Università degli Studi di Padova

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Master Thesis in ICT for Internet and Multimedia

Scheduling resources and managing HARQ retransmissions in Non-Terrestrial Networks

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To my parents
and friends

Abstract

Sommario

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TN Terrestrial Networks

NTN Non-Terrestrial Networks

NTNs Non-Terrestrial Networks

HAPs High-Altitude Platforms

HAP High-Altitude Platform

UAVs Unmanned Aerial Vehicles

UAV Unmanned Aerial Vehicle

MEO Medium Earth Orbit

HARQ Hybrid Automatic Repeat reQuest

NR New Radio

LEO Low Earth Orbit

GEO Geosynchronous Equatorial Orbit

UE User Equipment

RACH Random Access CHannel

gNB gNodeB

3GPP Third Generation Partnership Project

MAC Media Access Control

RTT Round-Trip Time

1 Introduction

Non-Terrestrial Networks (NTNs) denote a category of networks where at least one link is routed via an aerial or space-borne vehicle such as High-Altitude Platforms (HAPs), Unmanned Aerial Vehicles (UAVs) or telecommunication satellites.

1.1 The focus on non-terrestrial networks

The Third Generation Partnership Project [1] (3GPP), the standardization body developing protocols for mobile communication networks, recently put a great emphasis on the importance of the integration of different access technologies with the existing terrestrial mobile telecommunication infrastructure [1]. The envisioned future for mobile communications, starting with the already established 5G New Radio (NR) and expanding with the new sixth-generation cellular networks, foresees the integration of a non-terrestrial component. The latest releases (Rel. 17 and Rel. 18) require that 5G and 6G systems shall be able to provide connectivity exploiting non-terrestrial, satellite access [8] [7].

Limitations of terrestrial networks

Remote places While Terrestrial Networks (TN) make the well-established foundation of today's mobile communication infrastructure, their own nature

[1] `3gpp.org`

poses some intrinsic limitations to their deployment in certain scenarios, especially in rural and remote areas. Conditions such as harsh terrain and hard to reach places act as natural barriers to the deployment of terrestrial infrastructure, which also requires the presence of an already established reliable power grid, driving up the costs that telecommunication companies would have to sustain. Furthermore, the population density is often low in remote and rural places, making this kind of market particularly unattractive to private investors, further limiting the possibility for the people living there to access a resource which is becoming increasingly more important.

As studied and documented in [12], the issue of an inadequate broadband coverage to rural regions is an enormous challenge, but also a great opportunity to kick start the economy of currently underdeveloped countries, promoting a more fair access to the internet and alleviating the infamous digital divide between different parts of the world.

Redundancy Another limitation of the current terrestrial infrastructure is the lack of robustness against natural disasters. Extreme events such as earthquakes, fires and floods, but also deliberate behaviours such as targeted attacks by terrorist organizations and sabotages can disrupt the connectivity for a prolonged duration, hindering rescue efforts and causing significant economical damage. In this scenario, NTNs can act as redundant access methodology, both to reduce downtimes of terrestrial infrastructure and to provide additional capacity when required.

Long distances Remote equipment, offshore plants and distribution grids will also benefit from the research carried out in this field, since providing terrestrial connectivity in those scenarios would be a challenging task. The installation of an optical fiber link to serve a single endpoint, such as a wind turbine powered power plant in the ocean, or where many sensors needing a connection are placed in a large area, would be excessively costly [10].

Other scenarios where NTNs can become useful in overcoming the limitation of a terrestrial network are well descripted in [3] and [11].

1.1.1 Satellite types

Depending on the orbit, satellites are classified in three main categories: Geosynchronous Equatorial Orbit (GEO), Medium Earth Orbit (MEO) and Low Earth Orbit (LEO).

- **GEO satellites**: orbiting at 35.786Km, GEO satellites appear stationary since their orbiting period is the same as the Earth rotation period. This simplifies the tracking, and each satellite can provide connectivity to a fixed area. Their higher altitude creates a large cell footprint, larger than both MEO and LEO, so the cost per coverage area is lower.

  Cons are mainly linked to the large distance between the User Equipment (UE) and the satellite: the transmission power and the antenna gain have to be higher to account for the greater propagation losses, and the propagation delay of the signal travelling at the speed of light is 120ms, so if the UE sends a request to a server at time zero through a GEO link, the best-case delay will be of 480ms, taking into account only the propagation delay. The large cell footprint also means that a single satellite will be serving a massive number of users, so the total available capacity will have to be shared between more users, threfore the throughput experienced by each one of them will be reduced.

1.1.2 Current solutions

Current solutions for non-terrestrial communication do exist, but they mostly rely on telecommunications satellites placed in the GEO, at a height of 35.786 km. The distance that the signal has to travel offering limited throughput and large delays. While LEO constellations (400 km to 2.000 km) have proven to be a valid alternative, providing higher throughput and lower latency [13], they have the drawback of an increased Doppler shift due to their high speed relative to ground [4], and there is still no international standard with regard to the communication protocols to use.

This scenario led Third Generation Partnership Project (3GPP) to identify some work to be done to integrate Non-Terrestrial Networks (NTN) in cellular standards, calling for long-term research in this field [4]. This work will mainly focus on the

TODO: move this to state of the art Focusing on the Media Access Control (MAC) sublayer, the large propagation delay of satellite links affects different aspects, making the actual implementation not suited for a NTN scenario. In the Hybrid Automatic Repeat reQuest (HARQ) protocol, the retransmission timeout is likely to expire before a single Round-Trip Time (RTT), leading to unnecessary retransmissions. Moreover, the limit on the maximum number of concurrent HARQ processes leads to a stop-and-wait behaviour, which may increase the energy consumption [2]. On the other hand, it has been noted that disabling HARQ would lead to an even worse performance penalty, therefore requiring a redesign for NTN [9]. Another 5G NR protocol which is negatively impacted in NTN is the initial access, since users at the centre of the cell face a smaller propagation delay with respect to users at the cell edge [9] [6]. As a result, preambles of UEs placed near the cell edge may reach the satellite when the Random Access CHannel (RACH) opportunity has already expired, which may lead to collisions. During the initial access phase, UEs are not aware of their propagation delay, and the high mobility of gNodeB (gNB)s on LEO satellites causes a non-negligible Doppler shift. Those factors vary with the relative position and speed between the UE and the gNB, and the protocols for initial access must be modified in NTN to account for them [5].

It is clear that the future of mobile networks envisioned by 3GPP embraces NTNs, and considerable work has to be done. Research will bear a high impact towards a more connected, equal opportunity world.

1.2 Currrent state of the art

TODO: types of payloads: regenerative, and transparent or bent pipe

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Background

Algorithm 1 An algorithm with caption

Require: $n \geq 0$
Ensure: $y = x^n$
  $y \leftarrow 1$
  $X \leftarrow x$
  $N \leftarrow n$
  while $N \neq 0$ **do**
    if N is even **then**
      $X \leftarrow X \times X$
      $N \leftarrow \frac{N}{2}$ {This is a comment}
    else if N is odd **then**
      $y \leftarrow y \times X$
      $N \leftarrow N - 1$
    end if
  end while

$$e^{j\pi} + 1 = 0 \tag{2.1}$$

3 Analysis

3.1 A section

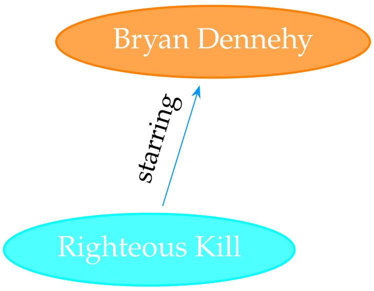

Figure 3.1: Image created with TikZ

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```
import numpy as np

def incmatrix(genl1,genl2):
    m = len(genl1)
    n = len(genl2)
    M = None #to become the incidence matrix
```

```
    VT = np.zeros((n*m,1), int)  #dummy variable

    test = "String"

    #compute the bitwise xor matrix
    M1 = bitxormatrix(genl1)
    M2 = np.triu(bitxormatrix(genl2),1)

    for i in range(m-1):
        for j in range(i+1, m):
            [r,c] = np.where(M2 == M1[i,j])
            for k in range(len(r)):
                VT[(i)*n + r[k]] = 1;
                VT[(i)*n + c[k]] = 1;
                VT[(j)*n + r[k]] = 1;
                VT[(j)*n + c[k]] = 1;

                if M is None:
                    M = np.copy(VT)
                else:
                    M = np.concatenate((M, VT), 1)

                VT = np.zeros((n*m,1), int)

    return M
```

Code 3.1: Code snippet example

4

Conclusions and Future Works

A	**B**
C	D
E	F
G	H

Table 4.1: Table example

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