# Clear Voice over Wi-Fi

## Overcoming Wi-Fi Challenges Facing Digital Voice in the Home

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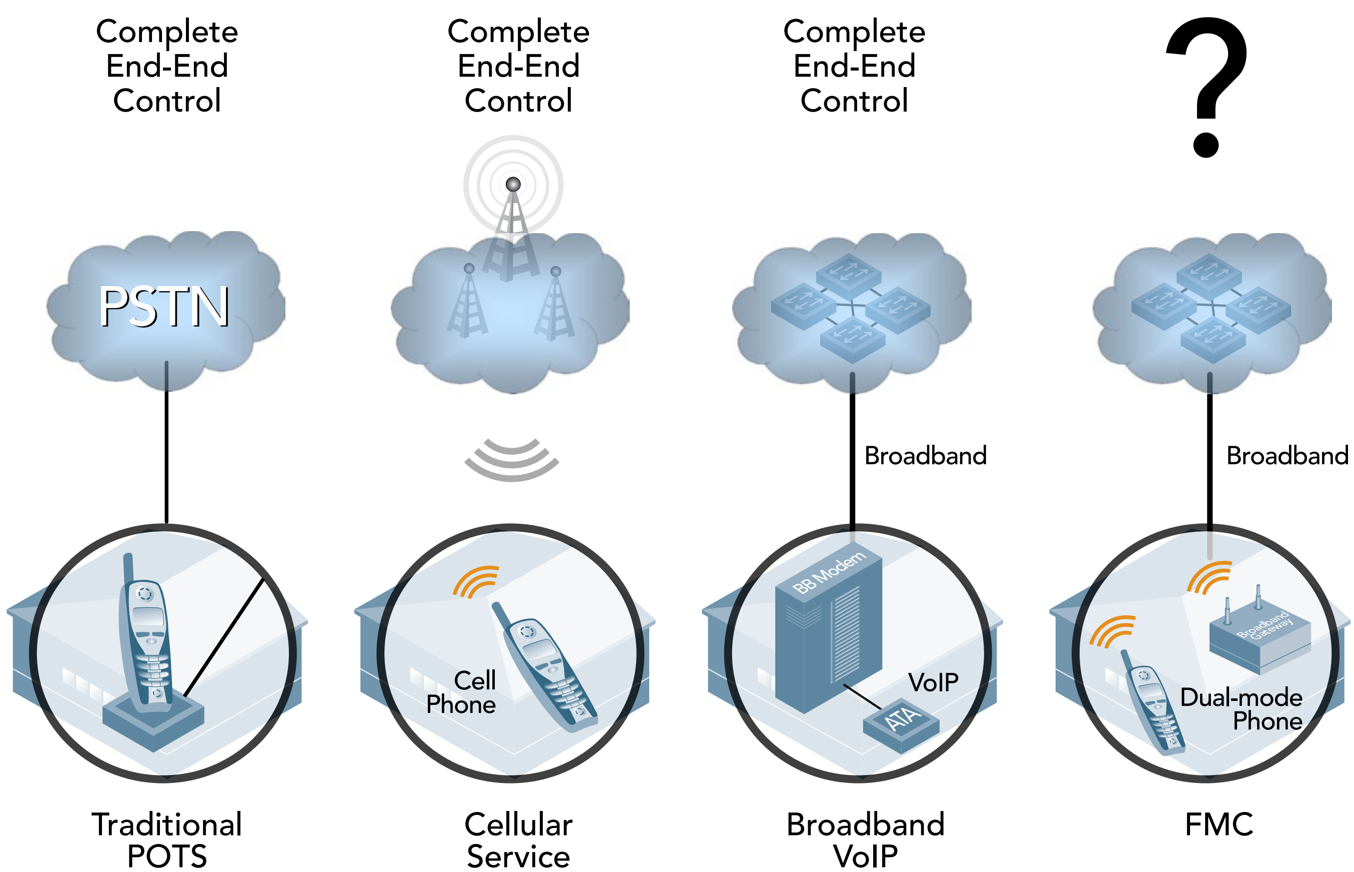
Ruckus™
WIRELESS

## EXECUTIVE SUMMARY

For consumers, Fixed/Mobile Convergence (FMC) means a world where integrated voice and data services are available everywhere through a single mobile handset that replaces disjoint cellular and landline telephones.  For carriers, FMC represents a lucrative opportunity to leverage inexpensive technologies to offload increasingly-rich multimedia traffic from costly licensed network infrastructures.  Broadband operators everywhere are interested in FMC to broaden the footprint of their services and infrastructure at a relatively low cost, augment coverage into buildings and increase subscriber "stickiness."

Worldwide FMC revenue is poised to explode, with estimates reaching $28 billion and 92 million subscribers by 2011.  To successfully tap this market, carriers will need to provide ubiquitous, reliable, cost-effective wireless coverage.

**Impact of fixed mobile convergence on operator managed voice services**
Source: Ruckus Wireless

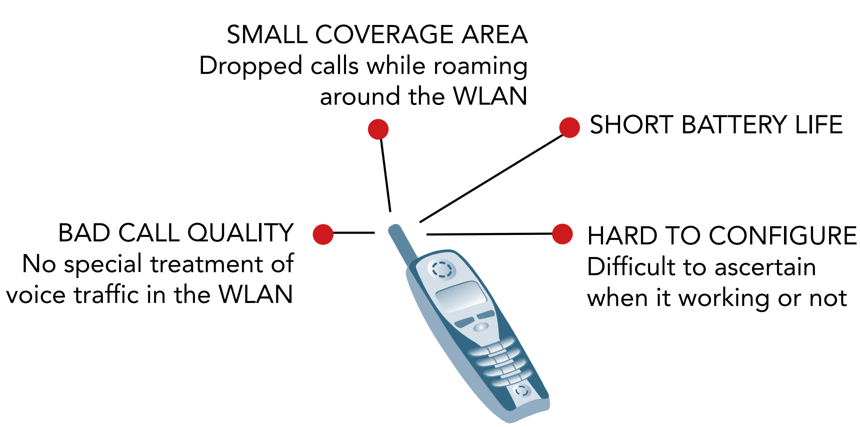


However FMC presents some new challenges for operators who have traditionally enjoyed control over voice connections on an end-to-end basis (see Figure on previous page). New dual-mode phones supporting both Wi-Fi and cellular technologies disable this control in the home where conventional Wi-Fi can wreak havoc due to interference and quality of service issues. Moreover, broadband operators are challenged to manage this last 100 feet. Existing voice services offered today over cellular, broadband VoIP and traditional POTs are all managed on and end-to-end basis. But with FMC there is no good way to gain visibility into or control over Wi-Fi connections in the home using conventional consumer-grade Wi-Fi. As a result, service quality can't be guaranteed.

Broadband operators around the world are preoccupied with delivering new multimedia services -- the so-called triple or quad-play -- over residential broadband connections. While data was the initial driver for broadband, IPTV and voice are the new focus. This requires developing a reliable infrastructure to support all traffic types simultaneously. But inside the home, wires, despite their reliability, simply won't cut it.

In particular, Wi-Fi has become the de-facto network for best-effort data delivery inside private residences, where cellular coverage is notoriously weak and costly to improve. Wi-Fi has great potential to enable converged service delivery inside the home with greater ubiquity, at lower cost, than licensed cellular -- IF Wi-Fi can be made sufficiently robust and reliable to carry paid voice services.
However, two-way, interactive voice conversations are extremely vulnerable to delay and interference. For voice to work over Wi-Fi, wireless systems must be able to adapt in just milliseconds to changes in the radio frequency (RF) environment. Presenting a stronger, more reliable Wi-Fi link to voice handsets is critically important to overcome low or fluctuating signal strength that degrades voice quality and saps precious battery.

**Issues affecting voice over conventional 802.11 Wi-Fi**
Source: Ruckus Wireless



By maximizing transmit signal strength and receiver sensitivity, voice handsets can send the same information in shorter times, at lower power. This can be accomplished by using smart Wi-Fi antennas to narrowly direct signal towards each voice handset, reducing retransmissions, extending battery life, and improving user satisfaction.

## ISSUES AFFECTING WI-FI PERFORMANCE AND STABILITY

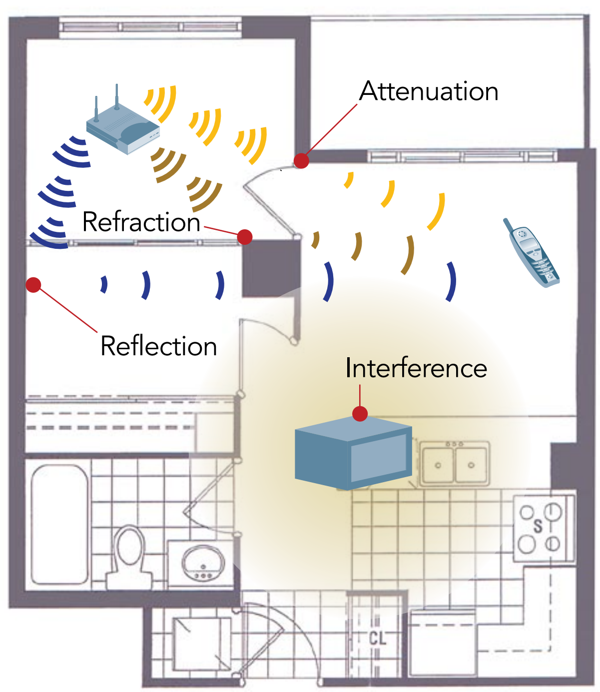
Because 802.11 traffic is transmitted over unlicensed radio bands, Wi-Fi networks can be easily and inexpensively deployed by home owners, businesses, hotspots, and carriers without any explicit cooperation or purchase of costly licensed spectrum. Today, many consumers combine Wi-Fi with residential broadband to enable web browsing and email access from nearby rooms inside their home. But, consumers who try to do more with Wi-Fi are often disappointed, particularly when trying to run real-time multimedia applications like voice.

To start, Wi-Fi faces stiff competition for the airwaves. The 2.4 and 5 GHz bands used by 802.11 wireless are shared by many other devices, including cordless telephones, Bluetooth peripherals, satellite services, and neighboring Wi-Fi networks. These common sources of interference make it harder for a home owner's Wi-Fi devices to differentiate between legitimate transmissions and background noise. Tuning an AP to a different frequency (channel) can reduce noise. But with only three non-overlapping channels available for use by 802.11b/g, most Wi-Fi networks end up co-existing with several interfering devices, inside and outside the home.

Wi-Fi signals degrade not only by noise, but by distance and intervening objects. A laptop and AP in the same room, with nothing but air between them, can experience relatively high data rates up to 54 Mbps. But put that laptop in the next room, and radio waves will be partially absorbed (attenuated) by the intervening wall (see Figure). Place the AP beneath a metal bookcase and waves will bounce (reflect) off that surface. Waves passing through walls, furniture, and even people become slightly bent (refracted). This is why radio waves sent through open air can be received 300 feet away, yet indoor transmissions are often too faint to reliably span even a small house.

**Wi-Fi signal degradation**

Source: Ruckus Wireless



When signal strength drops, Wi-Fi devices try to compensate by reducing data rate (i.e., less RF energy is needed to deliver fewer bits without error.) For example, an 802.11b laptop moving away from an AP adjusts from 11 to 5.5 to 2 to 1 Mbps, until signal is too weak to sustain a connection. Due to overhead, application throughput is typically no more than half the data rate. With 802.11b, an entire family may be limited to just 500 Kbps of throughput. Even with 802.11g, best case throughput is about 27 Mbps, assuming short, unimpeded (line of sight) paths to every device and no interference between the sender and receiver.

## MULTIPATH AND 802.11N

Wi-Fi networks are also impacted by RF phenomena like hidden nodes and multipath. Multipath occurs because radio waves are reflected to some degree by every object encountered between transmitter and receiver, especially liquid or metal surfaces (e.g., blinds, appliances, doors). Multiple reflections of the same signal may reach the receiver, where they increase, decrease, null, or corrupt the primary signal. This common phenomenon creates coverage holes and pockets where signals severely degrade. Avoiding multipath would be difficult, even if conditions remained constant. However, the RF environment changes continuously, from microwave ovens that generate noise bursts to people in motion that alter the way radio waves propagate throughout the home. Even small environmental changes can have huge impact on performance.

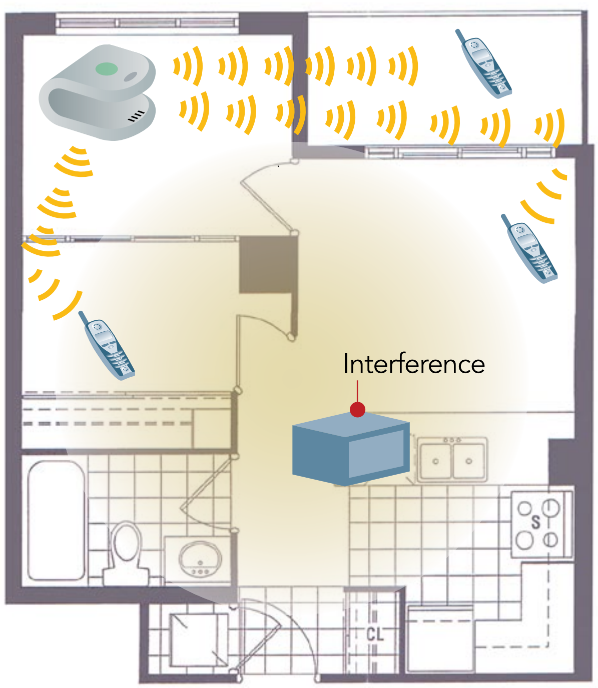
New Wi-Fi technology has taken this multipath problem and tried to turn it into an asset. The emerging IEEE 802.11n standard is designed to boost throughput by recombining multiple Wi-Fi signals that use different paths to reach a receiver. When ratified in 2007, 802.11n is expected to achieve data rates up to 200 Mbps through so-called "spatial multiplexing" and higher-capacity channels. Specifically:

- 802.11n increases maximum data rate by combining currently-defined 20 MHz channels to create 40 MHz channels in both the 2.4 and 5 GHz bands. Wider channels primarily benefit high-throughput data applications, but reduce the number of non-overlapping channels and increase susceptibility to interference.

- 802.11n exploits multipath to improve range and throughput. Most 802.11a/b/g APs transmit all data in every direction, using a pair of diversity antennas to listen to arriving data and process the stronger signal. In contrast, 802.11n APs split output data into two or more unique streams to be transmitted simultaneously along diverse spatial paths. Receivers combine input streams to reconstitute complete data frames. In locations where significant multipath occurs, this Multiple Input Multiple Output (MIMO) technique offers higher data rates at given distances.

However, 802.11n does not benefit applications that really need consistent delivery of short frames -- like Voice over IP. With voice, as with other real-time media and applications, more bandwidth isn't an issue; stable, predictable connectivity is.

**Real-time interference avoidance**
Source: Ruckus Wireless




Smart Wi-Fi provides dynamic path selection per device, directing Wi-Fi signals around interference in real time.

## PRIORITIZING WIRELESS TRAFFIC FLOWS

Wi-Fi was originally designed for best-effort data delivery. All 802.11 users contend for the same channel on a first-come, first-serve basis. When a device with traffic to send finds the channel busy, it must avoid collision by waiting for a random period. This is referred to as CSMA/CA (Carrier sense multiple access with collision avoidance). In a lightly-used Wi-Fi network, one user can easily hog the entire channel. As load increases, all users suffer equally by waiting longer to transmit.

This design fits many data applications, but creating a network suitable for voice delivery requires an entirely different mind-set. SIP, H.323, and proprietary VoIP protocols differ in detail, but share performance requirements. Specifically, jitter, latency, and loss must all be minimized when carrying real-time isochronous traffic. Variability in packet inter-arrival time produces jitter, manifested as audible gaps. Delayed delivery or loss of streamed audio or video packets can be smoothed through buffering, but VoIP packet latency can render phone calls unusable.

So the IEEE created 802.11e (MAC enhancements for Quality of Service) to improve audio, video, and voice delivery over Wi-Fi. Many enterprise products (but not consumer products) implement an 802.11e subset called Wi-Fi Multimedia (WMM) that prioritizes Wi-Fi traffic so that applications with diverse latency and throughput needs can receive more appropriate treatment. WMM defines four access categories: voice, video, best-effort, and background traffic. APs that implement WMM usually have per-class transmit queues that transmit voice over Wi-Fi (Vo-Fi) more frequently, for longer durations, than other traffic.

However, WMM still cannot differentiate between applications at the same priority. If traffic to one Vo-Fi device is lost due to interference or attenuation, the AP will retransmit to that device before servicing queued traffic for other Vo-Fi devices. WMM also cannot reduce latency when a Vo-Fi device roams from one AP to another (Wi-Fi devices continually assess signal strength and will automatically reconnect to the "best" AP in multi-AP networks). In short, WMM prioritization gives Vo-Fi a fighting chance, but still does not overcome physical issues that degrade voice quality.

## OPTIMIZING VOICE DELIVERY OVER WI-FI

Today's triple-play Internet data/video/voice services tend to leave Wi-Fi up to the consumer. VoIP services typically terminate at a broadband router. A few basic Wi-Fi handsets are available for residential use. However, conventional cordless phones offer far better coverage and battery life, at a fraction of the cost.

Consequently, consumer expectations for mobile voice handsets have been set very high. To succeed in the FMC market, carriers will need to exercise control over Wi-Fi customer premise equipment (CPE), choosing those devices with care. Widely-deployed residential 802.11b/g APs are clearly ill-suited for voice delivery. Newer MIMO APs can push data faster and farther, but do nothing to address voice quality or link stability. Although uncommon in today's residential APs, WMM is essential to delivering voice over mixed-use home Wi-Fi networks. Delivering reliable Vo-Fi services inside the home requires a new approach that works with both existing and future 802.11 technologies.

While 802.11n only uses diverse propagation paths to increase throughput, it is possible to use propagation paths to optimize delivery to an individual device. Accomplishing this requires both hardware and software -- specifically, an adaptive high-gain antenna array that can dynamically steer streams over specific propagation paths, accompanies by an intelligent algorithm that selects and configures antennas to optimize performance for each individual device and application.

Most residential APs (including MIMO APs) use dipole antennas that radiate output energy in all directions. This wastes power and creates interference. An adaptive antenna can focus output energy in a specific direction, letting radio waves travel farther, reducing interference with other devices, and avoiding intervening objects that contribute to attenuation and reflection.

An antenna array increases the number of possible propagation paths, creating more diverse options to reach a given device as it moves and environmental conditions change. When a consumer carrying a Wi-Fi handset walks from one room to another, the optimum propagation path changes (see Figure 2). When a nearby microwave oven or Bluetooth peripheral is activated, that path changes again. In fact, the optimal path is likely to change very frequently and rapidly. This make adaptation critical.

Data applications are generally resilient to variable delivery. Streaming video can deal with delays that last hundreds or thousands of milliseconds. But there is very little latitude with voice. To keep latency under 100ms, Vo-Fi devices must adapt in real-time to changes that impact delivery, including near-continuous handset movement. Some APs operate all the time at highest-possible power, hoping to "brute-force" their way through interference and obstacles that degrade signal and range. However, this just drains the handset's already-limited battery life, while increasing interference between multiple Wi-Fi users.

Alternatively, Wi-Fi systems that quickly recalculate the optimal path and steer Vo-Fi traffic along that path can reduce both latency and handset power consumption. Steering voice traffic towards each handset can increase overall range, let handsets operate at higher data rates at any given distance, and reduce roaming where more than one AP is present. Accomplishing this requires real-time measurement of per-device QoS and algorithms. These mechanisms enable the AP to make smart choices about where and how to transmit, what input to process, and what interference to ignore. Ideally, these physical-layer algorithms should be integrated with link-layer algorithms, like WMM, that understand application needs. Such an AP could make transmit decisions based not just on priority, but also the current performance of each individual device.

## SATISFYING CONSUMER EXPECTATIONS

Ultimately, residential Wi-Fi faces a myriad of technical challenges that make performance hard to predict, much less control. When it comes to voice delivery, consistency and reliability are critical. Improvements like MIMO and 802.11n will not make the situation any better for voice -- in fact, higher-throughput data will increases airwave competition and interference.

Carriers must deploy reliable wireless transport that can deliver predictable QoS in a typical home environment. Choosing the right CPE will be critical to satisfy consumer expectations and compete effectively in this lucrative growth market. To do so, carriers must understand factors that influence Vo-Fi QoS and seek innovative solutions that specifically address this application's needs. APs that not only support WMM, but deal effectively with physical challenges that are a deal-breaker for voice, are far more likely to deliver carrier-grade voice inside the home – and happy subscribers.

| NOT ALL WI-FI CREATED EQUAL | |
|---|---|
| Conventional Wi-Fi | Smart Wi-Fi |
| • Best effort VoIP over Wi-Fi | • Toll-grade voice over Wi-Fi |
| • Unmanaged spectrum | • Visibility into RF spectrum, spectrum management |
| • 50m Vo-Fi radius | • 100m+ Vo-Fi radius |
| • No control over signal path selection | • Adaptive signal path selection |
| • No synchronization between AP and handset | • Low power synchronization between AP and handset ensures no missed calls |
| • Single or dual omni directional antenna subject to interference | • Automatic interference mitigation and avoidance through directional, high-gain antenna subsystem |
| • No integrated QoS | • Voice traffic prioritized, queued and schedule over data and other non-delay-sensitive traffic |

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