



SUSTAINABLE CONSUMER DEMAND FOR CONVERGED WI-FI-PLUS-CELLULAR APPLICATIONS AND SERVICES WILL DEPEND ON CARRIER-GRADE FMC SERVICES THAT DELIVER A GOOD END-USER EXPERIENCE. BEFORE YOU CAN ACHIEVE THESE BENEFITS, HOWEVER, FMC PRODUCTS NEED TO DELIVER THE SAME QUALITY AS TODAY'S CELLULAR-ONLY SERVICES.

DRIVING THE CONVERGENCE BETWEEN FIXED AND MOBILE COMMUNICATIONS

INTO THE MAINSTREAM

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The universal demand for constant access to voice and data communication, along with the increasingly rich availability of Wi-Fi (wireless-fidelity) and cellular connectivity, is driving a widespread demand for converged Wi-Fi/cellular applications and services. Promising better access to voice and data services as well as lower communication costs, FMC (fixed/mobile convergence) has the potential to greatly affect the world of communications.

Before FMC technology can truly take off, however, it is critical for wireless-IP (Internet Protocol) networks and 802.11a/b/g/n devices to deliver the same underlying quality of ser-

vice as their cellular counterparts. As users move within Wi-Fi networks, as well as between Wi-Fi and cellular networks, FMC must deliver a satisfying end-user experience, featuring good

voice quality, few dropped calls, reliable and high-throughput data connectivity, long handset-battery life in standby and active states, and seamless voice and data roaming and hand-off. These user-experience metrics see direct influence from Wi-Fi statistics that define mobility performances such as range, roaming, and hand-in/handout capability.

For mobility-performance testing to be effective from quality, coverage, and cost perspectives, the test method must accurately re-create the real world in an efficient, repeatable, cost-effective, and scalable manner. As a result, an inte-



grated testing approach that allows engineers to evaluate the performance of their converged devices and networks from both the Wi-Fi and the cellular perspectives is necessary.

THE ABCs OF FMC

With its promise to seamlessly deliver quality fixed services and applications, including voice, video, and data over mobile wireless networks to handsets or endpoint devices, FMC represents a large commercial opportunity for infrastructure vendors to deliver back-end integration products and services, as well as for service providers to generate additional revenue from cellular-network-infrastructure investments, Wi-Fi approaches, or both. Despite this market opportunity, the industry has yet to deliver compelling FMC applications and services for end-user adoption. To drive such broad market acceptance, it's critical for infrastructure vendors and service providers to capitalize on the major benefit that FMC provides: the convenience of having one device and phone number for both mobile networks and corporate or home networks.

Using a voice call that the cellular network seamlessly transfers to the corporate or home network, users can enjoy continuous communication and benefit from improved coverage of the Wi-Fi network and reduce cellular-minute usage as a result of the call's moving off the cellular network. Alternatively, moving voice calls from a corporate or a home network to a cellular network enables continuous com-

AT A GLANCE

▣ FMC (fixed/mobile-convergence) technology can not take off until wireless-network and 802.11 devices deliver the same quality as their cellular counterparts.

▣ Vendors and service providers must capitalize on the major benefit of FMC: the ability to have one device and phone number for both mobile networks and corporate or home networks.

▣ It requires extensive testing to prove that the network efficiently conducts Wi-Fi (wireless-fidelity) roaming sufficient to maintain data throughput, voice quality, and call continuity.

▣ Engineering efficient Wi-Fi-to-cellular handovers requires complex changes to the back-end cellular network and to decision-making algorithms.

munication when users leave their office buildings or homes. The ability to use data applications where and when users want will also enable significant improvements in personal and professional productivity. While users are stationary or mobile in locations that a cellular or Wi-Fi network covers, they will have access to Internet-based applications such as e-mail, Web browsing, and online services, representing a huge draw for potential users of FMC services.

Beyond the importance of seamless voice and data communication, the

ability to provide cost savings that are not available from alternative Wi-Fi and cellular-only services, as well as a satisfying end-user experience, drive sustainable consumer demand for FMC services. Cellular services have established user-experience expectations that new converged services must meet or exceed. Failure to deliver a satisfying end-user experience will provide consumers with little motivation to adopt converged Wi-Fi-plus-cellular services, resulting in an industry that cannot generate sustainable demand for FMC services.

USAGE SCENARIOS

The primary driver of the growth in consumer demand for long-range cellular-network services has been improvements in mobile voice services and value-added data services, such as text messaging, e-mail, and Web access. FMC broadens the range of this capability by taking advantage of Wi-Fi technology indoors, where cellular coverage may be less reliable. Although moving coverage onto the Wi-Fi network provides users with access to potentially much faster services, it is critical that this Wi-Fi connectivity also sustains mobility and quality of service.

Converged Wi-Fi-plus-cellular services must also support the same or better quality of voice and data services while the user is in motion and transferring the networks. Mobility services require adequate performance in Wi-Fi range, Wi-Fi roaming, and hand-in/handout network transfers.

Wi-Fi range, the perceived quality of voice and data services as users move closer to and away from a Wi-Fi AP (access point), is a significant measure of Wi-Fi performance. Unlike cellular technology, Wi-Fi technology varies the transmission data rate to minimize packet errors. A Wi-Fi transmitter on the AP or the client uses dynamic-rate-adaptation algorithms to control the transmission data rate on a packet-by-packet basis. These algorithms consider many network and environmental variables, including received-signal strength and packet-error rate, in deciding to increase or decrease the transmission rate. If the implementation is poor, the movement of a user around a Wi-Fi AP will significantly affect the data

TABLE 1 TYPICAL MOBILE-PERFORMANCE SCENARIOS

User-experience scenarios	Mobile-performance scenarios
Using a Wi-Fi game controller while playing a console video game	Data throughput over range
Walking around a house while on a voice-over-Wi-Fi call	Voice quality over range
Downloading a new release of a band to a portable music player while walking around the airport	Data throughput during AP-to-AP roaming
Making a voice-over-Wi-Fi call between an office and a conference room	Voice quality and dropped calls during AP-to-AP roaming
Making a conference call while heading into the office	Voice quality and dropped calls during hand-in/hand-out network transfer
Making microwaved popcorn causes dropped calls	Interference from microwave oven
Experiencing more battery drain at home than at work when using Wi-Fi	Battery life over various network conditions



throughput and voice quality that the user experiences. Proving that the rate-adaptation algorithms are implemented properly requires extensive range testing of the client and AP devices.

Wi-Fi roaming, the ability to provide quality voice and data services while the user is moving between Wi-Fi APs, is another critical measure of Wi-Fi-device performance. Both cellular and Wi-Fi networks use algorithms to transfer connectivity from one infrastructure device, such as a cellular base station or Wi-Fi AP, to another as connection conditions require. Cellular networks use roaming algorithms on the base station, which the network manages, to make roaming decisions in consideration of real-time network conditions, such as base-station loading and base-station-service outage. In contrast, Wi-Fi networks use roaming algorithms on the client, which makes roaming decisions without considering real-time-network conditions. This difference means that Wi-Fi clients could decide to roam to an AP that is overloaded or functioning improperly, resulting in significantly reduced data throughput and voice quality or a session's termination.

In addition to the differences in the implementation of the roaming algo-



EXTENSIVE TESTING IS IMPORTANT TO VALIDATING THE IMPACT OF HANDOVER ON THROUGHPUT, VOICE QUALITY, AND CALL CONTINUITY.



rithm, cellular and Wi-Fi networks execute roaming through different means. When a voice call is in progress, cellular networks execute roaming using a make-before-break approach that establishes the connection between the handset and the base station that gains control of the session before terminating the connection between the handset and the base station that is giving up control of the session. Depending on network setup, data services over cellular networks can use either make-before-break

or break-before-make approaches.

Wi-Fi clients, however, always execute roaming with a break-before-make approach in which the client terminates connectivity with one AP before establishing connectivity with a new AP. A poorly implemented roaming algorithm on the client can result in a significant delay before establishing the connection with the new AP or even failure to make the connection. These issues can severely affect data throughput, voice quality, and call continuity.

Transferring session connectivity between Wi-Fi and cellular networks, a hand-in/handout transfer, is even more complex than a Wi-Fi-to-Wi-Fi roam or a cellular-to-cellular handover. In the case of voice calls, this Wi-Fi-to-cellular transition is always make before break, adding complexity to the normally simple Wi-Fi-to-Wi-Fi transition. With the differences between cellular and Wi-Fi handover and roaming-algorithm implementations, engineering efficient Wi-Fi-to-cellular handovers requires complex changes to the back-end cellular network, as well as significant changes to decision-making algorithms. With this increased complexity, extensive testing is important to validating the impact of handover on throughput, voice quality, and call continuity.

TABLE 2 REQUIRED WI-FI-MOBILITY-PERFORMANCE TESTS

Mobile-performance scenario	Wi-Fi-performance metric	Wi-Fi-performance test
Data throughput over range	Data rate, packet loss, error rate	Throughput in megabits per second as a function of distance from a Wi-Fi AP—the position of your office relative to AP, for example
Voice quality over range	Packet loss	Voice quality measurement—PESQ (perceptual-evaluation-of-speech-quality)-based scores—as a function of distance from the Wi-Fi AP, such as talking on the phone in front of the TV or in the kitchen
Data AP roaming	Roaming time, data rate	Roaming time in seconds for failover roam as a handset moves to a new AP because one has failed, such as during a power glitch or network failure; roaming times for smooth roaming as a handset moves between two Wi-Fi APs, such as during walking between work areas
Voice-over-Wi-Fi handover	Roaming time, packet loss, error rate	Number and percentage of voice calls dropped as handset moves between two Wi-Fi APs or transfers from Wi-Fi to cellular networks and vice versa, walking to another part of a building while talking on the phone or moving outside the building; voice-quality measurements—PESQ-based scores when handset moves between two APs or transfers from Wi-Fi to cellular networks and vice versa, such as maintaining call quality when moving around a house or when moving from a garden into a house

REAL-WORLD WI-FI MOBILITY

Unlike cellular networks, which are the sole occupiers of the licensed-RF spectrum in which they operate, a Wi-Fi network operates in unlicensed spectrum that it shares not only with other Wi-Fi networks, but also, potentially, with other RF networks, such as Bluetooth—or even with other RF devices, such as cordless phones and microwave ovens. As a result, when discussing the performance of FMC devices employing Wi-Fi, the impact of the real-world-environment conditions in which the devices operate also requires recognition.

In addition to the RF interference that Wi-Fi networks and RF devices competing for spectrum create, solid obstacles, such as walls and furniture, as well as the movement of objects, such as vehicles, can create RF-signal conditions—multipath and fading—that affect the performance of Wi-Fi devices. Most FMC approaches use a nondedicated IP network as a primary carrier of



the voice data, which can directly affect voice quality as traffic load varies. As a result, to maintain the best possible FMC services, converged Wi-Fi-plus-cellular handsets must deliver the best Wi-Fi-mobility performance in all of these real-world conditions.

To determine the impact of Wi-Fi performance on user experience, it is important to first identify the critical mobile-performance scenarios that directly affect the user (Table 1). These mobile-performance scenarios establish the fundamental Wi-Fi-performance metrics, including data rate, packet loss, error rate, and roaming time, that require testing. You can then develop a set of essential tests for the evaluation of the Wi-Fi-mobility performance (Table 2).

An integrated approach to testing FMC devices and networks must feature parametric measurement plus flexible protocol and triggering analysis and emulation of a network with full connectivity to the Internet. By providing an emulated generic-access network, such an approach enables engineers to test the conformance and functions on the GSM (global-system-for-mobile)-communications side, as well as the handover reliability between the generic-access and GSM networks.

METHOD FOR TESTING

OTA (over-the-air) testing, in which engineers test device performance by replicating the conditions of the environments in which the device will operate, is one common method of evaluating Wi-Fi-mobility performance. OTA testing relies on empty office buildings, homes, and live networks to accomplish its goals. OTA tests for mobility and roaming use mobile carts, moving Wi-Fi and cellular equipment to various locations in the test space and manually configuring tests and recording test results at each location.

Because this approach depends largely on the uncontrollable nature of OTA environmental conditions, engineers manually perform most testing. As a result, several critical factors limit the effectiveness of Wi-Fi-mobility-performance testing using OTA methods. The time-consuming manual test setup and execution typical of OTA tests limit the ability of this testing method to scale. Consistent, repeatable test measure-



DEVICE ISOLATION REPLICATES THE WI-FI NETWORK IN A CONTROLLED, CABLED ENVIRONMENT.



ments are also nearly impossible in OTA environments, thereby limiting the ability to reliably repeat the tests in the future. In addition, RF interference may vary with each test iteration, even at the same location, possibly making it impossible to reproduce results and issues.

The alternative to OTA testing is testing in a controlled RF environment, through approaches such as room isolation, which places the Wi-Fi-test setup in a screen room that filters out external RF interference. Due to the large installation and maintenance costs of the screen rooms, room isolation is costly. Additionally, the size of the screen room severely limits the effectiveness of testing distance, roaming, and mobility performance. Device isolation is a more advanced method of controlled RF testing, in which you place all testbed devices in individual isolated enclosures and connect them with cables to programmable RF attenuators, combiners, and switches. This test method replicates the Wi-Fi network in a controlled, cabled environment that stabilizes the RF connection by removing the variability of OTA systems.

Unlike other testing approaches, device isolation features a controllable testbed with numerous benefits. Isolation of devices under test from external RF interference provides a controllable RF environment to conduct repeatable mobility testing. By using a controlled, cabled RF environment, such testing approaches reduce costs by eliminating the need to design, build, and maintain homegrown testbeds and costly RF screen rooms. Other benefits of this test method include the programmable tes-

tbled and tools that enable automated test configuration and execution. Users can automatically configure any network device and dynamically position any network node to analyze the effect of mobility on both device and network performance. Additionally, automated test configuration allows for simple, effective setup and reuse. Using programming, you can create scripts that require little human intervention and can automatically run multiple iterations of configurations in a fraction of the time it takes for manual testing. This repeatability reduces the time you spend on the quality assurance and benchmark-test processes and, as a result, dramatically reduces time to market and testing costs.

Test scalability is an additional important benefit of the device-isolation approach. If you properly build the controlled RF environment, you can scale Wi-Fi testing from a single device to the entire network. Users can configure an entire Wi-Fi network and provide system-level testing of actual APs, clients,

and other wireless devices. You can test networks under a variety of traffic- and client-load conditions. Client- and traffic-load emulation enables the development of test setups that re-create a busy network environment for the devices under test. This approach provides the ability to test Wi-Fi-mobility performance in controlled conditions. By using this test approach, engineers can assess the impact of one or a combination of conditions, including RF multipath and fading, background Wi-Fi traffic, RF interference, and IP-network delay, on the mobility performance of 802.11a/b/g/n devices.

FMC developers, users, and service providers have a variety of testing requirements they can address with device isolation, ranging from a development environment in which controlled isolation in a crowded RF lab can be invaluable to integration. System-engineering groups within service-provider organizations conduct another critical test process. They use these same test scenarios to validate interoperability of devices

from different suppliers, to benchmark the performance of different configurations to make purchasing decisions, and to certify devices for deployment. For the engineers who select FMC handsets that will operate on service-provider networks, effective performance benchmarking provides a means of performing an apples-to-apples comparison of the Wi-Fi-mobility performance of FMC handsets. **EDN**

AUTHORS' BIOGRAPHIES

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