that missing segment recovery can be carried out proactively by exploiting "redundancy" packets added to "information" ones in FEC "codewords". If losses are less than redundancy packets in a codeword (with a small margin), the codeword can be successfully decoded, i.e. all original information packets delivered, thus eliminating the (minimum) one RTT delay implicit in ARQ. The main disadvantage is that sending additional packets in advance is costly in terms of bandwidth.

The idea of applying PL-FEC to LTP segments was first presented in [10], and then extended in a CCSDS "Orange" book [11], promoted by DLR. The same concept, with different codes, was later adopted by other researchers [12]. From the very beginning the University of Bologna and DLR started collaborating on the development of the original idea, which eventually led to the development of two different variants, ECLSA and HS-LTP, fully described in two recent papers [13], [9]. The interested reader is referred to them for all details. The corresponding code is available in official ION releases, in the "contrib" section. On interplanetary links, the advantage of packet-layer FEC is substantial.

DTN ROUTING IN SPACE

A. Challenges

Intermittent connectivity and delay also have a profound impact on DTN routing, which greatly differs from its Internet equivalent. An Internet route is a geographical route, consisting in an ordered series of routers. By contrast, a DTN route consists in an ordered list of contacts, because links between nodes are no longer available with continuity but only at scheduled times. In other words, while an Internet route is analogous to a route for cars, because both terrestrial links and roads are assumed continuously available, a DTN route looks more like the series of flights to get to a distant destination, because links are intermittent and contacts, like flights, are scheduled. As an Internet and a DTN route have different natures, obviously routing algorithms cannot be the same.

B. State of the art solutions

If link intermittency is a challenge, the fact that it is scheduled is a key advantage from which to profit. This is what has been done by the Contact Graph Routing (CGR) algorithm, designed by NASA JPL, which uses the contact plan information to derive the best route (series of contacts, as said) to get to destination [15]. The criterion is the earliest arrival time, i.e. the best is the fastest route to destination. This choice is dynamic, i.e. it may change bundle-by-bundle, because it must consider both contact plan information and traffic, i.e. bundles already associated to contacts (passenger bookings to flights).

A formidable problem is that link intermittency and propagation delay prevent a rapid exchange of state information (flight bookings) among nodes, which precludes CGR from being theoretically optimal, apart from all other possible considerations. In fact, CGR is necessarily a best effort algorithm, in spite of its complexity, due to the arduous nature of the problem it aims to solve.

CGR has continuously evolved since its first appearance, but an important milestone was reached when it was standardized by the CCSDS (Consultative Committee for Space Data System) under the name of SABR (Scheduled Aware Bundle Routing) [16]. This version is present in the latest ION releases.

C. Further studies and prospective solutions

Very recently an independent implementation of the SABR version of CGR has been developed at the University of Bologna, called Unibo-CGR. Its modular design uses an interface to isolate the CGR core from the specific details of the bundle protocol implementation on which is inserted. At present, only the interface to ION has been designed, but other interfaces could easily be added, hopefully leading to a wider adoption of SABR. Unibo-CGR was developed with research in mind, thus it also offers a series of experimental features, whose validity is at present under study.

ACKNOWLEDGEMENT

Our gratitude goes to all students that have contributed in the course of many years to the development of DTN research at University of Bologna. A special thanks also to Scott Burleigh at NASA-JPL for its continuous support and to Tomaso De Cola at DLR, with whom we have shared a large part of the research activity mentioned in this paper.

REFERENCES

[1] V. Cerf , A. Hooke, L. Torgerson, R. Durst, K. Scott, K. Fall, H. Weiss “Delay-Tolerant Networking Architecture”, Internet RFC 4838, Apr. 2007.

[2] K. Scott, S. Burleigh, “Bundle Protocol Specification”, Internet RFC 5050, November 2007.

[3] A. Schlesinger, B. M. Willman, L. Pitts, S. R. Davidson and W. A. Pohlchuck, "Delay/Disruption Tolerant Networking for the International Space Station (ISS)," 2017 IEEE Aerospace Conference, Big Sky, MT, 2017, pp. 1-14, doi: 10.1109/AERO.2017.7943857.

[4] C. Caini, H. Cruickshank, S. Farrell, M. Marchese, “Delay- and Disruption-Tolerant Networking (DTN): An Alternative Solution for Future Satellite Networking Applications”, Proceedings of IEEE, Vol. 99, N. 11, pp.1980-1997, Nov. 2011 DOI: 10.1109/JPROC.2011. 2158378

[5] M. Ramadas, S. Burleigh and S. Farrell, “Licklider Transmission Protocol – Motivation,” Internet RFC 5325, Sept. 2008.

[6] M. Ramadas, S. Burleigh and S. Farrell, "Licklider Transmission Protocol – Specification,” Internet RFC 5326, Sept. 2008.

[7] N. Alessi, S. Burleigh, C. Caini, T. De Cola, “Design and Performance Evaluation of LTP Enhancements for Lossy Space Channels”, Wiley, International Journal of Satellite Communications and Networking, Vol.37, No.1, pp.3-14, Jan-Feb 2019, DOI: 10.1002/sat.1238.

[8] ION code and manual: http://sourceforge.net/projects/ion-dtn/.

[9] T. D. Cola and M. Marchese, "Reliable data delivery over deep space networks: Benefits of long erasure codes over ARQ strategies," in IEEE Wireless Commun., vol. 17, no. 2, pp. 57-65, April 2010, doi: 10.1109/MWC.2010. 5450661.

[10] T. de Cola, E. Paolini, G. Liva and G. P. Calzolari, "Reliability Options for Data Communications in the Future Deep-Space Missions," in Proceedings of the IEEE, vol. 99, no. 11, pp. 2056-2074, Nov. 2011, doi: 10.1109/JPROC.2011.2159571.

[11] CCSDS, "131.5-O-1, “Erasure Correcting Codes for Near Earth and Deep Space communications,” 2014. https://public.ccsds.org/Pubs/131x5o1.pdf

[12] L. Shi et al., "Integration of Reed-Solomon codes to licklider transmission protocol (LTP) for space DTN," in IEEE Aerospace and Electronic Systems Magazine, vol. 32, no. 4, pp. 48-55, April 2017, doi: 10.1109/MAES. 2017.160118..

[13] N. Alessi, C. Caini, T. de Cola, M. Raminella, "Packet Layer Erasure Coding in Interplanetary Links: the LTP Erasure Coding Link Service Adapter," in IEEE Transactions on Aerospace and Electronic Systems, Vol.56, No.1, pp. 403-414, Feb. 2020 doi: 10.1109/TAES.2019.2916271

[14] N. Alessi, C. Caini, A. Ciliberti, T. de Cola, "HSLTP - An LTP Variant for High Speed Links and Memory Constrained Nodes," in IEEE Transactions on Aerospace and Electronic Systems, early access Jan. 2020, 10.1109/TAES.2019.2958190

[15] G. Araniti, N. Bezirgiannidis, E. Birrane, I. Bisio, S. Burleigh, C. Caini, M. Feldmann, M. Marchese, J. Segui, K. Suzuki. “Contact Graph Routing in DTN Space Networks: Overview, Enhancements and Performance”, IEEE Commun. Mag., Vol.53, No.3, pp.38-46, March 2015. DOI: 10.1109/MCOM.2015.7060480

[16] CCSDS 734.3-B-1 “Scheduled-Aware Bundle Routing”, recommended standard, Blue Book, July 2019, https://public.ccsds.org/Pubs/734x3b1.pdf