ECE 6213 – Design of VLSI Circuits

Fall 2022 – The George Washington University – Dr. Jerry Wu

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Problem 1 – 70 points

- **Explain how the "5G system" works in detail (compare with 4G).**

  Similar to 4G LTE, 5G systems are based on orthogonal frequency-division multiplexing (OFDM) and they operate on similar mobile networking principles. One of the main features for 5G architecture is the concept of "network slicing", which separates virtual networks into individual partitions, each of which resides on the same hardware but can support different services and applications. 5G's network slicing divides the user plane and control planes so that the user moves closer to the network edge compared to 4G technology.

  Another stark difference with 4G is the overall **network latency**. 4G offered a latency of 60 to 98 ms, but 5G promises latencies as low as 3 ms. 5G also has **massive MIMO** (multiple input, multiple output) transmission technology, which comprises of multiple antennas for communication at sources and their destinations.

  The overall working of a 5G system can be summarized as follows:

  - The service area is divided into small geographical areas called cells.
  - All 5G wireless devices in a cell communicate through radio waves with a base station through antennas, over frequency channels as assigned by the base station or node.
  - A base station is connected to routers by high-bandwidth optical fiber or wireless backhaul connections.
  - A device moving from one cell to another is automatically handed off seamlessly, such that the end-user of this device does not see any difference in the service it receives.

- **Research and find out the major challenges for 5G. Compare the following and their performance as a table: 5G towers, receiver/router, switch, mobile device, mobile vehicle, others?**

  5G technology is faced by the following major challenges:

Towers	Receiver/Transmitter	Router/Switch	Infrastructure
Power: 5G Towers consume up to 2x more power than 4G base station towers	**Power:** 5G antennas have a transmission power of around 250 mW (small cells) and 120W (large MIMO arrays), This was 20 W for the typical 4G antenna	**Power:** RF switches used in 5G need to be highly power/energy efficient, allowing access to 5G frequencies without adversely impacting device battery life.	**Cost:** Laying the physical groundwork for 5G-enabled devices such as mobile devices, autonomous vehicles, appliances, robots, and city infrastructure will require costly upgrades, estimated to be in the trillions of dollars
Logistics: Wireless carriers need to bid for higher spectrum bands in auctions as they build their 5G networks	**Deployment:** Deployment is challenging since a great number of antennas need to be installed in order to establish sufficient network coverage	**Specs:** Switches need to also have a high operating lifetime, as well as meet 5G system power specifications	**Security:** Carriers need to ensure that cloud-based services are highly secure in order to cope with the increased connectivity associated with 5G rollout amid the increasing cybersecurity threats
Deployment: Even though higher frequencies transmit more data, 5G towers are more susceptible to physical interference, making deployment difficult	**Efficiency:** 4G antennas convert energy inefficiently to radiating waves. 5G antennas need to be much more efficient to maintain 5G standards	**Performance:** RF switches & routers used in 5G need to be highly reliable and high performance.	**Integration:** Operators need to ensure that 5G networks work well with existing 4G networks. This is highly important because 5G non-standalone networks depend directly on LTE technology as an anchor for carrying control plane traffic

- **Based on above challenges, discuss the major <u>hardware chips</u> that 5G should be equipped for the whole system (such as tower, router/switch, mobile device, mobile vehicle, etc.). Compare the following and their performance as a table**
  - **You can choose at least <u>two</u> major challenge chips that you find out**

  <u>**Challenge 1 – 5G Operating Frequency:**</u>

  5G signals operating in higher frequency bands are more likely to face physical interference. The workaround that has become the standard in 5G deployment is to utilize smaller 5G base stations/towers need in close proximity of one another. A 5G system can be implemented in low-band, mid-band, or high-band millimeter-waves, posing new and unique hardware requirements. The coverage area of a 5G system and the resulting network speeds rely on the exact frequency a certain system employs, as indicated in the table below.

	Frequency	Speed	Cell-Tower Coverage (in radius)
Low-band	600-900 MHz	30-250 Mbps	Hundreds of sq. miles
Mid-band	1.7-4.7 GHz	100-900 Mbps	Tens of sq. miles
High-band	24-47 GHz (mm waves)	1-3 Gbit/s	One sq. mile (or lower)

The low-band 5G is the closest to its predecessor 4G technology in terms of the network speed and coverage, and it is expected to provide a base-level 5G service to virtually anywhere in the United States. The higher bands would be implemented in specialized areas as needed.

Challenge 2 – 5G Data Rate:

In order to achieve the data rates of 5G, the throughput of the network needed to be drastically improved.

Historically, base stations relied on single-input and output systems and had very low throughput, and could not support multiple devices with high reliability. As users increased, stations adopted MIMO technologies. This led to improvements in terms of the reliability, but the overall gain was still limited and sub-par the expected data rate performance for 5G. Therefore, 5G stations have to implement massive MIMO.

The idea in massive MIMO is to group a large number of miniature antennas together, so that the base station can focus energy into a smaller area. User devices can also receive and send data using multiple antennas integrated in mobile devices. As a result, a large-scale massive MIMO 5G system provides greater network capacity and improved coverage compared to previous technologies.

- **Based on above required hardware, discuss the computer system and required software or OS. (Analyze the software trend compared with the previous 4G system)**

Software and cloud computing are integral to 5G's core network, unlike the previous 4G which was heavily integrated and dependent on physical hardware components. Network operators and providers are leveraging cutting-edge virtualization technologies for the implementation and deployment of 5G.

- In the 5G Core Network, components that were traditionally physical (such as 4G servers, switches, and storage) are being offloaded to the cloud in a virtual environment through intelligent software tools. Cloud technologies also are being applied in the Radio Access Networks that allow user equipment, such as a mobile phone, smart sensor, or IoT device, to connect to the Core Network.
- Artificial intelligence and automation software are allowing 5G NR equipment to operate more efficiently through techniques such as targeted beamforming, delivering higher performance to end users and reducing network energy consumption.
- The deployment model for 5G is mostly Open RAN and virtualized RAN. Compared to 4G (and previous systems) where customers were locked into a limited selection of proprietary RAN hardware vendors to build out their networks, open and virtualized RAN technologies are allowing networks and network-based applications to mix and match both hardware and software components from different vendors, resulting in

increased transparency, more flexibility for operators, and the opportunity for greater software-driven innovation in RAN technology.

  - Overall, advanced MIMO antenna modules, routers and C-RAN units need to be deployed for IoT, Smart home, robotics, autonomous driving, and mission critical 5G applications.
  - In mobile devices, sophisticated modems and integrated antenna arrays will be used. Corresponding mobile operating systems (such as Android, iOS) need to be updated so as to utilize these new modules. Multiple wireless technologies like Gigabit Wi-Fi and latest generation of Bluetooth will be integrated for AR (Augmented Reality) and VR (Virtual Reality) applications in mobile devices.
  - Complex software algorithms are an integral part of 5G technology to handle huge amount of data from billions of smart devices and sensors (used in IoT and smart home).

References:

[1] https://software.org/wp-content/uploads/softwareorg_5Gsoftware.pdf

Problem 2 – 30 points

- **Find out at least two 5G cell phone processors, DSP (for 5G) and compare the following:**
  - **Roadmap for their 5G product**
  - **Technology (in nano-meter)**
  - **Compatibility (EU, USA, others)**

Two major 5G cell phone processors (SoCs to be specific) are summarized below:

Chip Name	**Chip Size**	**Tech**	**DSP**	**Commercial Device**	**Compatibility**
Qualcomm Snapdragon 695 5G	Kryo 660 – 8 processing cores @ 2.2 GHz	6 nm	Qualcomm® Hexagon™ Vector eXtensions (HVX)	OnePlus Nord CE 2 Lite 5G	Global
MediaTek Dimensity 800	Arm Cortex-A76 @ 2 GHz Arm Cortex-A55 @ 2 GHz Total 8 processing cores	7 nm	Coresonic AB (Proprietary)	Oppo Reno 4Z 5G	EU only

The Snapdragon 695 has an integrated on-chip 5G modem-RF system, which is a modem to antenna integrated system for 5G multimode. The Snapdragon SoC is one the first in Qualcomm's roadmap of developing software-compatible 5G mobile platforms. It uses second-generation 5G mmWave antenna module, and sub-6 GHz RFFE components and modules. The design motivation is to enable device makers to cost-effectively develop 5G smartphones for virtually any 5G network/region in the world. Overall, the following list presents a few important 5G products from Qualcomm’s roadmap, along with their announce dates:

1) Snapdragon 855 – December 2018
2) Snapdragon X55 – February 2019
3) Second-generation 5G mmWave and RFFE solutions - February 2019
4) Snapdragon 695 – October 2021

The MediaTek Dimensity 800 also fully integrates a 5G modem, however, it does not support mmWave technology which is used by several carriers in Japan and the USA. More recent versions, such as the Dimensity 9000, have mmWave support and MediaTek is targeting expanding into the 5G market in the USA. The following list highlights some important items from MediaTek’s 5G roadmap:

1) Dimensity 800, 7 nm – January 2020
2) Dimensity 900, 6 nm – May 2020
3) Dimensity 9000, 4 nm, APU 590 – Q3 2022 (expected)

Overall, both chips do a fairly good job at addressing the challenges summarized previously through various design-level considerations and mitigation strategies.

References:

[1] https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/product_brief_-_snapdragon_695_5g_mobile_platform.pdf
[2] https://www.mediatek.com/products/smartphones-2/dimensity-800

- **AI application in the processors based on what you found**

In this direction, both hardware chips summarized before have introduced new innovative technologies.
For example,
The Snapdragon 695 5G features:

1) Qualcomm 5G PowerSave
2) Qualcomm Smart Transmit
3) Qualcomm Wideband Envelope Tracking
4) Qualcomm **AI-Enhanced** Signal Boost

These hardware-software co-design features allow dynamic **AI-based optimization** of transmit and receive paths across a comprehensive set of use cases. Also, through the AI-Enhanced signal boost technology, user interaction and hand grips are dynamically detected.

Similarly, MediaTek’s Dimensity 800 features:

1) MediaTek 5G UltraSave
2) MediaTek HyperEngine 2.0

3) MediaTek APU 3.0

These hardware-software co-design features also allow for dynamic networking optimizations and overall experience improvements. In particular, MediaTek's **AI-based** APU is designed to achieve maximum effective performance in AI-multimedia experiences, while meeting strict power budgets set by device makers.