EXECUTIVE SUMMARY

Today, users demand home Wi-Fi that is reliable, high-speed, and consistent throughout the home. To meet these criteria, vendors have developed new solutions which includes multiple wireless access points (APs) to cover the entire home with Wi-Fi. Nokia commissioned Tolly to determine how Nokia WiFi performs against their competition.

Tolly benchmarked the Wi-Fi throughput of Nokia WiFi against other leading brands sold directly to consumers. To provide realistic data, testing was performed in a two-story, single-family house. Tests included multi-AP mesh scenarios with 10 clients distributed throughout the home.

Tolly Engineers verified that Nokia WiFi delivered the highest performance in single- and multi-AP mesh tests. Nokia WiFi was the system that supported the fastest client roaming. Nokia WiFi was also the most resilient system when interference was introduced in the home.

THE BOTTOM LINE

Nokia WiFi delivers

1. The fastest throughput access point in single-AP tests
2. Fastest throughput to “every corner” in 9 of 10 test locations in multi-APs tests
3. Seamless roaming throughout the home
4. Highest backhaul throughput
5. Reliable Wi-Fi in the presence of interference

Home Wi-Fi (Three APs) in a Mesh Speed Comparison
10 Clients, Average Throughput per Client

Notes: Each client was tested individually and the throughput data averaged. Clients included Apple MacBook Pro laptops and desktops with the ASUS AC88 WiFi adapter. See Figures 9 and 10 for test environment and client locations. Results are bidirectional TCP throughput reported by IxChariot.

Source: Tolly, September 2018

Figure 1
Test Results

Throughput

Single-AP, Single-client Throughput

Tolly engineers established the best-case Wi-Fi throughput for a single client by placing that client one meter away from the AP under test. Throughput tests were run between a wireless client and a computer connected directly to the AP via Gigabit Ethernet.

Nokia WiFi delivered 977 Mbps of bidirectional client throughput. Competitors delivered 672–698 Mbps (29–31% less). See Figure 2.

Two-AP, Wi-Fi Backhaul Throughput

In multi-AP mesh environments, client traffic can enter via one AP and traverse the backhaul to another AP before reaching its target destination. Tolly engineers established the best-case throughput for communication between access point (AP) pairs via the wireless backhaul link. Wired Gigabit Ethernet clients were used to send traffic across the wireless backhaul link between APs.

Nokia WiFi delivered 947 Mbps of bidirectional throughput across the wireless backhaul link. Competitors delivered 650–693 Mbps (27–31% less). See Figure 3.

Three-AP Mesh, Multi-client Throughput

Tests involved a combination of 10 laptop and desktop client systems, located at different locations of the house. See the Test Methodology section on Page 8 for additional setup details. Each client was tested individually and the throughput data averaged.

With the hi-gain antennas, Nokia WiFi’s average throughput was 531 Mbps to each client, where competitors delivered only 378–447 Mbps (16–29% less). See Figure 1 on Page 1.
Roaming Efficiency

Mesh networks provide multiple Wi-Fi signal sources that client devices can use as they move around the home. As a result, Wi-Fi systems can improve a client’s performance by dynamically moving them to a stronger signal.

Ideally, the user should not be aware that their device has “roamed” from one AP to another. Roaming should occur as quickly as possible, with minimal packet loss and no disruption to the session in progress. Tolly engineers measured the roaming efficiency of systems under test by using a phone app designed for this purpose.

The WiFi Moho app generates a steady stream of discrete network requests and tracks which AP the client is connected to/associated with. When the client roams to a new AP, WiFi Moho calculates (1) how long it takes the client and AP to associate and (2) the number of network packets lost during the roaming process.

Nokia WiFi afforded fast client roam times of 405ms on average. Competitors averaged 657-2,292ms. Packet loss statistics proved Nokia WiFi the winner with one packet lost, where competitors dropped 1–18 packets during six roams.

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**Roaming Efficiency**

(reported by WiFi Moho 3.9.6)

<table>
<thead>
<tr>
<th>Roaming Efficiency</th>
<th>Nokia WiFi</th>
<th>Vendor A</th>
<th>Vendor B</th>
<th>Vendor C</th>
<th>Vendor D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Roaming Time</td>
<td>405</td>
<td>1,726</td>
<td>2,030</td>
<td>2,292</td>
<td>657.0</td>
</tr>
<tr>
<td>Packet Loss during Roaming (Six Roams)</td>
<td>1</td>
<td>18</td>
<td>24</td>
<td>14</td>
<td>1</td>
</tr>
</tbody>
</table>

Notes: Roaming is what occurs when a moving client disconnects from one AP (e.g. in the living room) and connects to the new closer AP (e.g. in the bedroom). Time to roam should be as low as possible to avoid service interruption. Moto Z2 Play phone with Android 8 was used as the client. Engineers walked the phone between two APs of each system for three round trips (6 roams). WiFi Moho’s built-in roaming test https://moho.ruijienetworks.com/static/homepager/en/index.htm reported the time of each roam and the total ping packets lost during roaming. For vendor A and C’s solutions, the phone sometimes roams to the closer AP first and then switched the band between 2.4GHz and 5GHz. Total time of those two actions were considered as one roam’s result.

Source: Tolly, September 2018
Resilience: Channel Selection

Wi-Fi environments are constantly changing due to performance-degrading interferers including baby monitors, microwave ovens, and your neighbor’s wireless network. An access point’s (AP) resilience is important and can be demonstrated by its ability to recognize interference and select an alternative Wi-Fi channel for communication.

Automatic Channel Selection

Only Nokia WiFi demonstrated support for automatic channel selection (ACS) by detecting and avoiding interference at startup time. See Table 1. By choosing a channel not impacted by interference, a subsequent performance test showed that Nokia WiFi delivered 500 Mbps in the presence of interference on channel 42 while competitors’ throughput ranged from 156–367 Mbps. Similar results were seen when interference was introduced on channel 157. See Figure 5.

When 5GHz interference was on the lower band (channel 42), Nokia WiFi selected a higher band (channel 157) to compensate. When 5GHz interference was on the higher band (channel 155), Nokia WiFi selected a lower band (channel 48) to compensate.

In competitors the channel is either fixed (Vendor A on channel 36 and Vendor D on channel 149) or uses both lower and higher bands at the same time (Vendor B and Vendor C). Performance was degraded with interference in these channels.

### Comparison of Channel Selection Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Nokia WiFi</th>
<th>Vendor A</th>
<th>Vendor B</th>
<th>Vendor C</th>
<th>Vendor D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automatic Channel Selection (ACS)</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
<tr>
<td>Dynamic Channel Selection (DCS)</td>
<td>✔</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
<td>✗</td>
</tr>
</tbody>
</table>

Notes: Nokia WiFi automatically chose the channel to avoid existing interference during network startup. Nokia WiFi dynamically adjusted the channel to avoid sudden interference when the system was running.

Source: Tolly, September 2018

### Average Throughput With Interference

**Channel 42 Interference**

- Nokia WiFi: 500 Mbps
- Vendor A: 179 Mbps (-64%)
- Vendor B: 274 Mbps (-45%)
- Vendor C: 156 Mbps (-69%)
- Vendor D: 367 Mbps (-27%)

**Channel 155 Interference**

- Nokia WiFi: 519 Mbps
- Vendor A: 330 Mbps (-36%)
- Vendor B: 280 Mbps (-46%)
- Vendor C: 402 Mbps (-23%)
- Vendor D: 89 Mbps (-83%)

Higher is Better. Less Impact from Interference = faster downloads and better quality services (video chat, voice, etc.)

Notes: Interference came from a client on the interference channel running 100 Mbps traffic. Different systems chose different channels to run the service. 10 clients were used as in Figure 9.

Source: Tolly, September 2018

Figure 5
Dynamic Channel Selection

Only Nokia WiFi demonstrated dynamic channel selection (DCS) support by detecting and avoiding interference introduced into an existing network. See Table 1. Tolly engineers verified this feature with Wi-Fi and non-Wi-Fi interference.

Wi-Fi Interference

Tolly engineers verified Nokia DCS by starting a throughput test and then introducing Wi-Fi interference. Average throughput was reduced dramatically in the face of Wi-Fi interference, but recovered when Nokia WiFi detected it and selected a non-interfering channel. See Figure 6.

When the same test was performed on competitor systems, Tolly engineers observed the same decrease in throughput with introduction of interference. However, because competitors did not provide DCS, performance remained degraded for the test’s remainder. See Figure 6 for Vendor A performance results; other solutions degraded similarly.
Non-Wi-Fi Interference

Tolly engineers also verified Nokia DCS by starting a throughput test and then introducing non-Wi-Fi interference. Average throughput was reduced dramatically in the face of non-Wi-Fi interference, but recovered when Nokia WiFi detected it and selected a non-interfering channel. See Figure 7.

When the same test was performed on competitor systems, Tolly engineers observed the same decrease in throughput with introduction of interference. However, because competitors did not provide DCS, performance remained degraded for the test’s remainder. Vendor A and D did not adjust to the introduction of non-Wi-Fi interference. Vendor B and C changed the client’s radio (from one 5GHz to the other or from 5GHz to 2.4GHz) to avoid interference. When the radio was switched to the 2.4GHz one, client performance also degraded. See Figure 6 for Vendor A performance results; Vendor B degraded similarly.

Nokia Real-Time Spectrum Analysis

In addition to supporting ACS and DCS, Nokia APs also have a dedicated antenna for real-time spectrum analysis, detecting any Wi-Fi or non-Wi-Fi interference source, allowing for optimal channel and band selection.

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Source: Tolly, December 2018

Figure 7
**Backhaul Failover**

In addition to using Wi-Fi for inter-access point (AP) wireless backhaul connections, customers may want to build an Ethernet wired backhaul for redundancy. Not all vendors provide sufficient Gigabit Ethernet ports to support this.

Of the vendors included in this evaluation, only Nokia and Vendor A offered enough ports for a wired backhaul. In the event of failure on a wired link (e.g. an Ethernet cable is removed accidentally), it is important to understand how the APs respond and provide resilience to the user.

To evaluate AP resilience to backhaul failure, Tolly engineers sent a streaming video across the wired backhaul with the intent to measure how long the video paused when the Gigabit Ethernet connection was intentionally removed.

Engineers noted video interruption times of four seconds with Nokia WiFi and 135 seconds with Vendor A. Therefore, Nokia WiFi offers a better user experience during failure recovery. See Figure 8.

Engineers then verified how long it took the video to recover once Gigabit Ethernet was reconnected.

Nokia WiFi detected the Gigabit Ethernet connection and switched back to using it without service interruption. It took Vendor A’s 55 seconds service interruption to detect and switch back to using the wired Gigabit Ethernet connection.

**True Hybrid Backhaul**

Nokia Wi-Fi supports a true hybrid backhaul, allowing APs to select wired Ethernet, 5GHz or 2.4GHz wireless as the backhaul link.

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**Backhaul Re-routing Between Wired Ethernet and Wireless**

<table>
<thead>
<tr>
<th></th>
<th>Ethernet to Wireless</th>
<th>Wireless to Ethernet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Convergence Time (seconds)</strong></td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td><strong>Lower is Better</strong></td>
<td>135</td>
<td>55</td>
</tr>
</tbody>
</table>

Notes: Nokia WiFi and Vendor A provide enough Ethernet ports to build the mesh system using wired Ethernet connections. When the topology changes (e.g. an Ethernet cable is pulled out by accident), both systems can use wireless backhaul to continue running the mesh system. A live video stream was observed, while re-routing the backhaul from wired Ethernet to wireless. Nokia WiFi showed a 4-second pause in video and Vendor A showed a 135-second pause. Nokia WiFi provides a better user experience during failure recovery.

Source: Tolly, September 2018

Figure 8
Test Methodology

All tests were conducted in a single family house as shown in Figure 10. AP and client device positions are shown in Figure 9. In Figure 9, MacBook refers to an Apple MacBook Pro laptop; Desktop refers to a desktop computer with the ASUS AC88 Wi-Fi adapter. For each solution, the Gateway AP 1 had a connection to the Internet.

The DCS with non-Wi-Fi interference test was run in December 2018. All other tests were run in September 2018. See Table 2 for product details.

Performance Test Methodology

Performance tests used the Ixia IxChariot test tool. Each client used five pairs of downstream and five pairs of upstream traffic, provided by the IxChariot’s built-in TCP High_Performance_Throughput script. Each test was run three times and average results reported.

Single-AP, Single-client Throughput

One desktop with the ASUS AC88 wireless adapter served as the client to evaluate each access point’s (AP) maximum performance on the 5GHz band. Maximum aggregated bidirectional TCP throughput is reported. AP and client were one meter apart.

Two-AP, Wi-Fi Backhaul Throughput

Each solution used two APs configured to use the wireless backhaul. Each AP had one wired client connected via Gigabit Ethernet. Maximum aggregated bidirectional TCP throughput between the two clients is reported. APs were one meter apart.

Three-AP Mesh, Multi-client Throughput

Each solution used three APs. Once all three APs were online, they self-built the mesh system. Ten clients were deployed on two floors. See Figure 9 for locations of APs and clients.

Test Equipment Summary

The Tolly Group gratefully acknowledges the providers of test equipment/software used in this project.

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product Name</th>
<th>Web</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ixia</td>
<td>IxChariot v7.10 SP3 Console &amp; Endpoint</td>
<td><a href="http://www.ixiacom.com">http://www.ixiacom.com</a></td>
</tr>
</tbody>
</table>

Home Mesh Systems Under Test

<table>
<thead>
<tr>
<th>Vendor</th>
<th>Product Name</th>
<th>Devices</th>
<th>AP Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nokia</td>
<td>Nokia WiFi</td>
<td>3 APs as a Mesh Wi-Fi System</td>
<td>AC3000, Dual-band</td>
</tr>
<tr>
<td>Vendor A</td>
<td>-</td>
<td></td>
<td>AC3000, Tri-band</td>
</tr>
<tr>
<td>Vendor B</td>
<td>-</td>
<td></td>
<td>AC2200, Tri-band</td>
</tr>
<tr>
<td>Vendor C</td>
<td>-</td>
<td></td>
<td>AC2200, Tri-band</td>
</tr>
<tr>
<td>Vendor D</td>
<td>-</td>
<td></td>
<td>AC1200, Dual-band</td>
</tr>
</tbody>
</table>

Source: Tolly, September 2018

Table 2
Roaming Efficiency

Test measured (1) the time required for a client to roam from one AP to another, while running traffic and (2) the number of packets lost during the entire test.

The client was an Moto Z2 Play Android smart phone. Engineers walked the phone between two APs of each solution for a total of six round trips (12 roams). The WiFi Moho app's built-in roaming test reported the time of each roam and the total packet loss.

Resilience Tests

Co-channel and adjacent channel interference are two key reasons for low Wi-Fi performance. When interference is on a lower band (e.g. 5GHz channel 42) and the Wi-Fi signal is on an overlapped band (e.g. channel 36), the interference will cause the network's performance to drop significantly.

However, if the Wi-Fi signal is on an upper band (e.g. 5GHz channel 157), the interference won't significantly impact network performance.

Tolly ran two tests. The first evaluated channel selection around interference that was present during network startup. The second evaluated channel selection when interference was introduced to a running environment.

Channel Selection: Network Startup

For the network startup test, engineers used an access point (AP) and a Wi-Fi client device to create co-channel interference by running 100 Mbps TCP traffic before starting each system under test. The test procedure follows:

1. Start interference traffic
2. Start the system under test
3. Connect the test client
4. Start test traffic
5. Stop test traffic
6. Stop interference traffic

Source: Tolly, September 2018
Figure 9
Channel Selection: Network Running (Dynamic)

For the dynamic channel selection test, engineers used an octoScope iGen Interference Generator to create co-channel interference for the solution under test while the test traffic was running. The Wi-Fi interference used 802.11ac 80MHz bandwidth. The non-Wi-Fi interference used the built-in Continuous Wave profile. The test procedure follows:

1. Start system under test
2. Connect test client
3. Start test traffic
4. Start interference traffic
5. Stop test traffic
6. Stop interference traffic

Backhaul Failover

Nokia WiFi and Vendor A provide sufficient Ethernet ports to build a Wi-Fi mesh network using wired Ethernet connections. When the topology changes (e.g. an Ethernet cable is pulled out by accident), both systems can use wireless backhaul to continue running the mesh system.

To run this test, engineers started a live video stream across the backhaul and recorded total failover-to-recovery time seen when the wired backhaul was deliberately disconnected.

Home Wi-Fi Test Location

Source: Tolly, September 2018

Figure 10
**About Tolly**

The Tolly Group companies have been delivering world-class IT services for nearly 30 years. Tolly is a leading global provider of third-party validation services for vendors of IT products, components and services.

You can reach the company by E-mail at sales@tolly.com, or by telephone at +1 561.391.5610.

Visit Tolly on the Internet at: http://www.tolly.com

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**Nokia WiFi**

Nokia WiFi enables Service Providers to deliver their residential customers super-fast, reliable connectivity throughout a household. No longer will patchy Wi-Fi generate customer frustration, calls to your helpdesk or truck-rolls. The ultra-broadband service you deliver to the home will be just as good on every device in every corner of the home.

For more information, see:


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