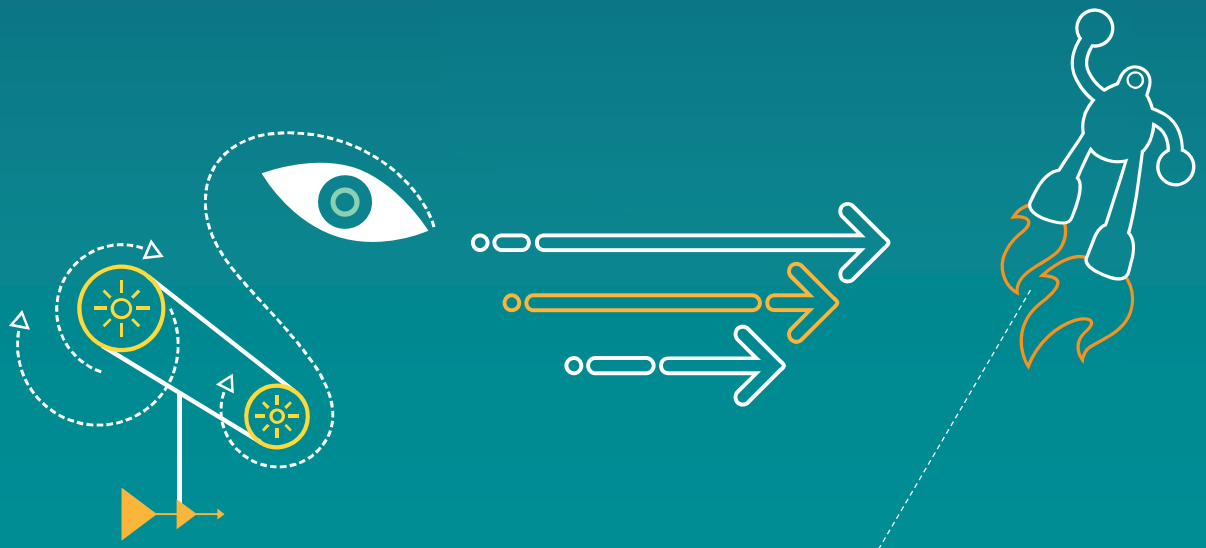
Rich Martin
Senior Engineer, November 2014, CR&D

FTC Wi-Fi Direct Characterization Testing

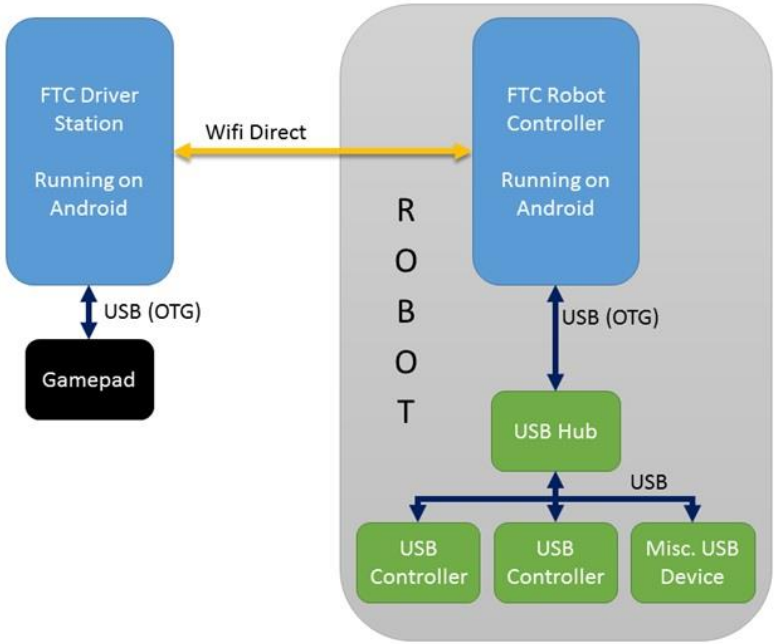
QUALCOMM®



Objective

- The QC-FTC platform is a joint effort between FIRST (www.usfirst.org) and Qualcomm to create a robotics platform using Snapdragon Powered Android devices. The platform will be part of a “kit of parts” FTC participants use to build qualified robots for competition.
- The platform consists of a Driver Station and Robot Controller connected through WiFi-Direct. The system operates in two modes: teleop and autonomous.
- In teleop mode, the competitor will drive the robot using a gamepad connected to the Driver Station.
- In autonomous mode, the robot autonomously tries to complete FTC challenges programmed by the competitors on the Robot Controller (mounted to the robot).

- In order for the robots to have high fidelity while in competition environments it is imperative that the WiFi-direct connection be fast, dependable, low latency, and noise resilient.
- These test notes will address requirements, test cases and parameters needed to characterize these requirements.



High-Level-Diagram illustrating the new FTC Robotics platform with Driver Station and Robot Controller

Executive Summary

- The Wi-Fi Direct link was tested for stability, delays, packet losses in a variety of scenarios and background traffic conditions including adjacent and same RF channel interference.
- The scenarios included the physical robot with the latest FTC Robot Controller and Driver Station, and a simulated robot set-up with UDP data streams transmitted between Robot Controller and Driver Station Nexus 5 and Nexus 7 devices.
- The Wi-Fi Direct link was tested in AWGN and Fading channel conditions without and with FTC simulated background users (up to 60) and its correspondent FTC Driver-Robot flows (3 for each) in both the 2.4GHz and 5GHz bands.
- A baseline in a AWGN RF channel, for delay, jitter and packet loss was established in all available channels for Nexus 7 devices in the 2.4GHz and 5GHz bands using both the demo application and Iperf udp with 66bytes size packets at 50 packets/second. No packet losses were observed in this case.

- Similarly, for Channel 6 (2GHz) and 157 (5GHz) delay, jitter, packet loss was measured using the application and iperf while transmitting 1,7, 15, 50 and 60 background users with the same traffic mix pattern as a FTC Driver-Control user using a Veriwave test system.
- No Packet losses were observed and jitter was very low in the order of nanoseconds.
- Subsequently the same scenarios in a RF Raleigh/Ricean/Fading (mobile) channel without users was tried followed by tests with the Veriwave system and 60 background users.
- A criteria/threshold of 10 consecutive heartbeat packet losses was established to stop the FTC Driver-Controller app from continuing in operation.
- Such condition was never observed in any condition or test executed with and without the FTC robot and controller while in a mobile environment with adjacent and co-channel RF interference and multiple background users.

- The most representative results of a real world "congested" scenario (60 FTC background users in the same RF Channel) in a mobile/fading user with co-channel and adjacent RF channels interfering are:

Channel 6:

- Avg Packet Round Trip Time (ms),9.51651210213661
- Med Packet Round Trip Time (ms),2.41
- StdDev Packet Round Trip Time (ms),62.966686724506
- Max Packet Round Trip Time (ms),1262.94
- Min Packet Round Trip Time (ms),0.89
- Count Packet Round Trip Time,11279
- Packets Above Threshold (500 ms),54
- Periods (10 consecutive packets) Above Threshold,0
- Percent of Missing Packets (162 / 11279),1.436298
- Max Number of Sequential Missing Packets,81

Channel 157:

- Avg Packet Round Trip Time (ms),6.381478147907 46
- Med Packet Round Trip Time (ms),1.65
- StdDev Packet Round Trip Time (ms),52.2973257157439
- Max Packet Round Trip Time (ms),1262.94
- Min Packet Round Trip Time (ms),0.89
- Count Packet Round Trip Time,10777
- Packets Above Threshold (500 ms),38
- Periods (10 consecutive packets) Above Threshold,0
- Percent of Missing Packets (84 / 10777),0.779438
- Max Number of Sequential Missing Packets,42

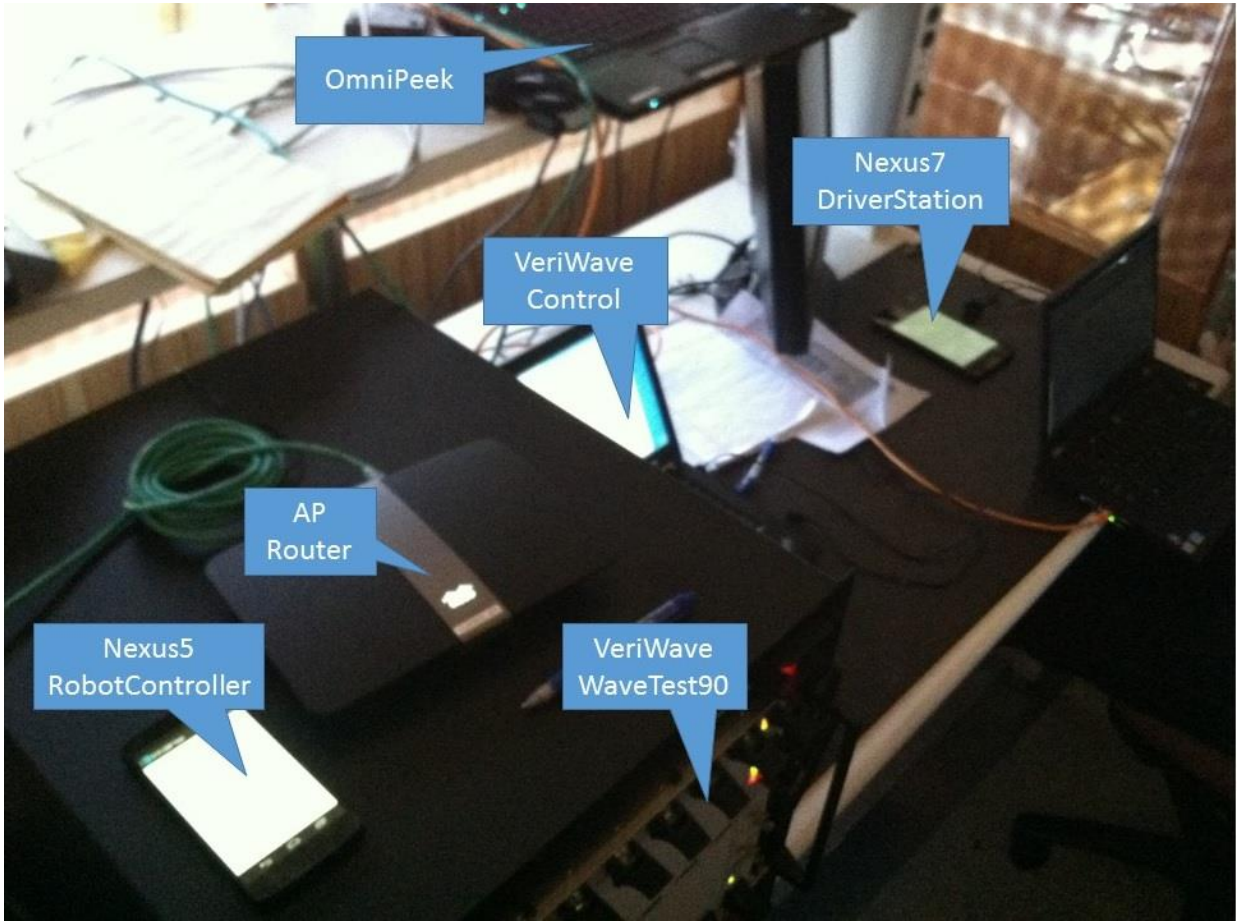
- In **Conclusion** the WiFi Direct Link was very stable and maintained in all circumstances. The FTC Driver-Controller application and communication was successfully maintained in all test scenarios were the thresholds for stopping the FTC robot was never achieved or experienced. Operation of the FTC robot in the 5GHZ band is marginally better than operation in the 2.4GHZ due to less RF interference and wider bandwidths of operation although path loss is higher.

FTC UDP Packet structure

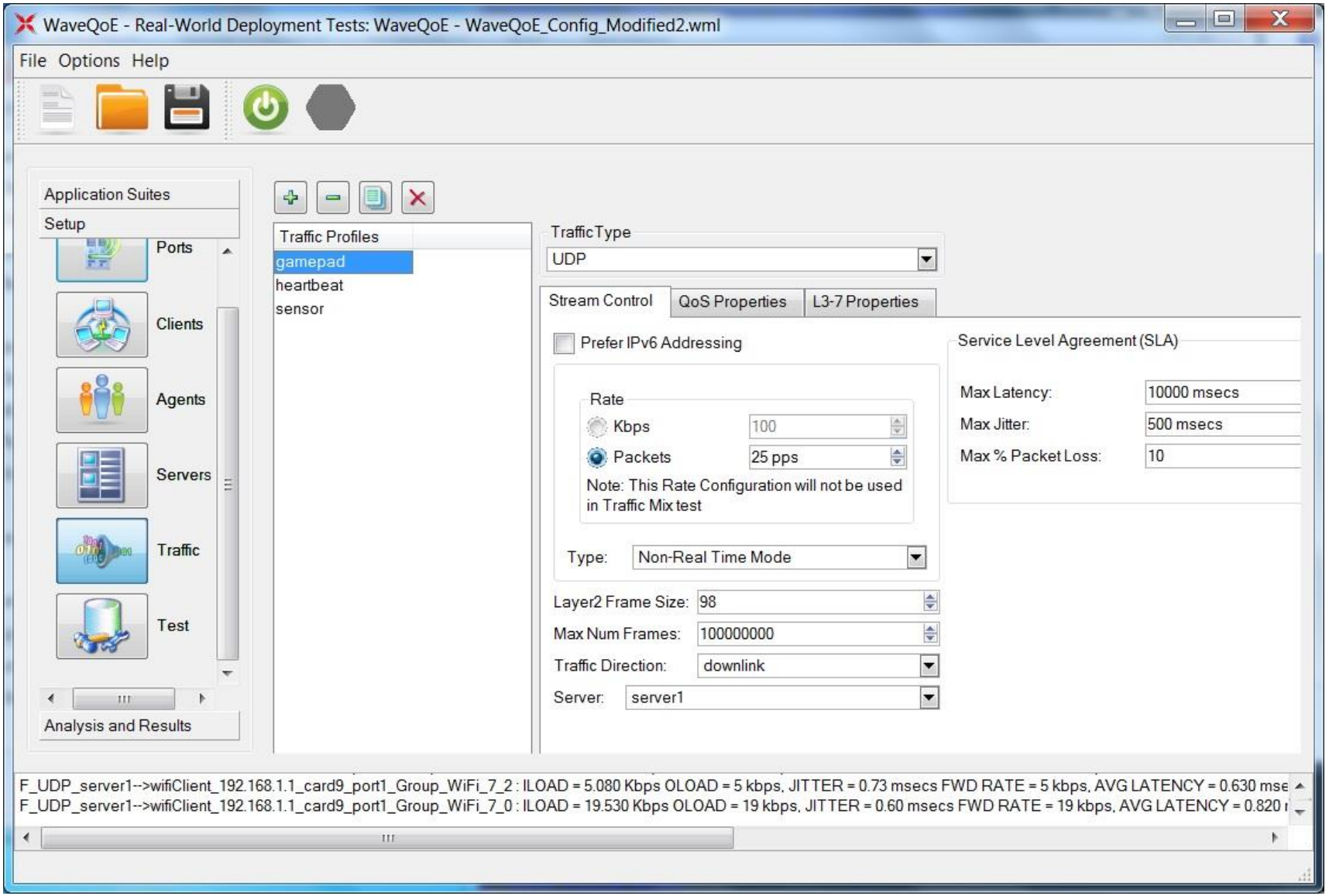
- FTC Platform Packets
  - Heartbeat
    - Maintains connection and speed from Driver Station to/from Robot Controller
    - 13 bytes/packet
    - 10 Hz (10 packets/sec or 100ms/packet)
    - roundtrip (DS to RC to DS)
  - Gamepad
    - Joystick movement and button presses
    - 45 bytes/packet
    - 25 Hz (25 packets/sec or 40ms/packet)
    - one-way to Robot Controller (DS to RC)
  - Sensor
    - Possible Types of Data
      - System Battery Voltage
      - Android Robot Controller Voltage
      - Left-Right Drive Motor Output
      - 5 Generic Sensors
    - 100 bytes (current estimate on average)
    - 4 Hz (4 packets/sec or 250ms/packet)
    - one-way (RC to DS)

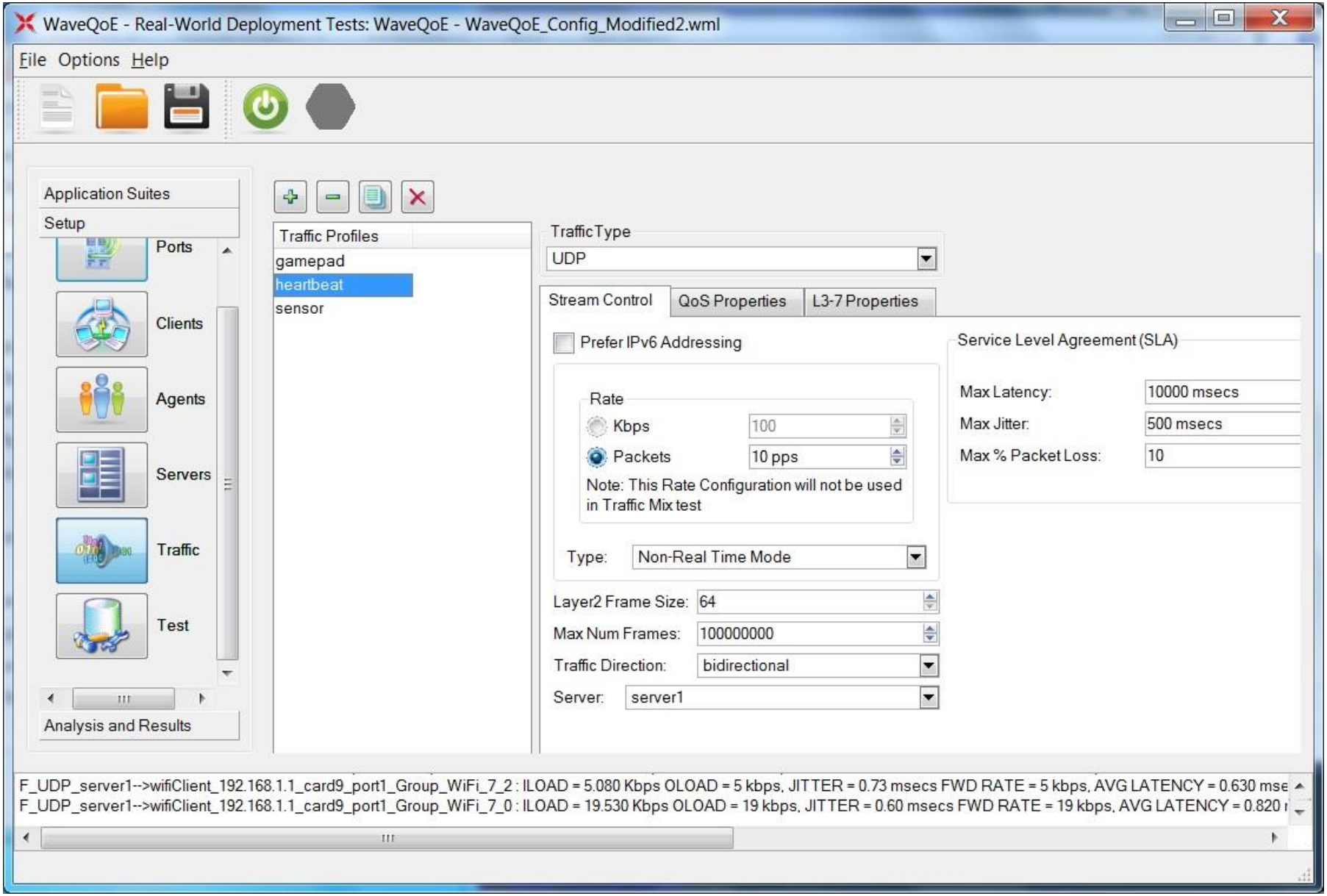
Screen Room Setup

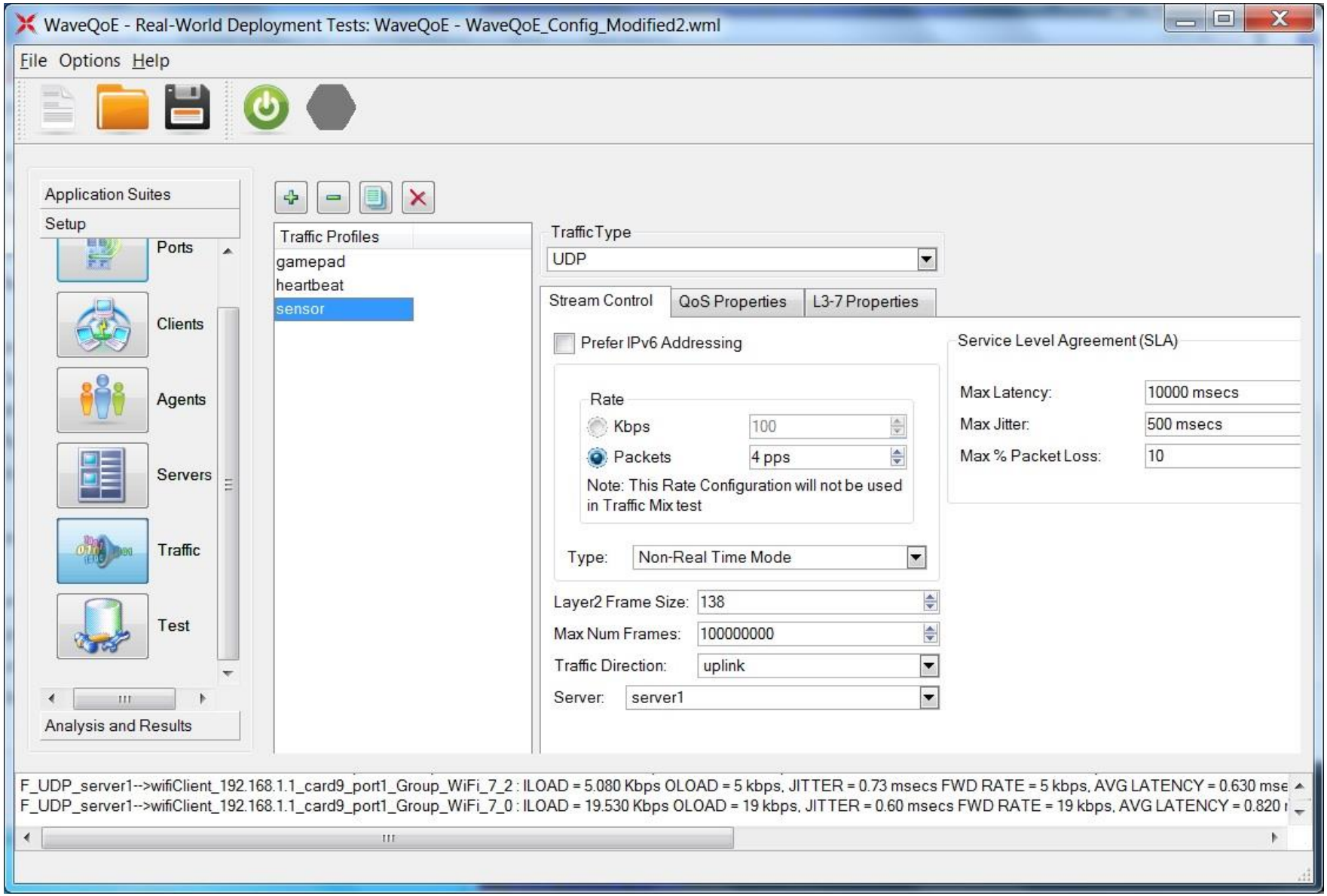
- The Robot Controller is run on a Nexus5 or a Nexus 7 and is placed on top of the VeriWave chassis. The Driver Station is run on a Nexus7 and is placed on the right side of the bench.
- The VeriWave WaveTest90 system is placed on the left side of the bench. The Ethernet card (in slot 1 of the VeriWave Chassis) is connected to the a network port on the AP Router with an Ethernet cable. The Wi-Fi card (in slot 9 of the VeriWave Chassis), is setup with two 2-5GHz antennas on port 1 (A and B RF connectors).
- The VeriWave Control system is run on a Windows7 laptop and is connected to the Ethernet control port on the back of the VeriWave chassis.
- Additionally, an OmniPeek sniffer is setup in the environment to capture wireless traffic during the test.


OmniPeek
Nexus7
DriverStation
VeriWave
Control
AP
Router
Nexus5
RobotController
VeriWave
WaveTest90

VeriWave Setup




WaveQoE - Real-World Deployment Tests: WaveQoE - WaveQoE_Config_Modified2.wml
File Options Help
Application Suites
Setup
Ports
Clients
Agents
Servers
Traffic
Test
Analysis and Results
Traffic Profiles
gamepad
heartbeat
sensor
Traffic Type
UDP
Stream Control
QoS Properties
L3-7 Properties
Prefer IPv6 Addressing
Rate
Kbps
100
Packets
10 pps
Note: This Rate Configuration will not be used in Traffic Mix test
Type:
Non-Real Time Mode
Layer2 Frame Size:
64
Max Num Frames:
100000000
Traffic Direction:
bidirectional
Server:
server1
Service Level Agreement (SLA)
Max Latency:
10000 msecs
Max Jitter:
500 msecs
Max % Packet Loss:
10
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_2 : ILOAD = 5.080 Kbps OLOAD = 5 kbps, JITTER = 0.73 msecs FWD RATE = 5 kbps, AVG LATENCY = 0.630 mse
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_0 : ILOAD = 19.530 Kbps OLOAD = 19 kbps, JITTER = 0.60 msecs FWD RATE = 19 kbps, AVG LATENCY = 0.820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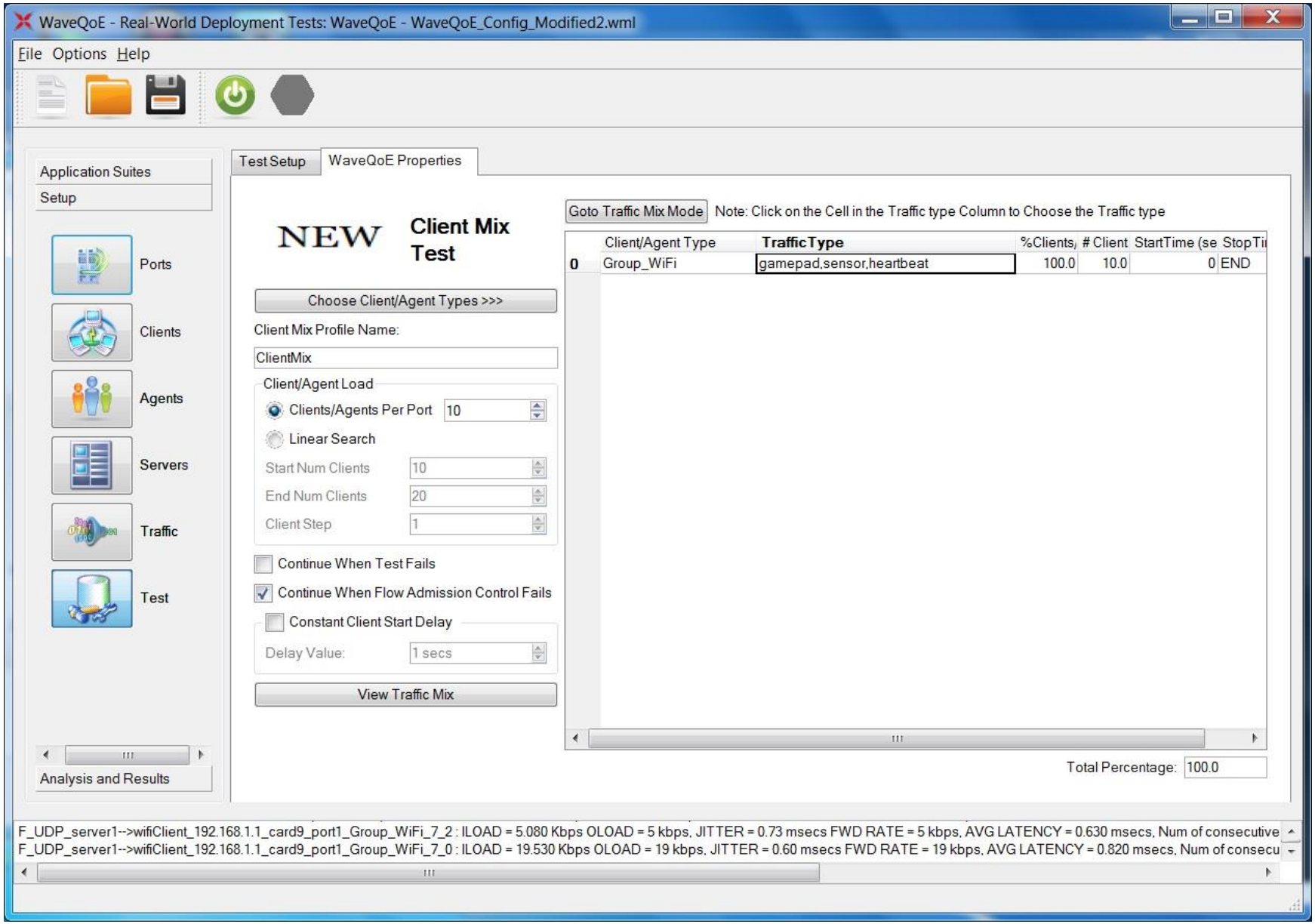
UDP
Stream Control
QoS Properties
L3-7 Properties
Prefer IPv6 Addressing
Rate
Kbps
100
Packets
4 pps
Note: This Rate Configuration will not be used in Traffic Mix test
Type:
Non-Real Time Mode
Layer2 Frame Size:
138
Max Num Frames:
100000000
Traffic Direction:
uplink
Server:
server1
Service Level Agreement (SLA)
Max Latency:
10000 msecs
Max Jitter:
500 msecs
Max % Packet Loss:
10
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_2 : ILOAD = 5.080 Kbps OLOAD = 5 kbps, JITTER = 0.73 msecs FWD RATE = 5 kbps, AVG LATENCY = 0.630 mse
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_0 : ILOAD = 19.530 Kbps OLOAD = 19 kbps, JITTER = 0.60 msecs FWD RATE = 19 kbps, AVG LATENCY = 0.820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Analysis and Results
Test Setup
WaveQoE Properties
NEW
Client Mix Test
Choose Client/Agent Types >>>
Client Mix Profile Name:
ClientMix
Client/Agent Load
Clients/Agents Per Port
10
Linear Search
Start Num Clients
10
End Num Clients
20
Client Step
1
Continue When Test Fails
Continue When Flow Admission Control Fails
Constant Client Start Delay
Delay Value:
1 secs
View Traffic Mix
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Note: Click on the Cell in the Traffic type Column to Choose the Traffic type
Client/Agent Type
TrafficType
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gamepad,sensor,heartbeat
100.0
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END
Total Percentage:
100.0
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_2 : ILOAD = 5.080 Kbps OLOAD = 5 kbps, JITTER = 0.73 msecs FWD RATE = 5 kbps, AVG LATENCY = 0.630 msecs, Num of consecutive
F_UDP_server1-->wifiClient_192.168.1.1_card9_port1_Group_WiFi_7_0 : ILOAD = 19.530 Kbps OLOAD = 19 kbps, JITTER = 0.60 msecs FWD RATE = 19 kbps, AVG LATENCY = 0.820 msecs, Num of consecu

Test Cases

Test No.	Test Name	Test Objective/Description	Test Procedure	Pass/Fail Criteria
1	One pair-one channel ideal conditions (AWGN RF Channel)	Measure average round trip time on each possible RF WiFi Direct Channel	Use a Faraday cage for testing Use WiFi Direct Channel configuration tool to set 1st channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) Separate devices 2 meters, approx. On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Let it run for 4 minutes and note the average round trip of the UDP packets Repeat for the next possible (on the app) Wifi Direct Channels on 2.4 Repeat for all WiFi channels available (on the app) on 5GHz Now, switch the roles for UDP server and UDP test app on each device Repeat tests on both bands and respective channels	Characterize results. Round-trip time should be less than 500ms.
2	One Pair-one channel with similar traffic interference on the same channel (AWGN RF Channel)	Measure average round trip time for devices(pair) under test while similar "interfering" traffic is generated on the same channel (one pair added incrementally)	Use a Faraday cage for testing Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) Separate devices 2 meters, approx. On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Configure the VeriWave tool (see details here: VeriWave Setup#WaveQoETests) to specify the same band/channel that was used to setup the DS/RC pair. Set the number of clients for the desired number of simulated pairs. Start with 1 interfering client. Start the demo application on the test device. Start the VeriWave tool and let it run for 4 minutes. At the conclusion of the 4 minute test, note the average round trip of the UDP packets on the demo application. Increment the number of clients in VeriWave by 1 and repeat the procedure. (Continue this loop upto 15 clients.) Repeat for an available channel (on the app) on 5GHz band. Now, switch the roles for UDP server and UDP test app on each device and repeat procedure.	Characterize results.Round-trip time should be less than 500ms.

3	Determine upper bound of interfering users on the same channel	Determine the the number of interfering users on the same channel in a collocated environment to the DUT.	Use a Faraday cage for testing Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) Separate devices 2 meters, approx. On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Configure the VeriWave tool (see details here: VeriWave Setup#WaveQoETests) to specify the same band/channel that was used to setup the DS/RC pair. Set the number of clients for the desired number of simulated pairs. Start the demo application on the test device. Start the VeriWave tool and let it run for 4 minutes. At the conclusion of the 4 minute test, note the average round trip of the UDP packets on the demo application. Based on the average round trip time, either increment or decrement the number of clients specified in VeriWave. Repeat procedure until the upper bound has been reached before surpassing the latency requirement. Repeat for an available channel (on the app) on 5GHz band	Characterize results.
4	Verify the ability to setup a WiFi Direct pair on a heavy loaded channel.	Verify that a DS/RC pair can be established in an environment of interfering users on the same channel as the DUT.	Use a Faraday cage for testing Select an available channel on the 2.4GHz band. Configure the VeriWave tool (see details here: VeriWave Setup#WaveQoETests) to specify the band/channel for the test. Set the number of clients for the desired number of simulated pairs (i.e. 15) Start the VeriWave tool Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) Separate devices 2 meters, approx. On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Start the demo application on the test device. Repeat for an available channel (on the app) on 5GHz band.	The WiFi Direct connection can be setup and traffic can be sent across the link.No more than 10 consecutive packet loss should be observed

5	Controller - Drive traffic profiling under open and Stationary RF channels, FTC background users on the same channel	Open RF stationary channel where other traffic and SSID/signals/traffic on the same channel are not controlled PLUS 60 FTC background traffic on the same channel	Setup system outside in normal bench lab, where other WiFi RF channels are present. Select an available channel on the 2.4GHz band. Configure the VeriWave tool to specify the band/channel for the test. Set the number of clients for the desired number of simulated pairs (i.e. 60) Start the VeriWave tool Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Start the demo application on the test device. Move around for 4 minutes/duration of test Repeat for an available channel (on the app) on 5GHz band.	The WiFi Direct connection can be setup and traffic can be sent across the link.No more than 10 consecutive packet loss should be observed
6	Controller - Drive traffic profiling under open/mobile RF channels, FTC background users on the same channel	Simulate RF channel conditions in real world (ricean, raleigh, slow pedestrian) around Controller driver and measure traffic jitter, packet loss while similar FTC background traffic	Setup system outside in normal bench lab, where other WiFi RF channels are present. Select an available channel on the 2.4GHz band. Configure the VeriWave tool to specify the band/channel for the test. Set the number of clients for the desired number of simulated pairs (i.e. 60) Start the VeriWave tool Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Start the demo application on the test device. Move around for 4 minutes/duration of test Repeat for an available channel (on the app) on 5GHz band	The WiFi Direct connection can be setup and traffic can be sent across the link.No more than 10 consecutive packet loss should be observed

7	Controller - Drive traffic with Real robot profiling under open/mobile RF channels, FTC background users	Using the real FTC robot, Simulate RF channel conditions in real world (ricean, raleigh, slow pedestrian) around Controller driver and measure traffic jitter, packet loss while similar FTC background traffic	Setup system outside in normal bench lab, where other WiFi RF channels are present. Select an available channel on the 2.4GHz band. Configure the VeriWave tool to specify the band/channel for the test. Set the number of clients for the desired number of simulated pairs (i.e. 60) Start the VeriWave tool Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Start the demo application on the test device. Move around for 4 minutes/duration of test Repeat for an available channel (on the app) on 5GHz band	The WiFi Direct connection can be setup and traffic can be sent across the link.
8	Fading Channel with 60 simulated FTC background users plus other uncontrolled WiFi RF signals/channels	Using the real FTC robot, Simulate RF channel conditions in real world (ricean, raleigh, slow pedestrian) around Controller driver and measure traffic jitter, packet loss while similar FTC background traffic and other RF adjancent and co-channel 802.11 frequencies and trafic is present	Setup system outside in normal bench lab, where other WiFi RF channels are present. Select an available channel on the 2.4GHz band. Configure the VeriWave tool to specify the band/channel for the test. Set the number of clients for the desired number of simulated pairs (i.e. 60) Start the VeriWave tool Use WiFi Direct Channel configuration tool to set to an available channel on 2.4GHz Pair and Connect Devices (Driver and Controller), using FTC Driver on one device and Robot Controller on other Launch Robot Controller Demo app On the Controller device select FTC server Echo Server option (note its IP address) On the Driver device select UDP Test app Enter the Controller IP address, packet size to test and frequency (packets/sec). See packet size/frequency in test scenario above. Start the demo application on the test device. Move around for 4 minutes/duration of test Repeat for an available channel (on the app) on 5GHz band	The WiFi Direct connection can be setup and traffic can be sent across the link. No more than 10 consecutive packet loss should be observed

Test Results

1	2.4GHz, Channel 1 Demo server app Controller side sending UDP and Driver echoing 66bytes longs at 50Hz: 51 pks/sec, 26.297kbps Iperf UDP dualmode: iperf -c 192.168.49.76 -u -fB -i1 -t240 -l66B -b13200b -d (driver side) iperf -s -u -i1 -l66B -fB (controller side) Server side report on the client: Interval, transfer, Bandwidth, Jitter, error/loss 0.0-240 sec 396066Bytes 1650Bytes/sec 0.537ms 0/6001 (0%) Server side report on the server: 0.0-240 sec 396066Bytes 1650Bytes/sec 0.254ms 0/6001 (0%) 2.4GHz, Channel 6 Demo server app Controller side sending UDP and Driver echoing 66bytes longs at 50Hz: 51/pkst/sec 26.297kbps Iperf UDP dualmode: 0.0-240 sec 396066Bytes 1650Bytes/sec 0.649ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 0.608ms 0/6001 (0%) 2.4GHz, Channel 11 Demo server app Controller side sending UDP and Driver echoing 66bytes longs at 50Hz: 51/pkst/sec 26.297kbps Iperf UDP dualmode: 0.0-240 sec 396066Bytes 1650Bytes/sec 0.886ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 0.886ms 0/6001 (0%) 5GHz, Channel 149 Demo server app Controller side sending UDP and Driver echoing 66bytes longs at 50Hz: 51/pkst/sec 26.297kbps

2	Channel 157, 1 background user 1 pair (controller-Driver) Demo app 51/pkst/sec 26.297kbps iperf udp bidrectional 0.0-240 sec 396066Bytes 1650Bytes/sec 0.467ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 0.644ms 0/6001 (0%) Channel 157, 15 background users 1 pair (controller-Driver) Demo app: 51/pkst/sec 26.297kbps iperf udp bidrectional 0.0-240 sec 396066Bytes 1650Bytes/sec 0.410ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 0.663ms 0/6001 (0%)
3	Channel 157, 50 background users 1 pair (controller-Driver) Demo app: 51/pkst/sec 26.297kbps iperf udp bidrectional 0.0-240 sec 396066Bytes 1650Bytes/sec 0.442ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 0.663ms 0/6001 (0%) Channel 6, 50 background users 1 pair (controller-Driver) Demo app: 51/pkst/sec 26.297kbps iperf udp bidrectional 0.0-240 sec 396066Bytes 1650Bytes/sec 0.379ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 1.701ms 0/6001 (0%) Channel 6, 60 background users 1 pair (controller-Driver) Demo app: 51/pkst/sec 26.297kbps iperf udp bidrectional 0.0-240 sec 396066Bytes 1650Bytes/sec 0.729ms 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 1.159ms 0/6001 (0%)

4	With 60 users in the background using the robot-controller-driver profile in traffic it was easy to setup a new wiFi direct link between a Driver-Controller app on 2 other device in Channel 6 With 60 users using same traffic profile as the FTC, 2 other WiFi direct links were setup and traffic exchange. No problems detected in Channel 6 and 157 Test repeated for multi-connect setup between 3 devices while Maintaining 60 background users in Channel 6
5	Channel 6, 60 background users 66 bytes at 50Hz Demo app 49/pkst/sec 25.266kbps iperf udp 0.0-240 sec 396066Bytes 1650Bytes/sec 1.79 0/6001 (0%) 0.0-240 sec 396066Bytes 1650Bytes/sec 2.8ms 134/6001 (2.2%)
6	Channel 6, 60 background users 66 bytes at 50Hz Demo app 66 bytes at 50 packet/sec received 48 packets at 24.756 packets per seconds unable to collect iperf data Channel 157, 66 bytes at 50 packet/sec received 50 packets at 25.781 packets per seconds

7	Channel 6 Avg Packet Round Trip Time (ms),9.18599288256228 Med Packet Round Trip Time (ms),2.2 StdDev Packet Round Trip Time (ms),62.0804909068804 Max Packet Round Trip Time (ms),1189.67 Min Packet Round Trip Time (ms),0.92 Count Packet Round Trip Time,1405 Packets Above Threshold (500 ms),6 Periods (10 consecutive packets) Above Threshold,0 Percent of Missing Packets (81 / 1405),5.765125 Max Number of Sequential Missing Packets,81 Channel 157, Avg Packet Round Trip Time (ms),7.56717980809343 Med Packet Round Trip Time (ms),1.89 StdDev Packet Round Trip Time (ms),56.3950068809268 Max Packet Round Trip Time (ms),1262.94 Min Packet Round Trip Time (ms),0.92 Count Packet Round Trip Time,4794 Packets Above Threshold (500 ms),20 Periods (10 consecutive packets) Above Threshold,0 Percent of Missing Packets (42 / 4794),0.876095 Max Number of Sequential Missing Packets,42
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Use for Qualcomm Technologies, Inc.

Thank you

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including its semiconductor business.

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