UNIVERSITY OF PUERTO RICO
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COMPUTER SCIENCE AND ENGINEERING
DEPARTMENT

Computer Networks

CIIC – 4070

Report 1: Bandwidth and Capacity of Wireless Communication Systems

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Table of Contents

List of Tables

List of figures

Introduction

In this report of Bandwidth and Capacity of Wireless Communication Systems will learn to handle and understand the different types of bandwidths and wireless communications. I will start looking for basic concepts such as components to define the bandwidth in a signal and in a wireless connection. Then I will analyze the Shannon Capacity in a wireless connection. From this I will inform myself about the regulations in 30dBi antennas, their transmission power, and the meaning of the different concepts. I will proceed to work with the standards imposed by the IEEE organization and seek answers to different questions from wireless network users. I will create tables where I will summarize the bands of famous systems such as Wi-Fi or Bluetooth. All the information about the satellites of the Starklink company will be sought and it will be shown how its satellites cover Puerto Rico at times of the day.

The Basics

1. To define the bandwidth of a signal, we need 3 essential data:
    - The Center Frequency (f_0)
    - The Higher Frequency Cut-Off $(f_{H)}$
    - The Lower Frequency Cut-Off (f_L)

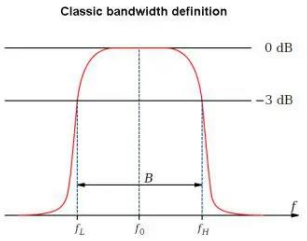

Figure 1.1 Bandwidth Example Definition

The bands of the signals are often calculated with the highest and lowest frequency managing to find the center frequency. It should be noted that some processes or protocols may limit the band and that the band itself can be a component.

2. To define the bandwidth of a wireless channel, we need 3 essential data:
    - Channel Bandwidth
    - Modulation Scheme

- Data Rate

These components are essential for wireless connection bandwidth. Starting with the bandwidth channel, we determined that it is critical as it is defined as the amount of data frequency available. The higher the bandwidth channel, the greater the amount of information it can receive. Following this we have the modulation scheme which is responsible for the efficiency of data transportation. Data rate is another essential component to the amount of data that can be transmitted per second ($S = A/T$) where A is the amount of data, T is the transfer rate and S are the seconds on a wireless channel.

3. Shannon Capacity

We can define the Shannon Capacity as the maximum mutual information of a channel in terms of wireless networks. This comes from Shannon's coding theorem and converse which shows what is the maximum amount that a transmission channel can support. The theorem depends on several factors such as the bandwidth of a channel, the power of the signal to be transmitted and the noise level in the signal and the quality of the signal that is being received.

$$C = B * log_2(1 + \frac{S}{N})$$

This is the formula of Shannon Capacity's theorem. It can be described as the Capacity (C) is equal to the bandwidth in the channel (B) multiplied by logarithm 2 of Signal (S) to Noise (N) ratio.

The Regulations

1. The maximum transmitter output power fed into the antenna is 30 dBm (1 watt).
2. EIRP stands for Maximum Effective Isotropic Radiated Power.

3. In simple words dBi stands for Decibels Relative to Isotropic. In networks it is the unit of measurement used to measure the gain of an antenna or a logarithmic relationship between the emission power of an antenna in relation to an isotropic radiator.
4. The following antennas can transmit 30dBi:

Figure 2.1 UISP airMAX 5 GHz, 30 dBi RocketDish Antenna

2x2 PtP Bridge Dish Antenna

Figure 2.2 Antenna world G5730 5.72-5.85 GHz 30 dBi Parabolic grid Directional antenna

Wireless Network Point-to-Point

Figure 2.3 Mikro Tik Mant30 Mtad-5g-30d3 30dbi Parabolic Dish Antenna

5. The cost of the antennas:

- UISP airMAX 5 GHz *(Figure 2.1)* cost **$150.00** on UISP store *(www.ui.com)*

- G5730 5.72-5.85 GHz 30 dBi Parabolic Antenna *(Figure 2.2)* cost **$75.00** on *(www.amazon.com)*
- Mikro Tik Mant30 Mtad-5g-30d3 30dbi Parabolic Antenna *(Figure 2.3)* cost **$140.00** on *(www.ebay.com)*

The Standards

1. The IEEE 802.11 has established several requirements for the use of $20MHz$ channel. The standards are as follows:
    - It must have a $0dBr$ of bandwidth and may not exceed $18MHz$.
    - Have to comply with $-20dBr$ at $11MHz$ offset frequency.
    - Have to comply with $-28dBr$ at $20MHz$ offset frequency.
    - Have to comply with a maximum of $-40dBr$ at $-53dBm/Mhz$ offset frequency.
    - The transmitted spectral density of the transmitted signal shall fall within the spectral mask.
    - The measurements shall be made using a $100kHz$ resolution bandwidth and a $30kHz$ video bandwidth.
2. Some people often claim that they have the same channel as an 18MHz bandwidth for the reasons mentioned below:
    - Many times a **guard band** *(narrow frequency range that separates two ranges of wider frequency)* reduces the channel managing to confuse people.
    - **Interference** from adjacent channels or from a guard band can limit bandwidth.
    - May be due to the **modulation scheme** to transmit the information.
    - **Product** specifications vary from standard.

3. Some people often claim that they have the same channel as an 22MHz bandwidth for the reasons mentioned below:
    - The channel could be seen wider if it is overlapping by another channel or an adjacent channel. Although there is a 22MHz model it is not the common reason.
    - **Device** specifications vary from standard bandwidth.

Systems	**Standard**	**Spectrum Band**	**Bandwidth**	**Maximal Transmission Power**	**Typical Transmission Power**	**Maximal Data Rate**
Near Field Communication (NFC)	ISO/IEC 18092 GSMA NFC Forum Standard	13.56MHz	1MHz	6mW in US 2W in EU	4 cm	424 Kbps
Bluetooth v. 5.0	SIG IEEE 802.15.1	2.402 – 2.480 GHZ	2MHz	2.5 mW	240 meters	2.1 Mbps
Zigbee	IEEE 802.15.4	2.4GHZ 900MHz 868 MHz	2MHz	1-4 watt (0dBm to 36dBm)	10-100 meters	250 Kbps
Wi-Fi 5	IEEE 802.11axc	5 GHz	80MHZ	~20dBm	15 meters	3.5 Gbps
WiGig	IEEE 802.11ad IEEE 802.11ay	60GHz	2.16GHZ	40dBm in US 20dBm in EU	10 meters	7 Gbps

Table 3.1 Features of the Different Systems

The Starlink System

1. Starlink satellites mainly hover around an altitude of 550 km (432 miles). May be subject to variation.
2. The Frequency Bands for the following orbits are:
    - $L-band$ $(1-2\ GHz)$
    - $C-band$ $(4-8\ GHz)$
    - $X-band$ $(8-12\ GHz)$
    - $Ku-band$ $(12-18\ GHz)$
    - $K-band$ $(18-27\ GHz)$
    - $Ka-band$ $(26-40\ GHz)$
    - $V-band$ $(40-75\ GHz)$
3. The Bandwidths for the above bands are:
    - $L-band$: $1\ GHz$
    - $C-band$: $4\ GHz$
    - $X-band$: $4\ GHz$
    - $Ku-band$: $16\ GHz$
    - $K-band$: $18\ GHz$
    - $Ka-band$: $14\ GHz$
    - $V-band$: $37.5\ GHz$
4. For an existing user the range of received power is between -120dBm and -50dBm.
5. The maximal uplink data observed at an existing user terminal is around 20 Mbps.
6. The maximal downlink data rate observed at an existing user terminal is around 200 Mbps.

7. The minimal uplink latency observed at an existing user terminal is 40ms

8. The minimal downlink latency observed at an existing user terminal is 20ms

9. Puerto Rico Covered by a Starlink satellite:

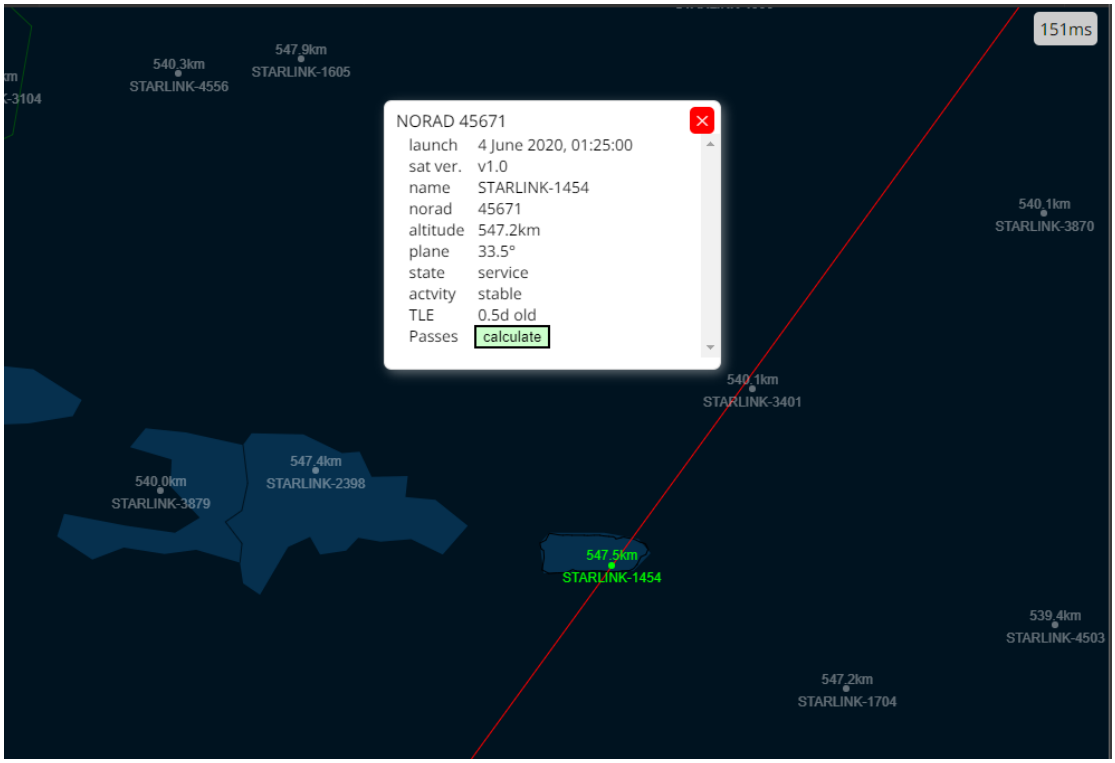

Figure 4.1 Starlink Satellite above Puerto Rico (NORAD 45671)

Conclusion

After completing the Bandwidth and Capacity of Wireless Communication Systems report I was able to learn several skills about the operation of the bands and how they are regulated. Starting with the basic knowledge on how to define the bandwidth of a signal, the bandwidth of a wireless channel and the handling of the Shannon Capacity theorem. Then by reading and searching the internet I analyze and observe the different regulations for 30dBi EIRP antennas. Also searched antennas that emitted 30dBi, their prices and photos of how they look. From this I started to the standards imposed in his majority by the IEEE. In the area of standards were the regulations of up to which quantities cannot exceed in bandwidth, compliance, and reasons for the different claims of people. This part ended up looking for several important data of different frequencies such as Bluetooth, Wi-Fi, NFC among others where the standard, the bandwidth Spectrum band, Maximal Data Rate, and others were studied. The area of the Starklink system was addressed looking for the frequencies, bandwidth, altitude of its satellites, uplink, downlink, and the minimum of both. Finally, I looked a satellite of the company Starlink covering Puerto Rico.

References

2022 5:57 pm U. T. C. Jon Brodkin - Sep 23, "Starlink is getting a lot slower as more people use it, speed tests show," *Ars Technica*, 23-Sep-2022. [Online]. Available: https://arstechnica.com/tech-policy/2022/09/ookla-starlinks-median-us-download-speed-fell-nearly-30mbps-in-q2-2022/#:~:text=On%20its%20website%2C%20Starlink%20says,of%2020%20to%2040%20ms. [Accessed: 18-Feb-2023].

"Antenna World G5730 5.72-5.85 ghz 30 DBI parabolic grid directional antenna." [Online]. Available: https://www.amazon.com/Antenna-World-G5730-5-72-5-85-Directional/dp/B00NQGVP7M. [Accessed: 18-Feb-2023].

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"C band (IEEE)," *Wikipedia*, 21-Sep-2022. [Online]. Available: https://en.wikipedia.org/wiki/C_band_(IEEE). [Accessed: 18-Feb-2023].

"DBI," *Wikipedia*, 09-Oct-2022. [Online]. Available: https://es.wikipedia.org/wiki/DBi. [Accessed: 18-Feb-2023].

E. P. B. Chattanooga, "How far will your wi-fi signal reach?," *EPB*, 19-Jan-2023. [Online]. Available: https://epb.com/get-connected/gig-internet/how-far-will-your-wi-fi-signal-reach/#:~:text=Wi-Fi%20signals%20will%20usually,about%2015%20meters%20of%20reach. [Accessed: 18-Feb-2023].

E. Team, "Everything RF," *everything RF*, 22-Sep-2018. [Online]. Available: https://www.everythingrf.com/community/what-is-wigig#:~:text=WiGig®%20(802.11ad)%20is,signal%20up%20to%2010%20meters. [Accessed: 18-Feb-2023].

"FCC rules," *AFAR Communications Inc. - Outdoor Wireless Networks*, 09-Sep-2020. [Online]. Available: http://www.afar.net/tutorials/fcc-rules. [Accessed: 18-Feb-2023].

H. Aronoff, “WIFI standards explained: WIFI 4 vs WIFI 5 vs WIFI 6,” *Minim, the residential managed WiFi and IoT security platform*. [Online]. Available: https://www.minim.com/blog/wifi-4-vs-wifi-5-vs-wifi-6. [Accessed: 18-Feb-2023].

“IEEE SA - IEEE Standard for Information Technology--Telecommunications and information exchange between systems - local and metropolitan area networks--specific requirements - part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications,” *IEEE Standards Association*. [Online]. Available: https://standards.ieee.org/standard/802_11-2020.html. [Accessed: 18-Feb-2023].

Jabra, “Bluetooth 5.0 headsets: Should you get one? · Jabra Blog,” *Jabra Blog*, 07-Jan-2022. [Online]. Available: https://www.jabra.com/blog/bluetooth-5-headsets/#:~:text=Longer%20range%3A%20Bluetooth%204.2%20can,240%20meters%20(800%20feet). [Accessed: 18-Feb-2023].

“L Band,” *Wikipedia*, 09-Feb-2023. [Online]. Available: https://en.wikipedia.org/wiki/L_band. [Accessed: 18-Feb-2023].

Lily, “ECE 5233 satellite communications,” *SlideServe*, 18-Jul-2014. [Online]. Available: https://www.slideserve.com/lily/ece-5233-satellite-communications. [Accessed: 18-Feb-2023].

“Live Starlink Satellite and coverage map,” *Starlink satellite tracker*. [Online]. Available: https://satellitemap.space/index.html#. [Accessed: 18-Feb-2023].

“Mikrotik Mant30 MTAD-5G-30D3 30dbi parabolic dish antenna for 5ghz for sale online,” *eBay*. [Online]. Available: https://www.ebay.com/p/1643524410?iid=284765876247. [Accessed: 18-Feb-2023].

“Near-field communication,” *Wikipedia*, 16-Feb-2023. [Online]. Available: https://en.wikipedia.org/wiki/Near-field_communication#:~:text=NFC%20standards%20cover%20communications%20protocols,defined%20by%20the%20NFC%20Forum. [Accessed: 18-Feb-2023].

“Satellite frequency bands,” *ESA*. [Online]. Available: https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Satellite_frequency_bands. [Accessed: 18-Feb-2023].

“Shannon capacity of wireless channels - stanford university.” [Online]. Available: https://web.stanford.edu/class/ee359/previous/pdfs/lecture7_handout.pdf. [Accessed: 18-Feb-2023].

Starlink. [Online]. Available: https://www.starlink.com/technology. [Accessed: 18-Feb-2023].

T. América, “¿Qué es entonces un dbi y un dbd?,” *Tes America*, 04-Nov-2020. [Online]. Available: https://tesamerica.com/faq/que-es-entonces-un-dbi-y-un-

dbd/#:~:text=«DBi»%20significa%20«ganancia%20de,en%20todas%20las%20direcciones%20espaciales. [Accessed: 18-Feb-2023].

T. Pultarova and E. Howell, “Starlink Satellites: Everything you need to know about the controversial internet megaconstellation,” *Space.com*, 14-Apr-2022. [Online]. Available: https://www.space.com/spacex-starlink-satellites.html#:~:text=Starlink%20satellites%20orbit%20approximately%20342,they%20move%20across%20the%20sky. [Accessed: 18-Feb-2023].

“UISP airmax 5 ghz, 30 dbi rocketdish antenna,” *Ubiquiti Inc.* [Online]. Available: https://store.ui.com/collections/operator-airmax-and-ltu-antennas/products/5ghz-rocketdish-30dbi-rocket-kit. [Accessed: 18-Feb-2023].

“What are the frequencies (lower and upper) of the band of ... - quora.” [Online]. Available: https://www.quora.com/What-are-the-frequencies-lower-and-upper-of-the-band-of-microwaves. [Accessed: 18-Feb-2023].

“What is a guard band? - definition from Techopedia,” *Techopedia.com*. [Online]. Available: https://www.techopedia.com/definition/7494/guard-band-telecommunications. [Accessed: 18-Feb-2023].

“The Wireless Channel - Stanford University.” [Online]. Available: https://web.stanford.edu/~dntse/Chapters_PDF/Fundamentals_Wireless_Communication_chapter2.pdf. [Accessed: 18-Feb-2023].

“Zigbee protocol,” *Zigbee Protocol - an overview | ScienceDirect Topics*. [Online]. Available: https://www.sciencedirect.com/topics/engineering/zigbee-protocol#:~:text=ZigBee%20is%20widely%20used%20to,Fig. [Accessed: 18-Feb-2023].