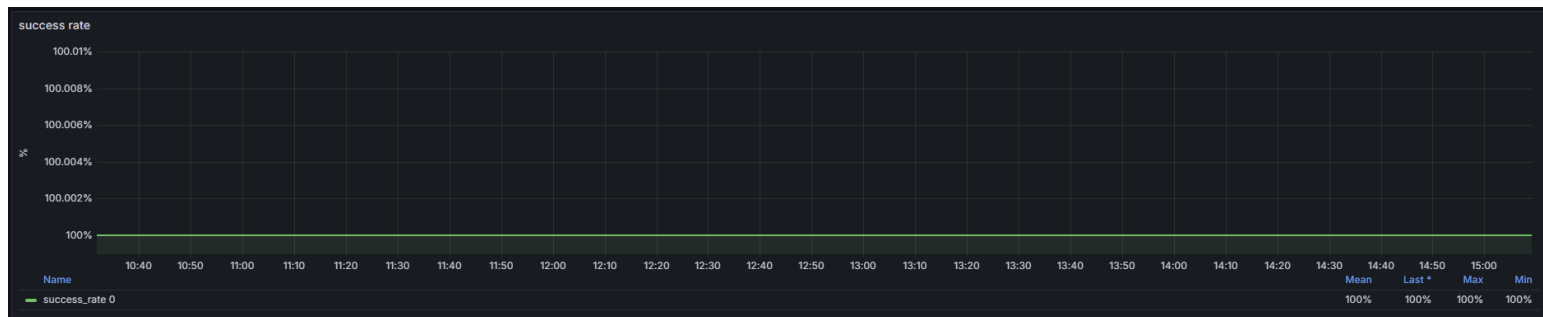
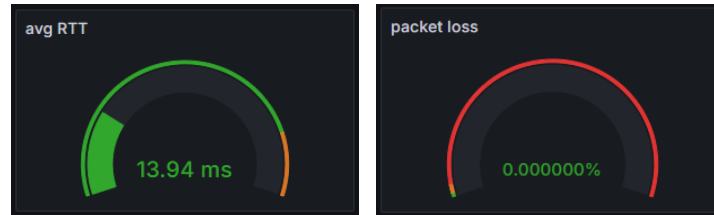


User experience of drone communication on mobile networks

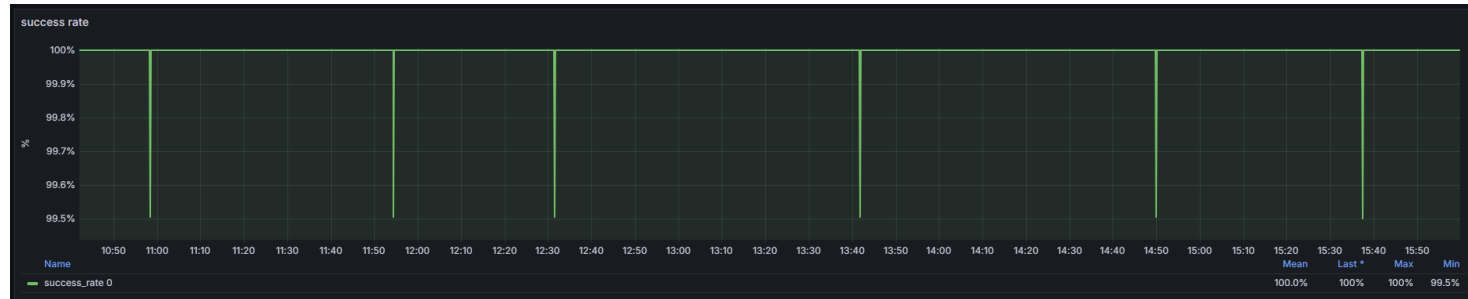
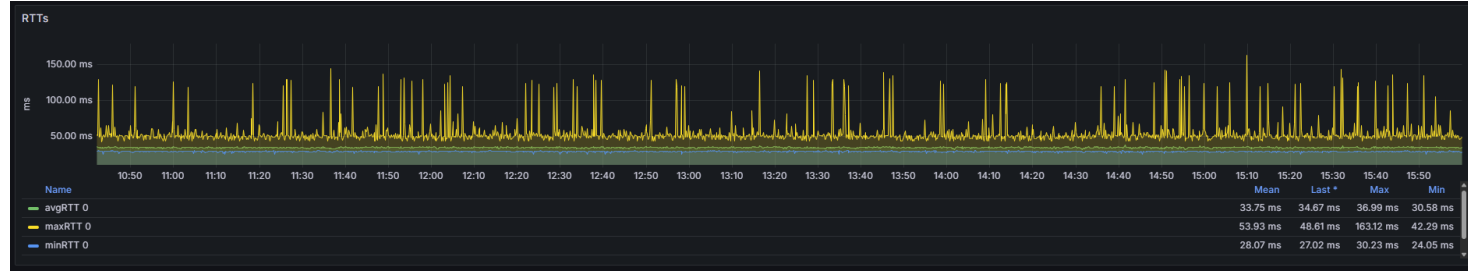
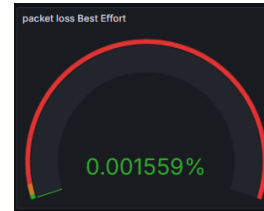
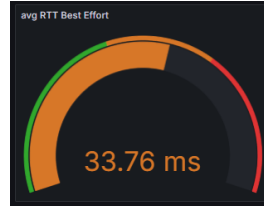
Zsolt Kovács
Magyar Telekom



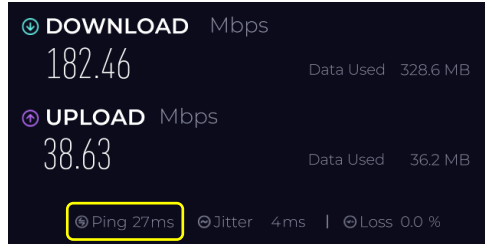
TWAMP measurement results at an optimal 5G connection



TWAMP measurement results at an average 4G connection



Ping values on mobile networks - 4G examples



```
Command Prompt
C:\>ping speedtest.net -t

Pinging speedtest.net [151.101.66.219] with 32 bytes of data:
Reply from 151.101.66.219: bytes=32 time=33ms TTL=54
Reply from 151.101.66.219: bytes=32 time=32ms TTL=54
Reply from 151.101.66.219: bytes=32 time=37ms TTL=54
Reply from 151.101.66.219: bytes=32 time=52ms TTL=54
Reply from 151.101.66.219: bytes=32 time=39ms TTL=54
Reply from 151.101.66.219: bytes=32 time=47ms TTL=54
Reply from 151.101.66.219: bytes=32 time=38ms TTL=54
Reply from 151.101.66.219: bytes=32 time=34ms TTL=54
Reply from 151.101.66.219: bytes=32 time=29ms TTL=54
Reply from 151.101.66.219: bytes=32 time=35ms TTL=54
Reply from 151.101.66.219: bytes=32 time=36ms TTL=54
Reply from 151.101.66.219: bytes=32 time=46ms TTL=54
Reply from 151.101.66.219: bytes=32 time=39ms TTL=54
Reply from 151.101.66.219: bytes=32 time=37ms TTL=54
Reply from 151.101.66.219: bytes=32 time=43ms TTL=54
Reply from 151.101.66.219: bytes=32 time=41ms TTL=54
Reply from 151.101.66.219: bytes=32 time=36ms TTL=54
Reply from 151.101.66.219: bytes=32 time=50ms TTL=54
Reply from 151.101.66.219: bytes=32 time=35ms TTL=54
Reply from 151.101.66.219: bytes=32 time=44ms TTL=54
Reply from 151.101.66.219: bytes=32 time=40ms TTL=54
Reply from 151.101.66.219: bytes=32 time=52ms TTL=54
Reply from 151.101.66.219: bytes=32 time=38ms TTL=54
Reply from 151.101.66.219: bytes=32 time=29ms TTL=54
Reply from 151.101.66.219: bytes=32 time=37ms TTL=54
Reply from 151.101.66.219: bytes=32 time=30ms TTL=54
Reply from 151.101.66.219: bytes=32 time=44ms TTL=54
Reply from 151.101.66.219: bytes=32 time=44ms TTL=54
Reply from 151.101.66.219: bytes=32 time=36ms TTL=54
Reply from 151.101.66.219: bytes=32 time=45ms TTL=54
Reply from 151.101.66.219: bytes=32 time=32ms TTL=54
Reply from 151.101.66.219: bytes=32 time=38ms TTL=54

Ping statistics for 151.101.66.219:
    Packets: Sent = 32, Received = 30, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 29ms    Maximum = 52ms,    Average = 39ms
```

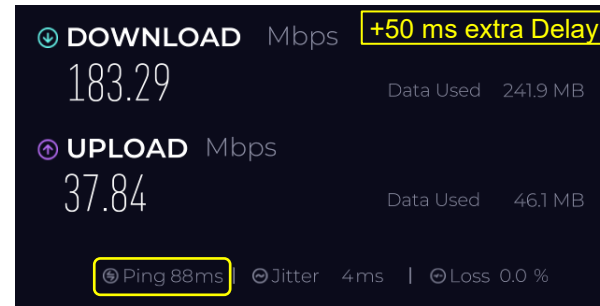
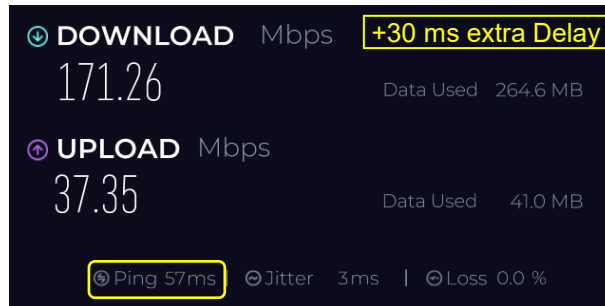
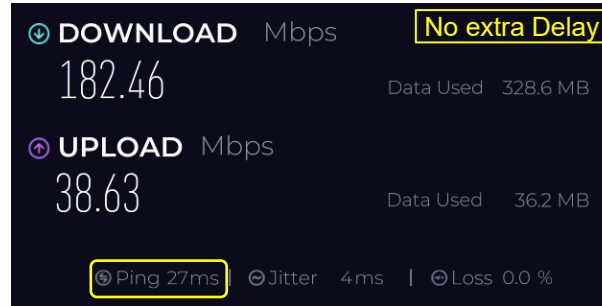
```
Command Prompt
C:\>ping speedtest.net -l 1472 -t

Pinging speedtest.net [151.101.66.219] with 1472 bytes of data:
Reply from 151.101.66.219: bytes=1472 time=59ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=46ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=52ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=56ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=55ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=42ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=43ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=51ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=52ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=40ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=43ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=48ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=47ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=55ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=52ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=63ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=46ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=39ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=61ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=56ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=52ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=46ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=48ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=64ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=57ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=58ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=45ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=47ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=46ms TTL=54
Reply from 151.101.66.219: bytes=1472 time=56ms TTL=54

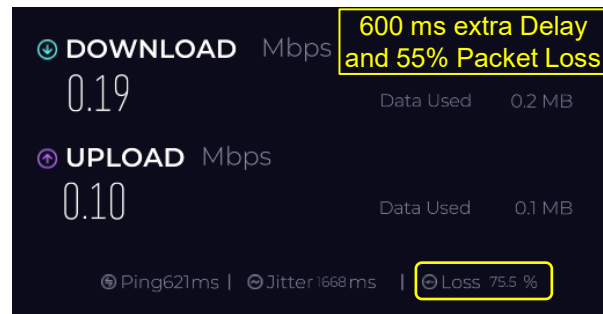
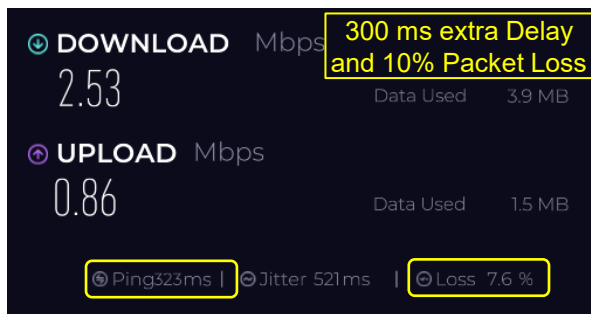
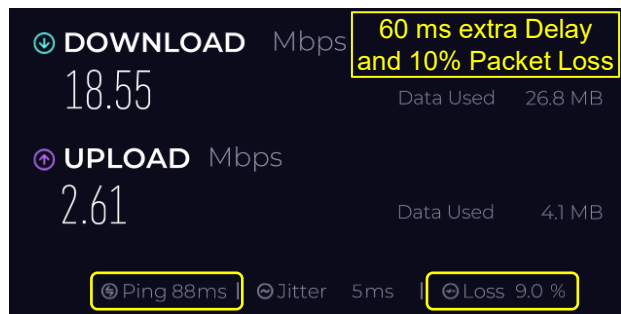
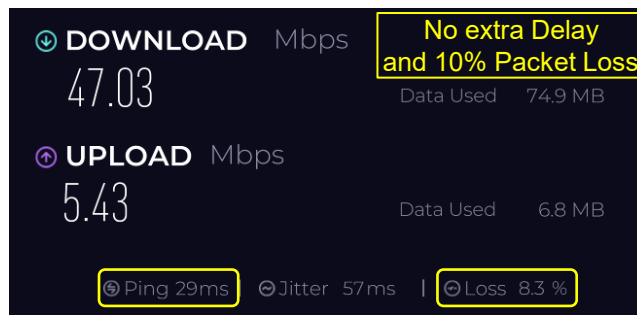
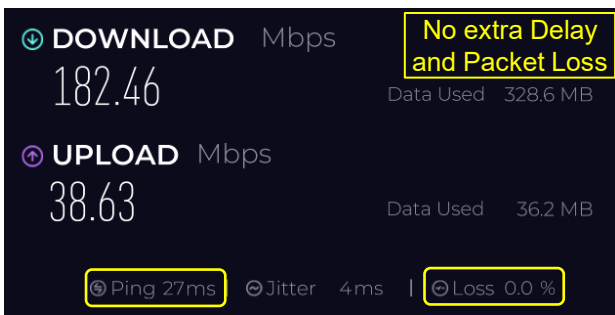
Ping statistics for 151.101.66.219:
    Packets: Sent = 30, Received = 30, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 39ms    Maximum = 64ms,    Average = 50ms
```



Speedtest.net values on mobile networks - 4G examples with extra Delay insertion only



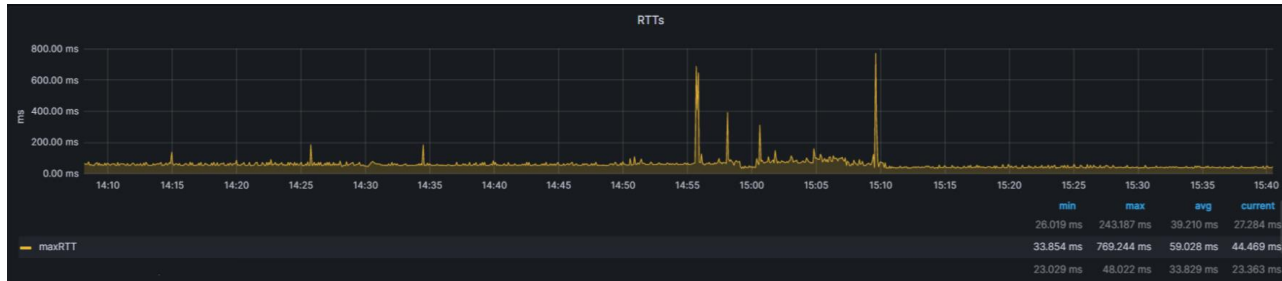
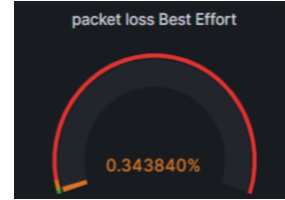
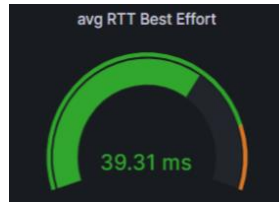
Speedtest.net values on mobile networks - 4G examples with extra Delay and Packet Loss insertion



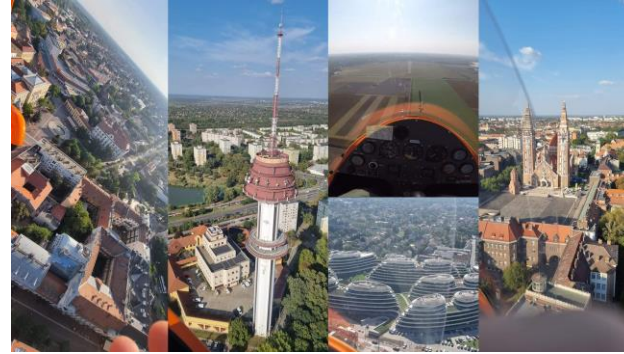
TWAMP measurement results from drone on 4G/5G network in 25-100 m height above a metropolitan area



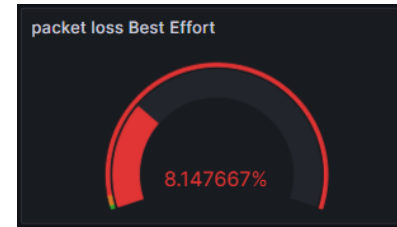
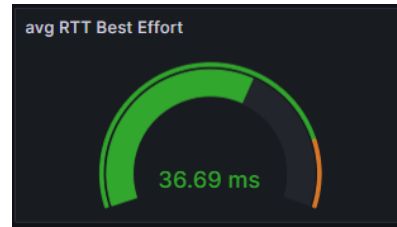
TWAMP measurement results from drone on 4G/5G network in 25-100 m height above a metropolitan area



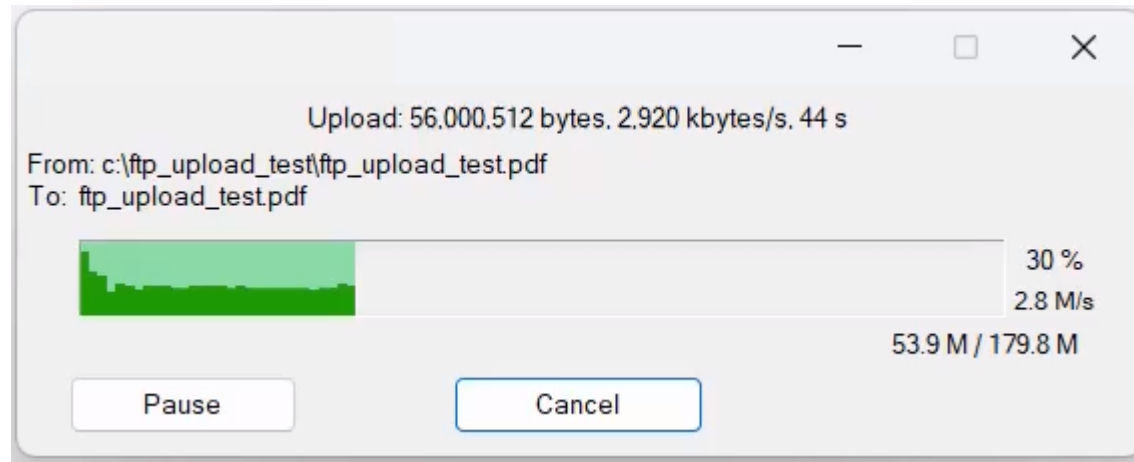
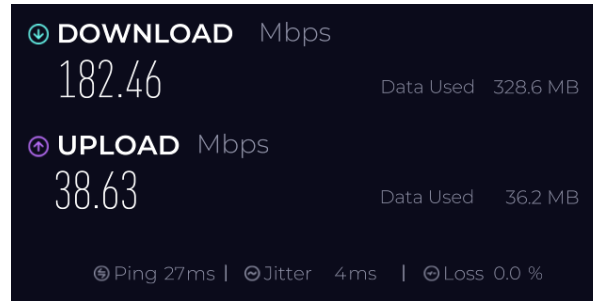
TWAMP measurement results from gyrocopter on 4G/5G network in 80-200 m height above metropolitan and rural areas



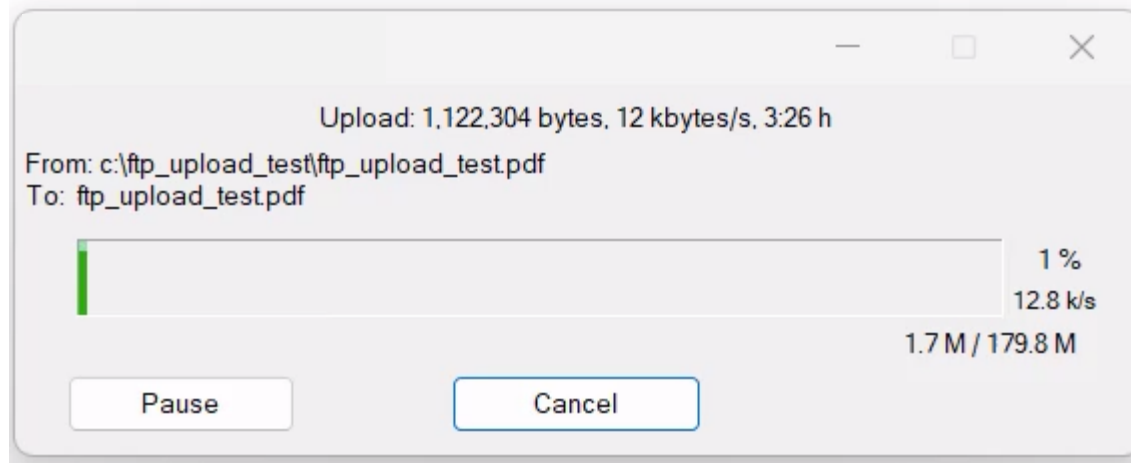
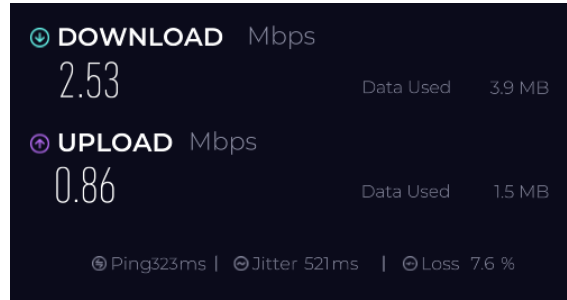
TWAMP measurement results from gyrocopter on 4G/5G network in 80-200 m height above metropolitan and rural areas



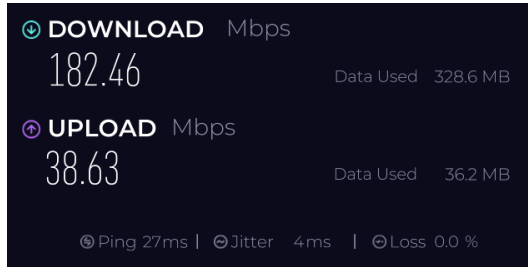
User experience example #1 - FTP file upload on optimal 4G mobile network connection



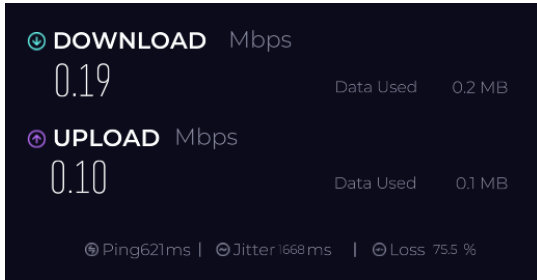
User experience example #1 - FTP file upload on non-optimal 4G mobile network connection - Extra 300 ms Delay and 10% Packet Loss insertion



User experience example #2 - Video streaming quality on optimal 4G mobile network connection



User experience example #2 - Video streaming quality on non-optimal 4G mobile network connection - Extra 600 ms Delay and 55% Packet Loss insertion



User experience example #3 - MQTT protocol-based message sending on optimal 4G mobile network connection

⬇️ **DOWNLOAD** Mbps
182.46
Data Used 328.6 MB

⬆️ **UPLOAD** Mbps
38.63
Data Used 36.2 MB

⌚ Ping 27ms | 📶 Jitter 4ms | 📶 Loss 0.0 %

Test Client

MQTT.Cool

Connection: tcp://broker.emqx.io:1883

Subscriptions

The topic filter: my/mqtt/topic QoS 0 **Subscribe**

Subscribed topics

my/mqtt/topic QoS 1

Publish

The destination of the message: my/mqtt/topic QoS 0 ☐ Retain

The message text to be sent

Publish

Messages

- 2025-9-1 12:22:34.584 **topic: my/mqtt/topic** QoS 1
Message_ID#20,uavID:123XYZ,latitude:19.047920,longitude:19.040248
- 2025-9-1 12:22:33.667 **topic: my/mqtt/topic** QoS 1
Message_ID#19,uavID:123XYZ,latitude:47.497919,longitude:19.040249
- 2025-9-1 12:22:32.627 **topic: my/mqtt/topic** QoS 1
Message_ID#18,uavID:123XYZ,latitude:47.497918,longitude:19.040248
- 2025-9-1 12:22:31.565 **topic: my/mqtt/topic** QoS 1
Message_ID#17,uavID:123XYZ,latitude:47.497917,longitude:19.040251
- 2025-9-1 12:22:30.643 **topic: my/mqtt/topic** QoS 1

broker.emqx.io
my/mqtt/topic

Message_ID#18,uavID:123XYZ,latitude:47.497918,longitude:19.040248,altitude_amsl_m:107,heading_deg:270
14:26:23, 01.10.2025

Message_ID#19,uavID:123XYZ,latitude:47.497919,longitude:19.040249,altitude_amsl_m:108,heading_deg:270
14:26:24, 01.10.2025

Message_ID#20,uavID:123XYZ,latitude:47.497920,longitude:19.040250,altitude_amsl_m:109,heading_deg:270
14:26:25, 01.10.2025

Message_ID#21,uavID:123XYZ,latitude:47.497921,longitude:19.040251,altitude_amsl_m:110,heading_deg:270
14:26:26, 01.10.2025

Send message...



User experience example #3 - MQTT protocol-based message sending on non-optimal 4G mobile network connection - Extra 600 ms Delay and 55% Packet Loss insertion

📶 DOWNLOAD Mbps
0.19
Data Used 0.2 MB

📶 UPLOAD Mbps
0.10
Data Used 0.1 MB

📶 Ping 621ms | 📶 Jitter 1668ms | 📶 Loss 75.5 %

Test Client

MQTT.Cool

Connection tcp://broker.emqx.io:1883

Subscriptions

The topic filter QoS 0 Subscribe

Subscribed topics

my/mqtt/topic QoS 1

Publish

The destination of the message QoS 0 Retain

The message text to be sent

Publish

Messages

2025-9-2 14:36:34.93 topic: my/mqtt/topic QoS 1
Message_ID#30,uavID:123XYZ,latitude:47.497930,longitude:19.040264,altitude_amsl_m:123,heading_deg:270

2025-9-2 14:36:27.503 topic: my/mqtt/topic QoS 1
Message_ID#29,uavID:123XYZ,latitude:47.497929,longitude:19.040265,altitude_amsl_m:124,heading_deg:270

2025-9-2 14:36:24.981 topic: my/mqtt/topic QoS 1
Message_ID#28,uavID:123XYZ,latitude:47.497928,longitude:19.040266,altitude_amsl_m:125,heading_deg:270

2025-9-2 14:36:15.830 topic: my/mqtt/topic QoS 1
Message_ID#27,uavID:123XYZ,latitude:47.497927,longitude:19.040267,altitude_amsl_m:126,heading_deg:270

broker.emqx.io my/mqtt/topic

Message_ID#34,uavID:123XYZ,latitude:47.497934,longitude:19.040264,altitude_amsl_m:123,heading_deg:270
16:37:08, 02.10.2025

Message_ID#35,uavID:123XYZ,latitude:47.497935,longitude:19.040265,altitude_amsl_m:124,heading_deg:270
16:37:14, 02.10.2025

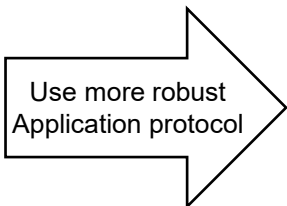
Message_ID#36,uavID:123XYZ,latitude:47.497936,longitude:19.040266,altitude_amsl_m:125,heading_deg:270
16:37:20, 02.10.2025

Message_ID#37,uavID:123XYZ,latitude:47.497937,longitude:19.040267,altitude_amsl_m:126,heading_deg:270
16:37:32, 02.10.2025

Send message...



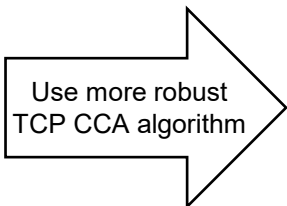
Tips and tricks for application developers



MQTT vs.
Speedtest HTTP

Advantages of MQTT Over HTTP

- **Small overhead:** few bytes of headers, minimal packet size
- **Persistent, duplex connection:** continuous TCP/TLS link; real-time push, no polling/long-polling
- **Publish/Subscribe model:** loose coupling of clients, topic-based distribution
- **QoS levels:** 0/1/2 delivery guarantees as needed
- **Retained messages:** new subscriber gets the last known state
- **Last Will & Testament:** automatic "last message" on disconnect
- **Network robustness:** well-suited to high latency, jitter, packet loss
- **Energy- and resource-efficient:** low CPU/battery use (IoT/edge devices)
- **Topic filtering & wildcards:** fine-tuned subscriptions (e.g., "sensor/+temperature")
- **Scaling for numerous small messages:** more efficient than HTTP



H.264 streaming with BBR vs.
Speedtest HTTP with Reno or Cubic

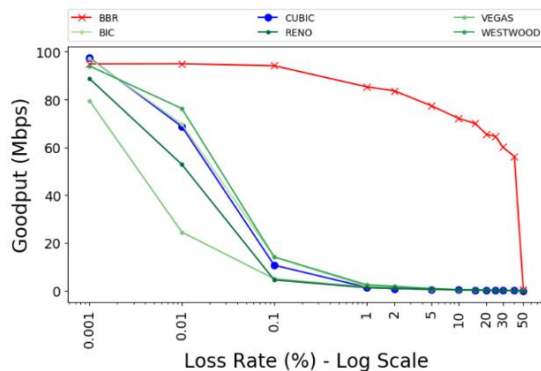
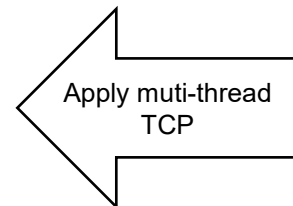
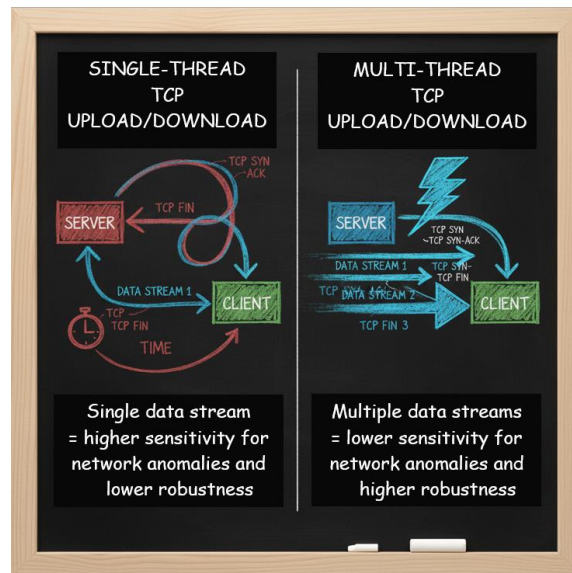


Figure 2: BBR compared to BIC, CUBIC, RENO, VEGAS, and WESTWOOD at various loss rates.



FTP with single-thread vs.
Speedtest HTTP with multi-thread



JPEG

19.02KB



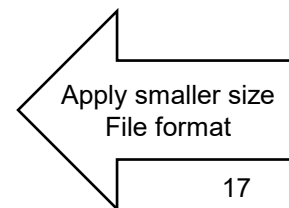
PNG

7.1KB



SVG

2.5KB



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kovacs.zsolt2@telekom.hu
[linkedin.com/in/zsolt-kovacs-813b1ab](https://www.linkedin.com/in/zsolt-kovacs-813b1ab)

