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Contact Graph Routing Enhancements for Delay Tolerant Space Communications

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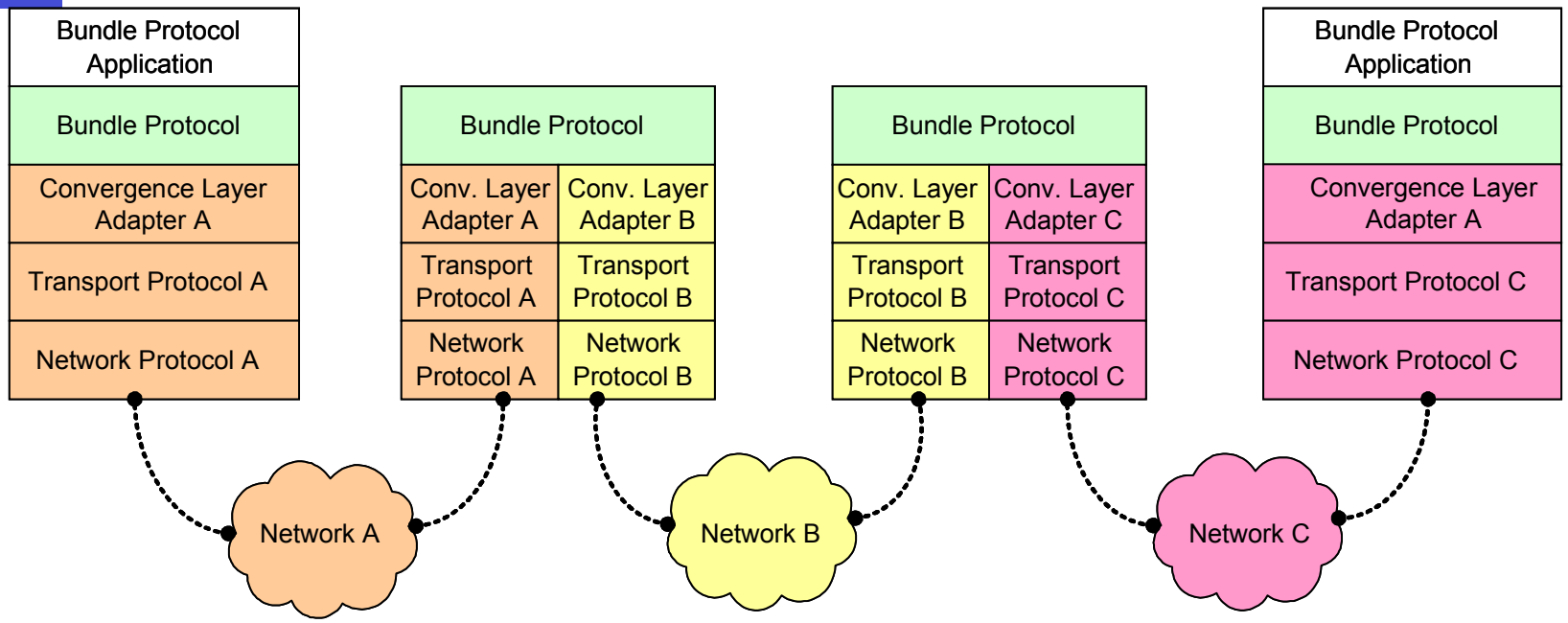
Introduction

- We present two enhancements to Contact Graph Routing (CGR), the DTN routing algorithm developed by NASA JPL for space environments with deterministic connectivity.
- CGR-ETO (developed by SPICE) aims to improve the accuracy of predicted bundle delivery time by considering the available information on queueing delay.
- Overbooking Management (developed by Unibo) aims to proactively handle contact oversubscription, which may occur in the presence of traffic of different priorities.
- The two enhancements are complementary and can significantly improve routing decisions.
- Thanks to the on going SPICE-Unibo collaboration, they have been jointly refined and merged in a common code submitted to NASA for possible inclusion in future CGR implementations.

DTN Bundle protocol architecture

- Based on the introduction of the new bundle layer (usually) between transport and application
  - "bundles" (large data packets) are exchanged between DTN nodes (store-and-forward)
- DTN as an overlay
  - the end-to-end path is divided into multiple DTN hops
  - End-to-end transport is now limited to a DTN hop
  - Possibility to use different Transport protocols on different portion of the network (DTN architecture actually extends satellite PEPs!)
- Storage information at DTN nodes
  - Essential to carry out communication in partitioned or disrupted networks
- Scheduled links
  - Some links may be scheduled, i.e. open and closed at given times, to match intermittent connectivity
  - This feature is essential in our tests

DTN protocol stack



- In our tests we have LTP at Transport because:
  - LTP is rate based; suitable to maximize the link usage efficiency
  - At present scheduled links in ION require LTP (no real choice indeed…)

Contact Graph Routing (CGR)

- DTN routing is more complex than IP routing
  - No assumptions of continuous connectivity between source and destination
    - Links can be intermittent and network partitioned
  - Connectivity can be either random (e.g. in MANET), or deterministic (e.g. deep space and LEO). Different solutions necessary.
- CGR is a DTN dynamic routing algorithm designed by NASA JPL to cope with deterministic intermittent connectivity of space links
  - Suitable also for LEO, because the kind of connectivity is the same
  - It is based on "contact plans", known a priori, informing all nodes of
    - Time availability of a link (contact windows)
    - Tx nominal speed
    - Their product is the "contact volume" (max amount of data that can be transferred)
- CGR is included in ION, the DTN BP implementation by NASA JPL

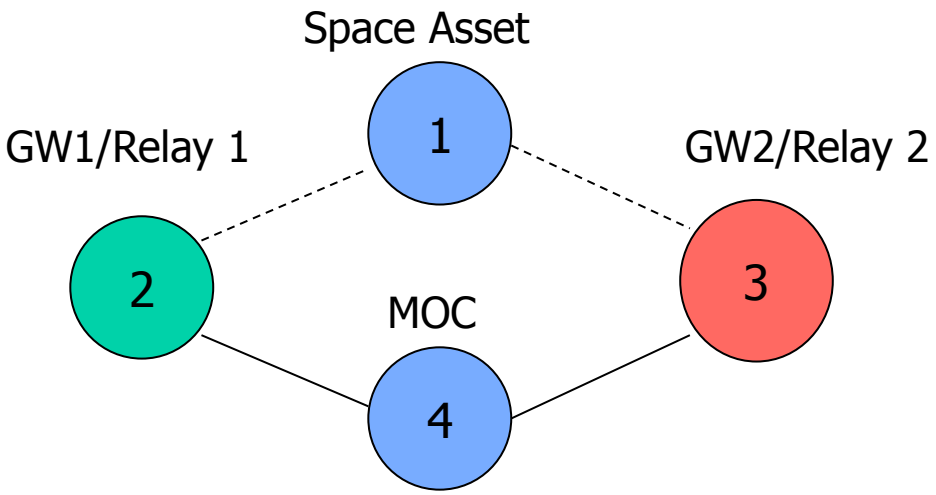
First CGR Enhancement: ETO

- CGR assumes that bundles can be sent at the start of a contact, or, if the contact is already open, immediately.
  - Queueing delay is not considered.
- CGR-ETO (Earliest Transmission Opportunity) uses knowledge of the queues to provide a better estimate of the actual Tx time (and thus of the delivery time).
  - The implemented version makes use of local information only.
- Contact start time is replaced by ETO which includes the expected queuing delay.
  - Different values for each level of priority: bulk, standard, expedited (including the 255 ordinal extended class-of-service levels present in ION).
- Advantages
  - Shorter delivery time
  - Load balancing

SECOND CGR ENHANCEMENT: "OVERBOOKING MANAGEMENT"

- To enforce priorities, contact "overbooking" (or more formally, "oversubscription") is allowed in CGR.
  - During the "residual volume" computation, candidate routes with an earlier delivery time are not discarded when "fully booked" by lower priority bundles.
  - As a result of overbooking, some low priority bundles forwarded to the neighboring node x (i.e. put in the queue to node x) will "miss" their contact, because some higher priority bundles have taken their "seats".
- Our proposal aims to improve the way overbooking is handled by CGR moving from "a posteriori" to "a priori" scheme
  - At present bundles that miss their contact because of overbooking are reforwarded "a posteriori", i.e. only once the forfeit time of these bundles expires (typically at contact end-time).
  - we suggest that they be reforwarded "a priori", before they miss their contact, *i.e.* immediately after forwarding the higher priority bundle that has caused the overbooking..

Scenario considered in the experiemnts: network topology

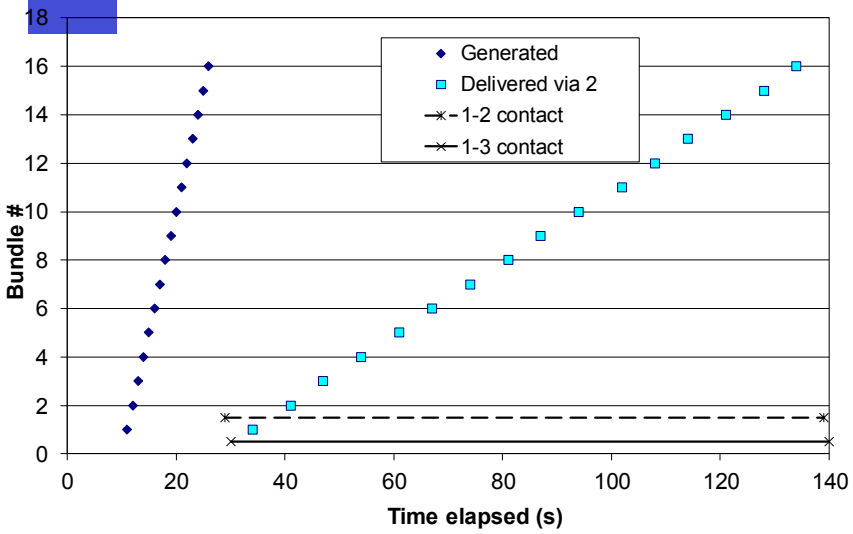


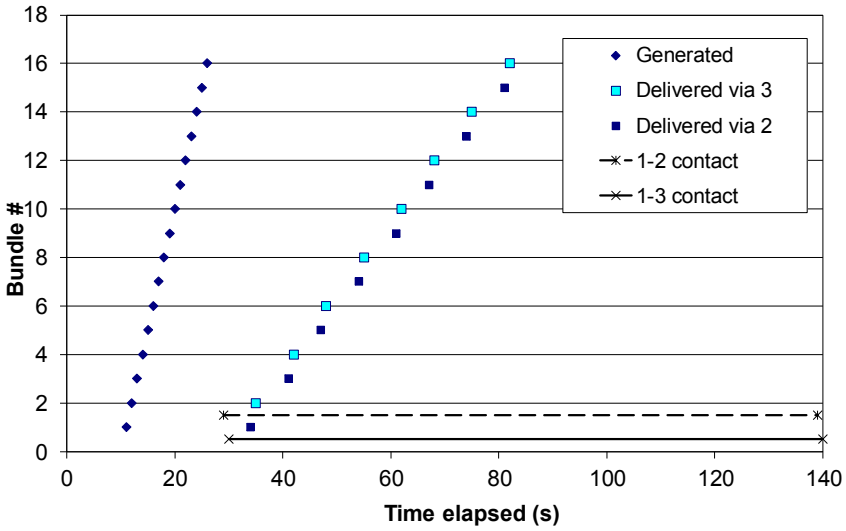
Default contact plan

Link	*Contact#*	*Start-stop time (s)*	*Tx rate*	*Contact Volume*
1-2	1	60-80	512kbit/s	1.28 MB (11.9 bundles)
1-3	1	30-90	128kbit/s	960 kB (8.9 bundles)
1-3	2	105-135	128kbit/s	480 kB (4.4 bundles)
3-4 & 2-4	Dummy (cont.)	1-200	10Mbit/s	

- Space links are intermittent
  - LTP, dotted lines
- Terrestrial links continous
  - TCP, continous lines
- The task of CGR is to find the optimal path from 1 to 4.
  - the best route may vary from bundle to bundle because of space link intermittency.

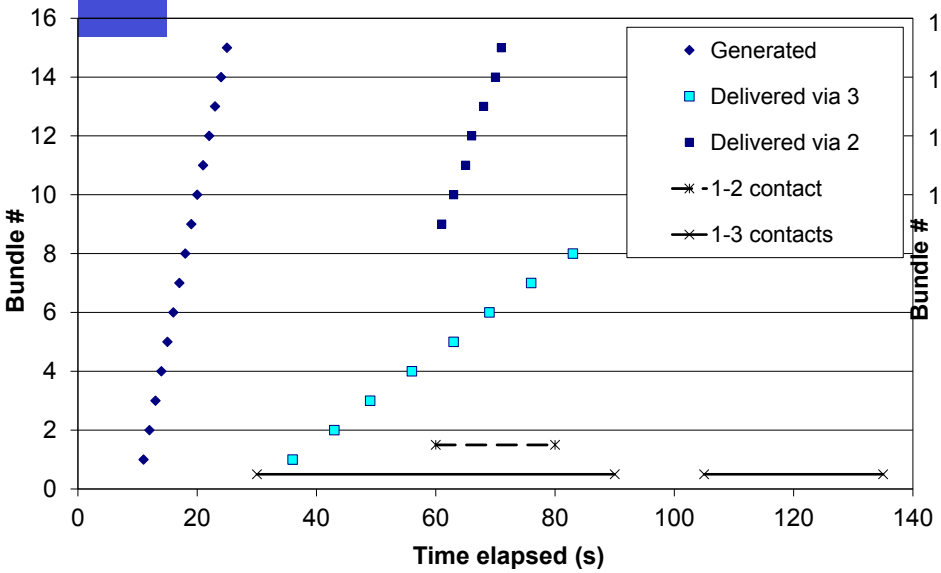
Parallel equivalent routes:
delivery time and load balancing in standard CGR and CGR-ETO

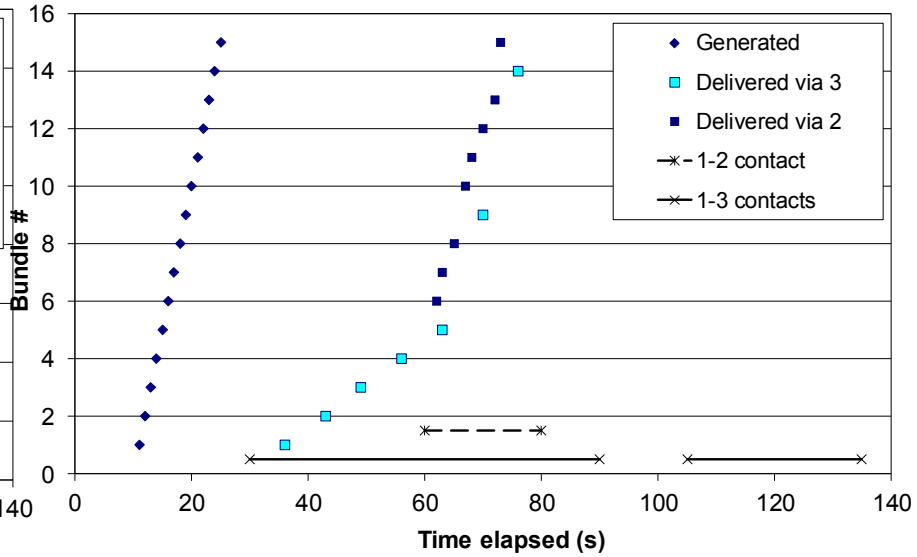




- Non default contacts: here 1-2 and 1-3 contacts are equivalent, but 1-2 starts 1 s in advance.
- Standard CGR
  - All bundles delivered via 2 because 1-2 contact starts first.
- CGR-ETO
  - Bundles alternately delivered via 2 or 3.
- Advantages
  - Shorter delivery time
  - Perfect load balancing

Routing bundle traffic of the same priority: CGR-ETO improvements.

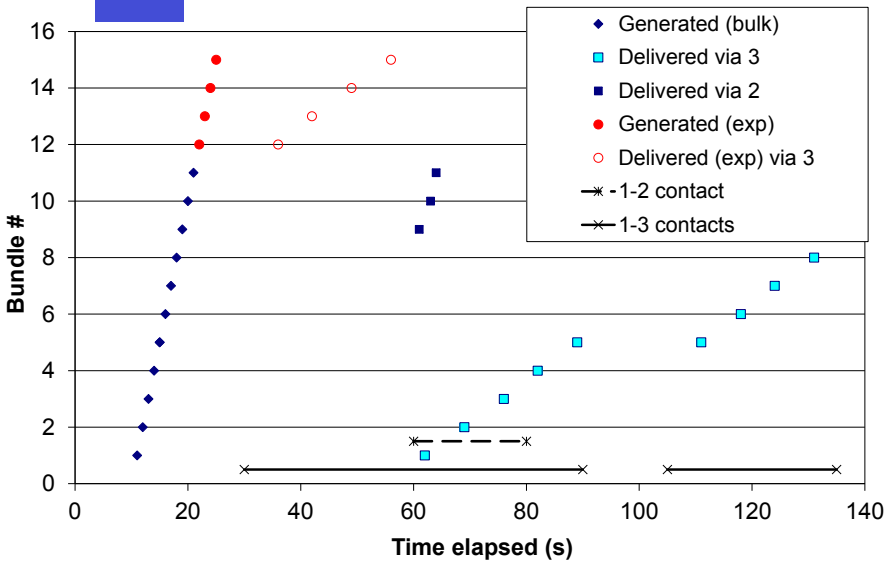


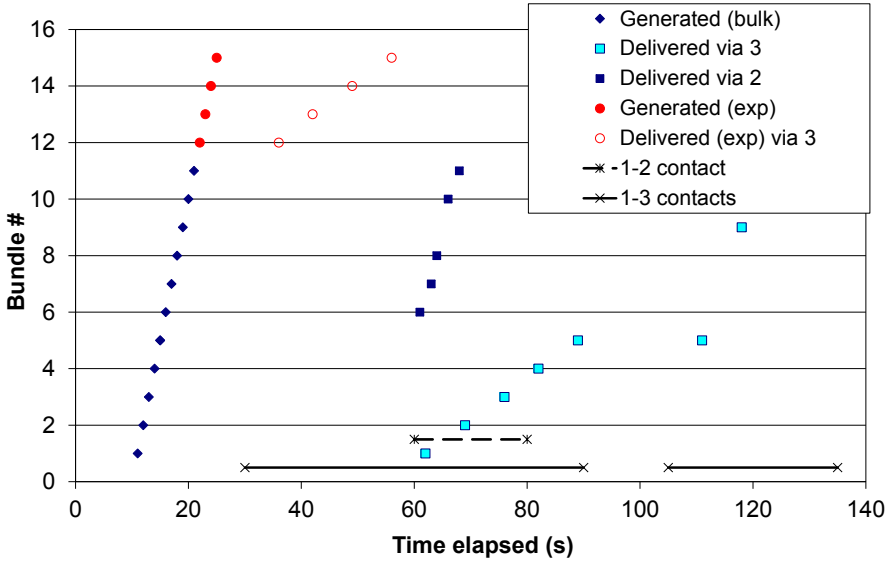


- Default contacts
- Standard CGR
  - First 8 bundles via 3 (because 1-3 contact starts first)
  - Other 7 bundles via 2 (once the first 1-3 contact is "fully booked")

- CGR-ETO
  - Bundles delivered either via 2 or 3.
- Advantages
  - Much more ordered delivery
  - Shorter delivery time
  - Load balancing when both contacts active

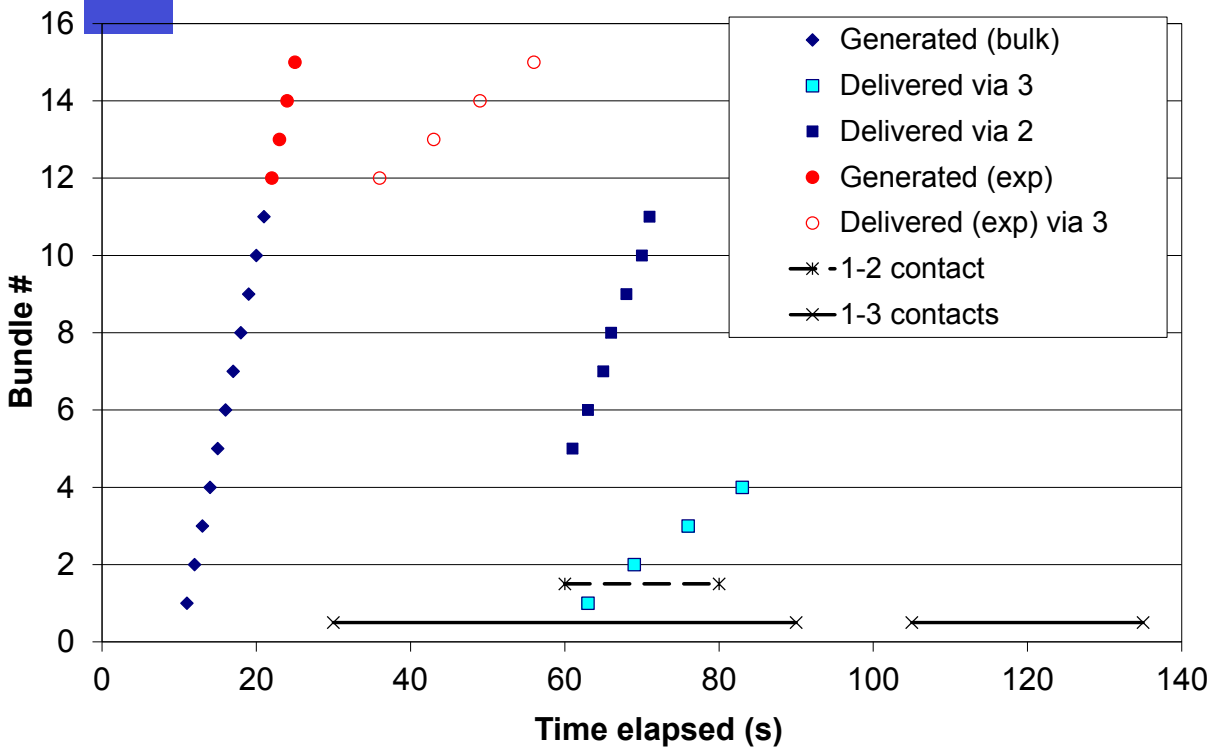
Routing bundle traffic of different priorities: The "Overbooking" problem.



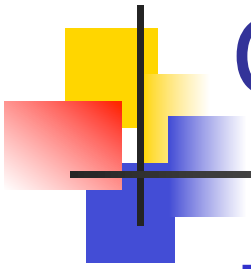


- Standard CGR
  - Expedited bundles delivered first (via 2) although generated last
  - Bundles 1-5 scheduled via 2 delayed
  - Bundles 6-8 scheduled via 2 reforw. because of overbooking
  - Bundles 9-11 via 3 unaltered.
- CGR-ETO
  - Bundles delivered via 2 or 3.
- Advantages
  - Only bundle 9 reforwarded
  - Shorter delivery time
  - Load balancing when both contacts active

Routing bundle traffic of the same priority: CGR-ETO improvements.



- CGR Overbooking management.
  - As before bundles 1-4 are just delayed.
  - Now bundles 5-8, first forwarded to 3, are reforwarded to 2 immediately after the insertion of expedited bundles.
- Advantages
  - No bundles on the second contact to 3.
  - Much shorter delivery time



Conclusions

- Two CGR enhancements, ETO and Overbooking Management, presented and jointly evaluated by SPICE and Unibo on GNU/Linux testbeds.
  - CGR-ETO exploits queue information to offer a shorter delivery time and better load balancing.
  - Overbooking Management improves performance in the presence of different priority traffic.
- The two enhancements complement each other and their use can significantly improve CGR performance.
- Merged in a common code submitted to NASA.