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Bundle protocol implementation for satellite applications

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Abstract: In the paper entitled "FPGA Implementation of Space Qualified Bundle Protocol for Satellite Communication" a CCSDS proposed Bundle Protocol for delay / disruption tolerant networks in space is designed. The paper presents software coding and hardware implementation of Bundle Protocol using VHDL programming and its implementation on Xilinx Vertex 4 xc4vfx60 Field Programmable Gate Array (FPGAs). The existing TCP /IP based Internet protocols have many assumptions built into their architecture which make them not suitable for space. Compared to the present Internet architecture, delay / disruption tolerant networking (DTN) technology uses store and forward paradigm for latency as long as a year, persistent storage of protocol data units, custody transfer and self delimiting numeric values (SDNV) encoding scheme to minimize the transmission bandwidth. The proposed methodology in this paper is useful in highly stressed communications in space environments especially those with long link delay, intermittent connectivity, network partitions, frequent link disruptions and fewer node resources. The main focus of this paper is to design and demonstrate a three node test set up delay and disruption tolerant network lacking end-to-end connectivity, asymmetric data rates, variable delays, and high packet error rates.

Key Words: Delay **/**Disruption Tolerant Networking, TCP/IP model, Self Delimiting Numeric Values (SDNV) encoding and decoding, Bundle Protocol.

1. Introduction

DTN stands for delay /disruption tolerant network is the most dominant area of research in computer networks and space communications. DTN is the area of networking which addresses challenges in disconnected, disrupted networks without end-to-end connection. This paper is an effort being put to present a novel way to improve communication in challenged internet areas characterized by high packet drop probability, link failure, network partitions due to node mobility or RF interference, power and memory constraints, limited node resources by designing CCSDS proposed DTN protocol namely Bundle protocol.

In above mentioned challenged Internet areas the existing Internet protocols fail to operate effectively because of a number of assumptions built in their architecture such as an end-to-end path exists between a data source and its destination(s), the maximum round-trip time is not large between any network node pairs, storage in network is in the order of few milliseconds, and the end-to-end packet drop probability is small. Lamentably, challenged networks, which may violate one or more of the assumptions of Internet protocols, are gaining priority and may not be well served by the current end-to-end TCP/IP model. Hence there is a requirement of DTN targeted at space internetworking environment [1].

While the concept of DTN is used for almost a decade and was originally developed for Inter-Planetary Network by the Internet Research Task Force (IETF), its scope was extended to all challenged networks whether spatial or terrestrial. DTN finds its applications in terrestrial mobile networks, exotic media networks that include near Earth satellite communications, deep space

RF communications, communication using acoustic modulation in air or water and few free space optical communications, Ad-Hoc Networks, Sensor Networks etc.

Organization

The paper is organized in the following sections. Section 2 describes DTN model for space. DTN architecture design is discussed in brief in section 3. CCSDS proposed bundle protocol is explained in section 4. Simulation results of designed bundle protocol are given in Section 5. Section 6 gives the conclusion of paper.

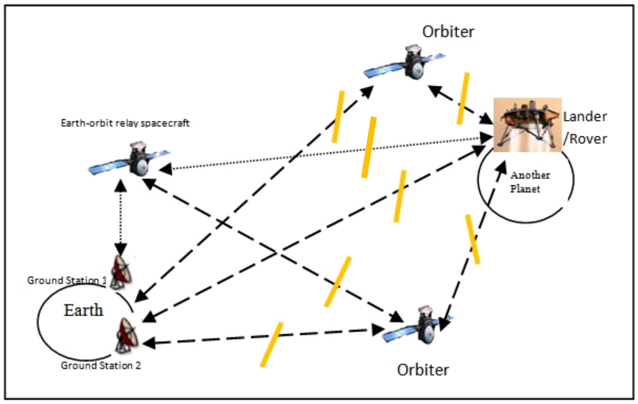
2. DTN Model for Space

To explain the disruption tolerant networking model for space we begin with the earth-orbiter-rover communication scenario of figure 1 wherein the ground station can communicate with the Lander via primary relay path (involving planet orbiting spacecraft) or secondary relay path (involving earth orbiting spacecraft). Recent study found that using dedicated direct communication circuits between Earth stations and Landers has limitations, which resulted in use of relaying in space communication for effective data transmission (95% of data was received from Mars Odyssey spacecraft used for communication between Mars Exploration Rovers and Earth) as in [2].

This kind of relay can be achieved in two ways

- Planet- orbiting spacecraft (Primary method)
- Earth-orbiting spacecraft (Backup /Secondary method)

Relay operation in space can involve use of many Orbiters which are controlled by different space agencies hence providing cross-support (space agency A can use the orbiter services controlled by space agency B to communicate with the landed element) as in [3]. Hence this reduces cost of operation and increases data return giving planetary Landers more opportunities to forward data to Earth making the mission more robust. This real-world situation is abstracted, according to the DTN architecture discussed in section 3.



Possible interoperability / cross-support points (sides may be controlled by different agencies / administrative domains)

Fig 1: Example DTN network for space

In the context of DTN, an orbiter has the ability to store-and-forward (persistent storage) protocol data units called bundles, and acts as a data carrying entity. These data carrying "DTN routers" become the point of retransmission when they accept custody of the bundle in contrast to the TCP /IP protocol suite where the source is the only point of retransmission. By taking figure 1 into consideration results are discussed for a three node test node, one each in earth and another planet and another node acting as an Orbiter.

3. Delay /Disruption Tolerant Network Architecture Design Description

CCSDS proposed overlay architecture for DTN suitable for space to overcome the problems associated with intermittent connections, long or variable delays, data rates that are asymmetric, and error rates that are high, as in [4]. A brief description of DTN architecture and design principles are discussed below

3.1 Store and Forward Virtual Message switching operation

DTN enabled application send messages of arbitrary length called bundles which are forwarded by DTN nodes. Bundles are stored persistently to survive application and operating system restart and queued until communication opportunity (contact) is available at the intermediate DTN nodes. This is in contradiction to very short-term storage provided by memory chips and buffers which store (queue) incoming packets for a few milliseconds while they are waiting for their next-hop routing table lookup and an available outgoing router port. This model is better than expecting a continuous connection with the destination far away from the source.

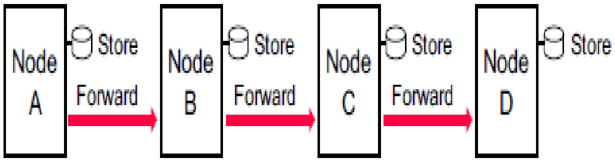


Fig 2: Store-and-Forward Message Switching

3.2 Endpoint Identifiers (EIDs) and Registrations

EIDs expressed using syntax of Uniform Resource Identifiers (URIs) are text strings that uniquely identifies a DTN endpoint. More details on EIDs can be found in [5]. The "dictionary byte array" field in the bundle's primary block contains concatenation of any number of null-terminated scheme names and Scheme Specific Parts. this enables a degree of block compression when the source and report to EID are the same endpoint then text of that endpoint's ID may be quoted twice yet appear only once in the dictionary. EID takes the following form, EID= <scheme name> : <scheme specific part>.

A process called "registration" is done if an application wishes to receive ADUs destined for a particular EID. This information is maintained persistently by a DTN node. At any time registration can be in either of the two states- active or passive. Bundles will be delivered to a node only if the registration is in active state.

3.3 Routing and Forwarding

DTN network is described using a multigraph where the edges are time varying with respect to delay, capacity and transmission direction. If C(t) is the capacity and D(t) is the delay of an edge at time t, and if B bits are placed in this edge at time t, then they completely arrive by time given by $t + D(t) + (1/C(t)) * B$ seconds. The period of time during which capacity is positive and delay is constant is called "contact". The product of capacity and the time interval is called contact volume.

Depending on the contact's volume large ADUs and bundles are divided into smaller routable units and forwarded to the next DTN node.

3.4 Congestion Control

Congestion occurs when storage sources become scarce due to the presence of too many bundle data. When congestion is encountered a node has several options to extenuate congestion by the following order of preference : drop expired bundles, move storage of bundles in the network, discard unexpired bundles for which it has not accepted custody, cease accepting regular bundles, and last option would be discard bundles for which it has accepted custody.

3.5 Convergence Layer Adapters (CLAs)

DTN architecture embraces the concepts of occasionally connected networks that comprise of more than one divergent set of protocols. In such a case CLAs provide necessary functions to carry bundles as they travel through the layers of protocol suite.

3.6 Security

In order to prevent unauthorised users from flooding the network with traffic easily and prevent denial of service to authorised users, DTN bundle security protocol is designed for data integrity (end-to-end or hop-by-hop integrity) and confidentiality. DTN nodes encrypt, decrypt, sign and verify and check the validity of cryptographic credentials.

3.7 Fragmentation and Reassembly

DTN supports two forms of Fragmentation/ Reassembly- Proactive and Reactive.

Proactive Fragmentation is used when contact volumes are known in advance. A block of application data is divided into multiple smaller blocks and each block is transmitted as an independent bundle. The final destination(s) is responsible for reassembling incoming bundles into original large bundle and ultimately, the ADU.

Reactive Fragmentation is used when a bundle is partially transmitted. The previous hop sender may learn that only a portion of the bundle has been delivered to the next hop and send the remaining portion when subsequent contacts become available. It requires certain level of support from underlying protocols.

3.8 Custody based Retransmission

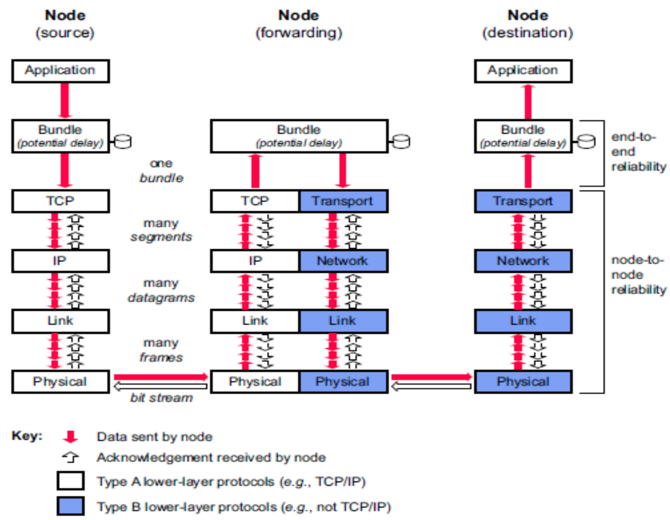


Fig 3: Custody based Re-Transmission

Node-to-node retransmission capability is supported by the bundle protocol by means of custody transfers arranged between the bundle-protocol agents of successive nodes, at the initial source application request. When the current bundle custodian sends a bundle to the next custodial node (not necessarily the next node in the path), it requests a custody transfer acceptance by that node and starts a time-to-acknowledge retransmission timer.

If the next DTN node accepts custody, it returns a custody transfer success acknowledgment to the previous custodian. If no acknowledgment is returned before the custodian's time-to-acknowledge expires, the custodian retransmits the bundle. The value of time-to-acknowledge retransmission timer can be computed locally, based on past experience with a particular node or by using routing information as in [6].

4. The Bundle Protocol (BP)

There exists a bundle protocol agent at each node that offers the following services to node's application agent

- Registering a node in an endpoint
- Terminating a registration
- Registration switching between active and passive states
- Polling passive state registration
- Delivering a receives bundle to the application

Bundle format includes a primary bundle block, bundle payload block, and few extension blocks for bundle security protocol which are discussed in detail in [5]. BP is designed to minimize transmission bandwidth consumption by using self delimiting numeric values (SDNV) encoding scheme. SDNV is a unsigned binary number, a collection of 'N' bytes in which the last byte has MSB set to zero and the remaining bytes have MSB set to one. Various fields of BP header take the form of SDNV encoded values.

In order to meet the requirements of DTN architecture discussed in section 3, a DTN protocol called the Bundle protocol is implemented in this paper as in [7]. This BP is present between the application and transport layer of the Internet protocol suite. The bundle protocol ties together the lower-layer protocols so that application programs can communicate across the same or different sets of lower-layer protocols under conditions that involve long network delays or disruptions.

Figure 4 compares the Internet protocol stack (left) with a DTN protocol stack (right).

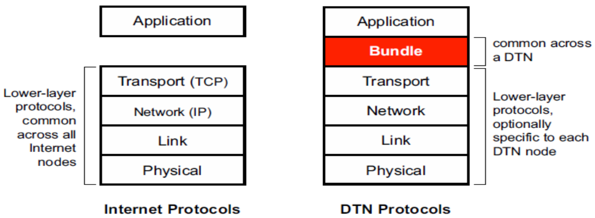


Fig 4: Internet protocol stack versus DTN protocol stack

The bundle protocol provides the following services

- **Authentication:** The method of digital signature used to verify the sender's identity and the integrity of the message.
- **Bundle Return Receipt:** Confirmation to the source, or its reply to entity, that the bundle has been received by destination application.
- **Custody Acceptance Notification:** Notification to the source, or its reply to entity, when a node accepts a custody transfer of the bundle.
- **Delivery Priority:** Bulk, Normal, or Expedited.
- **Bundle Forwarding Report:** Notification to the source, or its reply to entity, whenever the bundle is forwarded to another node.
- **Custody Transfer Success /Failure Acknowledgement:** Delegation of retransmission responsibility to a node which have enough resources to accept custody of a protocol data unit The accepting node sends custody transfer succes acknowledgement to the previous custodian.

5. Results

The results for a three node setup DTN are obtair using ModelSim simulator and the code is written in VHI using Xilinx ISE design tool and implemented on FPG FPGA implementation steps including synthesis, transla map and place and route are automatically performed by t tool to generate an FPGA programming file. From FP(clock frequency of 100 MHz, a 4 MHz clock is derived a the code is made to work at this frequency. Using Termi v1.9b, application user data is sent to FPGA via RS232 cal with the following selection of communication ports, ba rate, data bits, parity and handshaking as shown in figure 5.

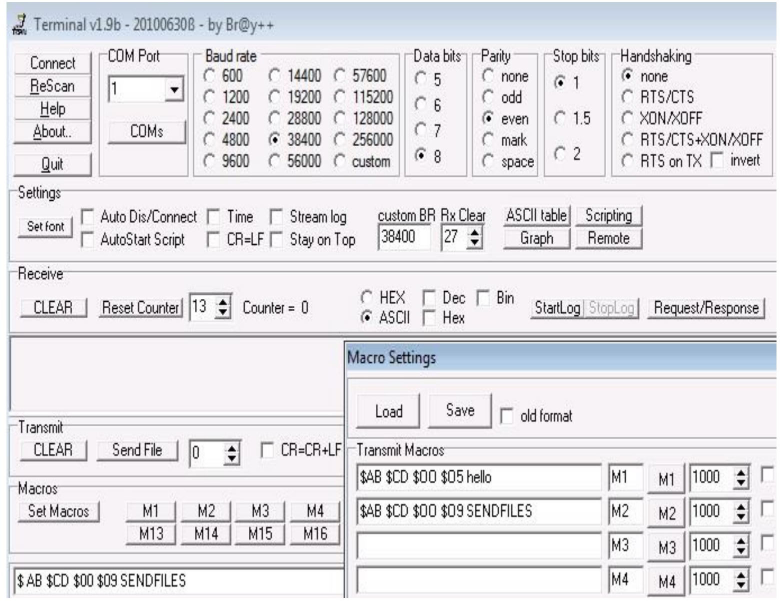


Figure 5: Terminal application to send data serially from PC to FPGA.

Consider for example Earth station wants to uplink command to Rover via the Orbiter (Intermediate DTN node) which is the point of persistent storage. ADU to be sent is taken (ex: SENDFILES= "53 45 4E 44 46 49 4C 45 53") from the application via terminal as shown in fig. 5, its size is decoded and stored in temporary memory (userramstore in figure 6) until the bundle header is formed. Persistent storage module then stores the bundle to be transmitted and sends bundle along with some predefined pattern when an outgoing link is available to the orbiter. Persistent storage module keeps track of number of rams used and the ram number currently in use.

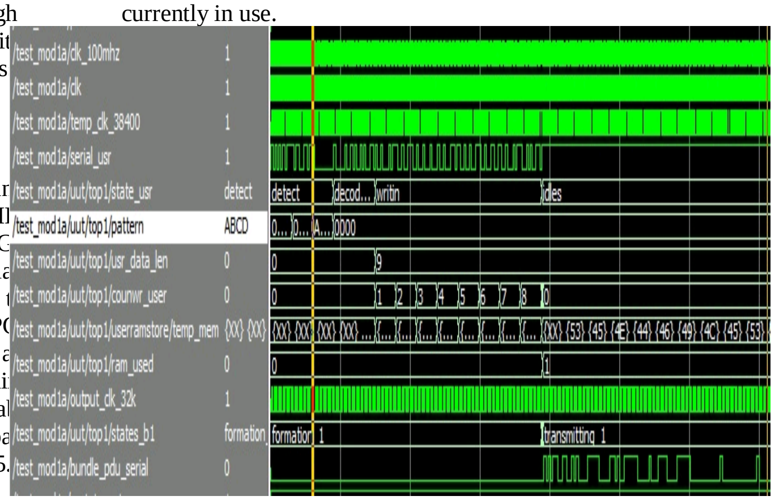


Figure 6: Simulation result showing DTN Transmitter node sending bundle header and user data from application

The orbiter stores in its memory as shown in figure 7, the bundle received from sending DTN node of either Rover or Earth station and delivers it to the destination DTN node. Only the required amount of memory is written, rest is left unused (denoted by XX).

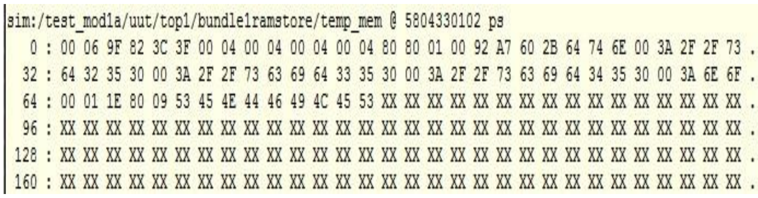


Figure 7: Persistent storage at Orbiter

The receiver DTN node decodes the bundle received (serial_in_line signal in figure8) and determines if the bundle is destined for itself or not. If the bundle's destination id matches with the receiving DTN node id, then it extracts the user data and delivers it to the receiving application using uart transmission (shown by signal uart_tx_out) as shown in figure 8. The destination, source, report-to and custodian EIDs pointing to offset values in dictionary byte array are also shown in fig 8 below.

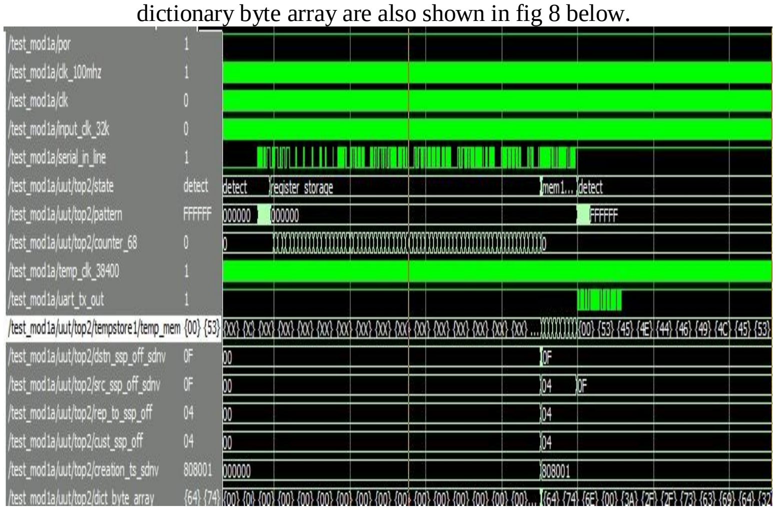


Figure 8: Simulation result showing DTN Receiver node delivering user data to application

DTN receiver module generates administrative record with respect to the bundle it has received like for example bundle recived ,bundle custody accepted if it has sufficient amount of memory to store incoming bundle, bundle deleted status report for a reason like lifetime expired, for congestion control etc. In this way with the help of bundle status report and custody signals, the status of the bundle in the network can be known at any point of time. Thus providing a fool proof mechanism.

Fig. 9 shows that with respect to fields that uniquely identify bundle like creation timestamp, sequence number, source eid a bundle status report is generated. Like in this case it is bundle received and custody accepted while the other status reports remain low. Also SDNV value of report to eid offset value within dictionary byte array(containing all DTN EIDs) becomes the destination of this status report.

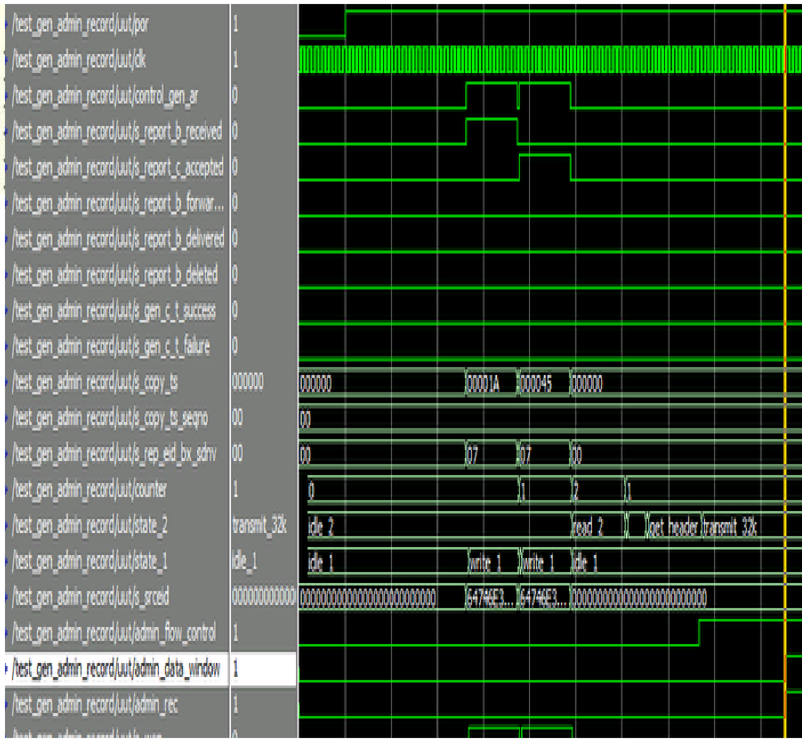


Figure 9: Simulation result showing DTN Receiver node generating bundle received and custody accepted status report

6. Conclusion

A network tolerant to delay and disruption suitable for space as proposed by CCSDS has been designed and tested on Xilinx vertex 4 FPGA. This FPGA is the commercial equivalent of the space qualified FPGA. The efficiency of the design will ensure the best possible resource utilization without compromising the performance. The proposed design works well in the presence of long time scale delays because of persistent storage and custody based retransmission method which was adopted. Hence even in case of "Challenged Internet" in areas with high error rates, disrupted environments and power and memory constraints efficient communication can take place with the design of bundle protocol and DTN architecture discussed in this paper.

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