Group 1 Final Project: Analysis of the System Performance of WiFi under Different Scenarios

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Abstract—IEEE 802.11, commonly known as WiFi, is a famous wireless communication protocol. In this final project, we aim to simulate WiFi and compare the system performance under different scenarios. First, We will evaluate the system performance of standalone WiFi. Then, we will evaluate the system performance of WiFi when 4G LTE coexists. Finally, we will evaluate the system performance of a hybrid system with uplink following WiFi and downlink following 4G. We find out that different architectures are suitable for different scenarios.

Index Terms—IEEE 802.11, DCF, PCF, 4G LTE.

1 INTRODUCTION

As mobile and wireless networks become ubiquitous, wireless communication is needed now more than ever. In general, WiFi is a well-designed protocol, and will surely continue to exist for a long time. However, we believe that in this highly diversified world, there is not a cure-all protocol. Therefore, how to combine different system architectures and how to dynamically modify parameters will be of great importance. In this final project, we will simulate WiFi, a hybrid system with WiFi and 4G LTE, and the coexistence of WiFi and 4G LTE, and compare their system performance under different scenarios.

First, We evaluate the system performance of standalone WiFi. We find out that standalone WiFi performs well at low traffic load but gets worse at high traffic load. We have also analyzed the system performance under different parameters.

Then, we evaluate the system performance of the coexistence of WiFi and 4G LTE. The downlink channel can choose between WiFi and 4G LTE, while the uplink channel can only use WiFi. In this way, we can better compare the system performance of the two different protocols. We find out that the system performance is good at both low and high traffic loads. Also, the packet loss rate of WiFi and 4G LTE will converge and the number of users using WiFi and 4G LTE will reach an equilibrium.

Finally, we evaluate the system performance of a hybrid system with uplink following WiFi and downlink following 4G LTE. We find out that the downlink performance is good, but the uplink is not.

We have provided our simulation programs. The instructions are written in Readme.txt.

The major contributions of this final project are as follows:

- The system performance of standalone WiFi under different scenarios is evaluated.
- The system performance of the coexistence of WiFi and 4G LTE under different scenarios is evaluated.
- The system performance of a hybrid system combining WiFi and 4G LTE under different scenarios is evaluated.

2 SYSTEM MODEL

2.1 Scenario

We implement a wrap-around mechanism for a 9-site square cluster. There are 16 access points (APs) distributed in 4-by-4 grids inside the square cell and 160 mobile stations (MSs) distributed uniformly. The architecture can be seen in Fig. 1. Each MS moves at a velocity in a given range and moves in a random direction.

There are 6 channels with different frequency bands. Different APs will be allocated with 3 different channels, and each AP can further divide the allocated channel into 2 sub-channels. An MS selects its AP whose downlink SINR is the largest, and this action repeats periodically. Note that the maximum number of MS under an AP is limited. In a channel, a collision occurs when multiple MSs inside transmit simultaneously and the interference threshold is exceeded.

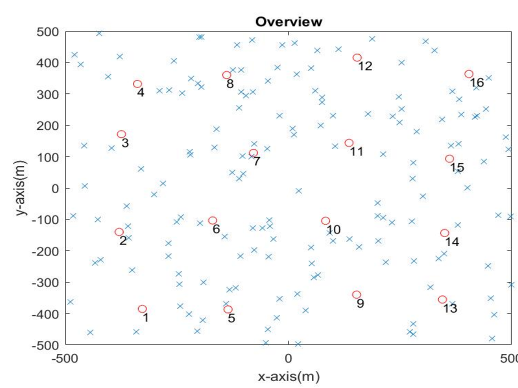

Fig. 1: system architecture (red: AP, blue: MS)

2.2 Uplink DCF

We follow the distributed coordination function (DCF) as taught in the lecture. When the timer of an MS becomes

0 and it considers the channel idle, it starts transmitting. Otherwise, it needs to wait. The MS will determine whether a channel is idle when the interference sensed is below a threshold.

A collision occurs when the SINR at the AP is below a threshold. When a collision occurs, the contention window size of the MS will double.

The difference between our model and the standard DCF is that when a new packet arrives, and during DIFS, the channel is idle, our model will still wait another backoff time instead of instantly transmitting the packet.

2.3 Uplink PCF

We follow the point coordination function (PCF) as taught in the lecture. For MSs under one AP, we classify them by allocated frequencies and wrap them up as queues. MSs in one queue are MSs with the same frequency and under the same AP. In one iteration time, all queues are popped once, and only with probability p to transmit data to its corresponding AP. The setting of probability p is to reduce the interference between cells. Collisions occur when the SINR received at APs is lower than a threshold, then the total packet will be counted as packet loss.

2.4 Downlink DCF

Downlink DCF is similar to uplink DCF. However, there are some differences. First, the SINR is calculated at the MS side rather than the AP side. Second, the two frequencies of each AP contend as two different users, called sub-APs. That is, in our system, 32 users are contending for downlink resources. When a sub-AP gets the channel, it will further use TDMA to transmit packets to its serving MSs.

2.5 Downlink PCF

Downlink PCF is similar to uplink PCF. However, the SINR is calculated at the MS side rather than the AP side. When SINR received at the MS side during one iteration is below a threshold, the total packet is counted as packet loss, too.

3 Coexistence of 4G LTE and WiFi (downlink only)

3.1 Scenario

Similar to the scenario of 802.11 in section 2, there are 16 WiFi APs and 16 4G BSs. At the beginning of the simulation, each MS randomly selects either WiFi or 4G. The downlink 4G LTE is similar to the simulation in our programming assignments. However, we additionally use FDMA and TDMA to transmit packets in order to lower packet loss rate. The bandwidth for it is 60 MHz.

3.2 Handover

Handover is based on packet loss rate. Each MS periodically measures the packet loss rate of both 4G and WiFi in a short period of time. Then, the protocol with lower packet loss rate is selected.

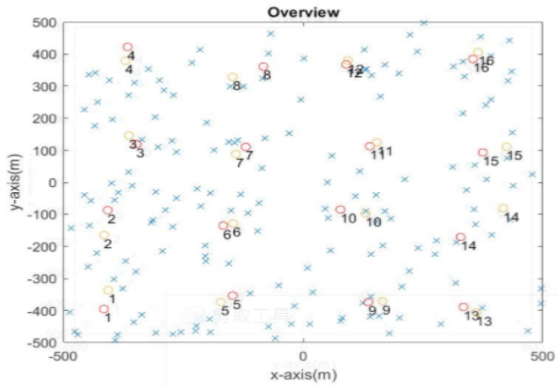

Fig. 2: coexistence of WiFi and 4G-system architecture (red: AP, orange: BS, blue: MS)

4 Results

The general parameters we use are listed in Table. 1, which are modified from [1]–[3]. For simulation, sometimes we will use different parameters. We will provide the parameters if they are not the same as the general parameters. Also, we will provide our programs, where parameters can be modified.

Note that we only run our programs for 5000 iterations to save time. However, to get a more stable result, it is better to simulate for more iterations. Nonetheless, despite some fluctuations, the tendency can be seen.

Since this section contains a lot of figures, we put all of them at the end of this report.

TABLE 1: Table of Parameters

Parameter	Value
Architecture:	
Boundary length	1000 (m)
Number of APs	16
Number of MSs per AP	10
Uplink λ	100K (bit/s)
Downlink λ	100K (bit/s)
Uplink bandwidth	10M (Hz)
Downlink bandwidth	10M (Hz)
Iteration time	25 (μs)
Total simulation time	5000 (Iteration time)
MS speed	0.001-0.006 (m/iteration time)
Interference threshold	0.01 (Watt)
SINR threshold	10 (dB)
Payload size	500 (bit)
DCF and PCF's parameters:	
Slot time	50 (μs)
DIFS	125 (μs)
PIFS	75 (μs)
SIFS	25 (μs)
CWmin	15 (slot time)
CWmax	127 (slot time)

4.1 Standalone WiFi

4.1.1 DCF

In this subsection, we only consider the DCF of WiFi. We have analyzed the system performance of DCF under different interference thresholds and minimum contention window size (CWmin). We set uplink λ and downlink λ to 200K (bit/s).

The interference threshold is used for an MS or an AP to decide whether the channel is idle. When the threshold is high, the transmitter is more likely to assume that the channel is idle and transmit. Therefore, the packet loss rate and the throughput will rise as the interference threshold increases, and the buffer utilization rate will decrease accordingly. The results can be seen in Fig. 3, Fig. 4, and Fig. 5.

Moreover, the downlink packet loss rate is generally lower than the uplink packet loss rate. This is reasonable since the antenna power of an AP is larger than that of an MS.

CWmin is used in the backoff timer. When the contention window is large, the transmitter is more likely to transmit. Therefore, the packet loss rate and the throughput will rise as the CWmin increases, and the buffer utilization rate will decrease accordingly. The results can be seen in Fig. 6, Fig. 7, and Fig. 8.

4.1.2 PCF

In this subsection, we only consider the PCF of WiFi. We have analyzed the system performance of PCF under different poll probabilities.

Poll probability is used in the PCF to decide the probability to transmit of a transmitter. When the poll probability is high, the transmitter is more likely to transmit. Therefore, the packet loss rate and the throughput will rise as the poll probability increases, and the buffer utilization rate will decrease accordingly. The results can be seen in Fig. 9, Fig. 10, and Fig. 11.

4.1.3 DCF+PCF

In this subsection, we consider a complete WiFi architecture: DCF and PCF. We have analyzed the system performance of WiFi under different λ and MS numbers.

Uplink λ and downlink λ are parameters indicating the traffic load of the system. When λ is high, the traffic is heavier, so the transmitter is more likely to transmit. Therefore, the throughput and the buffer utilization rate will increase. However, only the packet loss rate of the uplink DCF will increase significantly. Since PCF uses polling instead of random access, its packet loss rate is not greatly affected by traffic load. On the other hand, while the mechanism of downlink DCF is similar to uplink DCF, the downlink channel performs better since its antenna power is larger. Therefore, downlink DCF only increases slightly as traffic load increases. The results can be seen in Fig. 12, Fig. 13, and Fig. 14.

MS number per AP is another indicator of the traffic load. When the MS number is high, more users are competing for resources. Therefore, the throughput and the buffer utilization rate will increase. However, only the packet loss rate of the uplink DCF will increase significantly. Since PCF uses polling instead of random access, its packet loss rate is not greatly affected by traffic load. On the other hand, while the mechanism of downlink DCF is similar to uplink DCF, the downlink channel performs better since its antenna power is larger. Therefore, downlink DCF only increases slightly as traffic load increases. The results can be seen in Fig. 15, Fig. 16, and Fig. 17.

4.2 Coexistence of WiFi and 4G LTE

In this subsection, we consider a system composed of uplink using WiFi and downlink that allows MSs to choose between WiFi and 4G.

We focus on the performance of downlink only and observe the difference between 4G and WiFi. As λ and number of MS per cell increase, packet loss rate, throughput, and buffer utilization rate increase for these two cases. The packet loss rate of 4G is lower, but it has lower throughput and higher buffer utilization rate. The results can be seen in 31, Fig. 32, Fig. 33, 34, Fig. 35, and Fig. 23.

The equilibrium can be seen in Fig. 24.

4.3 Hybrid System of WiFi and 4G LTE

In this subsection, we consider a hybrid system combining WiFi and 4G LTE. The downlink channel follows 4G LTE with FDMA and TDMA. The uplink channel follows WiFi standards. When downlink, we only allow an AP to transmit. Therefore, the packet loss rate will approach zero even when the traffic load is heavy.

From the perspective of λ, the traffic load doesn't significantly affect the packet loss rate and the buffer utilization rate of uplink PCF and downlink. Both indicators for 4G LTE are very close to 0 whatever the value of λ is. The reason is that we only allow an AP to transmit. Surprisingly, the throughput of 4G LTE is higher than that of DCF. As for uplink DCF, both the packet loss rate and buffer utilization rate increase as λ increases, which is similar to the observation in the previous subsection. The results can be seen in 25, Fig. 26, and Fig. 27.

From the perspective of the number of MS under an AP, the observation is similar to λ. The results can be seen in Fig. 28, Fig. 29, and Fig. 30.

5 CONCLUSION

We use three indicators to analyze the system performance of WiFi: packet loss rate, throughput, and buffer utilization rate. There is a trade-off between them, and different system architectures are suitable for different scenarios. Also, different parameters will influence the system's performance a lot. Some parameters can not be controlled, such as traffic load, while other parameters can be controlled, such as interference threshold. Thus, when designing a real wireless communication system, we need to combine both experiments and simulations. We have simulated WiFi under different scenarios, and our programs can be extended to analyze more diversified scenarios, such as nonuniform traffic load distribution. In sum, WiFi is a simple and robust protocol and our final project has done an extensive analysis of it under different scenarios and provided a lot of guides for it to meet new needs.

REFERENCES

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[2] Anastasi, G., Lenzini, L. QoS provided by the IEEE 802.11 wireless LAN to advanced data applications: a simulation analysis. Wireless Networks 6, 99–100 (2000). https://doi.org/10.1023/A:1019169010241

[3] https://d2cpnw0u24fjm4.cloudfront.net/wp-content/uploads/802.11n-and-802.11ac-MCS-SNR-and-RSSI.pdf

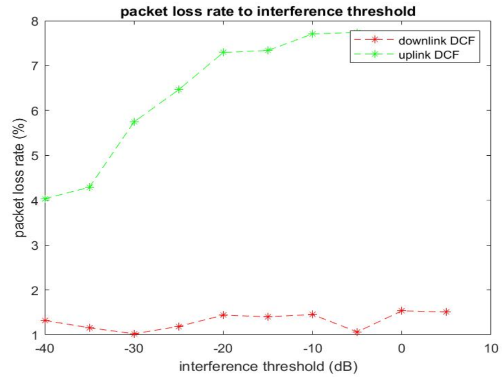

Fig. 3: packet loss rate under different interference threshold

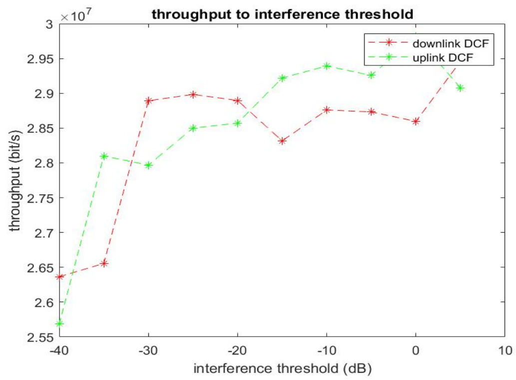

Fig. 4: throughput under different interference threshold

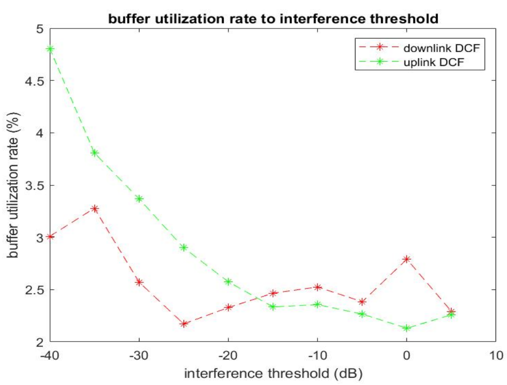

Fig. 5: buffer utilization rate under different interference threshold

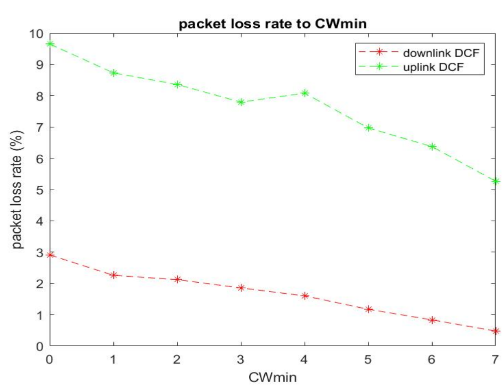

Fig. 6: packet loss rate under different minimum contention window size

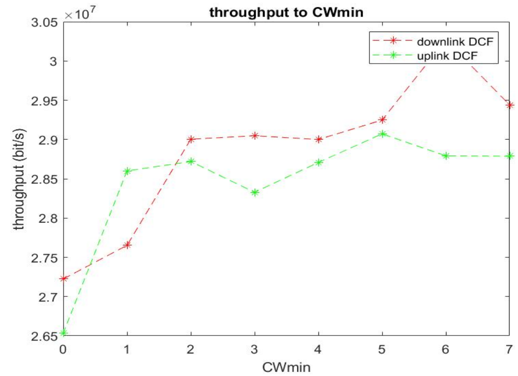

Fig. 7: throughput under different minimum contention window size

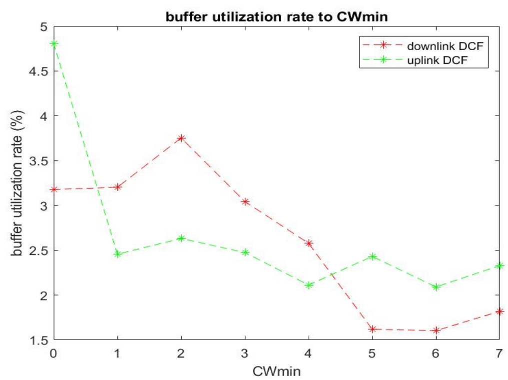

Fig. 8: buffer utilization rate under different minimum contention window size

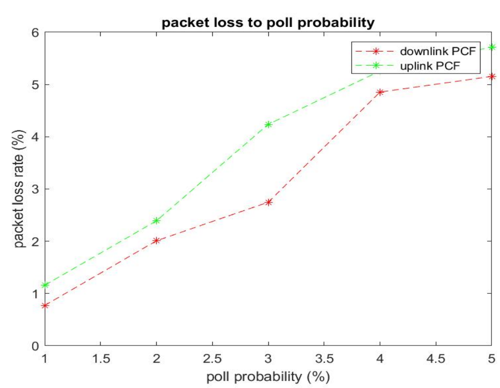

Fig. 9: packet loss rate under different poll probability

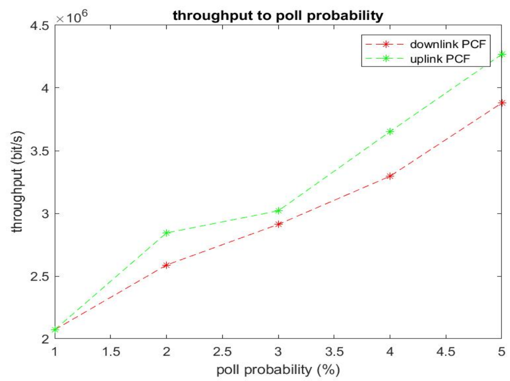

Fig. 10: throughput under different poll probability

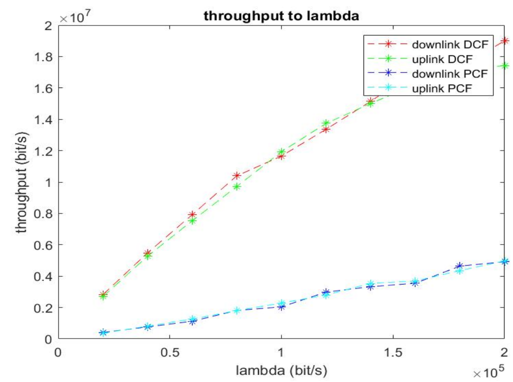

Fig. 13: throughput under different λ

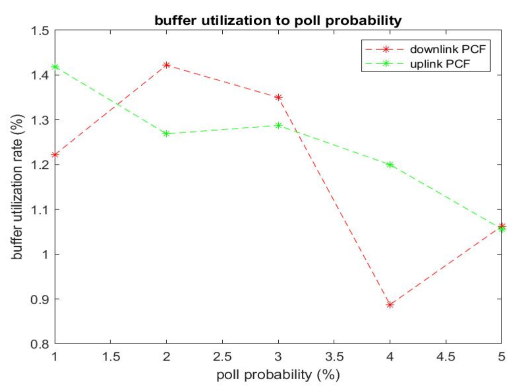

Fig. 11: buffer utilization rate under different poll probability

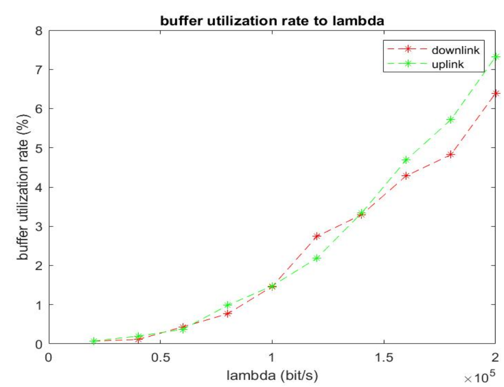

Fig. 14: buffer utilization rate under different λ

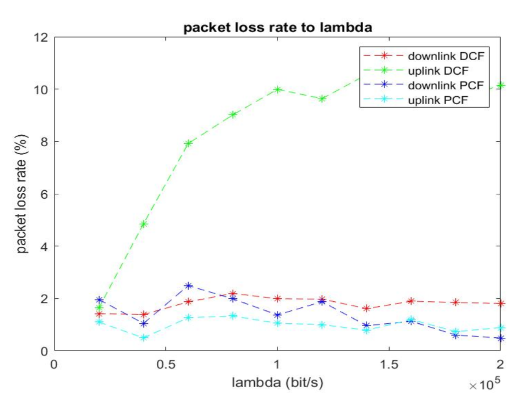

Fig. 12: packet loss rate under different λ

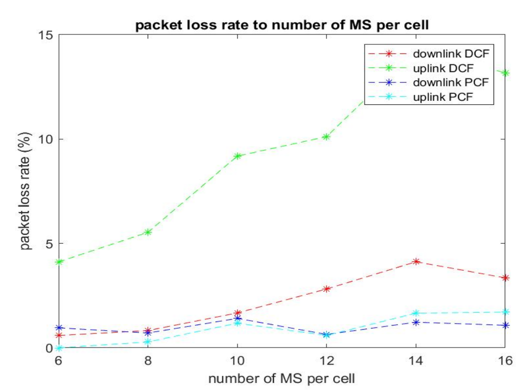

Fig. 15: packet loss rate under different number of MS per cell

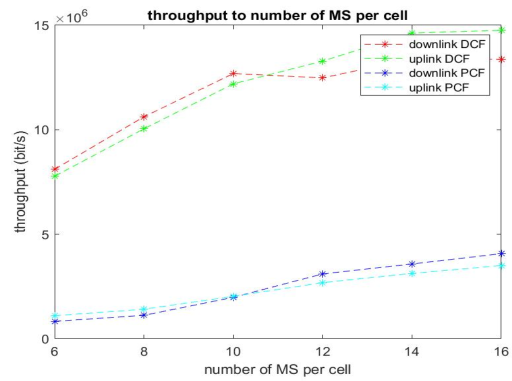

Fig. 16: throughput under different number of MS per cell

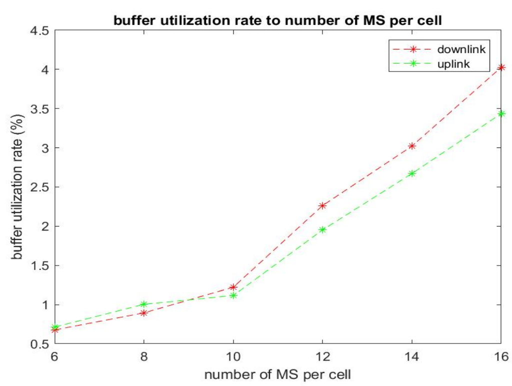

Fig. 17: buffer utilization rate under different number of MS per cell

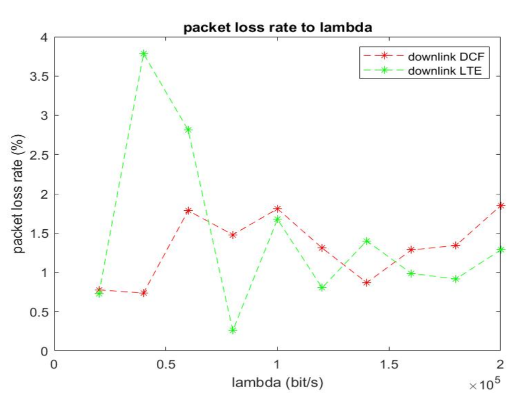

Fig. 18: packet loss rate under different λ

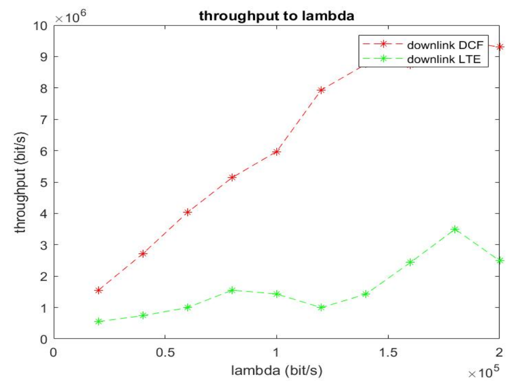

Fig. 19: throughput under different λ

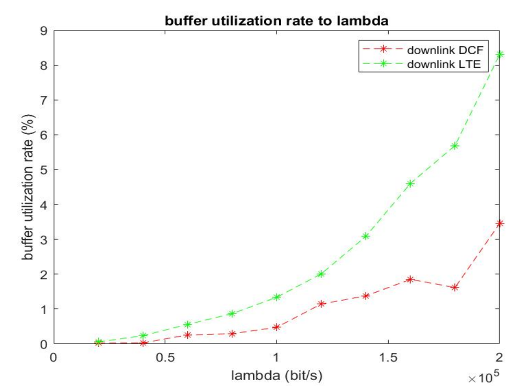

Fig. 20: buffer utilization rate under different λ

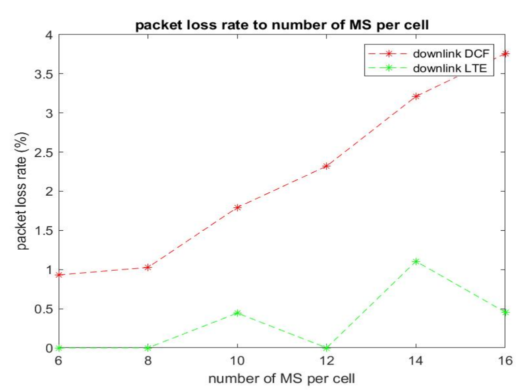

Fig. 21: packet loss rate under different number of MS per cell

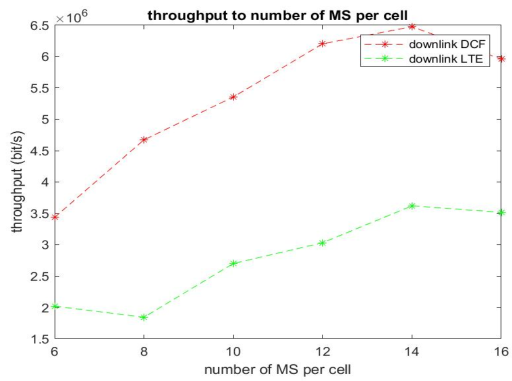

Fig. 22: throughput under different number of MS per cell

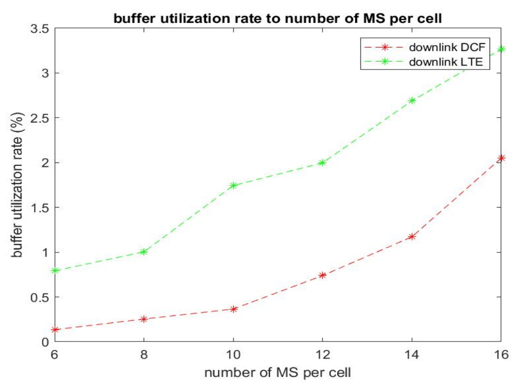

Fig. 23: buffer utilization rate under different number of MS per cell

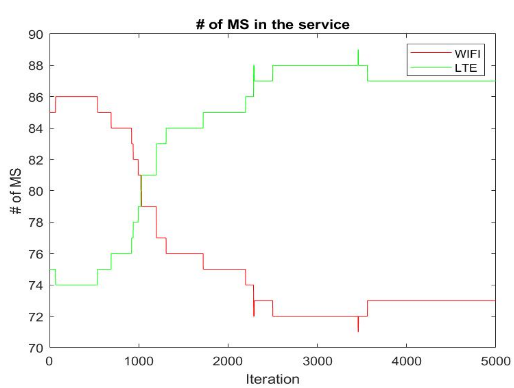

Fig. 24: Handover between 4G and WiFi

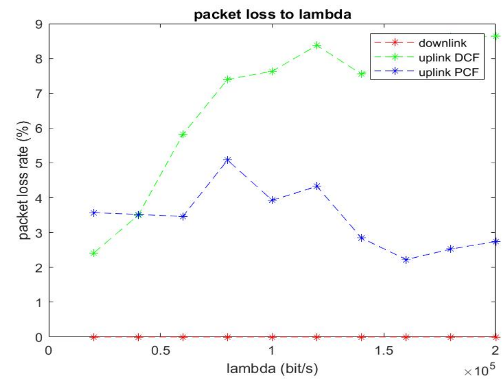

Fig. 25: packet loss rate under different λ

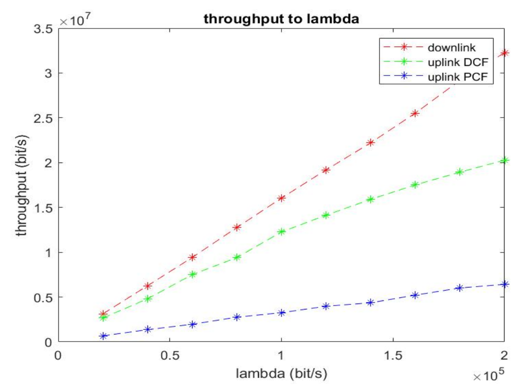

Fig. 26: throughput under different λ

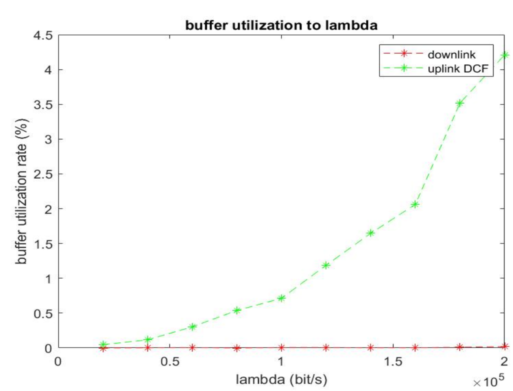

Fig. 27: buffer utilization rate under different λ

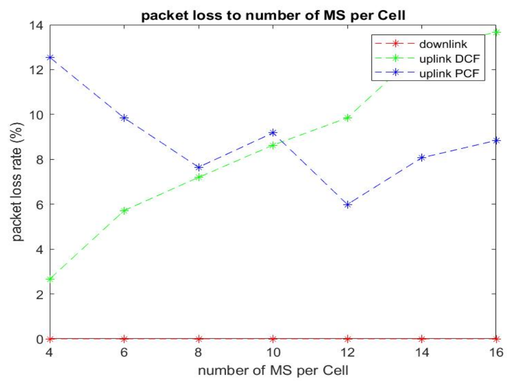

Fig. 28: packet loss rate under different number of MS per cell

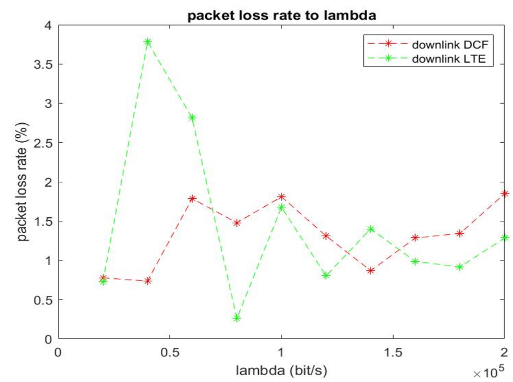

Fig. 31: hybrid of LTE and wifi's packet loss rate under different lambdas

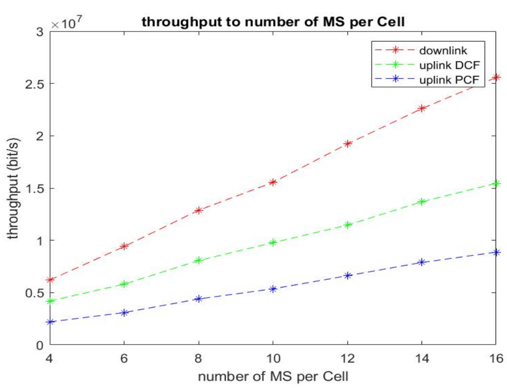

Fig. 29: throughput under different number of MS per cell

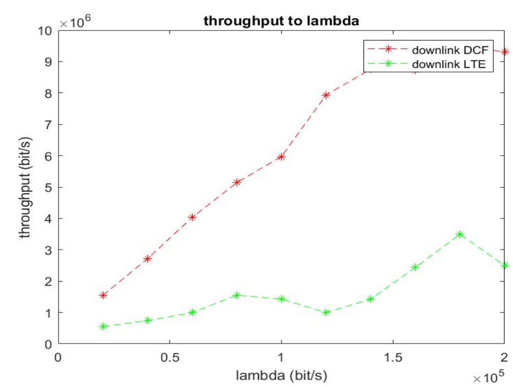

Fig. 32: hybrid of LTE and wifi's throughput under different lambdas

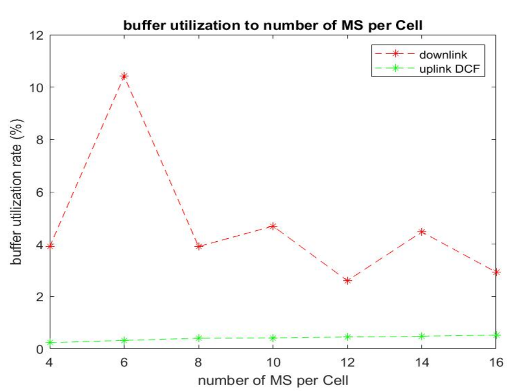

Fig. 30: buffer utilization rate under different number of MS per cell

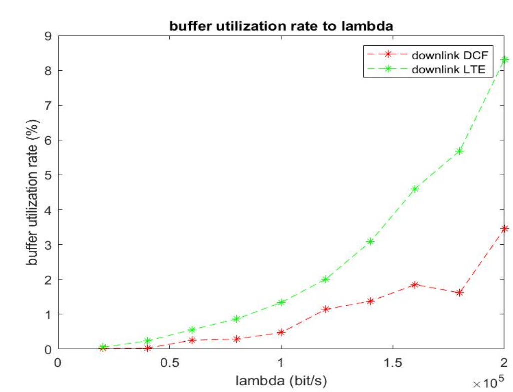

Fig. 33: hybrid of LTE and wifi's buffer utilization rate under different number of MS per cell

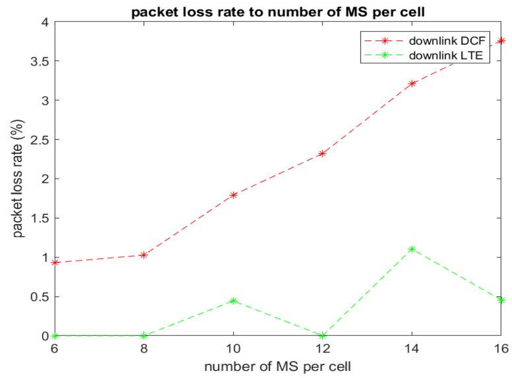

Fig. 34: hybrid of LTE and wifi's packet loss rate under different number of MS per cell

result/LTE_diff_msnum/throughput.jpg

Fig. 35: hybrid of LTE and wifi's throughput under different number of MS per cell

result/LTE_diff_msnum/buffer_util.jpg

Fig. 36: hybrid of LTE and wifi's buffer utilization rate under different number of MS per cell