Delay Tolerant Network (DTN) for Flexible Communication with Earth Observation (EO) Satellites – Study Results

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Study Goals

Earth Observation Missions are particularly data rich and require powerful antennas to transmit their high-bandwidth products. More data transfer means better images or exchange of information in important moments, e.g. for contingency.

The goal of this study is to analyse the impact that a Delay Tolerant Networks on spacecraft communication, particularly for Earth Observation Missions, and to provide recommendations for future use in upcoming spacecraft and mission control systems.

Identifying Communication Patterns

Once the scenarios to investigate were defined, the communication patterns were analysed in order to identify under-utilised communication bandwidth that could be used for DTN based communication, possibly as non-guaranteed service.

Various such communication windows were identified and are shown on the bottom left of this page.

Building a Simulator for Scenarios

The simulator consists of thin virtual machines and a highly configurable virtual network that can simulate the needed network coditions.

The simulator is utilising Virtual Bricks, a frontend for controlling QEMU/KVM virtual machines, which allows creating a large number of such machines on a single host.

By using its scripting capability, a scenario definition format was defined to set up the simulator environment for the respective scenarios.

Analysing the Effects and Benefits of DTN

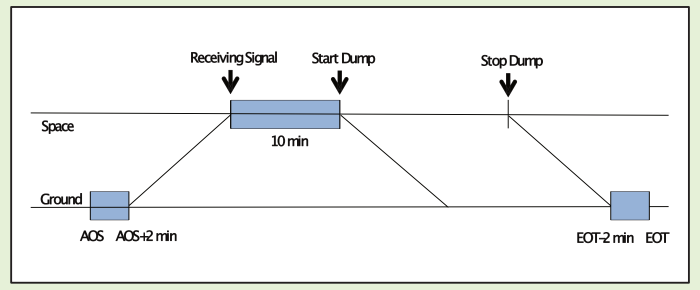
Based on the scenario definition, simulations were run with different modifiers, such as visibility durations, variations of network throughput and reliability of the space links.

The results and conclusion of the study are shown on the right hand side of this page and summarise the impact and benefit that DTN could have when used more extensively.

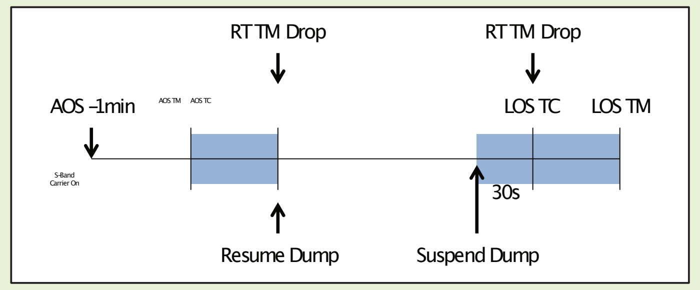
Finally, a set of proposed requirements has been created, which will be a valuable input for the design of future missions.

Spare Capacity Modeling

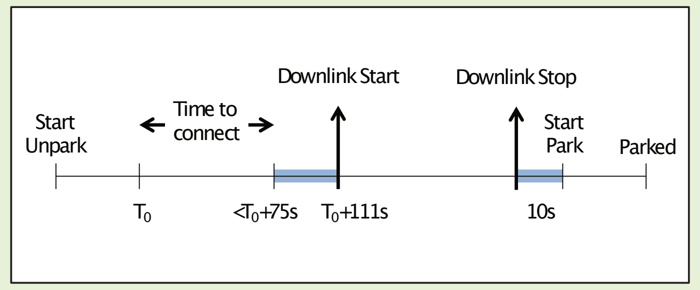
Conventional space craft communication is designed for the highest availability and is dimensioned conservatively, because mission critical systems are at play. With the scenarios investigated as part of this project, we explore alternative means to utilise those safety margins, in which communication *may* not be reliable, but can be used for optional DTN-based transmissions that improve overall service if they are successful.



Deep Space Pass Characteristics



Low Earth Orbit Pass Characteristic



EDRS Laser Link Characteristic

All buffer times are shown in the diagrams on the left in blue and are attempted to be used as "non-guaranteed service".

Deep Space Missions

Deep space missions have particularly long buffers, as the signal is traveling particularly far and the communication is established during a quick approach. While the link may not be 100% reliable, any additional data transmitted is beneficial for the mission.

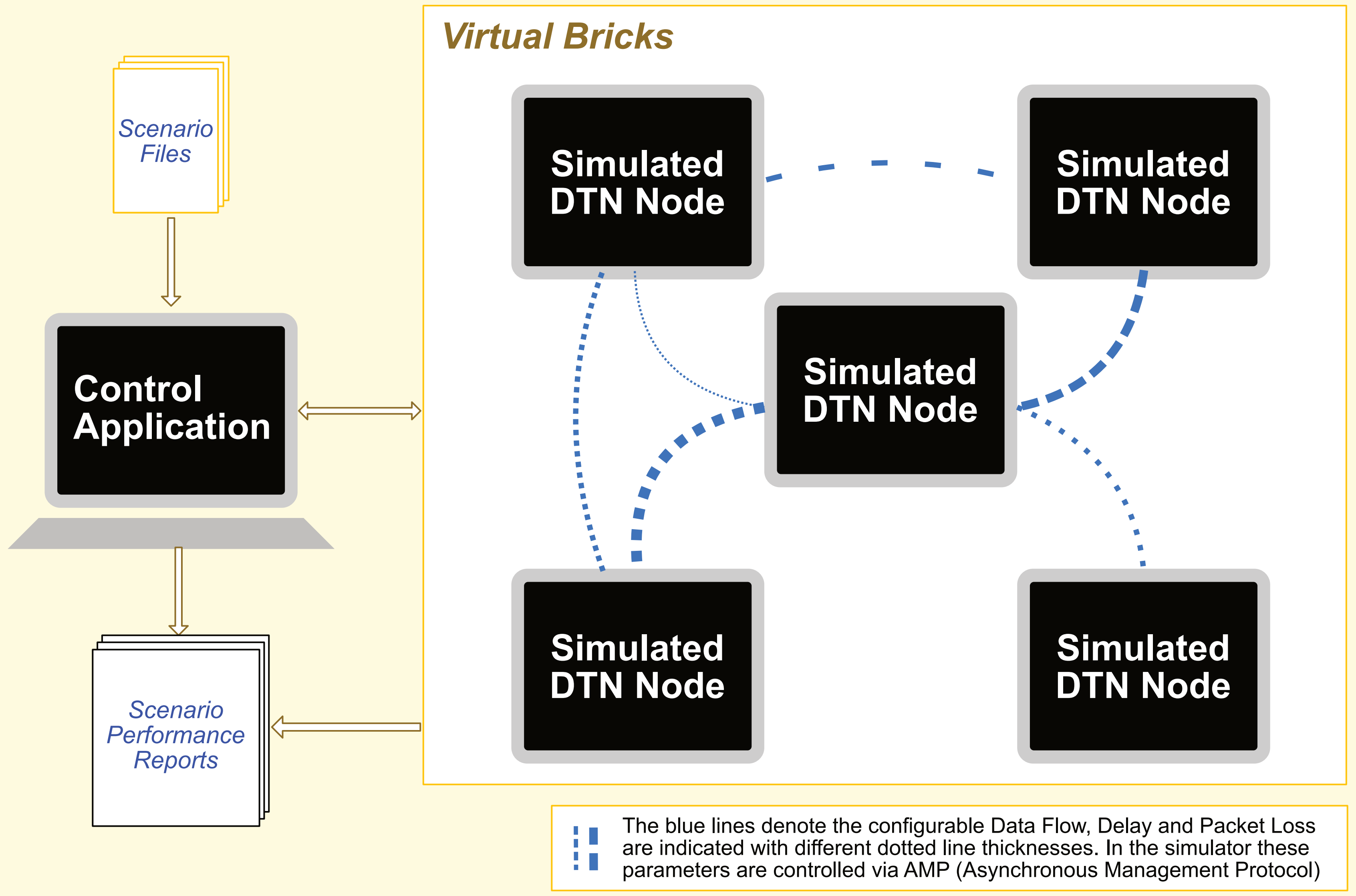
Low Earth Orbit (LEO) Missions

LEO satellites have shorter buffers but a much higher number of passes during the day. Additionally, some LEO missions have multi-station passes with buffer periods during station handovers, which were also targeted for DTN use.

EDRS Laser Link

The EDRS Laser Link is a special case, as the buffer is used to establish the communication via optical link. Usually the connection is established before the buffer passes, and is thus a target for DTN use.

Scenario Simulator



Based on Scenario Files, network links and DTN nodes are configured in the virtual environment *Virtual Bricks*.

Each node is represented as very slim virtual machine, allowing to simulate a large number of nodes.

These DTN nodes are used to simulate spacecraft, ground stations and other network elements

The simulated network can be adjusted for delayed transmissions, specific availability time windows, lossy transmission and unidirectional transfer.

Characteristics of space or ground links, redundant connections and packet loss can be simulated.

Based on the scenarios and communication time windows for typical missions, a series of scenarios and their resulting data link utilisation have been simulated, optimised and recorded. The obtained results are presented on the right.

Conclusion and Results

The following description of the results is based on the final report of the study. Further information and a deeper level of explanations can be found in that document. The results are presented based on the simulations carried out for the tested scenarios.

By using DTN nodes at the various network endpoints (satellites, ground stations, relays), the overall daily data throughput could be increased measurably. This is particularly due to the *Store and Forward* nature of DTN combined with its routing abilities.

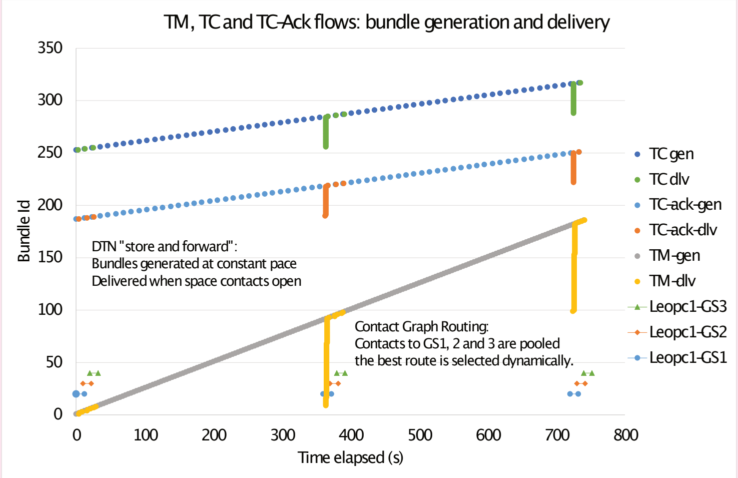
Additionally, Packet Prioritisation that is available in DTN could be used for *Emergency Communication*, which would allow sending pertinent information when it's needed most.

Telemetry and Commanding Data

A continuous stream of telemetry (TM) and commanding (TC) data was generated and transmitted via the DTN "Bundle Protocol".

The graph on the right shows the continuously increasing lines with the generated data packets for TM and TC.

When a visibility window was available, the data was transmitted to the simulated satellite or ground station.

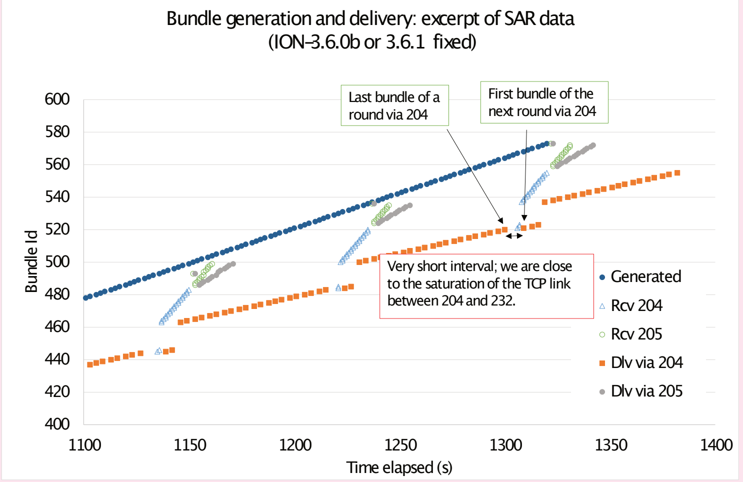


Because the transmission rate is generally higher than the commanding rate or the rate of telemetry generation, the connection could catch up and transmit a larger portion of data to the respective destinations than would be possible over conventional protocols.

Payload Data Throughput

Because Payload data requires a very high data throughput, the ability of DTN and its implementation ION-DTN to handle such data rates was verified as well.

During the study a bug has been found and fixed by the project team in ION-DTN, which caused problems with very high data rates (> 400MBit/s). The graph on the right shows a close-up of a payload transmission test, which comes very close to saturating the simulator's TCP network link after the fix was applied.



Recommendations

With the simulations carried out in this project, a wide range of expectations has been verified and validated, demonstrating that DTN is in fact a versatile network layer, which allows an efficient use over standard TCP networks and space links alike. Particularly its *Store and Forward* nature allows an efficient utilisation of visibility windows, even if those are not overlapping.

As part of this study, we have also analysed the requirements of integrating DTN into existing and future missions and mission control systems. In order to reap the most benefit from the use of DTN, as many of the network nodes should be capable of DTN-based communication. When this condition is a given, all of the strengths presented in this study can play out. For the use case of telemetry and commanding, bi-directional links are also must-haves for an improvement in availability, redundancy and response time.

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