Satellite Communications for 5G

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September 27, 2019

https://www.comsoc.org/publications/ctn/satellite-communications-5g-promising-yet-challenging
https://www.comsoc.org/publications/ctn/satellite-communications-what-will-happen-after-5g

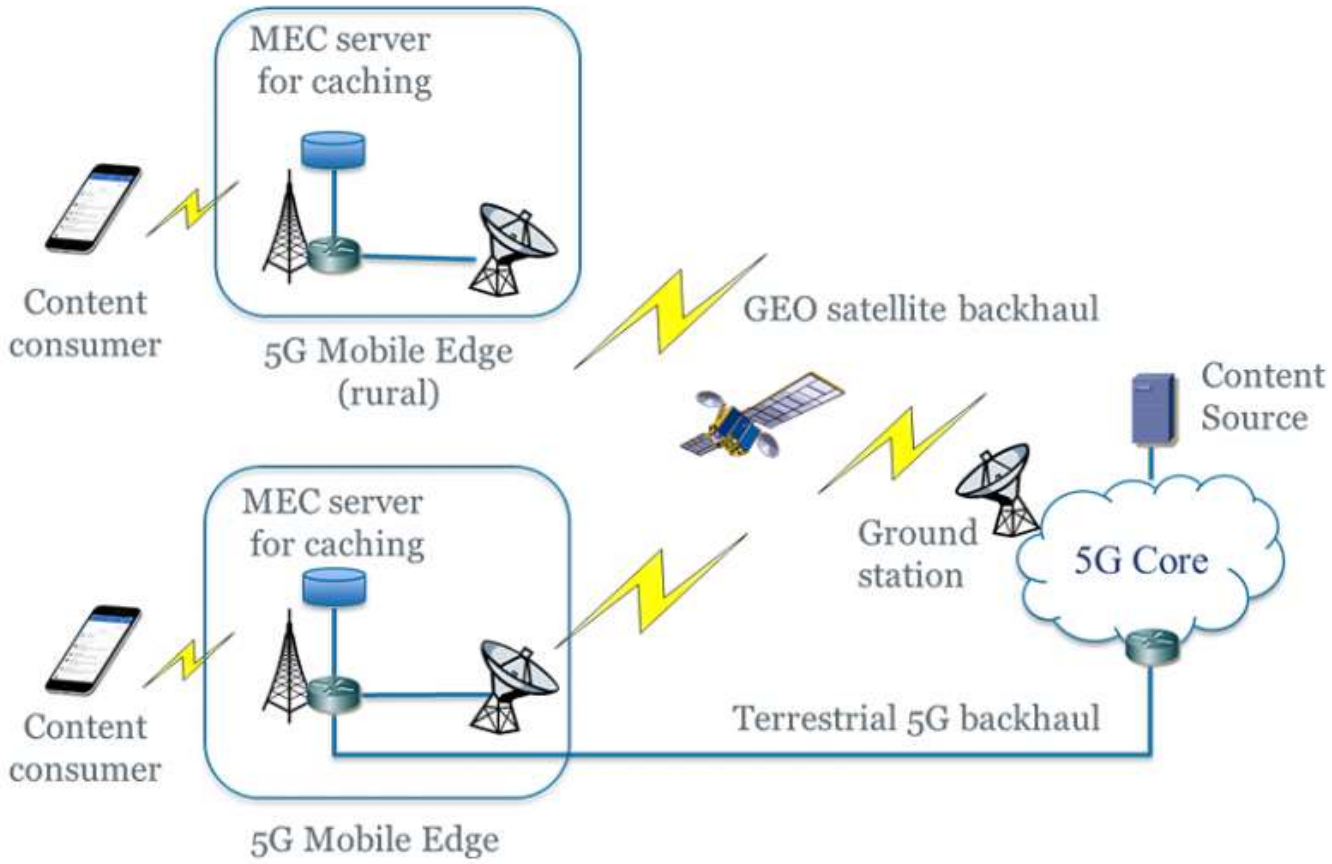
Introduction

- Traditionally, satellite communication has remained standalone and separated from the technical domain of mobile networking

- Satellite and Terrestrial Networking for 5G (SAT5G)
  - SaT5G project will bring satcom into 5G by defining optimal satellite-based backhaul and traffic offloading solutions. We are researching, developing and validating key 5G technologies in order to take the best value of satcom capabilities *(e.g. multicast for content and VNF delivery)* and mitigate its inherent constraints (*e.g. latency*)

Satellite communication

- Pros and cons –
  - On one hand, satellite communication enables wide geographical connectivity coverage without necessarily deploying fixed infrastructures such as cable links, making it an efficient solution for rural and remote area coverage
    - Additional strengths include high bandwidth capacity and the capability of content broadcasting and multicasting on a large scale
  - Latency incurred by satellite links has remained an issue for some services, especially for GEO satellite systems
    - However, by caching at the edge this can be avoided



A GEO satellite link connects the central 5G core network and multiple remote 5G mobile edges

- In rural areas satellite may be the only backhaul option but also in other areas satellite can still be used in conjunction with terrestrial means

- In content delivery networks the role of satellite can be to offline deliver (popular) content to the mobile edge and cache it at the local MEC servers
  - local users will be able to access the pre-cached content at the attached MEC server - enhanced user experiences and reduced content traffic volume

- SaT5G project has studied the feasibility of transmitting HLS (HTTP-based Live Streaming) based live streaming content with UHD 4K video at a bitrate of 20Mbps through satellite-backhauled 5G network infrastructure
  - With a conventional end-to-end delivery scheme, it has been verified that the user experiences were extremely poor due to limited TCP throughput incurred by satellite link latency
  - However, the project team have designed and developed a MEC-enabled scheme to break the end-to-end connection with a transient video segment holding technique at the mobile edge
    - The playback performance has been substantially improved with complete avoidance of streaming disruptions

Resource Optimization on Parallel Backhaul Links

- Given that satellite communication offers an additional channel for carrying traffic over 5G backhaul, context-aware policies or mechanisms need to be in place to properly steer traffic through either satellite or terrestrial backhauls
  - This will trigger research on backhaul optimization by taking into account a wide variety of contexts:
    - type of traffic, traffic load, location of destinations etc.
  - Investigate multipath connections based on MP-TCP or MP-QUIC for performance optimality

Holistic Orchestration of Network Functions

- The orchestration architecture of a satellite network operator (SNO) when used as transport networks for 5G mobile network operator (MNO) networks partly depends on how the SNO networks support the MNO networks and partly on the virtualization architecture underlying the SNO networks

- Both SNO and MNO networks may encompass specific network functions, so how to orchestrate them in a holistic way while confirming to their respective operational objectives is a key technical issue

Further Complexity in the Business Model

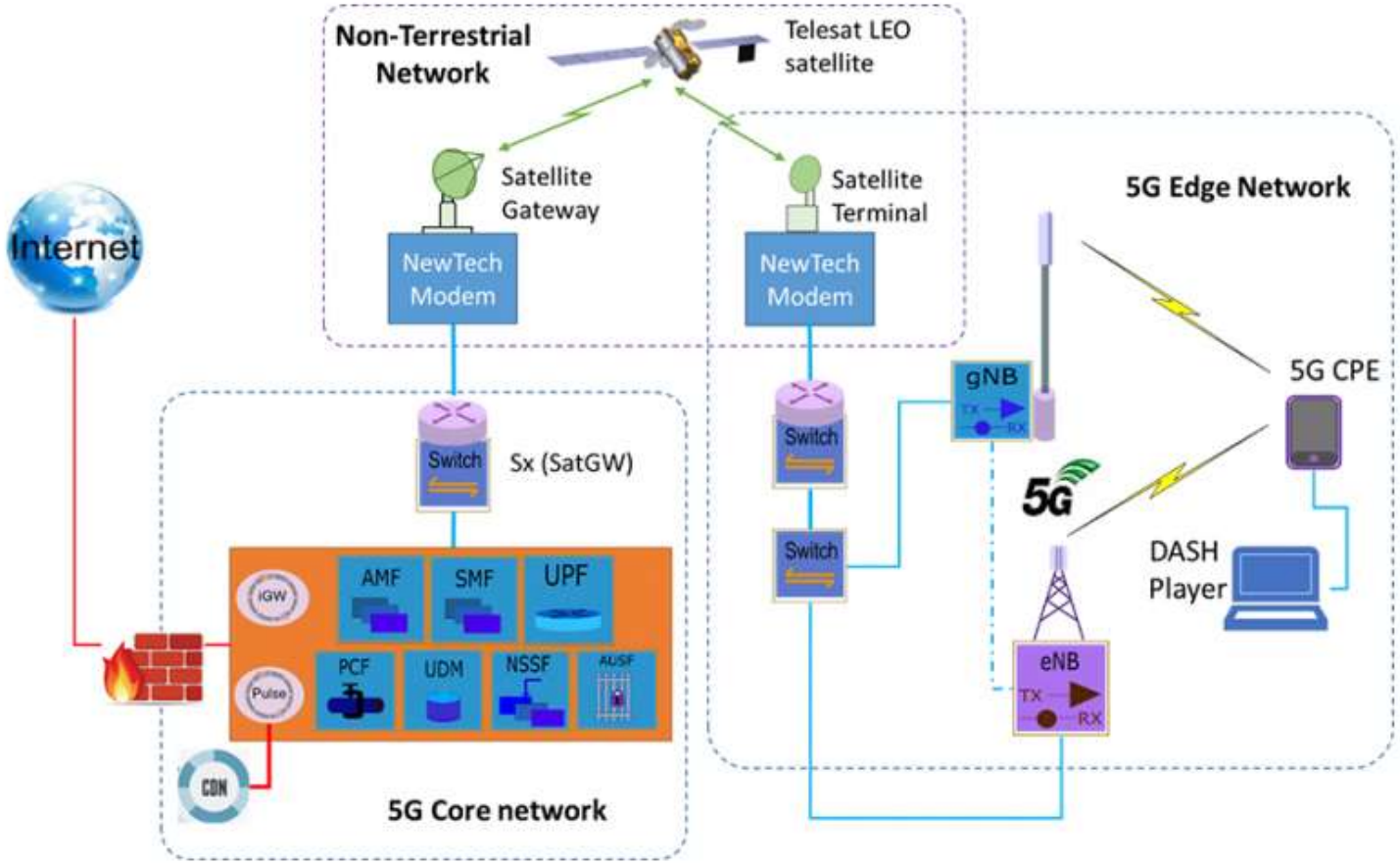
- The business implication is that the SNO will become a new stakeholder in the evolved 5G ecosystem
  - One SNO can virtualize the satellite link capacity and provide backhaul services to multiple MNOs, and here the role of a broker would be interesting
  - Meanwhile, a MNO can slice the overall resources (including both terrestrial and “leased” satellite backhaul) to support different vertical applications, and the satellite backhaul may only be used in a subset of these slices
- Concerning content delivery services, how to holistically enable a win-win business relationship between MNO, SNO and CDN operator in future satellite-enabled 5G environments?

- Role of satellite communications in the context of 5G where GEO satellite links can be used as 5G backhaul connecting the core network and remote mobile edge infrastructure is envisioned

- Compared to GEO satellites which introduce long latency and each alone covers limited geographic locations, networked LEO satellites become a more attractive solution to form a new layer of Internet in the space
  - *5G network backhauled by LEO satellite link with evaluations on throughput, latency and handover performance between the satellite and the ground infrastructures*

- In April 2019, Telesat, Vodafone and 5GIC University of Surrey as a World first tested the performance of integrated 5G core network backhauled with a Ka-band LEO satellite, successfully streaming end-to-end 4K/8K DASH video content

  – The main purpose is to carry out a realistic feasibility test on 5G network backhauled by LEO satellite link with evaluations on throughput, latency and handover performance between the satellite and the ground infrastructures


Non-Terrestrial Network
Telesat LEO satellite
Satellite Gateway
Satellite Terminal
NewTech Modem
NewTech Modem
5G Edge Network
Internet
5G CPE
gNB
Switch
Sx (SatGW)
Switch
Switch
5G
DASH Player
AMF
SMF
UPF
iGW
PCF
UDM
NSSF
AUSF
Pulse
eNB
TX
RX
CDN
5G Core network

How LEO satellite networks can play an active role towards the realization of future parallel space Internet to its terrestrial counterpart?

Challenges in Dealing with Mega-Constellation of LEO Satellite Networks

- Dynamic (but predictable) changes of network topology - leads to frequent handover events between LEO satellites and ground infrastructures

- A ground station is only able to connect to one particular LEO satellite passing by for less than 10 minutes (typical altitude of 1000Km) for each encounter, and the frequency of the encounters with that satellite is 3 per day

- If we have hundreds or even thousands of LEO satellites in space for global coverage, the high complexity of handovers will be a key issue to be addressed
  - The good news is that since the encounters are completely predictable, make-before-break strategies can be applied for seamless service assurance to customers

- From routing point of view, proposals from academia during the past two decades were mainly based on tunneling approaches across the LEO satellite network running dedicated protocols which are not necessarily exposed to the ground infrastructure

- There has been the vision of deploying an all-IP based solution in future LEO satellite networks for better interfacing with ground infrastructures
  - In this case, assuming LEO satellite networks will form their own domains (a.k.a. autonomous systems) in the space, then how BGP routing stability across boundaries between space- and terrestrial-based networks is affected by global scale of mega-constellations will also become a key technical issue

Challenges in Supporting Direct User Device Access

- Nowadays the default scenario is to connect user devices to the satellite network through ground stations
- In this case the ground station is an ideal location to deploy various network functions including protocol translation, security and access control etc.
  - When user devices are enabled to directly connect to the LEO satellites over the head, it will introduce new complexity

- It is required that all LEO satellites run the protocol stack, at least up to the IP layer, that can directly interface with the devices on the ground
  - Access/admission control functions will need to migrate to individual on-the-move LEO satellites rather than any ground-based network components
  - Potentially, one interesting issue is how to coordinate the admission control of incoming traffic among LEO satellites in order to avoid traffic congestion on those links, especially giving that each LEO satellite takes the role of both an “access” nodes interfacing user devices and at the same time a “core” node for forwarding packets along paths in the space

Challenges in Providing Edge Computing and Storage Services in the Space

- The current vision of constructing LEO satellite based parallel Internet in space is mainly for supporting data transmission as data pipes
  - Extension to enable content storage or even computing capabilities on board at LEO satellites

- Round-trip time (RTT) range is between 10 and 50 milliseconds largely depending on the satellite elevation, which can potentially outperform terrestrial Internet paths across continents

- While it is conceivable to localize services by bringing computing and storage capabilities closer to end users, once again such a solution faces the issue of short-time service period from each encountered LEO satellite, and thus seamless handover between neighboring satellites need to be in place, e.g. content caching management on board
  - Technical challenges on the feasibility for lightweight LEO satellites to fulfill complex jobs beyond packet forwarding, especially concerning energy consumption requirements in such an environment