数据通信作业

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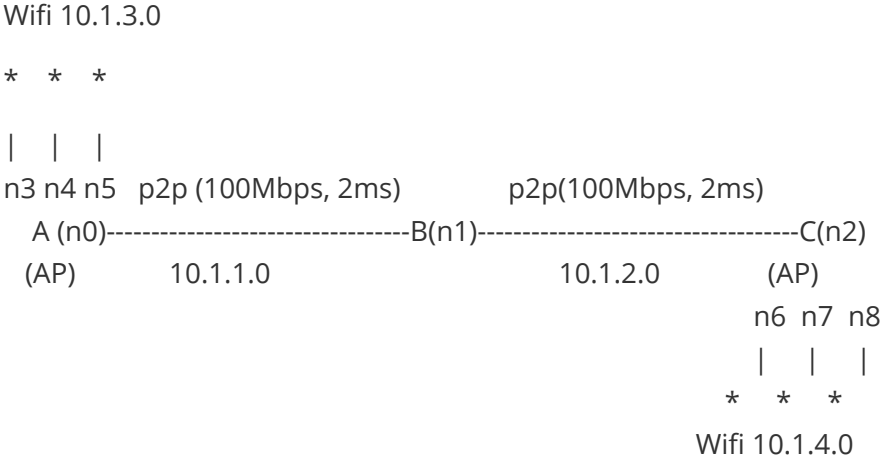
一、 实验名称及内容

名称： ns3 WiFi 实验

内容：使用 **ns3** 实现仿真两个不相邻 **WiFi** 子网间主机的通信：



二、实验过程和结果

环境

物理主机系统：*macOS Catalina 10.15.4*

虚拟机系统：*Ubuntu 18.04.4 LTS*

虚拟机软件：*VMware Fusion 专业版 11.5.3 (15870345)*

实验软件：*ns-3.28*

实验过程

首先完成了实验的第一题，阅读了第一题的代码及解析，了解了 **ns3** 模拟 **WiFi** 网络与之前的点到点网络和 **CSMA** 网络的不同之处，基本上掌握了 **WiFi** 网络与其他网络之间进行通信的编程技巧。

然后仿照第一题完成第二题的模块化编程。总体设计是在 **WiFi 10.1.3.0** 子网中最后创建的 **WiFi** 节点上安装 **UDP Echo Client**；在 **WiFi 10.1.4.0** 子网中最后创建的 **WiFi** 节点上安装 **UDP Echo Server**。

1. 确定 **LOG** 内容
2. 创建点到点链路节点
3. 创建并配置点到点通信链路
4. 在节点上安装相应网卡
5. 创建 **WiFi** 节点
6. 创建并配置 **WiFi** 通信链路
7. 在节点上安装相应网卡
8. 配置 **WiFi** 节点的移动范围与方式
9. 在节点上安装通信协议栈
10. 配置各子网地址与 **IP** 协议
11. 在不同节点创建并配置 **Echo** 用户与服务器应用程序
12. 开始仿真
13. 结束仿真
14. 查看输出

实验结果

第一题

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ ./waf --run scratch/mythird
Waf: Entering directory `/home/test/workspace/ns-allinone-3.28/ns-3.28/build'
Waf: Leaving directory `/home/test/workspace/ns-allinone-3.28/ns-3.28/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (1.963s)
At time 2s client sent 1024 bytes to 10.1.2.4 port 9
At time 2.01794s server received 1024 bytes from 10.1.3.3 port 49153
At time 2.01794s server sent 1024 bytes to 10.1.3.3 port 49153
At time 2.03371s client received 1024 bytes from 10.1.2.4 port 9
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$
```

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r third-0-0.pcap
reading from file third-0-0.pcap, link-type PPP (PPP)
2.008133 IP 10.1.3.3.49153 > 10.1.2.4.9: UDP, length 1024
2.026740 IP 10.1.2.4.9 > 10.1.3.3.49153: UDP, length 1024
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r third-0-1.pcap
reading from file third-0-1.pcap, link-type IEEE802_11 (802.11)
0.032090 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.032346 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.032362 Acknowledgment RA:00:00:00:00:00:09
0.032554 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.032570 Acknowledgment RA:00:00:00:00:00:08
0.032684 Assoc Response AID(1) :: Successful
0.032828 Acknowledgment RA:00:00:00:00:00:0a
0.032985 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
```

第二题

运行程序 *lab3*。正如程序中定义的，用户程序一共发了两个包，间隔 $1s$；服务器程序接收到包后立刻回复给发送者，完成 **Echo** 功能。并且可见，**UDP Echo Client** 安装在 **10.1.3.2** 上，**UDP Echo Server** 安装在 **10.1.4.2** 上。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ ./waf --run scratch/lab3
Waf: Entering directory `/home/test/workspace/ns-allinone-3.28/ns-3.28/build'
Waf: Leaving directory `/home/test/workspace/ns-allinone-3.28/ns-3.28/build'
Build commands will be stored in build/compile_commands.json
'build' finished successfully (1.451s)
At time 2s client sent 1024 bytes to 10.1.4.2 port 9
At time 2.01327s server received 1024 bytes from 10.1.3.2 port 49153
At time 2.01327s server sent 1024 bytes to 10.1.3.2 port 49153
At time 2.03151s client received 1024 bytes from 10.1.4.2 port 9
At time 3s client sent 1024 bytes to 10.1.4.2 port 9
At time 3.00712s server received 1024 bytes from 10.1.3.2 port 49153
At time 3.00712s server sent 1024 bytes to 10.1.3.2 port 49153
At time 3.01436s client received 1024 bytes from 10.1.4.2 port 9
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$
```

通过 PACP 文件分析通信过程

查看 **UDP Echo Client** 的网卡记录的 **pcap** 包。由于网络刚开启，**UDP Echo Client** 需要查询本子网的网关路由器以将报文发往其他子网，所以 **UDP Echo Client** 程序刚开始启动时会发送 **ARP** 报文查询网关 **MAC** 地址，收到 **A** 的 **ARP** 响应后再发送 **UDP** 报文。在收到 **UDP Echo Server** 的回复前 **UDP Echo Client** 也收到了本地网关 **A** 的 **ARP** 查询报文，响应后才收到 **UDP Echo Server** 的回复。而第二次发送报文和收到报文时就不需要再 **ARP** 查询了。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-4-0.pcap
reading from file lab3-4-0.pcap, link-type IEEE802_11 (802.11)
0.090119 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.090225 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.090381 Acknowledgment RA:00:00:00:00:00:06
0.090520 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.090580 Acknowledgment RA:00:00:00:00:00:05
0.090797 Assoc Response AID(1) :: Successful
0.090813 Acknowledgment RA:00:00:00:00:00:07
0.091020 Assoc Response AID(2) :: Successful
0.091080 Acknowledgment RA:00:00:00:00:00:07
0.192519 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
1.933319 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
2.002000 ARP, Request who-has 10.1.3.3 (ff:ff:ff:ff:ff:ff) tell 10.1.3.2, length 32
2.002172 Acknowledgment RA:00:00:00:00:00:06
2.002408 ARP, Request who-has 10.1.3.3 (ff:ff:ff:ff:ff:ff) tell 10.1.3.2, length 32
2.002626 ARP, Reply 10.1.3.3 is-at 00:00:00:00:00:07, length 32
2.002642 Acknowledgment RA:00:00:00:00:00:07
2.002747 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.004283 Acknowledgment RA:00:00:00:00:00:06
2.029723 ARP, Request who-has 10.1.3.2 (ff:ff:ff:ff:ff:ff) tell 10.1.3.3, length 32
2.029793 ARP, Reply 10.1.3.2 is-at 00:00:00:00:00:06, length 32
2.029965 Acknowledgment RA:00:00:00:00:00:06
2.031511 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
2.031527 Acknowledgment RA:00:00:00:00:00:07
2.035719 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
2.957319 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
3.000000 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.001536 Acknowledgment RA:00:00:00:00:00:06
3.014362 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.014378 Acknowledgment RA:00:00:00:00:00:07
3.059719 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

查看节点 **A** 的在第一个 **WiFi** 子网上的网卡记录的 **pcap** 包。可见在 **UDP Echo Client** 程序开始后 **A** 收到了来自 **UDP Echo Client** 的 **ARP** 查询报文，回复后收到了来自 **UDP Echo Client** 发往 **UDP Echo Server** 的 **UDP** 数据包。之后收到了来自 **UDP Echo Server** 回复 **UDP Echo Client** 的 **UDP** 数据包，于是和上面相呼应，**A** 先广播查询 **UDP Echo Client** 的 **ARP** 查询报文，收到响应报文后才转发 **UDP** 数据包。而第二次发送和收到 **UDP** 报文时就不需要再 **ARP** 查询了。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-0-1.pcap
reading from file lab3-0-1.pcap, link-type IEEE802_11 (802.11)
0.090011 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.090321 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.090337 Acknowledgment RA:00:00:00:00:00:06
0.090520 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.090536 Acknowledgment RA:00:00:00:00:00:05
0.090713 Assoc Response AID(1) :: Successful
0.090857 Acknowledgment RA:00:00:00:00:00:07
0.090936 Assoc Response AID(2) :: Successful
0.091080 Acknowledgment RA:00:00:00:00:00:07
0.192411 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.294811 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
1.830811 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
1.933211 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
2.002112 ARP, Request who-has 10.1.3.3 (ff:ff:ff:ff:ff:ff) tell 10.1.3.2, length 32
2.002128 Acknowledgment RA:00:00:00:00:00:06
2.002296 ARP, Request who-has 10.1.3.3 (ff:ff:ff:ff:ff:ff) tell 10.1.3.2, length 32
2.002514 ARP, Reply 10.1.3.3 is-at 00:00:00:00:00:07, length 32
2.002686 Acknowledgment RA:00:00:00:00:00:07
2.004223 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.004239 Acknowledgment RA:00:00:00:00:00:06
2.029611 ARP, Request who-has 10.1.3.2 (ff:ff:ff:ff:ff:ff) tell 10.1.3.3, length 32
2.029905 ARP, Reply 10.1.3.2 is-at 00:00:00:00:00:06, length 32
2.029921 Acknowledgment RA:00:00:00:00:00:06
2.030035 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
2.031571 Acknowledgment RA:00:00:00:00:00:07
2.035611 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
2.854811 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
2.957211 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
3.001476 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.001492 Acknowledgment RA:00:00:00:00:00:06
3.012886 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.014422 Acknowledgment RA:00:00:00:00:00:07
3.059611 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
3.162011 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

查看节点 **A** 的在点到点链路 **10.1.1.0** 上的网卡记录的 **pcap** 包。可见该节点转发了两次从 **UDP Echo Client** 到 **UDP Echo Server** 的 **UDP** 报文，又接收了两次从 **UDP Echo Server** 到 **UDP Echo Client** 的 **UDP** 报文。且由于和 **B** 是点对点直接连接，不需要 **ARP** 查询。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-0-0.pcap
reading from file lab3-0-0.pcap, link-type PPP (PPP)
2.004223 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.022611 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.001476 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.012886 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$
```

之后的过程与上类似，以下就不详述。

查看节点 **B** 的在点到点链路 **10.1.1.0** 上的网卡和 **10.1.2.0** 上的网卡记录的 **pcap** 包（路由器没有转发时延）。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-1-0.pcap
reading from file lab3-1-0.pcap, link-type PPP (PPP)
2.006307 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.020527 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.003560 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.010802 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-1-1.pcap
reading from file lab3-1-1.pcap, link-type PPP (PPP)
2.006307 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.020527 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.003560 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.010802 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$
```

查看节点 **C** 的在点到点链路 **10.1.2.0** 的网卡上记录的 **pcap** 包。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-2-0.pcap
reading from file lab3-2-0.pcap, link-type PPP (PPP)
2.008391 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.018442 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.005644 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.008717 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$
```

查看节点 **C** 的在点到点链路 **10.1.4.0** 的网卡上记录的 **pcap** 包。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-2-1.pcap
reading from file lab3-2-1.pcap, link-type IEEE802_11 (802.11)
0.019174 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.019421 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.019437 Acknowledgment RA:00:00:00:00:00:08
0.019683 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.019699 Acknowledgment RA:00:00:00:00:00:09
0.019840 Assoc Response AID(1) :: Successful
0.019984 Acknowledgment RA:00:00:00:00:00:0a
0.020090 Assoc Response AID(2) :: Successful
0.020234 Acknowledgment RA:00:00:00:00:00:0a
0.121574 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
2.011391 ARP, Request who-has 10.1.4.2 (ff:ff:ff:ff:ff:ff) tell 10.1.4.3, length 32
2.011694 ARP, Reply 10.1.4.2 is-at 00:00:00:00:00:09, length 32
2.011710 Acknowledgment RA:00:00:00:00:00:09
2.011797 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.013333 Acknowledgment RA:00:00:00:00:00:0a
2.016385 ARP, Request who-has 10.1.4.3 (ff:ff:ff:ff:ff:ff) tell 10.1.4.2, length 32
2.016401 Acknowledgment RA:00:00:00:00:00:09
2.016506 ARP, Request who-has 10.1.4.3 (ff:ff:ff:ff:ff:ff) tell 10.1.4.2, length 32
2.016760 ARP, Reply 10.1.4.3 is-at 00:00:00:00:00:0a, length 32
2.016932 Acknowledgment RA:00:00:00:00:00:0a
2.018442 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
2.018458 Acknowledgment RA:00:00:00:00:00:09
2.067174 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
2.988774 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
3.005644 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.007180 Acknowledgment RA:00:00:00:00:00:0a
3.008717 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.008733 Acknowledgment RA:00:00:00:00:00:09
3.091174 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

查看 **UDP Echo Server** 的网卡记录的 **pcap** 包。在 **C** 收到了 **UDP** 报文后， **UDP Echo Server** 收到了来自 **C** 的 **ARP** 查询报文，响应后收到了 **UDP** 数据包。之后本该立即回复 **UDP Echo Client**，但在回复前先要知道本地网关的 **MAC** 地址，于是先广播 **ARP** 查询报文并收到响应。之后立即回复 **UDP Echo Client** 以 **UDP** 报文。而第二次收到和发送 **UDP** 报文时就不需要再 **ARP** 查询了。

```
test@ubuntu1804:~/workspace/ns-allinone-3.28/ns-3.28$ tcpdump -nn -tt -r lab3-6-0.pcap
reading from file lab3-6-0.pcap, link-type IEEE802_11 (802.11)
0.019282 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
0.019421 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.019481 Acknowledgment RA:00:00:00:00:00:08
0.019587 Assoc Request (ns-3-ssid) [6.0 9.0 12.0 18.0 24.0 36.0 48.0 54.0 Mbit]
0.019743 Acknowledgment RA:00:00:00:00:00:09
0.019924 Assoc Response AID(1) :: Successful
0.019984 Acknowledgment RA:00:00:00:00:00:0a
0.020174 Assoc Response AID(2) :: Successful
0.020190 Acknowledgment RA:00:00:00:00:00:0a
0.121682 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
1.964882 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
2.011503 ARP, Request who-has 10.1.4.2 (ff:ff:ff:ff:ff:ff) tell 10.1.4.3, length 32
2.011582 ARP, Reply 10.1.4.2 is-at 00:00:00:00:00:09, length 32
2.011754 Acknowledgment RA:00:00:00:00:00:09
2.013273 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
2.013289 Acknowledgment RA:00:00:00:00:00:0a
2.016273 ARP, Request who-has 10.1.4.3 (ff:ff:ff:ff:ff:ff) tell 10.1.4.2, length 32
2.016445 Acknowledgment RA:00:00:00:00:00:09
2.016618 ARP, Request who-has 10.1.4.3 (ff:ff:ff:ff:ff:ff) tell 10.1.4.2, length 32
2.016872 ARP, Reply 10.1.4.3 is-at 00:00:00:00:00:0a, length 32
2.016888 Acknowledgment RA:00:00:00:00:00:0a
2.016966 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
2.018502 Acknowledgment RA:00:00:00:00:00:09
2.067282 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

```
2.988882 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
3.007120 IP 10.1.3.2.49153 > 10.1.4.2.9: UDP, length 1024
3.007136 Acknowledgment RA:00:00:00:00:00:0a
3.007241 IP 10.1.4.2.9 > 10.1.3.2.49153: UDP, length 1024
3.008777 Acknowledgment RA:00:00:00:00:00:09
3.091282 Beacon (ns-3-ssid) [6.0* 9.0 12.0* 18.0 24.0* 36.0 48.0 54.0 Mbit] ESS
```

三、问题与思考

这次实验让我继续熟悉了 **ns3** 的模块化编程和各模块的编程技巧，特别是新学习到了 **WiFi** 子网通信的仿真，这必将对我之后的学习工作大有用处。另外，在分析通信过程的过程中，还复习了一遍 **ARP** 协议、 **UDP** 协议的通信方式，加深了对协议的理解。