802.11b Wireless LAN and Bluetooth Data Transmission Lab Report

Michael (Jiashu) Zhou

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Abstract

- Main Goal of The Experiment: Getting familiarized with wireless data communication methods through IEEE 802.11b Wireless LAN and Bluetooth data transmission
- 802.11b Wireless LAN data transmission
  - Measure the effects of device distance and electromagnetic interference on transmission throughput
- Bluetooth data transmission
  - Measure the effects of device distance, packet types, Piconet's size on transmission throughput
  - Explore the effects of interferences between 802.11b WLAN and Bluetooth connections on data transmission

Theory: 802.11b Wireless LAN

- Link Layer Characteristics
  - Frequency Range: 2.400 – 2.4835 GHz, Frequency 83.5 MHz
  - Access Point Range: about 100 - 150 meters
  - Modulation of Digital Signals: Phase-shift Keying (PSK) and Quadrature Phase-shift Keying (QPSK)
  - Multiple Access: Multiple Access with Collision Avoidance (MACA) with Binary Exponential Back-off
- Transport Layer in the Internet Protocol Stack
  - User Datagram Protocol (UDP)
    - Connectionless, unreliable data transmission emphasizing low-latency
  - Transmission Control Protocol (TCP)
    - Connection-oriented, full-duplex, reliable and ordered data transmission with flow & congestion control

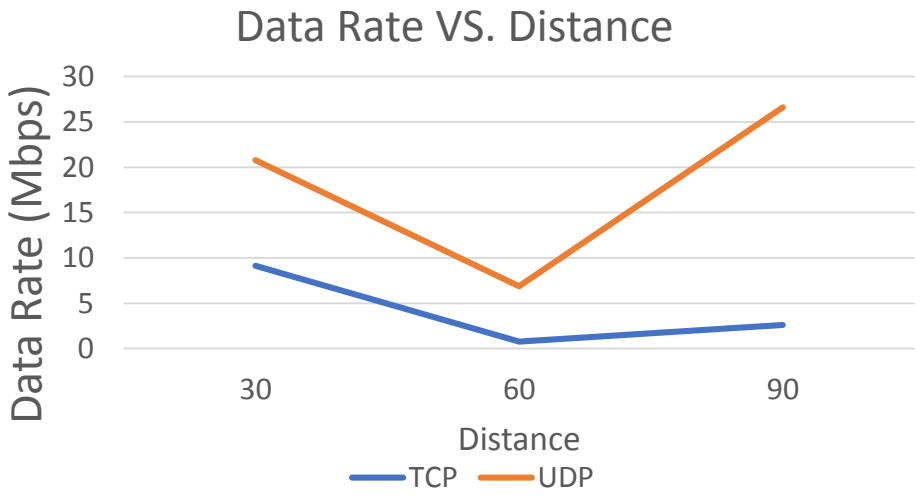
Theory: Bluetooth (802.15)

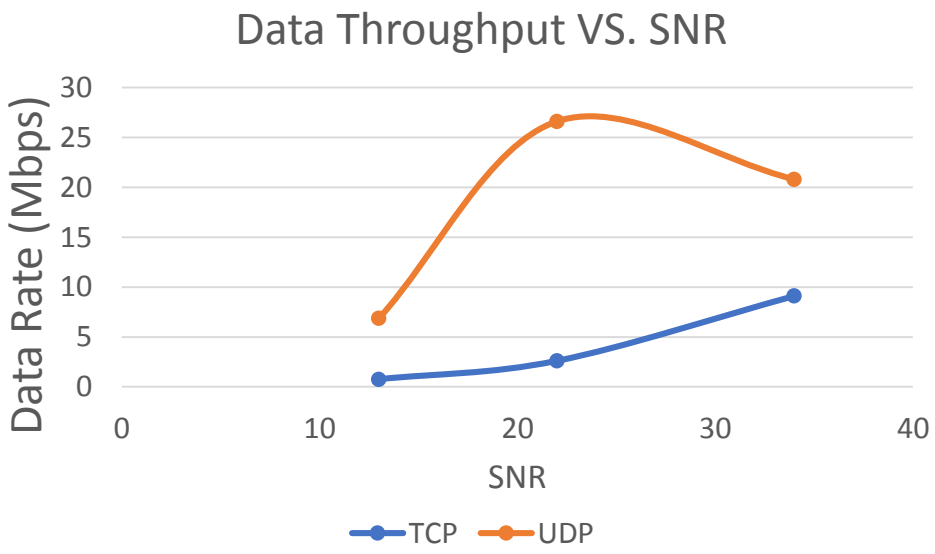
- Wireless standard for low-cost, low-power, short-distance data exchange on simple systems
  - Range: 10 meters
- Peer-to-Peer Ad Hoc connectivity without infrastructure
  - 1 Master & 2+ Slaves form a Piconet
- Link Layer characteristics
  - Frequency Range: 2.45 GHz unlicensed ISM band with 79 hop carriers defined at 1 MHz spacing
  - Multiple Access: FH-CDMA (Frequency Hopping) with dwell time 625 microseconds
  - Voice: Synchronous Connection Oriented (SCO) links
  - Data: Asynchronous Connectionless (SCL) links

Result: 802.11b Wireless LAN

Distance	Signal Strength (dBm)	Noise Power (dBm)	SNR (dB)	UDP Data Rate (Mbps)	TCP Data Rate (Mbps)	Observations
30	-49	83	34	20.8	9.12	
60	-69	82	13	6.87	0.755	The second point has significantly smaller data rate
90	-87	87	22	26.6	2.6	

Table 1. Data Rate VS Distance between measured point and wireless source. As can be seen from the plot, the second distance (60 ft) has a significantly smaller data rate. On the other hand, there is a positive correlation between data throughput and SNR.

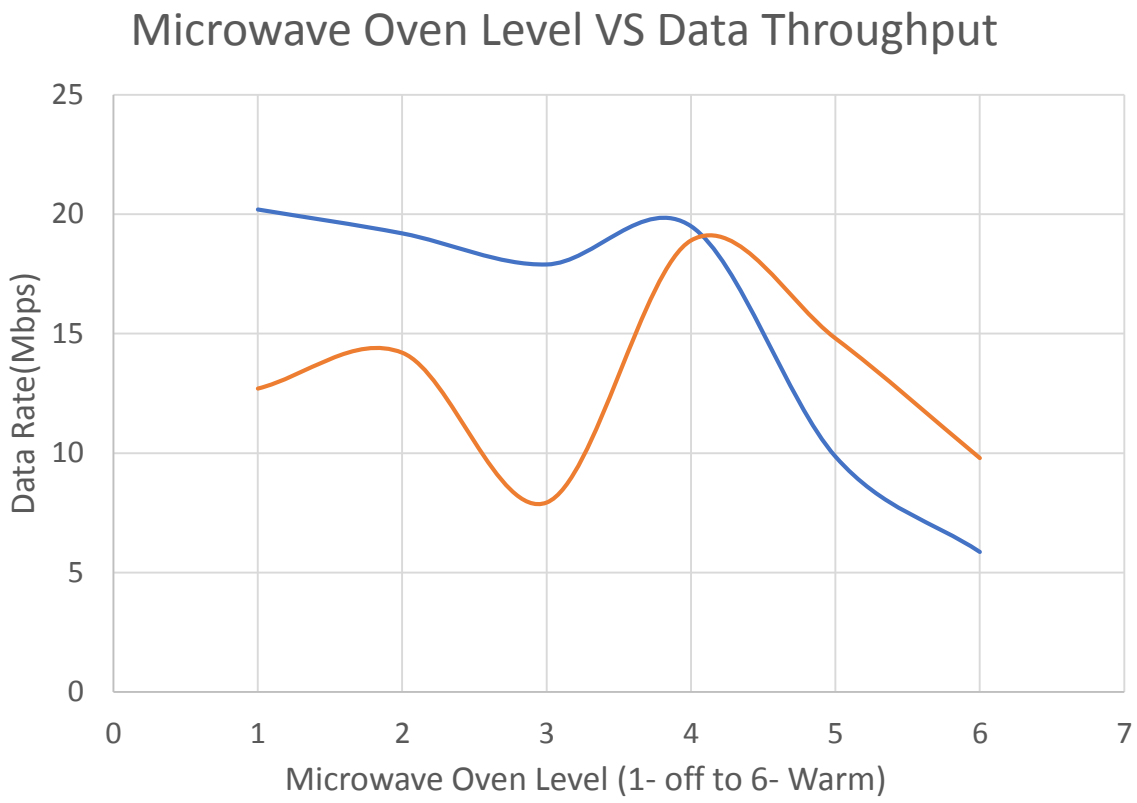




Result: 802.11b Wireless LAN

Microwave Oven Level	Signal Strength (dBm)	Noise Power (dBm)	UDP Data Rate (Mb/s)	TCP Data Rate (Mb/s)	Observations
Off	-22	-80	20.2	12.7	
High	-14	-83	19.2	14.2	1-2 datagram loss
Medium High	-27	-80	17.9	7.93	1-2 datagram loss
Medium	-18	-80	19.5	18.9	
Defrost	-14	-80	9.86	14.8	
Warm	-18	-81	5.87	9.79	
Approximate distance from AP: 10 ft					

Table 2. Microwave Oven Level VS Wireless LAN measured data rate and signal strength



The plot demonstrates that the change of microwave oven level will have an impact on the wireless LAN data rate transmitted in the lab.

Result: Bluetooth

Distance (feet)	Packet Type	Data Rate (kilobyte/s)
10	DH1	261.2
	DH3	270.4
	DH5	281.3
15	DH1	170.0
	DH3	190.0
	DH5	210.0
30	DH1	130.0
	DH3	170.0
	DH5	190.0

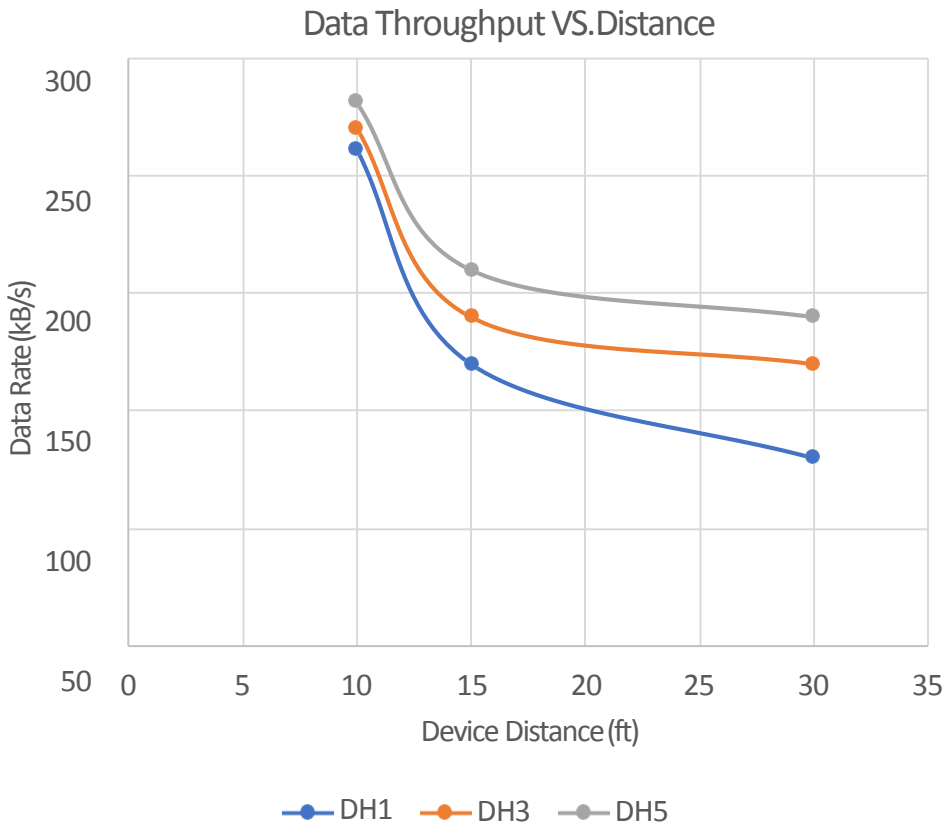


Table 3. Data throughput VS. distance between devices and packet types

It can be clearly seen that data throughput decreases as distance between device increases.

Result: Bluetooth

Number of Slaves	Packet Type	Data Rate (kB/s)
1	DH1	60.3
	DH3	196.9
	DH5	262.9
2	DH1	11.0
	DH3	44.0
	DH5	55.0
3	DH1	7.3
	DH3	30.0
	DH5	40.0
Distance from Mater to Slave nodes: 3 ft		

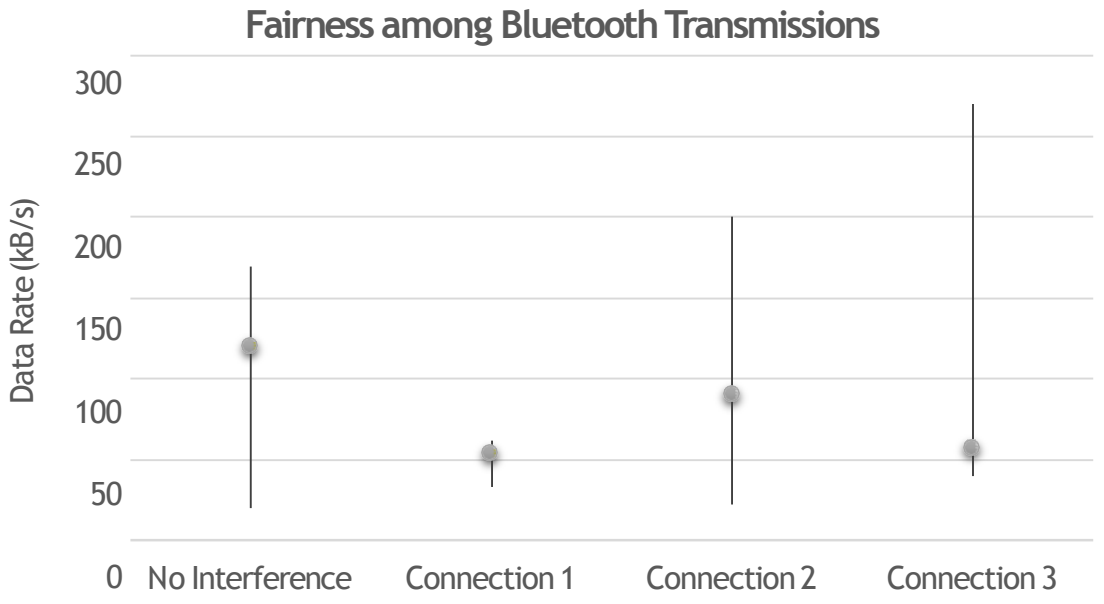
Table 4. Data throughput VS. size of Piconet

According to the collected data from table and plot, it can be seen that DH5 Packet has the highest data throughput as compared to DH1, which has the lowest.

Result: Bluetooth

Measurement Case	Average Data Rate for Each Pair of Connections (kB/s)	Range of Data Rate (kB/s)
Before interference	120	20 -170
3 Connections Crossing	54	33 -62
	90	22 -200
	57	40 -270
Distance from Mater to Slave nodes: 5 ft		

Table 5. Interference between Bluetooth connections



Multiple Bluetooth and 802.11b WLAN connections that are transmitting at the same time and are crossing each other would decrease the throughput of each other due

Result: Bluetooth

	Data Rate without Interference	Average Data Rate with Interference	Range of Data Rate with Interference
Bluetooth	60.3 kB/s	58.0 kB/s	34.0 - 62.0 kB/s
TCP in 802.11b WLAN	20.7 mB/s	15.6 mB/s	relatively stable
Distance from Mater to Slave nodes: 5 ft			
Percentage of Data Rate (Bluetooth) with Interference: 4% to 44%			
Percentage of Data Rate (802.11b WLAN) with Interference: 25%			

Table 6: Result of Interference between Bluetooth and 802.11b WLAN connections

Discussion: 802.11b Wireless LAN

1. There are multiple sources of high level of interference among other computers in lab room
   - We notice that, around 10 laptops were conducting the experiment simultaneously in the room, so the microwave oven was not the only source of electromagnetic interference.
   - When other laptops in-range were transmitting data, the level of interference became higher, causing the data throughput to drop (even if operating mode of the microwave remains the same)
2. In the second part, the power of the microwave oven was incrementally reduced
   - This may be a self-protection mechanism as the microwave oven had operated for a long time during the experiment
   - Thus, the power of microwave wave may have varied considerably even when set at a particular level. Therefore we may have over-estimated the level of interference it caused when its power output dropped
3. We also tested the different results as we moved closer to the access point
   - Multiple groups moved position subtly during the measurement in order to set up the equipment in the second half of Part 2
   - For our group, this shortened the distance to Access Point and increased the Signal-to-Noise ratio, so the data throughput would slightly increase in the later trials during the experiment

Discussion: Bluetooth

1. Master sometimes failed to send data to multiple Slaves simultaneously
   - During our lab session, there has been multiple times in our experiment that the connection cannot be setup as the master to accept multiple slaves.
   - Only the data transmission to one Slave would start when the Master laptop tried to simultaneously connect to 2+ Slaves in more than one terminal using *l2test*.
   - We tried *l2ping* from Master to every Slave and all succeeded, which means devices were in range and Bluetooth connections could be correctly established.
   - One of the causes to this failure to execute multiple instances of *l2test* simultaneously may be *race conditions* in the Bluetooth driver or firmware-level implementation.
   - The experimental result also reflects the inherent nature of Bluetooth's instability when processing large number of connections, because Bluetooth is designed as a low-energy and low-throughput protocol.
2. Bluetooth can be characterized as having a high variance of data throughput during high level of interference
   - For example, cases such as having multiple Bluetooth connections crossed each other, or having Bluetooth and 802.11 WLAN devices were transmitting at the same time.
   - Data rate may be influenced by different multiple access policies of related protocols, and devices with lower transmission power (Bluetooth, in this case) may encounter more serious drop on throughput.

Conclusion: 802.11b Wireless LAN

After the experiment on 802.11b Wireless LAN and analysis of collected data, we conclude that:

- Longer distance between devices lowers the Signal-to-Noise ratio (SNR), negatively impacts TCP and UDP data transmission throughput, and increases the percentage of datagram loss.
  - Because SNR is defined logarithmically, a linear decrease in SNR implies an exponential decrease in signal strength and data throughput.
  - UDP and TCP throughput does not decrease linearly with SNR; data throughput decreases faster when SNR is lower.
  - UDP and TCP throughput decreases roughly at the same rate because datagram loss has similar impact on both protocols, no matter if they are re-transmitted or not.
- Electromagnetic interference from a microwave oven and among different laptops also negatively affects TCP and UDP transmission throughput.
  - Under the same condition, UDP in average has a slightly higher throughput than TCP, because it is a type of datagram that sends packages of information without flow or congestion control.

Conclusion: Bluetooth Experiment

After the experiment on Bluetooth and analysis of collected data, we conclude that:

- Longer distance between devices decreases the Bluetooth transmission throughput.
  - The relation is non-linear and the decrease rate of throughput is higher when distance is smaller.
- Under the same network condition, DH5 packets have the highest transmission throughput and DH1 packets have the lowest.
  - Packets that stretch over higher number of time slots carry more bits of data in a single packet, so the overhead caused by the packet header is smaller which leads to higher throughput.
- Having data transmitted from one device to multiple devices at the same time would slow down the transmission of every connection.
  - The sum of throughputs would be smaller than the previously measured throughput of a single connection, possibly due to extra overhead of switching between multiple Piconet's frequencies.
- Multiple Bluetooth and 802.11b WLAN connections that are transmitting at the same time and are crossing each other would decrease the throughput of each other due to electromagnetic interference.

References

- R Dzhanidze, M. Gerla, Course Notes and Handouts for CS M117. 2018 Winter.
- “IEEE 802.11.” *Wikipedia*, Wikimedia Foundation, 2 May 2018, en.wikipedia.org/wiki/IEEE_802.11.