# Multi-Attribute Decision Making Routing Strategy for Interplanetary Communications

Igor Bisio and and Mario Marchese
Department of Communication, Computer and System Sciences, University of Genoa
Via Opera Pia 13, 16145, Genoa, Italy
{igor.bisio, mario.marchese }@unige.it

Tomaso de Cola
DLR- German Aerospace Center
Institute for Communications and Navigation
82234 Wessling, Germany
tomaso.decola@dlr.de

*Abstract* — **As current Internet frontiers are rapidly extending towards space, the scientific community's interest is increasingly addressed to next-generation network architectures suited to enable data communications over interplanetary networks. In this light, given the networking and communication challenges posed by such environments, the design of complex telecommunication infrastructures deserves particular attention, especially with regard to routing and congestion control strategies. To this end, this paper proposes a *congestion-aware routing* paradigm that applies Multi Attribute Decision Making (MADM) concepts for next-hop selection, by formulating an optimisation problem and proposing some possible resolution criteria. Effectiveness of the proposed solutions is assessed through a preliminary performance analysis that shows promising results.**

*Index Terms* – **Interplanetary Networks, Congestion Control, Next-Hop selection, Delay Tolerant Network architecture.**

## I. Introduction

OVER the last years, the interest for space networking has fostered the study and the design of novel transmission paradigms, tailored to the harsh communication conditions experienced in this environment [1]. In particular, the performance limitations shown by TCP-based protocols over interplanetary networks in consequence of large propagation delays as well as consistent information losses opened the doors to the design of more effective protocol architectures [2]. In more detail, particular effort has been made by standardisation bodies such as the Consultative Committee for Space Data Systems (CCSDS) and the Delay Tolerant Networking working group within the Internet Research Task Force (IRTF). The former developed a full protocol stack, alternative to the TCP/IP Suite, specifying protocol layers, from the application downwards to the physical, more appropriate to the deep space peculiarities [3]. The latter has devised an overlay network architecture named Delay Tolerant Architecture (DTN), working over the transport layer and able to tolerate frequent link disruptions and long delays, owing to the advanced networking features offered by the Bundle Protocol [4].

In spite of the relevant efforts made by the scientific community, some research areas are still only partially explored. In more detail, some attention has to be drawn to the performance issues related to the transport layer, in terms of recovery procedures and congestion control schemes. In fact, several proposals attempting to address reliability issues have been worked out recently. Akyildiz *et al.* [5] developed TP-PLANET, a new transport protocol, building on Additive Increase Multiple Decrease concepts, able to cope with blackout events by taking advantage of probing packets. The proposal, though promising, basically implements a feedback control system and, consequently, requires a return link for acknowledgement transportation. In turn, the case of unavailable return links is addressed in [6], where reliability of communication is ensured by using appropriate erasure codes. Yet, Modiano *et al.* [7] approach the problem through a Dynamic Programming formulation, finalised to minimize data transfer time or power consumption, alternatively.

On the contrary, the study of congestion control over deep space networks has received less attention by the scientific community. Burleigh *et al.* [8] investigated the problem of congestion events occurring at deep space gateways and proposed a call-admission-control scheme, relying upon economics concepts. Marano *et al.* [9] designed a hop-by-hop flow control scheme for Delay Tolerant Network architectures. Interestingly, Fall *et al.* [10] propose an extension of Delay Tolerant Network architecture paradigm to cope with congestion events in wireless networks suffering from frequent link disruptions. In more detail, the authors argue that congestion events can be efficiently managed also in case of link disruptions by performing an effective storage routing, which actually consists in selecting the best next-hop to which forward messages, according to the weighted sum of different performance metrics (e.g., normalised transmission delay and power consumption). Although the environment analysed in [10] shows physical peculiarities that differ from those commonly experienced in an interplanetary scenario, explored in this paper, the idea of next-hop selection is very attracting indeed. In fact, the need for optimising different performance indicators (i.e., message completion rate, data transfer time and power consumption) at the same time, suggests to introduce a vector-optimisation problem that builds on Multi Attribute Decision Making (MADM) concepts [11]. In this light, this work explores the potentials of MADM methodology for performing next-hop selection over congested deep space networks previously employed in the Satellite Sensor Networks scenarios [12]. Hence, the major contribution of this work is to extend the features offered by

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the Delay Tolerant Network architecture, here taken as reference, by implementing advanced next-hop selection schemes aimed at guaranteeing high performance, through a multi-attribute optimisation strategy.

The remainder of this paper is structured as follows. Section II introduces the general framework, by giving an overview of the protocol architecture and the reference scenario [13] considered in this work. Section III considers the general system model and the mathematical formulation of next-hop selection based upon MADM strategy. A preliminary performance analysis of the proposed solutions is given in Section IV, while discussion of results and final remarks are drawn in Section V.

## II. General Framework

### A. Delay Tolerant Network (DTN) architecture

This work takes as reference the Delay Tolerant Network architecture [4] for its robustness against link disruptions owing to the advanced recovery capabilities of the Bundle Protocol in terms of store/forward operations and retransmission procedures. In more detail, the Delay Tolerant Network architecture basically consists in the Bundle Protocol layer implemented under the application layer and running directly over transport, network or even datalink layers. Actually, it fragments messages coming from the application layer (where present) into smaller units, commonly referred to as *bundles*. It provides a number of advanced networking capabilities, useful to improve performance in harsh environments, such as interplanetary networks and very sparse MANETs. In fact, it implements the custodial transfer option that allows suspending and resuming data transfer sessions, thus applying store-carry-forward concepts. Furthermore, it offers also other facilities in terms of administrative notifications (*reports*) that help find out the network state on the basis of the number of successful bundle transmissions.

In this work, we assume that the Bundle Protocol Layer lies directly over the datalink layer, implementing the Licklider Transmission Protocol (LTP), detailed in next section along with the rest of the protocol stack. Moreover, we assume that custodial transfer option is not enabled, and, consequently, communication reliability is ensured by proper mechanisms implemented at the underlying layers.

### B. Licklider Transmission Protocol and Physical Layer Protocols

The Licklider Transmission Protocol (LTP) [14] is a point-to-point protocol basically implemented at the datalink layer and responsible for reliably transferring data over deep space links. To this end, it implements a recovery procedure, essentially consisting in Selective-ARQ strategy, which allows retransmitting all the LTP units (hereafter *packets*) missing at the destination. In more detail, depending on the transferred content, the transmitted packets can be classified into either red or green information blocks. In case of green flag, the corresponding packets are not expected to be retransmitted in case of loss: this approach is pursued for transfer of data that 1) exhibit some information loss tolerance or 2) require high priority forwarding. On the other hand, the presence of red flag indicates that specific reliability constraints have to be matched; hence, selective retransmission of missing packets will be performed upon information loss detection. In this work, the only case of red-flagged packets is considered in order to evaluate the impact of lengthy retransmission cycles on the overall system performance.

As far as physical layer protocols are concerned, it is necessary to distinguish between deep space and proximity links: the former allow data communications between nodes that are very far apart and experience a propagation delay as high as several seconds (e.g., case of cislunar operations). The latter are commonly established between nodes that are in proximity one with another and whose propagation delay is below the second (e.g., case of satellite communications). On the basis of this differentiation, two protocol choices have been performed: in the case of deep space links, the CCSDS Telemetry/Telecommand Protocols (TC/TM) [3] have been taken as reference, whereas the CCSDS Proximity-1 Link Protocol [3] has been considered for the case of proximity links.

### C. Reference Scenario

The scenario considered in this work (depicted in Fig. 1) refers to complex interplanetary network constellations [13], composed of two main portions: planetary (placed on the corners of Fig. 1) and backbone (centre of Fig. 1) regions. In more detail, on the one hand, each planetary region is composed of several planetary nodes (white circles) that can work as both traffic source and destination nodes. On the other hand, the backbone region is composed of several interplanetary nodes (black circles), serving as relay nodes, connected one with another through a mesh topology. Finally, the planetary regions are connected one with another through specialised gateway nodes (grey nodes), which are responsible for forwarding data towards destination through the backbone region.

For the sake of exemplification, Fig.1 reports the case of 4 planetary regions, composed of two planetary nodes. In particular, nodes 0, 9, and 10 are assumed as traffic source nodes, nodes 1, 4, and 6, as destination nodes, whereas nodes 3 and 7 can both transmit and receive data. Finally, nodes from 12 to 17 belong to the backbone region, whereas nodes 2, 5, 8, and 11 are gateway nodes.

As far as the protocol stack of each node is concerned, a full DTN architecture working over LTP protocol is assumed in this work, as detailed in Section II-B. On the one hand, LTP will be responsible for point-to point retransmission procedures that will take place upon packet loss detection; on the other hand, the Bundle Protocol will take care of storing and forwarding data amongst regions. In this light, the role played by the Bundle Layer buffer is topical to achieving high performance in terms of data communication reliability. In fact, being routing operations performed at this layer, the buffer occupancy is key factor influencing the overall performance. On the one hand, saturation of buffers may cause long data queuing times and, lastly, loss of bundles, thus leading to an increase of the overall data transfer time. On the other hand, we argue that a reactive management of congestion events is not applicable in the context of interplanetary networks because of the large latencies that imply much delayed congestion control decisions. In this light, to overcome the limitations of a reactive management, this work, instead, proposes a proactive strategy founded on a next-hop selection problem, which aims at optimising both routing and congestion control.

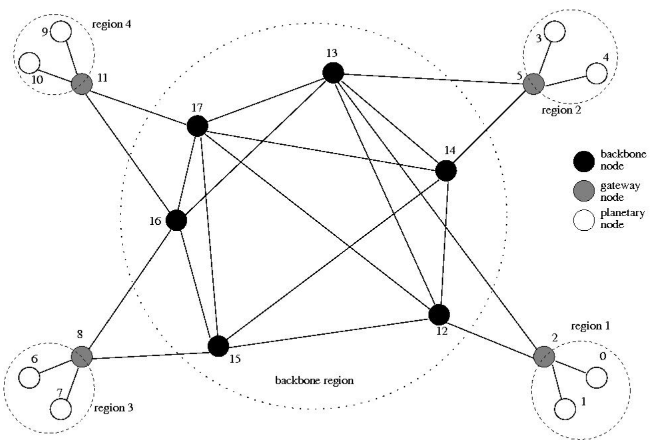


Fig. 1. The reference scenario

## III. THE NEXT-HOP SELECTION PROBLEM

As pointed out in Section II-C, the overall system performance is strictly dependent on effective management of Bundle Layer buffers. To this end, a congestion-aware routing algorithm has been formally defined by exploiting the features of Multi Attribute Decision Making theory. In more detail, the proposed algorithm performs, for each queued bundle, a next-hop selection aimed at computing the best path on the basis of performance metrics. Essentially, the decision is taken hop by hop and indicators of node congestion level such as bundle layer buffer occupancy and bandwidth availability are considered to select the node to which information has to be forwarded.

### *A. The MADM Approach*

The aim of the proposed approach is to select the Next-Node towards which bundles have to be forwarded. The decision is performed by virtual entities called Decision Makers (DMs), implemented within each node.

Let $DM^{(n)}$ denote the Decision Maker for node *n*. It selects the Next-Hop to which the bundles stored at a given time instant by node *n* have to be forwarded. The selection process is implemented periodically, in order to track interplanetary network dynamics, and, consequently, to adapt the routing strategies.

Let $T_{D,h}^{(n)}, n \in [1,N], h \in \mathbb{N}$ denote the selection period, where the decision is valid for the overall length of the *h-th* decision period for node *n*, which is kept fixed $\forall h, \forall n$ in this paper. Upon decision performing, the forwarding strategy is applied to the bundles scheduled for transmission. In practice, within each $T_{D,h}^{(n)}$ period, the nodes neighbours to node *n*, notify it about their congestion levels in terms of proper metrics, suited to the decision process that can be defined in dependence on the Quality of Service requirement of the network. It is immediate to point out that a proper tuning of the period $T_{D,h}^{(n)}, n \in [1,N]$ would be beneficial to the overall performance in order to take into account the large propagation delays experienced by interplanetary networks as well as sudden traffic changes. The trade-off between traffic interference and fast reaction to traffic changes is not reported here for the sake of brevity and will be the object of future performance evaluation.

Being the mentioned metrics possibly in contrast each other (i.e., increasing one may imply decreasing another), the selection algorithm is conveniently based on the *Multi Attribute Decision Making* (MADM) [11]. Let index $k \in [1,K]$ identify the metrics (e.g., bundle layer buffer occupancy, bandwidth availability), $j \in [1,J]$ any possible Next-Hop (selection *alternatives*) for a generic node *n* (where the decision algorithm is being applied).

Let each $DM^{(n)}$ be characterised by a decision matrix: $\hat{X}_{jk}^{n}(t)$ is the value of the metric *k* measured at the time instant $t$ for the node *n* when Next-Hop *j* is used.

Let $X_{jk}^{n}(t) = \hat{X}_{jk}^{n}(t) / \max_{j} \hat{X}_{jk}^{n}(t)$ be the normalized metric (*attribute* hereafter) over its maximum measured value.

From this formulation, it is immediate to see that for $DM^{(n)}, \forall n \in [1,N]$, the vector containing the attributes related to Next-Hop *j*, at the time instant $t$, is:

$$\left[ X_{j1}^{n}, ..., X_{jk}^{n}, ..., X_{jK}^{n} \right] \quad (1)$$

Hence, the matrix $J \times K$ of the attributes for $DM^{(n)}$ at the time $t$ for all possible $J$ alternatives is:

$$\begin{bmatrix} X_{11}^{n}, ..., X_{1k}^{n}, ..., X_{1K}^{n} \\ ............................... \\ X_{j1}^{n}, ..., X_{jk}^{n}, ..., X_{jK}^{n} \\ ............................... \\ X_{J1}^{n}, ..., X_{Jk}^{n}, ..., X_{JK}^{n} \end{bmatrix} \quad (2)$$

### *B. The Selection Algorithm*

In this paper, three possible approaches, directly taken from the MADM basic theory, have been proposed and evaluated: Simple Additive Weighting (**SAW**) [11], Minimum Distance with Utopia Point (**MDUP**) [12], and Technique for Order Preference by Similarity to Ideal Solution (**TOPSIS**) [11, 15].

The principle of the **SAW** selection algorithm is to minimize the sum of all the attributes of interest. In practice, amongst the *J* alternatives, the selection algorithm chooses the Next-Hop denoted as $j_{opt}^{n,SAW}(t)$, such as to minimize its distance, in term of Euclidean Norm, from an ideal alternative:

$$j_{opt}^{n,SAW}(t) = \left\{ j^n = \arg\min_{j\in[1,J]} \sum_{k=1}^{K} X_{jk}^n \right\} \quad (3)$$

The **MDUP** selection algorithm is based on the knowledge of the *ideal* alternatives, called *utopia point*, characterized by the *utopia vector* of attributes at the time instant $t$, defined in (4), where the superscript *id* stands for *ideal*:

$$\left[ {}^{id}X_1^n, \ldots, {}^{id}X_k^n, \ldots, {}^{id}X_K^n \right] \quad (4)$$

where each component is given by:

$${}^{id}X_k^n = \left\{ \begin{array}{l} X_{jk}^n : j = \arg\min_{j\in[1,J]} X_{jk}^n, \text{ for "cost" metrics} \\ X_{jk}^n : j = \arg\max_{j\in[1,J]} X_{jk}^n, \text{ for "benefit" metrics} \end{array} \right\} \quad (5)$$

In practice, the *utopia vector* defined in (4) and detailed in (5), contains both "cost" (e.g., the bundle layer buffer occupancy) and "benefit" metrics (e.g., the bandwidth availability). To this regard, it is immediate to see that the utopia vector allows to select the best value for each single attribute amongst all the alternatives, by taking the minimum and the maximum of cost and benefit metrics, respectively. More precisely, the Next-Hop selection algorithm chooses the Next-Hop called $j_{opt}^{n,MDUP}(t)$ amongst the *J* alternatives, by minimizing the distance, in term of Euclidean Norm, from the ideal alternative:

$$j_{opt}^{n,MDUP}(t) = \left\{ j^n = \arg\min_{j\in[1,J]} \left[ \sum_{k=1}^{K} \left( X_{jk}^n - {}^{id}X_k^n \right)^2 \right]^{1/2} \right\} \quad (6)$$

The **TOPSIS** selection algorithm extends the concepts applied by the MDUP scheme, by taking advantage of the knowledge of both the *utopia points* defined in (4) and the *nadir points*, which, on the contrary, represent the worst alternatives. Definition of nadir points is given in (7), where superscript *wr* stands for *worst*:

$$\left[ {}^{wr}X_1^n, \ldots, {}^{wr}X_k^n, \ldots, {}^{wr}X_K^n \right] \quad (7)$$

In this case, each component of the vector is:

$${}^{wr}X_k^n = \left\{ \begin{array}{l} X_{jk}^n : j = \arg\max_{j\in[1,J]} X_{jk}^n, \text{ for "cost" metrics} \\ X_{jk}^n : j = \arg\min_{j\in[1,J]} X_{jk}^n, \text{ for "benefit" metrics} \end{array} \right\} \quad (8)$$

Similar considerations drawn for (5) hold also for (8).

The Next-Hop selection algorithm chooses the Next-Hop called $j_{opt}^{n,TOPSIS}(t)$ amongst the *J* alternatives, by minimizing the so called *Similarity to Positive-Ideal Solution* (9):

$$j_{opt}^{n,TOPSIS}(t) = \left\{ j^n = \arg\min_{j\in[1,J]} \frac{S_j^{ng}}{S_j^{ps} + S_j^{ng}} \right\} \quad (9)$$

where:

$$S_j^{ps} = \left[ \sum_{k=1}^{K} \left( X_{jk}^n - {}^{id}X_k^n \right)^2 \right]^{1/2} \quad (10)$$

is the distance, in terms of Euclidean norm, between the alternatives and the utopia point called *Positive Separation* and

$$S_j^{ng} = \left[ \sum_{k=1}^{K} \left( X_{jk}^n - {}^{wr}X_k^n \right)^2 \right]^{1/2} \quad (11)$$

is the distance, in terms of Euclidean norm, between the alternatives and the nadir point called *Negative Separation*.

### C. *The Proposed Solutions*

Although the validity of the mathematical framework is general, in this work the attention has been paid to a reduced set of metrics: *Bundle Buffer Occupancy (BBO)*, *Available Bandwidth (AB)*, and *Transmission Time (TT)*.

The *Bundle Buffer Occupancy* is the ratio between the number of bundles stored in the bundle layer buffer and the maximum size of the buffer itself. $BBO_j^{(n)}(t)$ is the value of this attribute, valid at the time instant *t*, for node *n*, notified from its neighbour *j*. In short, $BBO_j^{(n)}(t) = X_{j1}^{(n)}$ and it represents a "cost" attribute.

*Available Bandwidth (AB)*, is the capacity in [bit/s] available on the links between node *n* and its neighbour *j*. As observed in the previous case: $AB_j^{(n)}(t) = X_{j2}^{(n)}$ but, here, it represents a "benefit" attribute.

Alternatively to *Average Bandwidth*, the *Transmission Time (TT)* attribute can be used. In fact, it is the ratio between the bundle size (expressed in bit) and the link capacity in [bit/s] available in link between node *n* and its neighbour *j*. In this case, we have: $TT_j^{(n)}(t) = X_{j2}^{(n)}$ corresponding to a "cost" attribute.

The corresponding Congestion Aware Routing techniques can then be classified into three main classes:

- **SAW**. They are implemented with $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = AB_j^{(n)}(t)$ (termed ***SAW-BBO-AB***), and $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = TT_j^{(n)}(t)$ (termed ***SAW-BBO-TT***). In addition, also traditional mono-attribute schemes have been evaluated: $X_{j1}^{(n)} = BBO_j^{(n)}(t)$

(termed ***SAW-BBO***) and $X_{j1}^{(n)} = TT_j^{(n)}(t)$ (termed ***SAW-TT***).

- **MDUP**. They are implemented with: $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = AB_j^{(n)}(t)$ (termed ***MDUP-BO-AB***), and $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = TT_j^{(n)}(t)$ (termed ***MDUP-BBO-TT***).
- **TOPSIS**. They are implemented with: $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = AB_j^{(n)}(t)$ (termed ***TOPSIS-BBO-AB***), and $X_{j1}^{(n)} = BBO_j^{(n)}(t)$, $X_{j2}^{(n)} = TT_j^{(n)}(t)$ (termed ***TOPSIS-BBO-TT***).

## IV. Performance Analysis

Evaluation of the presented MADM-based Congestion Aware Routing Techniques has been performed through ns-2, by properly extending the DTN module and implementing the Decision Making entities within the Bundle Protocol layer. In particular, we assumed that operations of attribute notifications amongst node and related neighbours take a time negligible with respect to simulation duration. Moreover, the attribute exchange period $T_{D,h}^{(n)}$ has been kept fixed $\forall n \in [1, N], \forall h \in \mathbb{N}$ and equal to 50 s; therefore, the routing decisions are performed any 50 s and kept fixed during this period. Finally, for the sake of simplicity, the MADM-based routing capabilities have been implemented just on the interplanetary backbone nodes, whereas the other nodes implement static routing schemes. This assumption does not limit the validity of this study because, commonly, nodes either belonging to the planetary regions or serving as gateways implement large storage units, which therefore prevent from congestion events and then make the use of MADM techniques unnecessary.

The performance analysis has been conducted by taking network topology depicted in Fig. 1 as reference. In more detail, the propagation delay amongst interplanetary backbone nodes has been set to 20 s. The (full-duplex) capacities of link connecting backbone and gateway nodes are summarised in Table I (in Kbit/s). Moreover, each node implements a bundle layer buffer size equal to 400 bundles. On the other hand, the propagation delay between planetary nodes and gateway nodes has been set to 0.5 s, whereas the available link capacity to 2 Mbit/s.

Constant Bit Rate (CBR) traffic sources are considered: they are kept active for 150 s of simulation and generate data bundles of 64 Kbytes at rate of 4 bundles/s, yielding 2.048 Kbit/s. Furthermore, the traffic sources have been set on the planetary regions, as already discussed in Section II-A. In particular, nodes 1, 3 and 7 send data encapsulated into Non Custodial Transfer bundles, whereas nodes 0 and 10 generate inject background traffic into the network, in order to assess the robustness of the proposed MADM-based solutions. All the other planetary nodes are set as receivers. Finally, the simulation time has been set to 10000 s.

TABLE I
BACKBONE REGION LINK CAPACITIES [KBIT/S]

| Nodes | 2 | 5 | 8 | 11 | 12 | 13 | 14 | 15 | 16 | 17 |
|---|---|---|---|---|---|---|---|---|---|---|
| **2** | - | - | - | - | 800 | 650 | - | - | - | - |
| **5** | - | - | - | - | - | 650 | 800 | - | - | - |
| **8** | - | - | - | - | - | - | - | 850 | 600 | - |
| **11** | - | - | - | - | - | - | - | - | 780 | 1000 |
| **12** | 800 | - | - | - | - | 700 | 700 | 100 | - | 400 |
| **13** | 650 | 650 | - | - | 700 | - | 400 | - | 400 | 400 |
| **14** | - | 800 | - | - | 700 | 400 | - | 250 | - | 350 |
| **15** | - | - | 850 | - | 100 | - | 250 | - | 200 | 150 |
| **16** | - | - | 600 | 780 | - | 400 | - | 200 | - | 80 |
| **17** | - | - | - | 1000 | 400 | 400 | 350 | 150 | 80 | - |

The performance analysis addressed the performance provided by the whole network. In this light, two metrics have been considered: *Bundle Loss Rate* (**BLR**) and *Data Delivery Time* (**DDT**). The first is defined as ratio between the number of received and of transmitted bundles. It gives a quantitative indication on how effective the considered solution is over the whole interplanetary network. The second accounts for the time interval time required to complete the data delivery to destinations. It gives an indication on how fast the exchange of data was, by taking into account bundle buffer queue traversal times, which can impair the overall performance when congestion events are likely to happen.

It is possible to observe from Fig. 2, reporting the *Bundle Loss Rate* (BLR %) performance that TOPSIS-BBO-TT outperforms the other solutions, achieving a BLR value of 0.06, far below numerical values offered by the other proposals. Also SAW-BBO and MDUP solutions are quite effective and offer satisfactory values of BLR (below 0.08). Finally, SAW-BBO-AB performs poorly, giving rise to a Bundle Loss Rate of about 0.53. On the other hand, as far as *Data Delivery Time* (DDT) is concerned, it can be observed from Fig. 3 that both TOPSIS and MDUP solution offer promising solutions, thus confirming the added-value of a MADM approach. Finally, it is also worth noting that SAW-BBO and SAW-BBO-TT as well offer very satisfactory results; nonetheless, it is important to remark (see Fig. 3) that the reduced delivery time with respect to other solutions is achieved at cost of higher bundle loss rate.

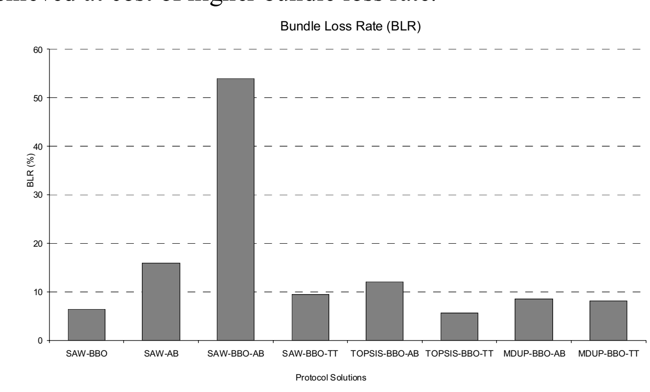


Fig. 2. Bundle Loss Rate performance

## V. Conclusions

This work focused on routing and congestion control issues in interplanetary environments. Taking as reference findings of [10] and features offered by MADM theory [11], two novel classes of solutions named TOPSIS and MDUP have been devised and evaluated through simulative campaigns, by taking into account also traditional techniques relying upon either mono-attribute or attribute weighted sum formulations. The performance analysis showed that TOPSIS and MDUP solutions are really promising, in terms of satisfactory congestion event tolerance and effective routing decisions. In fact, advantages offered by MADM approach are far more evident in the case of TOPSIS implementations (particularly for TOPSIS-BBO-TT), which, on the one hand, achieved very good results in terms of bundle loss rate and data delivery time, and, on the other hand, showed adaptability features against congestion events as well as network state changes.

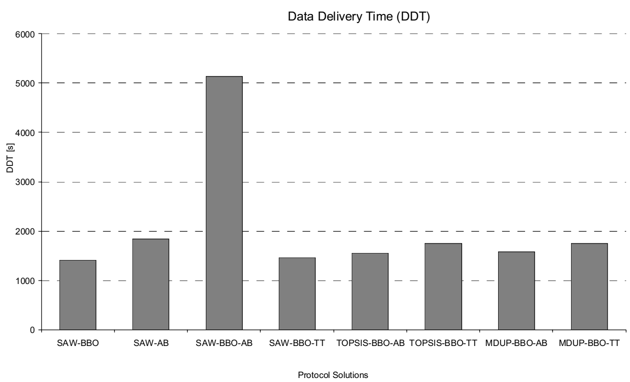

Fig. 3. Data Delivery Time performance

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