Impact of channel access and transport mechanisms on QoE in GEO-satellite based LTE backhauling systems

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Abstract—Backhauling services through satellite systems have doubled between 2012 and 2018. There is an increasing demand for this service for which satellite systems typically allocate a fixed resource. This solution may not help in optimizing the usage of the scarce satellite resource.

This study measures the relevance of using dynamic resource allocation mechanisms for backhaul services through satellite systems. The satellite system is emulated with OpenSAND, the LTE system with Amarisoft and the experiments are orchestrated by OpenBACH. We compare the relevance of applying TCP PEP mechanisms and dynamic resource allocations for different traffic services by measuring the QoE for web browsing, data transfer and VoIP applications.

The main conclusions are the following. When the system is congested, PEP and layer-2 access mechanisms do not provide significant improvements. When the system is not congested, data transfer can be greatly improved through protocols and channel access mechanism optimization. Tuning the Constant Rate Assignment can help in reducing the cost of the resource and provide QoE improvements when the network is not loaded.

Index Terms—BACKHAUL, SATCOM, PEP, ACCESS

I. INTRODUCTION

Mobile Network Operators (MNO) have the regular need to optimize their communication infrastructure in order to better manage congestion, guarantee the quality of the service and maximize income. The end user demand may not be located close to the already deployed core network of a MNO and answering to it may not be economically viable. The deployment of LTE cells and their connection to the core network with a satellite system has proved to be an efficient solution to this issue.

The satellite backhauling service represented 36,750 sites served by satellite in 2018, which is twice the amount served in 2012. As this service is growing strongly and a source of significant revenue for operators, it is important to present the issues related to this use case and the necessary considerations allowing to define future satellite systems.

Figure 1 shows an architecture of a LTE backhauling service through satellite. End users (User Equipment, EU) access Radio Access Network (RAN) of a MNO using LTE standards. The satellite system connects the RAN to the core network of the MNO.

The backhauling services need for relatively strong end-to-end Quality of Service (QoS) requirements. In general, variable data rates should be guaranteed by the QoS mechanisms, the voice from 64 kbps and video from 256 kbps should also be guaranteed. There may also be strong requirements on the round trip time, jitter and packet loss rate.

▶ GEO satellite backhauling accesses are facing a trade-off between quality of network service, quality of the user experience and the price of the access.

Satellite systems may allocate Constant Rate Assignment (CRA) for backhauling services (as opposed to Rate-Based Dynamic Capacity, RBDC). With CRA, a portion of the satellite resource is dedicated to a user even if it does not actually use it. The reduction of the CRA would let the satellite resource management mechanisms to allocate the unused resource to the systems that actually need it. However, decreasing the CRA and increasing the RBDC may reduce the Quality of Experience (QoE) due to the request-allocation loop inherent to RBDC mechanisms.

This study measures the relevance of using dynamic resource allocation mechanisms for backhaul services through satellite systems and their impact on the QoE. The satellite system is emulated with OpenSAND [1], [2], the LTE system with Amarisoft [3], and the experiments are orchestrated by OpenBACH [4]. We compare the relevance of applying PEP [5] mechanisms and dynamic resource allocations when the system is loaded by measuring the QoE for Web browsing, data transfer and VoIP applications.

The main conclusions are the following.

▶ When the system is congested, PEP and layer-2 access mechanisms do not provide significant improvements.
▶ When the system is not congested, data transfer can be greatly improved through TCP optimizations.
▶ Tuning the Constant Rate Assignment can help in reducing the cost of the resource and provide QoE improv-
ments when the network is not loaded.

II. PLATFORM DETAILS

This sections provides details on the exploited platform.

A. On the need for a controlled emulation

The exploitation of an emulated platform let us consider mechanisms and algorithms [6] that are close to those implemented in deployed systems. When it comes to considering QoE measurements, simulations may not map actual protocol performances [7].

However, using different proprietary equipments may result in outputs that are difficult to undersand and analyse. To cover this issue, we propose the exploitation of a maximum number of opensource softwares towards reproducible and controlled tests while considering systems as close as possible to real ones.

B. End-to-end emulated platform

Figure 2 presents the different equipments that compose the platform:
- Proprietary Performance Enhancing Proxies (PEP);
- The cellular network is emulated with AMARISOFT [3];
- The satellite system is emulated with OpenSAND [1],[2];
- The tests are orchestrated by OpenBACH [4].

The PEPs are not deployed within the LTE emulation network since our equipment could not deal with packets encapsulated within GTP-U tunnels.

III. PLATFORM VALIDATION

This sections provides details on how the exploited platform has been validated.

A. Validation strategy

The experience feedback from previous activities shows that the platform needs to be set up carefully, especially when it integrates so many elements provided by different entities. The following step-by-step procedure has been exploited:
- Prepare the test architecture with the Amarisoft platform and two OpenBACH agents (to emulate the clients);
- Launch OpenBACH scenarios allowing an end-to-end QoS analysis and QoE measurements to validate the Amarisoft component;
- Add the PEPs in "deactivated" mode (TCP acceleration disabled) at the ends of the system;
- Launch OpenBACH scenarios allowing an end-to-end QoS analysis to validate the Amarisoft along with "deactivated" PEP;
- Add OpenSAND between the eNodeB and the Core of Amarisoft;
- Launch OpenBACH scenarios allowing end-to-end QoS analysis to validate the Amarisoft along with OpenSAND and "deactivated" PEP;
- Activate PEP;
- Launch OpenBACH scenarios allowing QoS analysis of end-to-end to validate the Amarisoft along with OpenSAND and activated PEP.

B. Validation results

The results related to the QoS measurements are presented in Figure 3, Figure 4, Figure 5. The traffic has been generated by iperf3 (TCP), nuttcp (TCP/UDP), fping (ICMP ping) and hping (TCP/IP ping) The forward channel rate is limited to 20 Mbps and 10 Mbps in the return channel. Changes in TCP throughput already illustrate the impact of congestion losses on TCP throughput and its ability to use all of the available capacity. Moreover, the use of OpenBACH makes it possible to
obtain these curves with less effort and greater control and thus assuring the consistency of the results. The delay measured by hping is 0 because the traffic is intercepted by the PEP, which gives an illusion of low latency.

IV. IMPACT OF CHANNEL ACCESS MECHANISMS

This section provides the experiments that have led to assess the impact of channel access mechanism in a GEO-satellite backhaul system. The PEP mechanisms are not activated.

A. Dynamic SATCOM access and uncongested network

The characteristics of this test scenario are as follows:
- Number of connected UEs: 10;
- Same application for all UEs: data transfer in download;
- All UEs start downloading at the same time;
- OpenSAND limits: 20 Mbps Forward / 1 Mbps in Return;
- Flow limitation per UE (SLA) in download: 2 Mbps;
- OpenSAND access (total return channel at 1 Mbps):
  - CRA = 50 kbps / RBDC = 1000 kbps
  - CRA = 100 kbps / RBDC = 900 kbps
  - CRA = 500 kbps / RBDC = 500 kbps
  - CRA = 1000 kbps / RBDC = 0 kbps

The metric reported in this report is the rate convergence time, i.e. the time required for the UE to reach the rate of its SLA. This enables the analysis of the impact of the access mechanism on the speed of convergence of congestion control.

| Access Method       | Rate convergence time (s) |
|---------------------|--------------------------|
| CRA = 50 kbps / RBDC = 1000 kbps | 10 |
| CRA = 100 kbps / RBDC = 900 kbps | 9  |
| CRA = 500 kbps / RBDC = 500 kbps | 6  |
| CRA = 1000 kbps / RBDC = 0 kbps  | 7   |

The results of this experiment are presented in Table I. A low value of CRA impacts the end user speed convergence time. That being said, once the threshold of 50% of the capacity on the return link is reached, increasing it beyond does not seem to bring significant gains.

B. Dynamic SATCOM access and congested network

The previous test has shown that considering a low value of CRA, for example at 10% of the capacity, increases the rate convergence time. That being said, an actual system will likely be loaded. The test presented in this section considers 9 UEs whose connection is established before the last UE starts downloading.

The characteristics of this test scenario are as follows:
- Number of connected UEs: 10;
- Same application for all UEs: data transfer in download;
- 9 UEs start downloading from the start, and one UE starts the download 10 seconds later;
- OpenSAND limits: 20 Mbps Forward / 1 Mbps in Return;
- Flow limitation per UE (SLA) in download: 2 Mbps;
- OpenSAND access (total return channel at 1 Mbps):
  - CRA = 50 kbps / RBDC = 1000 kbps
  - CRA = 100 kbps / RBDC = 900 kbps
  - CRA = 500 kbps / RBDC = 500 kbps
  - CRA = 1000 kbps / RBDC = 0 kbps

The reported metric in this report is the rate convergence time, i.e. the time required for the 10th UE to reach the rate of its SLA. This enables the analysis of the impact of the access mechanism on the speed of convergence of congestion control.

| Access Method       | Rate convergence time (s) |
|---------------------|--------------------------|
| CRA = 50 kbps / RBDC = 1000 kbps | 4  |
| CRA = 100 kbps / RBDC = 900 kbps | 11 |
| CRA = 500 kbps / RBDC = 500 kbps | 10 |
| CRA = 1000 kbps / RBDC = 0 kbps  | 10 |

The results of this experiment are presented in Table II. The result of the case 'CRA = 50 kbps / RBDC = 1000 kbps' shows a very short convergence time. This may be due to the link load which is variable. This phenomenon could have been absorbed by a larger number of tests, which could not be carried out due to lack of time. Moreover, the comparison of the other cases completes the results of the previous section. When the CRA is set to a value greater than 100 kbps, the convergence performance is the same. Once the network is loaded, it is not necessary to dynamically adapt the use of the resource on the return path.

C. Dynamic SATCOM access and mixed upload and down-load traffic

In order to complete the results observed in the previous sections, tests with mixed download and upload traffic were carried out and a subset of the results is presented in this section.

The characteristics of this test scenario are as follows:
- Number of connected UEs: 10;
• Application data transfer in download for 8 UEs and Upload for 2 UEs;
  – Long flows for download and upload last 30 seconds;
  – Short flows are 1 MB in download and 300 kB in upload;
  – 7 UEs start long flows (download) and 1 UE start long flows (upload) at the beginning of the experiment;
  – Short flows (1 UE in download and 1 UE in upload) start 10 seconds later;
• OpenSAND limits: 20 Mbps Forward / 1 Mbps in Return;
• Flow limitation per UE (SLA): 2 Mbps (download) and 300 kbps (upload);
• OpenSAND access (total return channel at 1 Mbps):
  – CRA = 50 kbps / RBDC = 1000 kbps
  – CRA = 100 kbps / RBDC = 900 kbps
  – CRA = 500 kbps / RBDC = 500 kbps
  – CRA = 1000 kbps / RBDC = 0 kbps

| Access Method | 1 MB download time (s) | 300 kB upload time |
|---------------|------------------------|--------------------|
| CRA = 30 kbps / RBDC = 1000 kbps | 10.3 | 7.5 |
| CRA = 100 kbps / RBDC = 900 kbps | 10.7 | 7.2 |
| CRA = 500 kbps / RBDC = 500 kbps | 9.9 | 7.1 |
| CRA = 1000 kbps / RBDC = 0 kbps | 11.6 | 7.5 |

A. Experiment set up

This section presents the results for a web access or for a short file transfer. The characteristics of the scenarios presented in this section are the following:
• Number of connected UEs: 10;
• Test duration: 30 seconds;
• Data transfer is started for 9 UEs to load the link: 7 in download and and 2 in upload;
• The 10th UE consumes a given type of service (VoIP, video, Web or File transfer);
• The 9 UEs that load the link start their activity at the same time;
• The 10th UE that consumes the service starts a few seconds later, once the link is loaded;
• OpenSAND limits: 20 Mbps Forward / 1 Mbps in Return;
• OpenSAND access: CRA = 100 kbps / RBDC = 900 kbps or CRA = 500 kbps / RBDC = 500 Kbps;
• Flow limitation per UE (SLA) of 2 Mbps in download and 100 kbps in upload.

The results presented in this section do not take into account the diversity of web pages and protocols used. For example, a page using the HTTP1 protocol and multiple objects has very different characteristics and probably different performance than a page using HTTP2.

The tests concerning the use of application traffic representative of a voice over IP or a video transmission did not show different results, whether the WAN accelerators are activated or not and whatever the configuration of the access (CRA = 100 kbps / RBDC = 900 kbps, CRA = 500 kbps / RBDC = 500 kbps).

B. Focus on web transfer

In order to limit the complexity of the analysis, it was decided to test a single web page with the following characteristics: 6.5 MB page size using the HTTP protocol. On a 2 Mbps capacity link, the optimal transfer time would be 26 seconds.

| Access Method | CRA=100kbps RBDC=900kbps | CRA=500kbps RBDC=500kbps |
|---------------|---------------------------|---------------------------|
| No PEP | PEPE | No PEP | PEP |
| Average (s) | 33.9 | 36.1 | 34.5 | 34.8 |
| Max (s) | 35.9 | 40.8 | 41.1 | 38.0 |
| Min (s) | 31.0 | 32.2 | 31.6 | 32.4 |

The calculation of a statistic analysis based on 10 experiments is presented in Table IV. The transfer times of the page vary between 31 and 41 seconds, all configurations combined. The introduction of a PEP does not bring significant gain on web browsing in a congested context. It is worth pointing out that these experiments do not consider the exploitation of a PEP equipment where it should provide benefits, i.e. within the SATCOM system. This was not possible due to the lack of GTP-U capable PEPs.
C. Focus on file transfer

The client proceeds to two different downloads during the experiment. During the first one (fetch 1), the network is loaded with cross-traffic. The second download (fetch 2) occurs when no other UE are using the satellite resource. Each configuration is tested five times.

| TABLE V | SIMPLE WEB PAGE DOWNLOADING TIME AND CRA=100 KBPS, RBDC=900 KBPS |
|---------|---------------------------------------------------------------|
|         | No PEP         | PEP                         |
| Fetch 1 | Average download time (s) | Fetch 1 | Fetch 2 | Fetch 1 | Fetch 2 |
|         | 11.67          | 11.34 | 9.44 | 8.16 |

| TABLE VI | SIMPLE WEB PAGE DOWNLOADING TIME AND CRA=500 KBPS, RBDC=500 KBPS |
|---------|---------------------------------------------------------------|
|         | No PEP         | PEP                         |
| Fetch 1 | Average download time (s) | Fetch 1 | Fetch 2 | Fetch 1 | Fetch 2 |
|         | 11.91          | 11.49 | 9.32 | 6.88 |

Tables V and VI present the results for this experiment. In general, all fetchs 1 show the same values. It means that whatever the channel access characteristics and whatever the transport layer, when the network is loaded, the results are the same. However, when the network is not loaded (fetch 2), including a PEP results in 3% to 26% performance improvements. The gains are more important when the CRA is high.

D. Discussion

Regarding file transfer, the gains brought by WAN acceleration are significant without congestion, and amplify the conclusions on the adaptation of the access method: the higher the CRA, the higher the gain brought by the PEP. Regarding web browsing, for a simple web page and in congestion, the WAN accelerator does not bring significant gains.

VI. DISCUSSION

The main contributions of all these studies are as follows:

- Different proofs of concept for the GEO backhaul service have been implemented;
- If the system is congested, the protocol optimizations offered by a PEP (to improve QoE) or adaptation of access mechanisms (to reduce costs) do not bring significant gains;
- If the system is not congested:
  - Protocol optimizations bring significant gains for file transfer;
  - Adaptation of access mechanisms, i.e. the constant reduction of the allocated throughput, enables to reduce the costs of access while having a negligible impact on services.

The tests carried out do not take into account the complexity of the operator’s core networks. The introduction of WAN accelerator equipment (i.e. PEP) ensures performance in the part for which the operator is responsible and neglects the impacts of the network conditions between the operator’s network and the data servers. These equipments isolate error segments, perform local retransmissions and tune the protocols to the network where it is deployed. They also implement caching mechanisms. Although negligible gains were measured by the introduction of these equipments, this observation does not allow us to deduce its uselessness given that many functions were not considered and evaluated.

The results nevertheless show the importance of studying the impacts of the different protocol layers for SATCOM systems offering a backhauling service for mobile networks. This includes many multi-layered technical interactions, as well as the understanding of which is necessary to optimally size and implement such systems.

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