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THE UNIVERSITY OF NEW SOUTH WALES

Research Survey Assignment for COM9336 Mobile Data Networking Semester 2, 2017 (Individual Assignment)

Lecturer

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Table of Contents

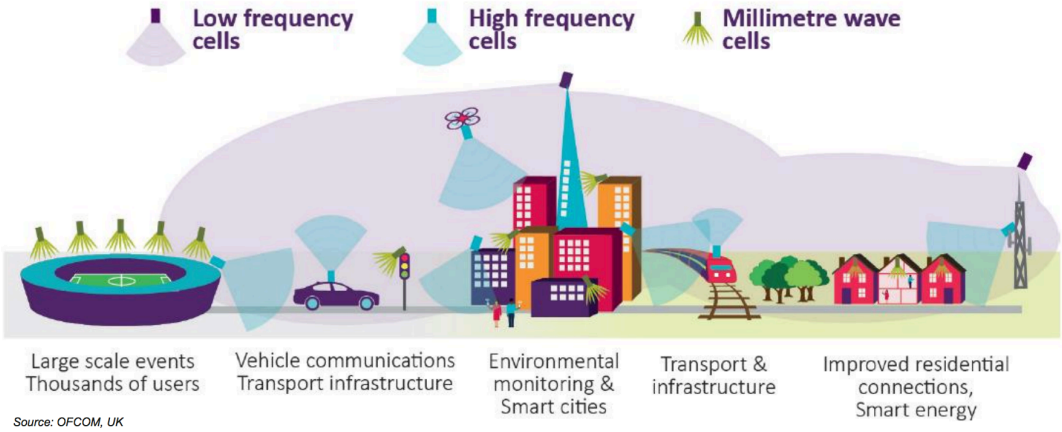
1. Introduction 5G and Millimeter Wave

In 2001, 5G communication technology was proposed as a conceptual technology by the NTT Corporation in Japan.

In 2015, the International Telecommunication Union made a clear timetable for the stand ardization of 5G, and many countries proposed the target of commercializing 5G by 2020. At present, 5G has become a new commanding height of competition among all the international communication technologies. And among the top 20 enterprises that apply for the most intern ational PCT patents in nearly 30 years, the mobile communication enterprises have accounted for 60%, and the mobile communication technology has become the most concentrated areas that the international intellectual properties compete for, because of the large industry scale of the mobile communication and the extensive application of the mobile communication servic e.

2. Why do people need 5G?

Mobile phone is the most popular product in the world. In 2015, the penetration of the global Mobil communication is generation communication system. Currently, the combination of intelligent terminal and broadband wireless has greatly expanded the function of mobile communication. Mobile phones have become a digital assistant of personal life and work and enhanced people's perception ability. However, people's pursuit of communication capacity is endless. The goal of being higher, faster and broader is what constantly motivates the tech workers to move forward which leads to the birth of 5G.



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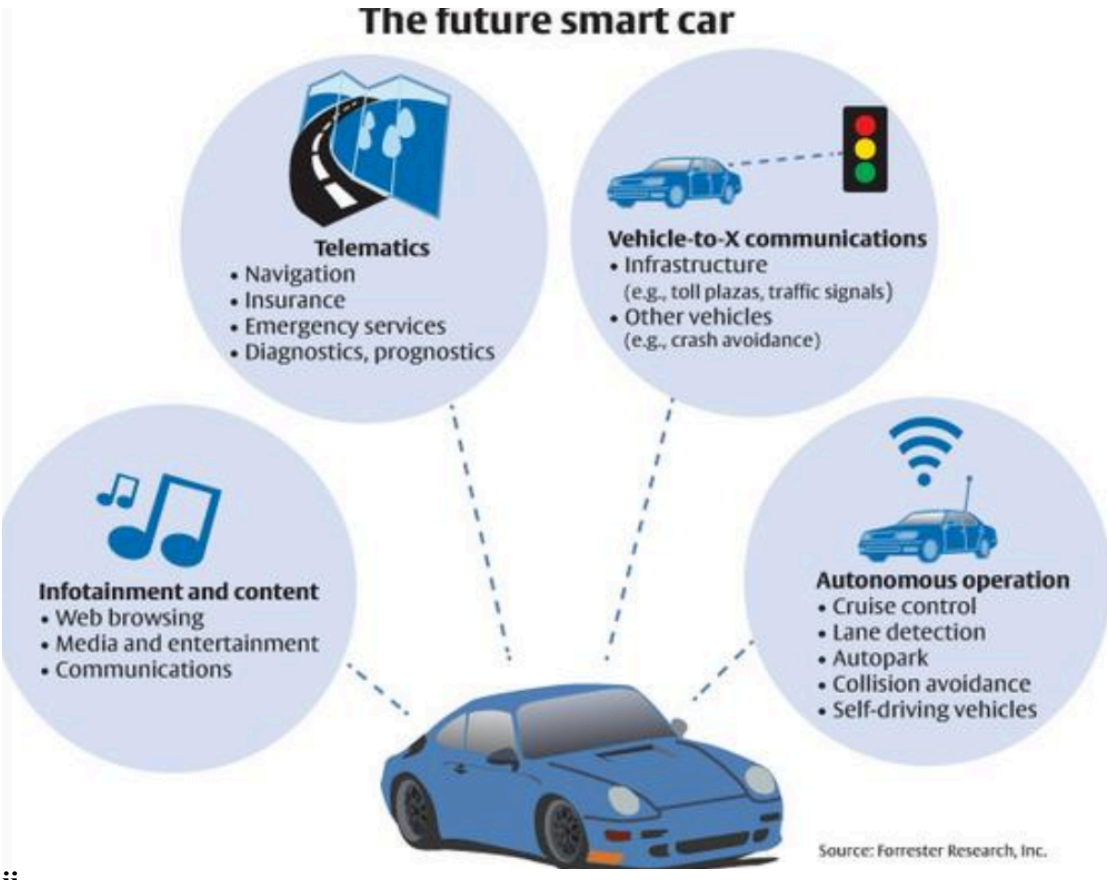
Here are some examples:



ii

- ## Self-driving cars

In the 4G network, the limit of the end-to-end delay is around 50 milliseconds, which is difficult to realize the remote real-time control. However, in the 5G era, the end-to-end delay is only 1 millisecond. The automatic driving equipment can connect to all kinds of equipment around the vehicle to learn the road environment and provide traffic information, analyze real-time data and predict the traffic condition intelligently. The drivers can know well the surroundings of his vehicles, get a warning ahead of time when in danger without being affected by the weather. It can meet the requirement of intelligent transportation or even unmanned driving.

- ## Virtual reality

When you put on a VR headset, you will enter a virtual world where you can interact with others, play games with them or even high-fives. With 5G, collaboration among uses will Usher a new era. Two people in the same physical location will be able to cooperate. Various body sensing functions require fast network transmission to enhance virtual reality.

- **Cheaper Internet funding**

Network fee could be very high in 2G and 3G era. However, in 4G eras, the cost of the unit flow dropped substantially, but due to the high rate of 4G and the rise of various applications such as HD video, user demand for traffic is growing geometrically. Therefore, a big drop of the unit total flow rate does not reduce the cost of the users' flow, but some applications favored by the users which demand traffic stimulate substantial increase of aggregate expenditure of user traffic. In the age of 5G, according to the development of mobile communication technology in previous generations, the network speed has increased by more than 100 times, and users' demand for traffic will also grow exponentially. Although the demand for traffic increases geometrically, the total cost of the user's actual expenditure is not more than that of the 4G era. This is because, on the one hand, 5G is more than 100 times faster than 4G, but the cost of building a 5G network for carriers is not necessarily more than that of 4G networks. Therefore, the cost of unit traffic is bound to fall substantially. On the other hand, with the continuous improvement of the network and the increasing number of users, the cost of both voice and data communication is decreasing in general.

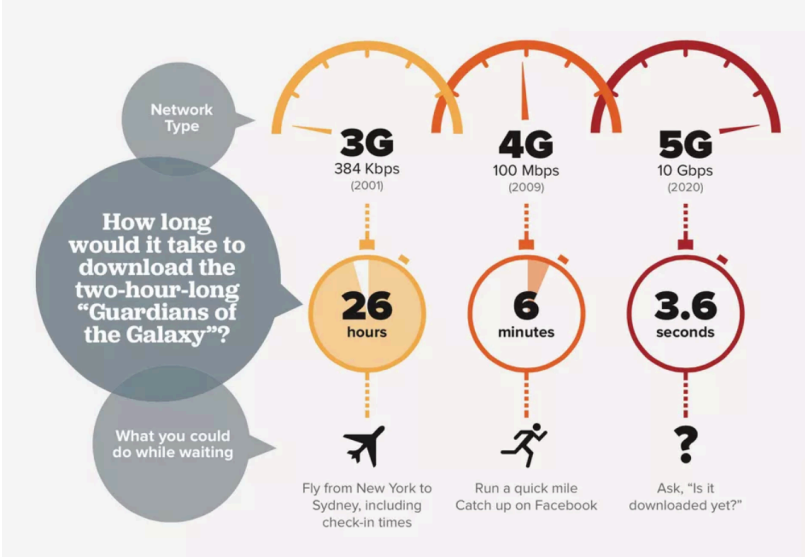
3. What is the 5G?

5th generation mobile networks or **5th generation wireless systems**, abbreviated **5G**, are the proposed next telecommunications standards beyond the current 4G/IMT-Advanced standards.[iii]

5G communication technology, the fifth generation of mobile network technology. 5G wireless communication technology is developing on the basis of 2G, 3G, 4G and many other technologies. It makes full use of wireless Internet work and thus becomes a more perfect and scientific wireless communication technology. These new wireless communication technologies are different from previous generations of communication technology. 5 g wireless communication technology is not exist independently of the network technology, but a brand new technology revolution which integrates various wireless communication technology advantage, and integrates the existing wireless technology into communication technology effectively. 5G wireless communication technology has become

the topic of global mobile communication technology. Internet companies around the world are constantly improving their communication technology equipment and speeding up the speed of technological innovation.

The Next Generation Mobile Networks Alliance defines the following requirements that a 5G standard should fulfill[iv]:

- Data rates of tens of megabits per second for tens of thousands of users
- Data rates of 100 megabits per second for metropolitan areas
- 1 Gb per second simultaneously to many workers on the same office floor
- Several hundreds of thousands of simultaneous connections for wireless sensors
- Spectral efficiency significantly enhanced compared to 4G
- Coverage improved
- Signaling efficiency enhanced
- Latency reduced significantly compared to LTE.
- 

[v]

Simple summary,
the first is the faster transmission speed.
The second is lower energy consumption.

4. How to make speed faster?

There are two main ways to increase the transmission rate. One is to increase the frequency of the spectrum and the other is to increase the bandwidth of the spectrum. In wireless transmission, data is transmitted in the form of a symbol. In the case that the element transfer rate remains unchanged, and the wireless bandwidth of the signal is invariable, the amount of information transmitted by each code element is determined by the modulation method.

Modulation method produces different states of carrier by manipulating the amplitude and phase of radio waves. When modulation mode changes from simple to complex, the number of the carrier state increases, so does the information (bits) that a symbol represents. However, the spacing between each code element is smaller, so it is easy to be disturbed by noise, so that the code element deviates from where it was supposed to be, causing the decoding to go wrong. So requirement of complex modulation for channel is high. In the case that channel noise is very loud, the use of complex modulation can lead to a high data transmission error rate, and circuit needed by decode is also very complicated, leading to large power consumption. Compared with improving the spectrum efficiency, it is simpler and more straightforward to increase the spectrum bandwidth. In the case of spectrum

utilization rate being constant, double the available bandwidth can achieve doubled data transmission rate. But now the commonly used band below the 5 GHZ is very crowded, so the new method is to use high frequency transmission technology of millimeter wave (mmWave)

5. What is high frequency transmission technology - millimeter wave (mmWave)?

Due to the fact that rapid development of all kinds of wireless communication and wireless applications, and that the low frequency spectrum is very tense, it is hard to find a new spectrum that is suitable for 5 g technology.

Because of this advantage, 5G technology has first applied the frequency greater than 24 GHz to mobile broadband communication (now millimeter-wave is mainly used in radio astronomy, remote sensing and other fields). A large number of available high frequency spectrums can provide extreme data transmission speed and capacity, which will reshape mobile experience. All major communication enterprises and research institutes are actively conducting related research work. For example, the Samsung Company of the South Korean has conducted channel measurements for the channel propagation characteristics of 28GHz and 37GHz bands, and developed a system prototype based on the 28GHz band. After field verification, the prototype has reached the download rate of 1Gbit/s, which proves the feasibility of high frequency band application in mobile communication. Millimeter wave refers to the order of magnitude of wavelength in mm electromagnetic wave. Its frequency is at around 26.5 GHz ~ 300 GHz.

5G encompasses wide variations of spectrum[vi]

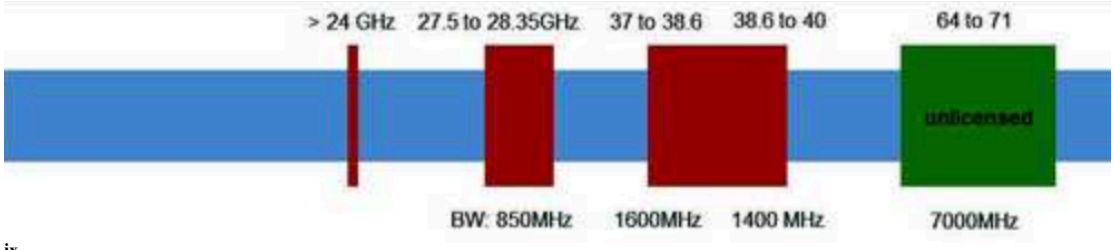
There is no precise definition for the millimeter wave frequency bandwidth. It is located in the wavelength range of microwave and far-infrared wave, and thus has two characteristics of spectrum. The theory and technology of millimeter wave are the extension of microwave to high frequency and the development of light wave to low frequency.

The International Telecommunication Union (ITU) and 3GPP have aligned on a plan for 2 phases of research for 5G standards. The first phase defines a period of research for frequencies under 40 GHz to address the more urgent subset of the commercial needs completing September 2018. The second phase is slated to begin in 2018 and completing December 2019 to address the KPIs outlined by IMT 2020. This second phase focuses on frequencies up to 100 GHz.

In an effort to globally align the standardization of mmWave frequencies, ITU released a list of proposed globally viable frequencies between 24 GHz and 86 GHz after the most recent World Radiocommunications Conference (WRC)[vii]**:**

24.25–27.5GHz	31.8–33.4GHz
37–40.5GHz	40.5–42.5GHz
45.5–50.2GHz	50.4–52.6GHz
66–76GHz	81–86GHz

Shortly after ITU proposal, the Federal Communications Commission (FCC) in the United States issued a Notice of Proposed Rule Making (NPRM)on October 21st 2015 that proposed new flexible service rules among the 28 GHz, 37 GHz, 39 GHz, and 64-71 GHz bands.[viii]



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July 2016, the US Federal Communications Commission announced 27.5 ~ 28.35 GHz, 37 ~ 38.6 GHz, 38.6 ~ 40 GHz, 64 ~ 71 GHz. Four 11 GHz bandwidth of the millimeter-wave band

6. The characteristics of millimeter wave communication

• Advantage:

1) Extremely wide bandwidth

Extremely wide bandwidth is 10 times more than the total bandwidth from dc to microwave. Even if atmospheric absorption is considered, only four main Windows can be used for propagation in the atmosphere, but the total bandwidth of these four Windows can also reach 135GHz, which is five times as much as the sum of the bandwidth of the following bands

2) Narrow beam

In the same antenna size, the beam of millimeter-wave is much narrower than that of the microwave. For example, a 12cm antenna has a beam width of 18 degrees at 9.4GHz while the beam width of 94GHz is only 1.8 degrees. So you can tell smaller objects that are closer to each other or more clearly to see the details of the target.

3) Strong detection capability

Wideband broad-spectrum ability can be used to suppress multipath effects and clutter. There are plenty of frequencies available to effectively eliminate interference. At the radial velocity of the target, a large multi-spectrum Doppler shift can be obtained to improve the detection and recognition of low-speed moving objects or vibrating objects.

4) High transmission quality

Due to that there is basically no interference sources for the high frequency band millimeter wave communication, so the electromagnetic spectrum is very clean, therefore, millimeter wave channel is very stable and reliable, and the bit error rate can be keep for a long time in 10-12 orders of magnitude, which is equivalent to that of fiber optic cable transmission quality

5) Small size of Millimeter-wave components

Compared to the traditional 6GHz band, one feature of millimeter wave is that the physical size of the antenna can be relatively small. This is because that the physical size of the

antenna is proportional to the wavelength of the wave segment, and the wave length of the millimeter-wave band is less than that of the conventional 6GHz band, and the corresponding antenna size is smaller. Therefore, it can be conveniently equipped with millimeter-wave antenna array on mobile devices to realize various MIMO technologies.

- **Disadvantages:**

1) the attenuation is larger and the diffraction ability is weaker in air

High frequency transmission still faces many practical difficulties Because of the characteristics of electromagnetic propagation. Because of the absorption of the air, the higher the frequency of the electromagnetic wave path, the greater the loss is. For example, a 60GHz electromagnetic path loss is more than 20 dB higher than a 5GHz electron wave. At the same time, the high frequency transmission gives priority to direct path, and diffraction ability is poorer, so when the direct path between the base station and users are blocked, transmission performance will be dropped significantly, and transmission of signal even cannot penetrate the wall (recall how easily family 5 GHZ Wi-Fi can be blocked by walls)

2) The machining accuracy of the device is high

The technology of high frequency segment devices is very difficult and the relevant process is not mature. Therefore, high frequency band related devices are less and more expensive, which brings great technical challenges to high band communication.

3) It faces problems of waveform and energy consumption

However, the characteristics of millimeter wave transmission attenuation in the air can be used. Mobile phone use of millimeter wave signal attenuation is really big, but the millimeter wave signal emitted from other terminal in the same way is also very large (for you are interfering signal), so there is no need to consider how to deal with the interference signal when designing the millimeter-wave system, so long as the different terminals don't get too close to each other. Selection of the 60 GHZ is an extreme use of this point; 60 GHZ is the oxygen resonance frequency, so the electromagnetic wave signal of 60 GHZ decays very fast in the air, which can entirely avoid the interference between different terminals. Of course, millimeter-wave attenuation in the air is very large and it is also destined that millimeter wave technology is not suitable for use in outdoor cell phone terminals and distance from base stations. As for 5 g spectrum using planning, each manufacturer uses more traditional band under 6 GHZ frequency outdoors to ensure signal coverage, while uses micro base station and millimeter wave technology indoors to achieve high-speed data transmission.

7. Currently progress

Qualcomm has made some progress in antenna and signal processing technology. By using the multiple antennas in the base station and the equipment, and combining with the intelligent beam forming and beam tracking algorithm, the coverage of 5G millimeter-wave can be significantly improved and interference can be eliminated. At the same time, using the frequency band under 6GHz and 4G LTE, the connection performance of millimeter-wave will be better.

8. References

[i] (image credit: GRUPPO TIM Regional Seminar for Europe and CIS - Spectrum Management and Broadcasting Aurelia Antica Convention Centre – Roma, May 29-31 2017 Future use of millimetre waves for 5G Session 9: Towards the WTDC 2017 and WRC 2019 Source: OFCOM, UK.)

[ii] (Source: Forrester research Inc.)

[iii] ("ITU towards "IMT for 2020 and beyond" - IMT-2020 standards for 5G". *International Telecommunications Union*. Retrieved 2017-02-22.)

[iv] (Osseiran, A.; Boccardi, F.; Braun, V.; Kusume, K.; Marsch, P.; Maternia, M.; Queseth, O.; Schellmann, M.; Schotten, H. (2014-05-01). "Scenarios for 5G mobile and wireless communications: the vision of the METIS project". IEEE Communications Magazine. 52 (5): 26–35. ISSN 0163-6804. doi:10.1109/MCOM.2014.6815890.)

[v] (https://www.cnet.com/news/how-5g-will-push-a-supercharged-network-to-your-phone-home-and-car/)

[vi] （Image Credit: QUALCOMM.）

[vii] **(**Resolution Com6/20, Provisional Final Acts WRC-15. WRC-15 (pp. 424-426). Geneva: ITU. http://www.itu.int/dms_pub/itu-r/opb/act/R-ACT-WRC.11-2015-PDF-E.pdf.**)**

[viii] (Use of Spectrum Bands Above 24 GHz for Mobile Radio Services, GN Docket No. 14-177, Notice of Proposed Rulemaking, 15 FCC Record 138A1 (rel. Oct. 23, 2015)))

[ix] (5G & Millimeter Wave Band Challenges- — Rolland Zhang, Senior Product Manager, Keysight Technologies.)