Networking Challenges for Non-Terrestrial Networks Exploitation in 5G

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Abstract—The standardization process of the fifth generation of mobile communications (5G) is still ongoing and it will end in 2020 as scheduled. A lot of changes have been made from the previous generations involving different technologies, concepts, and paradigms, which will deeply affect the telecommunication infrastructure and its management. Besides, a higher number of use cases and application scenarios are envisioned in the near future. This will contribute to generate higher and higher traffic volumes from a higher number of connected devices/users with different performance requirements. Additional network resources are required to fulfill users' requirements in order to guarantee the expected Quality of Experience (QoE). The integration of Non-Terrestrial Networks (NTNs) within the 5G framework is under standardization and can lead to manifold advantages, such as coverage extension and additional communication link among many others. However, NTN integration is also leading to challenges related to the employment and adaptation to aerospace networks of technologies originally designed for terrestrial networks. This paper provides an overview of the role of NTNs in the 5G ecosystem, of the application scenarios that can benefit from the integration among terrestrial and non-terrestrial networks, and of some identified challenges from the networking viewpoint, which still require further analysis towards possible solutions.

Index Terms—UAV/satellite 5G integration, smart gateway diversity, satellite-based hybrid backhaul, multi-path

I. The role of Non-Terrestrial networks in 5G

The overall communication network that will rise with the employment of the 5G technology can be considered as *a network of networks*, since it will allow adapt and combine (as needed by the overlaying applications) different and alternative network stacks and communication technologies. Thanks to their intrinsic ubiquity and broadcasting/multicasting capabilities, NTN, and in particular Satellite Communication (SatCom) networks, can play multiple roles in 5G [1], acting as a Radio Access Network (RAN) and as backhaul connection for remote 5G deployments. A satellite component may be useful as:

- *backup link*: users are linked to the network through a default connection (e.g. ADSL or terrestrial mobile radio) and secondary connections (e.g. the satellite one). The primary connection is used in normal conditions, while the other one is enabled in case of outage or fault to replace the default one (failover), leading to higher service availability and reliability;
- *offloading data*: users select a primary connection to send/receive data. The satellite network may provide an additional connection aimed at addressing traffic peaks and preserving the performance of specific sensitive flows. An ad-hoc router can be configured to define and apply rules depending on traffic statistics and defined mechanisms, such as fixed or dynamic traffic thresholds, in order to activate the additional connection and offload the primary route;
- *parallel independent links*: two or more independent access or backhaul links may be present in the network and can be used at the same time. Each link (one of them may be the satellite) is operated by a distinct Internet Service Provider (ISP), characterized by the target technology and subscribed Service Level Agreement (SLA). An ad-hoc router at the user premises can be configured to collect all the locally generated traffic and forward it based on cost/performance criteria to implement multi-link aggregation.

The ETSI document in [2] is aimed at identifying the potential role of the satellite in 5G systems, along with 5G use cases for satellite and High Altitude Platform Systems (HAPSs), and to depict different implementation options and architectures for the satellite integration. The intent is to identify the necessary standardization activity concerning the integration of satellite and HAPS in the 5G system. The 3rd Generation Partnership Project (3GPP) has been focusing its efforts to address such an integration. It has carried on studies aimed at

defining the possible role of NTNs and the technical details about their integration in Release 15 [3]. Possible solutions from the networking viewpoint are reported in Release 16 document [4]. The main difference among these solutions is related to which functionalities are implemented on-board non-terrestrial objects. They can act either as relay nodes between 5G User Equipment (5G-UE), or as 5G access points (5G-gNB) to extend 5G-RAN coverage, or as backbone supports (e.g. satellite backhauls). Besides, the additional study in [5] investigates the possible employment of SatCom networks as active nodes in the 5G access operations.

The role of NTNs and their integration within the 5G framework is also the topic of research projects such as the EU H2020 project *SaT5G* and the ESA project *SATis5*. The SaT5G project (Satellite and Terrestrial Network for 5G) [6] is developing the role of SatCom in 5G by defining optimal satellite-based backhauls and traffic offloading solutions [7]. The goal is to enhance 5G networks with the SatCom benefits by seamless integration and to create new business opportunities. A testbed implementing an integrated satellite-terrestrial 5G network will be built in the SATis5 project [8], in order to evaluate this kind of network and show the benefits of the satellite integration with the terrestrial infrastructures. The demonstrator is an open federation of resources that can integrate or incorporate additional resources and testbeds in the future, allowing a large set of experiments and demonstrations.

II. 5G USE CASES AND APPLICATION SCENARIOS SUITABLE FOR AEROSPACE INTEGRATION

The real advent of 5G will be characterized by deep changes in the telecommunication infrastructure and employed technologies. This change is mainly driven by M2M/IoT traffic requirements which are different from those of human-generated traffic. besides, the fraction of M2M/IoT traffic is growing larger and larger, and aerospace networks can play a significant role in supporting such data exchanges, also taking into account different requirements coming from application scenarios [9]. The International Telecommunication Union (ITU) groups together different applications sharing the same needs in terms of performance requirements and offered user Quality of Experience (QoE), so defining three different usage scenarios which have been adopted in 5G:

- *Ultra-Reliable Low Latency Communications (URLLC)*: critical communications which require high availability, low latency, and high reliability are in this category, such as remote medical surgery, distribution automation in smart grids, autonomous vehicles, and tactile Internet.
- *enhanced Mobile Broadband (eMBB)*: it addresses the human-centric use cases to access multimedia contents and services requiring high data rates across wide coverage areas.
- *massive Machine Type Communication (mMTC)*: it is characterized by a very large number of connected devices located in a small area, typically transmitting a low volume of non-delay-sensitive data, as in the case of IoT applications.

The 3GPP report [3] provides many examples for the NTN use in the eMBB and mMTC scenarios, such as:

- eMBB case: users in underserved areas, passengers on-board vessels, airplanes or public transport vehicles, deploy or restore (disaster relief) 5G service, emergency communications, media and entertainment content broadcasts. This scenario is more suitable for GEO and LEO constellations.
- mMTC case: global service continuity for telematic applications based on a group of sensors/actuators with many application environments, such as smart agriculture, environmental protection, transportation, animal tracking, and so on. This scenario is more suitable for LEO/HAP/UAVs cases.

Particularly critical for the case of mMTC communications is the direct access to satellite, a requirement only met by LEO satellites today. The alternative is to aggregate sensor data on the ground by using rendez-vous nodes [10] before delivering traffic via satellite-based backhaul service; this scenario may require additional ground network infrastructures.

Satellite systems can support URLLC-like services requiring high reliability and high availability, but taking into account that extremely low latency is physically unfeasible in satellite systems.

Several service categories, shown in Figure 1, have been identified in the last two decades, in which aerospace networks have already been offering broadcast, broadband, and content caching services via satellite trunks.
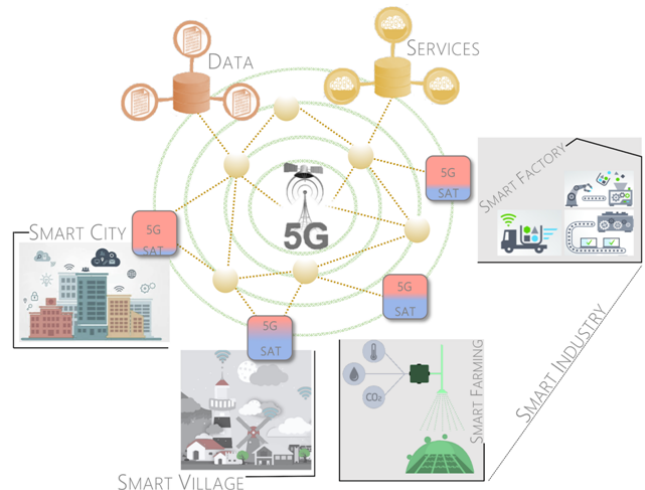

Fig. 1. 5G application scenarios.

Many of these services are mapped to 3GPP suitable use cases to be implemented in the following 5G scenarios [11] [12]:

- *smart city*: in recent years, the push towards the development of smart cities is significantly increasing due to the rapid growth of urbanization experienced around the world. Urban areas, characterized by a high density of users, can dramatically benefit from technological

solutions devised to sustainably manage resources, as evident from the numerous pilot projects (smart parking, smart transport, smart wastes, smart lightning) running worldwide [13]. In such a scenario, the communication infrastructure, providing connectivity between users and myriads of smart sensors and devices, has a critical role. Although in urban areas terrestrial networks are usually characterized by good coverage, redundancy of access points, and high capacity, the role of satellite and aerial networks is predicted to grow. There are at least three main needs that can justify such a trend: (*i*) to guarantee service resilience and continuity by providing global coverage for high mobility nodes or in case of disasters; (*ii*) to add on-demand capacity by deploying additional cells (in space and time) when needed; (*iii*) to monitor applications by building high-level views of the city status and to improve the predictions of particular events (turbulence dynamics, traffic jam origins, pollution propagation).

- *smart industry*: companies are witnessing the rapid renewal of industrial technologies thanks to the IoT paradigm. Trend reports [14] show that at the end of 2017 hundreds of millions of industrial devices were IoT-ready: the so-called Industrial IoT (IIoT). Nowadays, most small and medium industrial manufacturers are still endowed with wired connections, failing in the fast adoption of recent ICT innovations. This is due to the requirements of reliability, low latency, and long-range communication imposed by industrial processes, so that the conversion to IIoT systems can result rather expensive. Such problems can be mitigated through the recent advances in 5G and aerospace communications technologies by exploiting the cost reduction that will be brought by economies of scale in the ICT sector.

- *smart village*: low populated and low-income areas are the ones suffering more from the so-called digital divide, including the absence of ICT infrastructure providing Internet connectivity. Connectivity can be considered an urban phenomenon, where high revenues are the main driver for operators. The same cannot be said in rural/isolated scenarios. The real barrier to deployments is the lack of potential revenue per square mile, which can be several orders of magnitude lower than in urban or industrial scenarios. Low-cost and energy-efficient equipment, along with Software Defined Networking (SDN) and Network Function Virtualization (NFV) approaches, is the most promising solution to overcome such an issue, accounting for the joint use of terrestrial, aerial, and spatial communication networks in hierarchical network architectures [15]. The role played by aerospace platforms is crucial because they allow wide coverage also including under-served areas. Unmanned Aerial Systems (UASs) are already one of the fundamental pieces to provide connectivity in resource-less scenarios [16], [17]. They can be deployed on-demand, providing adjustable coverage and platform topology.

III. NETWORKING CHALLENGES AND SOLUTIONS

In this paper, we focus our attention on two specific networking challenges, described in Sections III-A and III-B.

A. Smart Gateway Diversity

Due to the continuous increase of the traffic volume on the Internet, traditional terrestrial systems will not likely meet users' demands all over the world. Employing SatCom networks in order to support the terrestrial ones and to overcome their limitations is one of the key solutions to increase the offered coverage and network throughput, both as requirements to match the rapid 5G ecosystem growth. Data exchanges through satellite links should exploit higher frequency bands than the ones used in current SatCom systems in order to guarantee the 5G Key Performance Indicators (KPIs). Q/V frequency bands ($33 \div 75$ GHz) seem suitable for this purpose, even if attenuation due to rain and clouds is significant at these frequencies, thus leading to temporary outages in the feeder links. Some impairment mitigation techniques have been developed: for instance, Adaptive Coding and Modulation (ACM) involves the adaption of modulation and code robustness (MODCOD) depending on the measured attenuation level. Even if ACM has been proved useful, being employed in different satellite communication protocols such as DVB-S2 and DVB-S2X, this technique may be less effective to cope with attenuation on the link between gateways and satellites at these frequencies. The main reason is the decrease of the spectral efficiency induced by the change of waveform (i.e., a set of transmission parameters) affecting user terminals, which can lead to network congestion. The concept of Smart Gateway Diversity was introduced to help overcome this issue. In a SatCom network, where a set of terrestrial gateways is connected through high-speed terrestrial links, the proper design of the ground segment can exploit spatial decorrelation to reduce the impact of the aforementioned issues, taking into account minimum distances among gateways. In this way, when the satellite link of a gateway suffers from high attenuation and consequent outage, other gateways can deliver its traffic until the outage ends, so obtaining an increase of the network availability and throughput. Gateway Diversity has been initially introduced in [18]. Based on this first article, studies have been conducted to tackle the issue of moving the traffic to upload on a satellite from one gateway to another in case of outages [19]–[22].

In this work, we introduce the smart gateway solution under development that we propose, able to properly choose to which satellite gateway data flows can be forwarded among a set of gateways operating at Q/V band, all in visibility of the satellite at the same time, in order to guarantee minimum performance requirements. Figure 2 shows a schematic representation of the considered scenario.

Satellite gateways (GWs) are the access nodes to the space segment and are interconnected through a common terrestrial infrastructure. A set of Network Control Centers (NCCs) are co-located in the GWs and periodically collect measured Signal-to-Noise Ratio (SNR) of the feeder links. Information
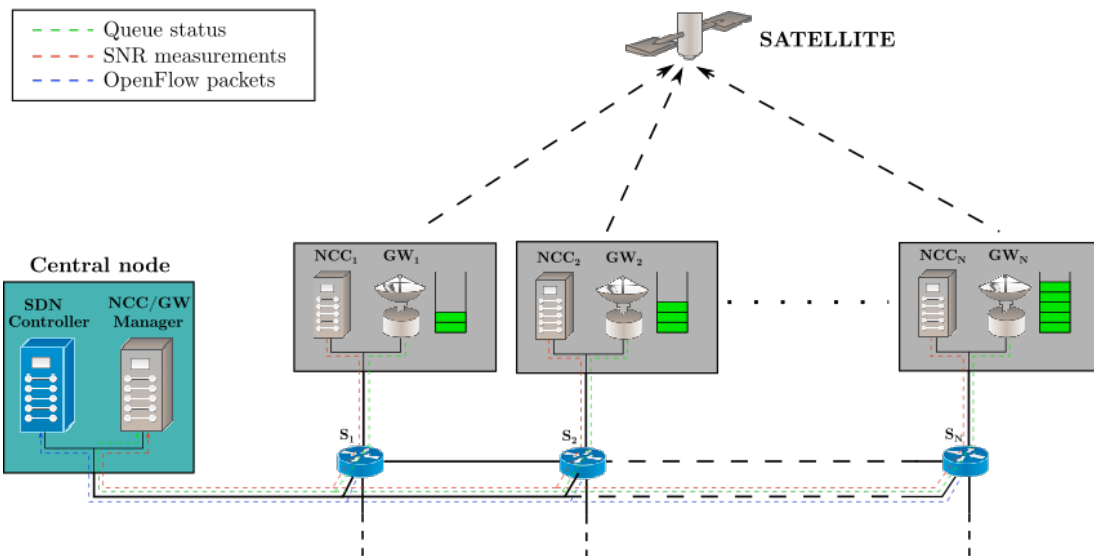
Fig. 2. Smart gateway diversity scenario.

about the current status of the network, such as gateway queues and satellite links' SNR, will be considered as possible input variables of the decision process. The exchange of network status information will be investigated by considering the employment of de-facto standard protocols, such as OpenFlow, to allow exploiting the SDN paradigm to re-route data traffic. A central entity, such as an SDN controller, canalizes traffic flows through the selected GWs by computing and sending proper forwarding rules to SDN-enabled devices, such as SDN switches. These nodes follow the received rules keeping them stored in a *flow table*. When a new flow enters the network, the incoming SDN switch checks its flow table to find the rules related to that flow. If the rule is present, data is forwarded according to the rule, otherwise, the SDN switch asks the controller for instructions. Information about required data delay, throughput, loss, as well as GW buffer occupancy, can be exploited for rule computation. A prediction algorithm based on machine learning (e.g. linear regression) will estimate how each measured SNR evolves over time and will predict outage events in order to take countermeasures in advance by properly re-distributing the traffic volume among the gateway set. The NCC/GW Manager is where the algorithm computation is performed. SNR trends and predicted link outage events will be additional information considered in the rule computation process. We will also investigate the possibility of splitting traffic flows into more gateways, by sending the data packets belonging to the same flow to multiple gateways simultaneously. It is also worth considering that the smart strategy can be implemented as a Virtual Network Function (VNF) dynamically allocated/deallocated when required closer to the gateway set, i.e. at the edge of the network by exploiting the Mobile Edge Computing (MEC) paradigm [23].

B. Satellite-based hybrid backhaul exploitation

The reference 5G architecture, shown in Figure 3, envisages UEs connected to a RAN which, in turn, provides connections to the public Data Networks (DNs).

Such connections typically leverage terrestrial backhaul links, actually linking RAN with the 5G core site hosting Core Network (CN) functions. In this baseline communication scenario, 5G system specifications define and foster edge computing enablers, to deploy local applications and services at the network edges. In this way, MEC and 5G collaboratively interact in traffic routing and policy control operations by spreading the User Plane Function (UPF) of the 5G-CN [24] along with both edge and core sites, while the control is still in charge of the 5G-CN. This advanced feature can further benefit from the introduction of a hybrid satellite-terrestrial backhaul with optimized performance. Regarding IP services, it is possible to exploit the role of Performance Enhancing Proxy (PEP) architectures in 5G scenarios. Virtual PEP (vPEP) can be herein defined as a set of VNFs optimized for the exploitation of either a complementary or an alternative satellite link. We then observe the latest transport layer technology developments with the aim to better deal with packet flow management. PEP-PEP communications can work on per-flow-basis, allowing multiplexing, multi-path, and dynamic switching. Performance analysis will be carried out in order to test the efficiency of a PEP-PEP architecture enabling a satellite backhaul, where vPEP instances are composed by VNFs leveraging the most recent transport layer technologies. Specifically:

- *TCP Wave* [25]–[27]: it is a recent alternative transport protocol that pursues by design the objective to work around the optimal operating point, i.e. the achievement of the maximum throughput without inflating physical delays.
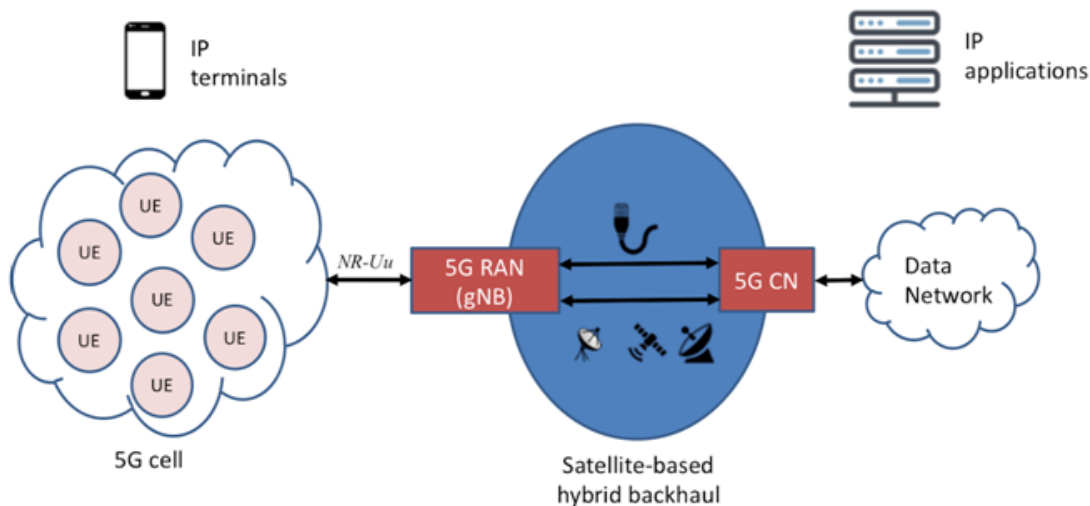
Fig. 3. 5G scenario with hybrid satellite-terrestrial backhaul links.

- *MP-TCP* [28]: it has been designed and developed as a new transport protocol placed in a so called *shim* layer between transport and application layers, transparently exploiting multi-homing.
- *QUIC* [29]: it is a general-purpose transport layer protocol exploiting some of the winning concepts of HTTP/2 (i.e. streams, multiplexing) by introducing several cutting-edge features, among which the most important is establishing multiple multiplexed connections between two final users through UDP. This implies to move all the functions traditionally performed by TCP (i.e. congestion control, retransmissions) to an upper layer.

IV. Conclusions

NTN can play an important role in the development and growth of the 5G network by supporting the terrestrial infrastructure and overcoming some of its limitations. Different application scenarios will benefit from the integration between terrestrial and non-terrestrial networks. This paper briefly surveys some of them. Different research challenges are yet to be solved, thus requiring additional efforts to properly guide the final steps of the 5G standardization process.

In this paper, we highlight two networking aspects still open to investigations. The first one is related to gateway diversity, which translates into choosing the proper satellite gateway, within a given set, for data deliver via satellite, in the case of a temporary outage of one of the other gateways, in order to meet the expected QoE.

Additional information about the current and future predicted status of the network, such as the measured SNR of satellite feeder link and gateway buffer occupancy, could improve the overall traffic flows' performance, better exploiting the available bandwidth and quickly reacting to possible outage events. The second challenge is related to the exploitation of satellite links as additional backhaul to terrestrial networks.

In particular, we match the definition of strategies to properly assign different traffic flows to multiple available paths, also considering the simultaneous use of more than one path with optimized traffic load share. This traffic engineering/traffic offloading scheme could take path congestion and RTT into account, as well as traffic flow characteristics and QoS requirements.

Careful attention is needed in the last steps of the 5G standardization process in order to effectively include satellites as part of the 5G network. The architectural effort toward it is partially relieved by the exploitation of network virtualization techniques, as in the case of NFV, MEC, and slicing.

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