QoS-Aware Handover Strategies for Q/V Feeder Links in VHTS Systems

Mario Marchese, Aya Moheddine, Fabio Patrone
University of Genoa, Genoa, Italy
mario.marchese@unige.it, aya.moheddine@edu.unige.it, f.patrone@edu.unige.it

Tomaso de Cola
DLR - German Aerospace Center
Wessling, Germany
tomaso.decola@dlr.de

Maurizio Mongelli
CNR - National Research Council
Genoa, Italy
maurizio.mongelli@ieiit.cnr.it

***Abstract*—Offering very large data rates is one of the main objectives of Very High Throughput Satellite (VHTS) systems to boost enhanced Mobile Broadband (eMBB) services in converged 5G-satellite systems. To this end, the exploitation of Q/V frequency bands for the satellite feeder link is a key factor for guaranteeing unprecedented data rates provided that efficient handover algorithms are implemented to counteract link outage events caused by severe weather impairments. Moreover, Quality of Service (QoS) of data flows is typically affected when gateway handover is initiated, hence calling for sophisticated ground segment management solutions. In this light, this paper proposes a novel gateway handover strategy and validates its design through simulation campaigns, whose preliminary results show important performance gains with respect to other solutions available from the existing literature.**

I. Introduction

The potentials of satellite communications with respect to ubiquitous coverage and intrinsic multicast capabilities have been recognised as pivotal to boost further the penetration of 5G services in many use cases. In particular, quite some attention is currently being dedicated by the ongoing 5G standardisation as part of 3GPP with respect to *Non-Terrestrial Networks* (NTN) [1] in order to specify converged network architectures enabling *enhanced Mobile Broadband* (eMBB) and *massive Machine Type Communication* (mMTC) services. The former results particularly attractive for the multimedia distribution to mobile users, even at very high quality and resolution (e.g., 4k/8k UHD), by exploiting the multicasting capabilities offered by satellite systems [2]. In this context, in spite of the important technology progress made with respect to video compression and edge caching, a major role is played by the data rate offered by the satellite systems in order to meet users' Quality of Experience (QoE) requirements.

The target of providing very high data rate through satellite systems has gained quite some interest in the satellite industry in the last ten years through the concept of *terabit/s satellites* [3], which has pushed the scientific community to investigate new design solutions aimed at supporting the so-called very-high and ultra-high throughput satellite (VHTS, UHTS) systems [4]. To this regard, the main design novelty consists in assigning Ka-band spectrum entirely to the user link, whereas the feeder link will operate in EHF-band (i.e., Q/V, or W) that can offer largely unused spectrum portions. The main technology challenge deriving from this design is that EHF spectrum is heavily affected by water absorption, so that link outage events may occur in case of severe weather conditions. Since satellite operations target availability figures larger than 99.9%, the most suitable approach to mitigate feeder link outage consists in the application of *smart-gateway diversity* (SGD) solutions [5] [6], essentially applying space diversity concepts so that redundant gateways can be coupled to nominal ones and organised in clusters [3]. More specifically, the gateways taking part to the clusters are selected to be at distance sufficient to guarantee rain uncorrelation, which is typically in the order of nearly $100\ km$ at Q/V frequency band. In this respect, the scientific community has dedicated quite some effort in analysing different solutions and proposing optimised network configurations. On the one hand, different studies have focused on the specific clustering configurations in terms of the number of gateways associated to the redundant ones with all the design implications stemming from carrier operations and on-board satellite switching functions [7] [8]. On the other hand, some attention (though minor) has been also dedicated to the handover algorithms to be applied when a feeder link is subject to outage and data flows have to be forwarded to destinations through alternate feeder links [9].

As a matter of fact, the joint dimensioning of gateway cluster along with the definition of proper handover strategies has profound implications in terms of Quality of Service (QoS) management. On the one hand, conservative strategies would consist in early handover procedure initiation to avoid any packet losses due to the outage event, though at the cost of large bandwidth waste. Conversely, more risky approaches target to use the affected feeder link as much as possible in order to exploit the available bandwidth, though incurring in possible packet losses. Moreover, independently of the specific approach being taken, the data flow forwarded on alternate gateways can suffer from additional delivery latency caused by the traffic load spike experience there, whereby more attentive handover and load-balancing strategies should be devised. A partial response to tackle this problem has been given in terms of network coding [10], in order to guarantee efficient use of the available feeder link bandwidth and ensure at the same time

978-1-7281-5089-5/20/$31.00 ©2020 IEEE

satisfactory levels of reliability. The study in [10], however, focused only on the case of two gateways, hence neglecting possible scalability and load-balancing issues appearing in a full satellite network.

In general, a systematic approach towards an effective and flexible QoS management in a comprehensive satellite network is to the best of authors' knowledge still missing. To bridge this gap, the present paper proposes a novel handover strategy able to more efficiently track the feeder link capacity fluctuations due to weather impairments and to implement optimised data flow forwarding between gateways according to the corresponding QoS requirements. To this end, the link prediction schemes elaborated in [11] [12] have been taken as reference and then combined to the smart forwarding concept under an optimisation framework. The proposal has been validated through simulation campaigns and compared to existing solutions available from the literature (e.g., network coding-based and static schemes). The collected preliminary results are quite promising in favour of the proposed solution, although a more refined investigation is still to be completed.

The remainder of this paper is organised as follows. The reference scenario and the system model are provided in Section II. The proposed handover algorithm is illustrated in Section III, where also other candidates solutions taken as benchmark are briefly discussed. Preliminary results of the performance evaluation are then provided in Sections IV, while the final conclusions are drawn in Section V.

II. Aim and Scope

A. Reference Scenario

In this paper, we consider the same reference scenario as in our previous contribution [11], i.e. the star multi-beam multi-gateway satellite network depicted in Figure 1.

Satellite gateways (GWs) are the access nodes to the space segment and are interconnected through a terrestrial infrastructure. Satellite feeder link between a Geostationary (GEO) satellite and the GWs operates in Q/V frequency bands implementing the DVB-S2 technology. A set of Network Control Centers (NCCs), co-located in the GWs, contributes in the network management periodically collecting measured Signal-to-Noise (SNR) values of the feeder links. NCC/GW Manager is in charge of estimating the evolution of each gateway channel's quality and predicting future outage events exploiting the information received from the NCCs. Current and estimated future network status could affect the dynamic GW selection, i.e. the data routing strategy within the ground segment, in order to better exploit the available network resources.

The Software Defined Networking (SDN) concept [13] helps achieve this task allowing to dynamically set up different routing paths for different traffic flows. A central entity, called SDN controller, canalizes traffic flows through the selected GWs computing and sending proper forwarding rules to SDN-enabled devices (Ss), called SDN switches. These nodes follow the received rules keeping them stored in a table called flow table. When a new flow enters the network, the incoming SDN switch checks if a proper rule is already stored in its flow table. If it succeeds, it proceeds forwarding data, otherwise, it asks for instructions. Information about traffic flows' maximum acceptable delay, minimum required throughput, maximum tolerated loss, as well as GW buffer occupancy and future feeder link outage events, can be considered for rule computation.

B. System model

N gateways ($GW_1, \ldots, GW_N$) are connected to the GEO satellite and to the terrestrial infrastructure through N SDN switches ($S_1, \ldots, S_N$). Each GW includes its local NCC ($NCC_1, \ldots, NCC_N$) in the same physical node. SDN switches are controlled by an SDN Controller by using the standard de-facto protocol OpenFlow (OF) [14]. GWs and NCCs are managed by the NCC/GW Manager through dedicated control protocols. Both SDN controller and NCC/GW manager are included in a central joint entity (Central node) that encases the intelligence of the entire network. The central node is in charge of associate each new incoming traffic flow to the proper GW, predict feeder link outage events exploiting satellite links' SNR measurements, and manage all additional functionalities related to the outage events reaction.

We assume that each traffic flow f generates packets at a mean bit rate $r(f)$. In this way, the Central Node is able to compute the current mean input data rate r_{I_n} of each gateway GW_n as $r_{I_n} = \sum_{f=0}^{F_n} r(f)$, F_n being the number of flows currently allocated to GW_n. The current achievable output data rate r_{O_n} of each gateway GW_n is affected by the employed Modulation and Coding (MODCOD) and their related spectral efficiency, which is tuned according to the measured SNR. Table 13 in [15] contains all the required information to obtain current r_{O_n} values from measured SNRs for the DVB-S2 standard. B_n denotes the buffer occupancy of GW_n, i.e. the amount of data stored in its buffer waiting to be sent through its satellite link.

We consider C traffic priority classes whose traffic flows generate packets with mean bit rate r^c and require different minimum performance in terms of guaranteed throughput. The mean input rate of GW_n can be re-defined as $r_{I_n} = \sum_{c=0}^{C} r_{I_n^c} = \sum_{c=0}^{C} r^c \cdot F_n^c$, F_n^c being the number of flows of the c-th traffic class associated to the n-th gateway. In the same way, by using the same notation, we can re-define the buffer occupancy of GW_n as $B_n = \sum_{c=0}^{C} B_n^c$. r_{O_n} can be split in C portions $r_{O_n^c}$ employing a proper scheduling policy, e.g. Weighted Round Robin (WRR), in order to reserve a proper portion of the available bandwidth to each class, such that $r_{O_n} = \sum_{c=0}^{C} r_{O_n^c}$.

III. Handover Strategies

A. Proposed strategy

Our proposed handover strategy aims to properly balance the incoming traffic through all the available GWs in order to guarantee the required performance for each traffic flow. In case of outage events, i.e. the satellite channel attenuation is high enough to prevent communications even by using

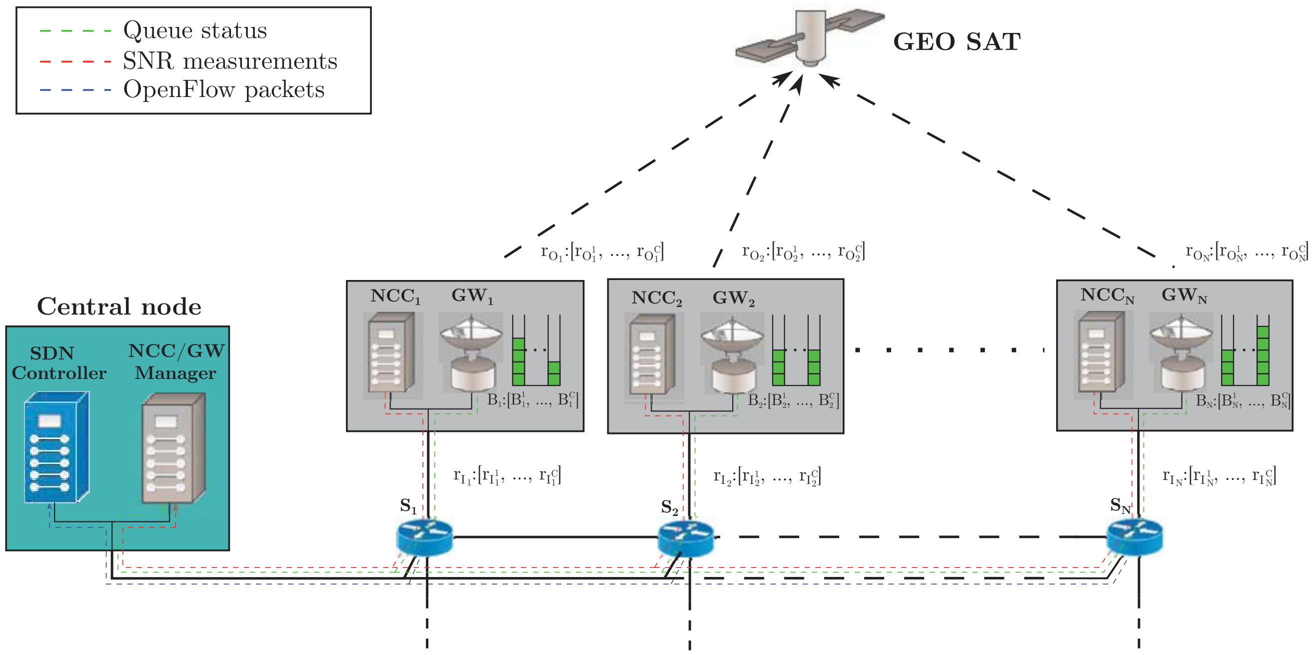

Fig. 1. Smart Gateway Diversity scenario

the strongest MODCOD, the affected GW is unable to send packets until the outage period ends, forcing SDN controller to properly update SDN switches' flow tables and re-route traffic packets, if necessary. The strategy is structured in the following steps:

traffic flow association: For each traffic class, we set a performance constraint in terms of minimum guaranteed throughput per flow r_g^c. When a new traffic flow of the c-th class enters the network, the Central Node starts the *traffic flow association procedure*. Let $\mathcal{GW}$ denote the set of GWs available for the association process, $r^*_{O_n^c}(s)$ denote the estimation of the output data rate of GW_n related to the c-th traffic class at time p, P the number of considered estimated samples, and α_p a weight assigned to the p-th sample, the Central node associates the new flow to the gateway $GW_{\bar{n}}$ which maximizes Λ_n^c, after verifying it can ensure the minimum throughput r_g^c:

$$\bar{n} = \arg\max_{n\in\mathcal{GW}}[\Lambda_n^c];\ \Lambda_n^c = \sum_{p=0}^{P} \alpha_p r^*_{O_n^c}(s) - r_{I_n^c} \qquad (1)$$
$$\Lambda_n^c \geq r_g^c$$

For simplicity, the current value of $r_{O_n^c}$ will be henceforth referred to $r^*_{O_n^c(0)}$. Including both the current and P estimated values of $r_{O_n^c}$ allows considering the achievable output rate trend in an arbitrarily long future. The set of values $\alpha_p \in [0,1]$, $p = 0,\ldots,P$, $\sum_{p=0}^{P}\alpha_p = 1$ allows arbitrarily setting the contribution of each sample.

traffic flow re-allocation: If a satellite link's SNR $SNR_{n'}$, and $r_{O_{n'}}$ consequently, starts decreasing, $r_{I_{n'}}$ can become higher than $r_{O_{n'}}$, and $B_{n'}$ starts increasing (congestion situation). A re-allocation of one or more traffic flows to one or more other GWs would relieve the congestion and avoid packet losses due to buffer overflow. Besides, a decision about traffic flow re-allocation can take place exploiting $r^*_{O_n^c}$ knowledge. We exploit SNR prediction to make congestion prediction and react in advance. The Central Node periodically updates all Λ_n^c values and initializes the *traffic flow re-allocation procedure* in case of predicted congestion, re-allocating the minimum number of traffic flows. First, it selects the traffic class of the GW that will give rise to the congestion, i.e. the c'-th class of the n'-th GW such that $\Lambda_{n'}^{c'} < 0$. Then, it re-selects another GW among the not congested ones as in Eq. (1). The first re-allocated traffic flows are the more recent ones, in order to try minimizing the number of times the re-allocation process is performed and, as a consequence, the number of re-allocated flows. In this way, the SDN switches' flow tables will be updated in order to forward the new incoming packets of the re-allocated flows to the new selected GWs, lowering $r_{I_{n'}}$ until $\Lambda_{n'}^{c'}$ becomes positive again.

outage: When the prediction algorithm identifies an upcoming outage event in t_d, the SDN controller has to properly react in order, on the one hand, to allow the affected GW $GW_{\mathcal{N}}$ to empty its buffer before the outage begins and, on the other hand, to avoid waste of available satellite bandwidth, i.e. allow $GW_{\mathcal{N}}$ to upload packets to the satellite for as long as possible. The Central node starts the *outage procedure*. First, it avoids that new traffic flows will be associated to $GW_{\mathcal{N}}$ removing it from $\mathcal{GW}$. Afterward, it periodically estimates the amount of data that $GW_{\mathcal{N}}$ can send before the predicted outage begins as:

$$\lambda_{\mathcal{N}} = \sum_{c=1}^{C}\lambda_{\mathcal{N}}^c = \sum_{c=1}^{C}\int_0^{t_d} r^*_{O^c_{\mathcal{N}}(t)}\, dt \qquad (2)$$

If $\lambda_{\mathcal{N}} > B_{\mathcal{N}}$, the SDN switches keep forwarding packets to $GW_{\mathcal{N}}$. When $\lambda_{\mathcal{N}}$ becomes lower or equal than $B_{\mathcal{N}}$, the re-allocation process starts re-allocating all traffic flows from $GW_{\mathcal{N}}$ to one or more other GWs. If $\lambda_{\mathcal{N}}$ is already greater than $B_{\mathcal{N}}$ when the outage is predicted, $GW_{\mathcal{N}}$ will not be able to send all the packets stored in its buffer before the outage begins. To prevent a long waiting time until outage end, a *packet re-routing procedure* moves packets from $GW_{\mathcal{N}}$ to one or more other GWs through the terrestrial segment. $\sigma^c_{\mathcal{N}} = \lambda^c_{\mathcal{N}} - B^c_{\mathcal{N}}$, $\sigma^c_{\mathcal{N}} > 0$, $\forall c = 0, \dots, C$ denotes the amount of data of the c-th traffic class that needs to be re-routed. The GW which will receive the re-routed packets is selected for each traffic class as in Eq. (1). An additional control is also performed on the selected GWs' buffer occupancy to avoid packet losses due to buffer overflow. When the prediction algorithm output is again a 'no outage' decision, i.e. the outage is ending, $GW_{\mathcal{N}}$ is considered available again and re-inserted in $\mathcal{GW}$ for the association process before the outage end. In this way, $GW_{\mathcal{N}}$'s buffer will not be empty when its satellite link will be active again, avoiding waste of bandwidth right after the end of outage events.

B. Static strategy

When an outage event is predicted for the GW $GW_{\mathcal{N}}$, the Central Node always re-allocates the traffic flows from $GW_{\mathcal{N}}$ to another gateway statically selected. These static bonds between couples of GWs can be set by using different criteria, such as the geographical distance between GWs, are bidirectional, and are fixed over time. No information about the current or predicted status of the network is needed. GW selection for packet re-routing after the outage beginning is performed in the same way. This strategy offers a simpler outage event management even if the static GW selection can have several drawbacks, such as traffic flow performance degradations and congestion situations on the selected GWs.

C. Network Coding-based strategy

Let P^c_n denote the number of class c's packets stored in GW_n's buffer, every time the Central node predicts an outage event in a GW $GW_{\mathcal{N}}$, C sets of m^c network coding packets each are generated from the C sets of k^c original data packets, where $k^c = P^c_{\mathcal{N}}$, $c = 0, \dots, C$ and the m^c values are dynamically set. In detail, the Central node periodically estimates the amount of data $\lambda_{\mathcal{N}}$ that $GW_{\mathcal{N}}$ can send before the predicted outage begins as in Eq. (2), and, consequently, the $\lambda^c_{\mathcal{N}}$ values. If $\lambda_{\mathcal{N}} > B_{\mathcal{N}}$, the SDN switches keep forwarding packets to $GW_{\mathcal{N}}$, and when $\lambda_{\mathcal{N}} \leq B_{\mathcal{N}}$, the outage procedure is triggered. The amounts of generated network coding packets are set as $m^c = \mathcal{P}(B^c_{\mathcal{N}} - \lambda^c_{\mathcal{N}})$, where the operation $\mathcal{P}(x)$ indicates the lowest amount of stored packets whose overall size is greater or equal to x. In this way, assuming reliable the estimation, the first $\mathcal{P}(\lambda^c_{\mathcal{N}})$ packets stored in $GW_{\mathcal{N}}$ will be sent by $GW_{\mathcal{N}}$, while the m^c generated packets will be forwarded through another GW selected as in Eq. (1). When the outage starts, the packets still stored in $GW_{\mathcal{N}}$'s buffer are dropped. The packets reception is considered successful if at least k^c packets are correctly received, otherwise, the all block of received packets cannot be decoded and they are considered lost. This strategy allows high robustness against packet loss due to outage at the cost of an increase of the traffic volume; this is the reason why the m^c values should be set considering the trade-off between increased traffic volume and loss protection.

D. Drop strategy

When an outage event is predicted for the GW $GW_{\mathcal{N}}$, the Central Node re-allocates the traffic flows from $GW_{\mathcal{N}}$ to another gateway selected as in Eq. (1). If $GW_{\mathcal{N}}$'s buffer is not empty when the outage event starts, all the stored packets are dropped. There is not packet re-routing among GWs. This strategy aims at reducing the traffic volume which "horizontally" traverses the ground segment.

IV. Performance Evaluation

A. Simulation Setup

To simulate the scenario depicted in Figure 1, we use a discrete event simulator written in Python and based on the process-based discrete-event simulation library Simpy[1].

The design parameters of the considered scenario are summarized in Table I.

TABLE I. Simulated scenario design parameters

Number of GWs N	5
GW buffer size	10 Gb
Number priority classes C	3
Flow guaranteed throughput r^c_g	[8 4 2] $Mbps$
Packet inter-generation time	[25 50 100] ms
Packet size	200 kb
Flow duration	1 200 s
Number predicted samples P	10
Size of the observation windows T	10
Predicted sample weights α_p	$\frac{1}{P+1} = \frac{1}{11}$
SNR outage threshold (SOT)	$-2.35\ dB$
Simulation duration	100 $days$

The simulated traffic flows are Constant-Bit-Rate (CBR) flows whose parameters are reported in Table I. Traffic flows' start times are randomly generated with an uniform distribution for the all simulation duration. Each flow's priority class is also randomly generated with an uniform distribution.

Since we are interested in assessing our proposed handover strategy which acts on the feeder link, simulated traffic is generated from the ground segment and forwarded up to the GEO satellite (user link is not included in the simulation environment).

We decided to homogeneously set the α_p values for all the considered estimated samples and the current one, i.e. both

[1]https://simpy.readthedocs.io/en/latest/

current and estimated values contribute to the GW selection with the same weight.

The set outage threshold on the measured SNR is the one of the strongest MODCOD of DVB-S2 (QPSK 1/4), as reported in [15], Table 13.

Since rain attenuation is a time varying process, we modeled it as a first order Gauss Markov process of the Ornestein-Uhlenbeck type, generating N different and independent attenuation traces in dB as detailed in [7]. We obtained N SNR traces from these attenuation traces through a proper link budget and, in run time, the simulator computes the current GW output rate values from the related SNR samples considering the spectral efficiency of the selected DVB-S2 MODCOD reported in [15], Table 13.

B. Results

In order to better highlight the network behaviour in case of outage events, the shown results regard a small portion of the overall simulation results: the one collected in preparation, during, and after one outage event. In this considered time window, one of the GW (G_0) is approaching to an outage event which takes place and lasts about 100 seconds. Figure 2 shows the SNR trends of all the simulated GWs in the considered time window.

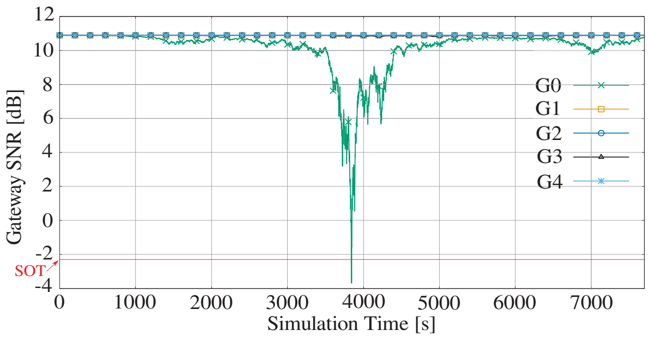

Fig. 2. Gateway SNR traces

Looking at the SNR trend of G_0, it starts fluctuating approaching to the outage event and then decreasing until it reaches the outage threshold. To mitigate the effect of fluctuations, we employ a hysteresis mechanism that prevents the frequent transitions between normal and outage states and vice versa, "merging" together more small outage intervals in a single one.

The obtained performance has been assessed considering two typical performance metrics: Normalized Throughput (NT) and Packet Loss Rate (PLR). The performance obtained by using our proposed strategy has been compared with the one obtained by using the other three strategies described in Section III considered as a benchmark.

Figure 3 shows the NT of the GW uplink channels.

When all the GWs have the same SNR values, the Central node homogeneously distributes the new incoming traffic flows to the all GW set, as testified by the GW NT values. When G_0's channel quality starts decreasing, we can see fluctuations of G_0's NT due to the formed unbalanced situation among GWs which is automatically recovered by the traffic association process. However, when G_0 approaches to the outage, its channel quality rapidly decreases, leading to congestion due to the severe unbalance between overall input and output rates. Our solution is the only one among the considered which can sense this situation and triggers the traffic flow re-allocation procedure, avoiding packet losses and keep guaranteeing each traffic flow's required throughput. Looking at G_0's NT right before the outage beginning, it never reaches the maximum value with our solution (Figure 3a), unlike with the other solutions, avoiding an increase of the GW buffer occupancy and, consequently, possible losses due to buffer overflow.

Figure 4 shows the NT of a traffic flow affected by congestion. Looking at Figure 4a, the employment of our solution guarantees the required throughput of the analysed traffic flow for its all duration, while it cannot be fulfilled by the other strategies.

When the outage starts, G_0 is no longer able to send packets and its NT becomes zero, while the other GW's NT have different trends depending on the tested strategy. This leads also to different performance from the traffic flow viewpoint, as highlighted by the NT of a traffic flow affected by outage, i.e. associated to G_0 when the outage is predicted, shown in Figure 5.

With our proposed strategy, the Central Node starts re-allocating traffic flows from when it sensed the congestion, and possible packets still stored in G_0 buffer when the outage starts are homogeneously distributed to all the other GWs. Also in this case, the required throughput of the analysed traffic flow is fulfilled (Figure 5a). No packet loss has been detected during the simulation.

With the static solution (Figure 3b), the traffic flow re-allocation takes place only in the time interval between the outage prediction and the outage beginning, and all packets stored in G_0's buffer which cannot directly be uploaded to the satellite are statically forwarded to another GW (G_1), independently by its buffer occupancy and channel quality. This leads to a rapid increase of G_1's NT and packet losses due to buffer overflow. The analysed traffic flow's NT (Figure 5b) demonstrates this behaviour, where the low values are due to the pre-outage congestion and the peak due to the re-routing of the block of packets still stored in G_0's buffer when the outage starts. An overall PLR of 0.06% has been measured.

With the network coding-based strategy (Figure 3c), the traffic flow re-allocation takes place only in the time interval between the outage prediction and the outage beginning, all packets stored in G_0's buffer are not re-routed, and the generated network coding packets per traffic class are sent to other gateways. In this test, the three packet blocks, one for each defined priority class, are forwarded to three different GWs (G_1, G_2, and G_3). This lowers the congestion effect spreading the packet through more selected gateways than the single one of the static case, offering better performance as can be seen looking at the higher peak in Figure 5c and lower overall PLR of 0.03%. However, the network coding-based

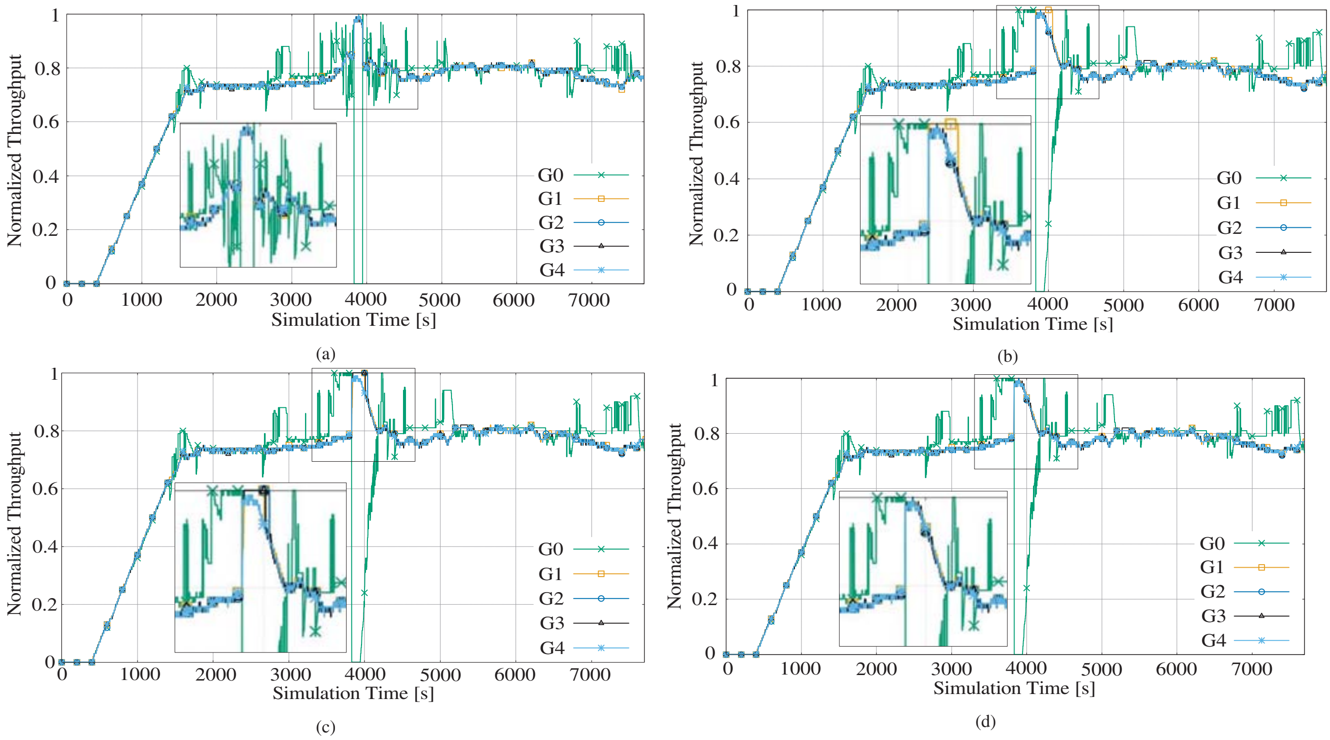

Fig. 3. GW uplink channels' NT: our (a), static (b), network-coding based (c), and drop (d) solutions

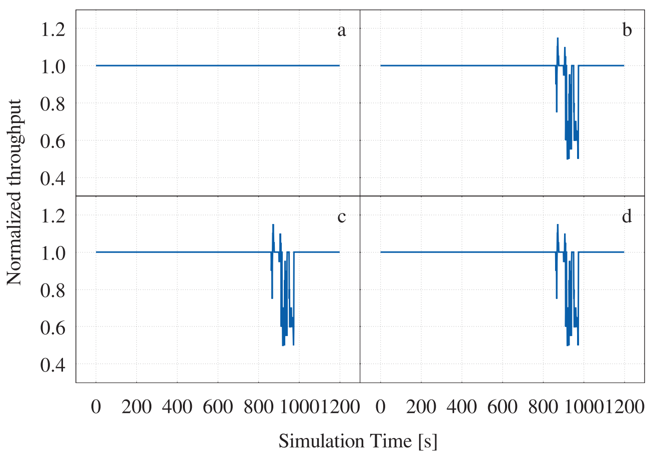

Fig. 4. NT of a traffic flow affected by gateway congestion: our (a), static (b), network-coding based (c), and drop (d) solutions

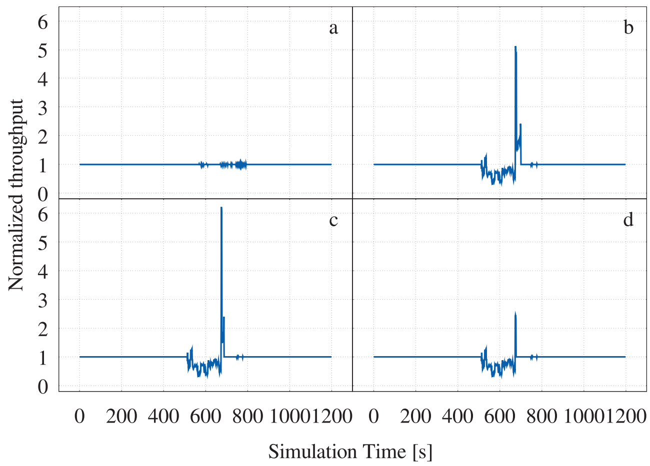

Fig. 5. NT of a traffic flow affected by gateway outage: our (a), static (b), network-coding based (c), and drop (d) solutions

strategy can relieve but not solve the problem already noticed with the static solution.

With the drop strategy (Figure 3d), the traffic flow re-allocation takes place only in the time interval between the outage prediction and the outage beginning, all packets stored in G_0's buffer are not re-routed and if they are not sent before the outage begin they are dropped. This affects the GW's NT which homogeneously increases to compensate G_0 outage and leads to a severe performance worsening of the traffic flow affected by outage, as can be seen looking at the analysed traffic flow's NT in Figure 5d and by the obtained overall PLR of 0.09%.

Finally, when the outage ends and G_0's link comes back active, G_0's NT with our solution almost instantly reaches the other GW's NT, avoiding waste of G_0's link bandwidth. On the contrary, G_0 and the others' NT with the other solutions gradually increases and decrease, respectively, until reaching the balanced pre-outage situation, slowly relieving the additional load on the other GWs.

V. Conclusions

The problem of traffic routing management in Very High Throughput Satellite networks has still open challenges. Moving to higher frequency bands, e.g. Q/V bands, involves additional attenuation factors that hinder the communications between the satellites and the ground and may lead to temporary outage events. Proper handover strategies are required to distribute the traffic flow throughout the available gateways and to re-allocate traffic flows in case of gateway link outage.

This paper proposes a handover solution that exploits the available information about the current network status (periodically measured SNR values of satellite links and GW buffer occupancies) to move traffic flows among gateways in case of congestion or outage events. A prediction algorithm is also employed to predict outage events and allow the network to react in advance in order to minimize additional delays, packet losses, and satellite bandwidth waste.

A performance evaluation has been performed through a simulation tool comparing our proposed strategies with others in the literature in terms of achieved throughput and obtained packet loss. The obtained preliminary results assess the performance improvement of the proposed solution.

References

[1] A. Guidotti, A. Vanelli-Coralli, M. Conti, S. Andrenacci, S. Chatzinotas, N. Maturo, B. Evans, A. Awoseyila, A. Ugolini, T. Foggi, L. Gaudio, N. Alagha, and S. Cioni, "Architectures and Key Technical Challenges for 5G Systems Incorporating Satellites," *IEEE Transactions on Vehicular Technology*, vol. 68, no. 3, pp. 2624–2639, 2019.

[2] C. Ge, N. Wang, I. Selinis, J. Cahill, M. Kavanagh, K. Liolis, C. Politis, J. Nunes, B. Evans, Y. Rahulan, N. Nouvel, M. Boutin, J. Desmauts, F. Arnal, S. Watts, and G. Poziopoulou, "QoE-Assured Live Streaming via Satellite Backhaul in 5G Networks," *IEEE Transactions on Broadcasting*, vol. 65, no. 2, pp. 381–391, 2019.

[3] A. Kyrgiazos, B. Evans, P. Thompson, P. T. Mathiopoulos, and S. Papaharalabos, "A terabit/second satellite system for European broadband access: a feasibility study," *International Journal of Satellite Communications and Networking*, vol. 32, no. 2, pp. 63–92, 2014.

[4] Z. Katona, F. Clazzer, K. Shortt, S. Watts, H. P. Lexow, and R. Winduratna, "Performance, cost analysis, and ground segment design of ultra high throughput multi-spot beam satellite networks applying different capacity enhancing techniques," *International Journal of Satellite Communications and Networking*, vol. 34, no. 4, pp. 547–573, 2016.

[5] N. Jeannin, L. Castanet, J. Radzik, M. Bousquet, B. Evans, and P. Thompson, "Smart gateways for terabit/s satellite," *International Journal of Satellite Communications and Networking*, vol. 32, no. 2, pp. 93–106, 2014.

[6] P. Angeletti, R. De Gaudenzi, E. Re, N. Jeannin, and A. Vernucci, "Multibeam satellite communication system and method, and satellite payload for carrying out such a method," 2016, US Patent 9,356,685.

[7] A. Gharanjik, B. Shankar M. R., P. Arapoglou, and B. Ottersten, "Multiple Gateway Transmit Diversity in Q/V Band Feeder Links," *IEEE Transactions on Communications*, vol. 63, no. 3, pp. 916–926, 2015.

[8] A. Kyrgiazos, B. G. Evans, and P. Thompson, "On the Gateway Diversity for High Throughput Broadband Satellite Systems," *IEEE Transactions on Wireless Communications*, vol. 13, no. 10, pp. 5411–5426, 2014.

[9] R. Nebuloni, C. Riva, L. Luini, T. Rossi, M. De Sanctis, M. Ruggieri, G. Codispoti, and G. Parca, "Optimization of Q/V-band Smart Gateway Switching in the framework of Q/V-Lift Project," in *IEEE Aerospace Conference*, 2019, pp. 1–8.

[10] M. Muhammad, G. Giambene, and T. de Cola, "QoS Support in SGD-Based High Throughput Satellite Networks," *IEEE Transactions on Wireless Communications*, vol. 15, no. 12, pp. 8477–8491, 2016.

[11] M. Mongelli, T. De Cola, M. Cello, M. Marchese, and F. Davoli, "Feeder-link outage prediction algorithms for SDN-based high-throughput satellite systems," in *IEEE International Conference on Communications (ICC)*, 2016, pp. 1–6.

[12] T. De Cola and M. Mongelli, "Adaptive Time Window Linear Regression for Outage Prediction in Q/V Band Satellite Systems," *IEEE Wireless Communications Letters*, vol. 7, no. 5, pp. 808–811, 2018.

[13] D. Kreutz, F. M. Ramos, P. E. Verissimo, C. E. Rothenberg, S. Azodolmolky, and S. Uhlig, "Software-defined networking: A comprehensive survey," *Proceedings of the IEEE*, vol. 103, no. 1, pp. 14–76, 2015.

[14] N. McKeown, T. Anderson, H. Balakrishnan, G. Parulkar, L. Peterson, J. Rexford, S. Shenker, and J. Turner, "Openflow: enabling innovation in campus networks," *ACM SIGCOMM Computer Communication Review*, vol. 38, no. 2, pp. 69–74, 2008.

[15] "Digital video broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications (DVB-S2)," ETSI EN 302 307 V1.4.1, Tech. Rep., 2013.