Air Traffic Control - The Foundation for Wireless Without Compromise™

The Rise of Enterprise Wireless Networking

The last decade of the 20th century witnessed the use of Internet. The first decade of the 21st century has seen the rise of wireless connectivity. Wireless networking is now commonplace—mobile connectivity is becoming a rule, not an exception. But getting there was not as easy as it may seem today. Wireless networking requires a basic understanding of the world of Radio Frequency (RF)—where concepts like channel planning, cell sizes and frequency reuse are the norm.

In this white paper, we have discussed the three phases of WLAN architecture evolution i.e. WLAN for convenience (limited adoption), WLAN as the network of choice (instead of wires) and WLAN for business critical applications. We have also compared legacy microcell architectures to Meru's Air Traffic Control™ architecture and provided guidance on selection of the right architecture.

Phase 1: Infancy "Wireless LAN—Network of Convenience"

In early 2000, wireless LANs were deployed in a limited fashion to enable convenient mobile access for workers with laptops, without the need to plug into the network. For many networks the primary application was casual access to email and the Internet, for both guests and employees. The solution to this problem was groundbreaking: plug in wireless access points (APs), wherever network access was needed.

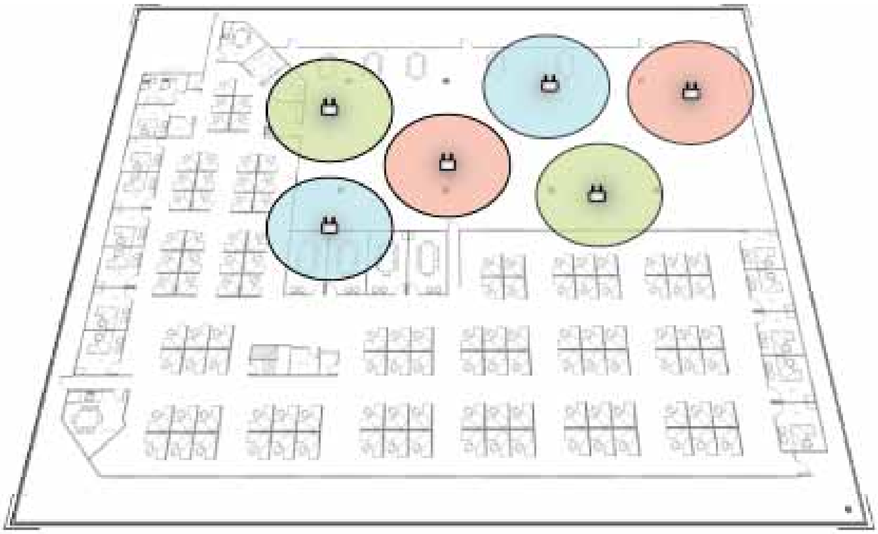


Figure 1 - The Beginnings of a Casual Wireless Access Network

These access points were deployed in standalone mode for providing connectivity to a few users. Soon the demand on the network increased as more and more users wanted to use the standalone access point for wireless access. Adding access points to improve the coverage area and capacity required careful selection of non-overlapping channels to avoid interference between access points.

IEEE 802.11 APs operate in an unlicensed RF spectrum—specifically, the 2.4GHz and 5GHz Industrial, Science, and Medicine (ISM) bands. The 2.4 GHz band is also used by microwave ovens, cordless phones and many other wireless devices. This band is divided up into three distinct, non-overlapping channels, known as channels 1, 6 and 11. APs operating physically close to each other and on the same channel interfere with one another. Adding more APs to boost capacity causes interference between new and old APs and actually reduces the overall aggregate capacity of the network. One approach to avoiding co-channel interference was to follow the typical hexagonal cell tiling model, borrowed from the cellular world, which allows the three channels to be separated as far as physically possible.

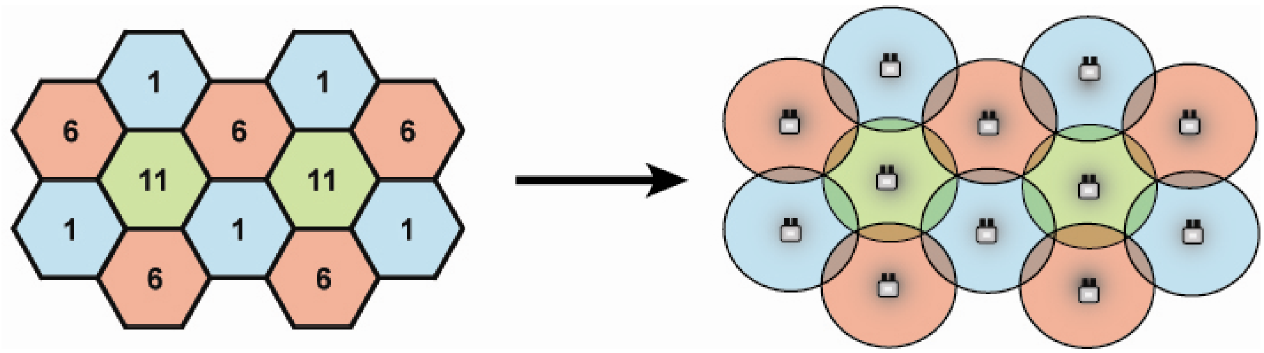


Figure 2 - Hexagonal Tiling to avoid co-channel interference

Phase 2: Adolescence "Wireless LAN—Network of Extending Coverage"

Microcells Enable Enterprise Wireless Adolescence

In 2004, IEEE 802.11g enterprise grade WLAN access points were introduced to the market. OFDM-based 802.11g operates at a maximum raw data rate of 54 Mbps but has the same number of non-overlapping channels as 802.11b. The 802.11g standard provided some increase in available throughput but was not enough to meet the growing requirements of the wireless network. Most 802.11g access points delivered 22-27Mbps.

The hexagon tiling approach worked to a certain point. In 2004-2005, the wireless network usage model began to shift from one of casual access, to one in which wireless is used for providing connectivity in areas where it was not possible to draw wires. This made WLAN access an integral part of the enterprise-network, now for business critical operations. The number of users on the network started increasing and it was no longer possible to meet the requirement of a growing network using the hexagonal tiling approach alone. Hexagonal tiling was combined with limiting the access point power settings in the microcell approach since a microcell is basically a smaller cell—created by turning down the power level of the radio. Smaller cells mean that more APs can be packed into the building without increasing the interference since the relative distances between the APs stay the same.

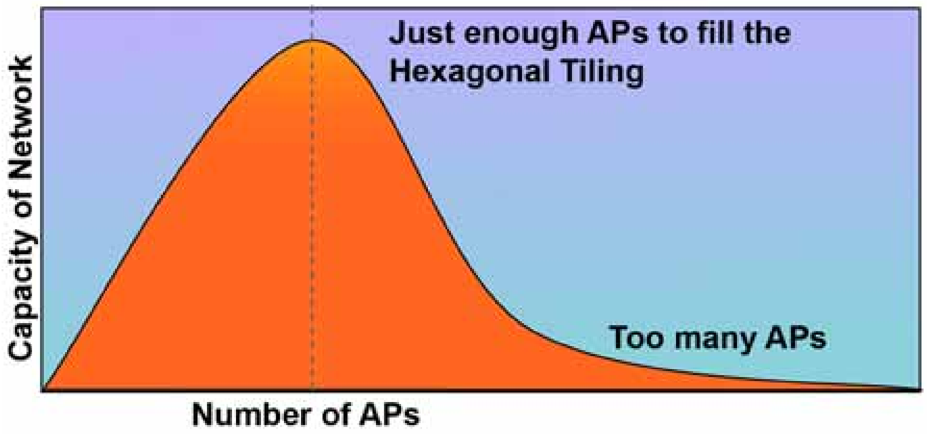


Figure 3 - Too Many APs Hurt Capacity

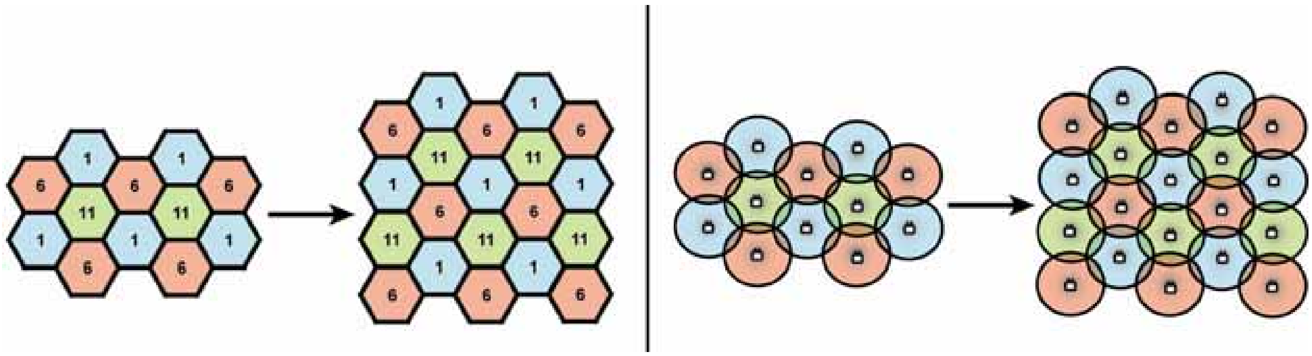


Figure 4 - Shrinking Cells Shrinks the Hexagons As well, Packing More in

Microcells, while solving the capacity issue to some extent, introduce several other problems in the network such as latency due to frequent hand-offs, interference from non-802.11 devices, and more coverage holes. Most importantly, it increases the number of APs by 20%-30% which has a direct impact on the cost of the WLAN infrastructure.

Trade-off between coverage holes and load-balancing

To provide ubiquitous access, coverage holes need to be filled. One approach is to selectively increase the power levels of the cells wherever coverage holes are detected. This results in irregular hexagonal tiling pattern and makes it difficult to use dynamic RF load balancing features. RF load balancing features were first introduced in the products so that the RF environment could readjust itself if interference occurred. But if the coverage of some access points are selectively adjusted to eliminate dead spots, dynamic RF load balancing can not function properly. So, either RF load balancing is disabled or coverage holes are ignored. Smaller cells result in more frequent handoffs between cells. While frequent hand-off does not affect data clients, latency significantly disrupts for voice communication. The more APs a client sees, the more they may choose to hand off—especially if the loads on the APs vary.

Signal resiliency is sacrificed

Lower signal strength reduces the signal-to-noise ratio, allowing interference from other 802.11 sources and non-802.11 sources (such as Bluetooth and microwave ovens) to become more disruptive to the network.

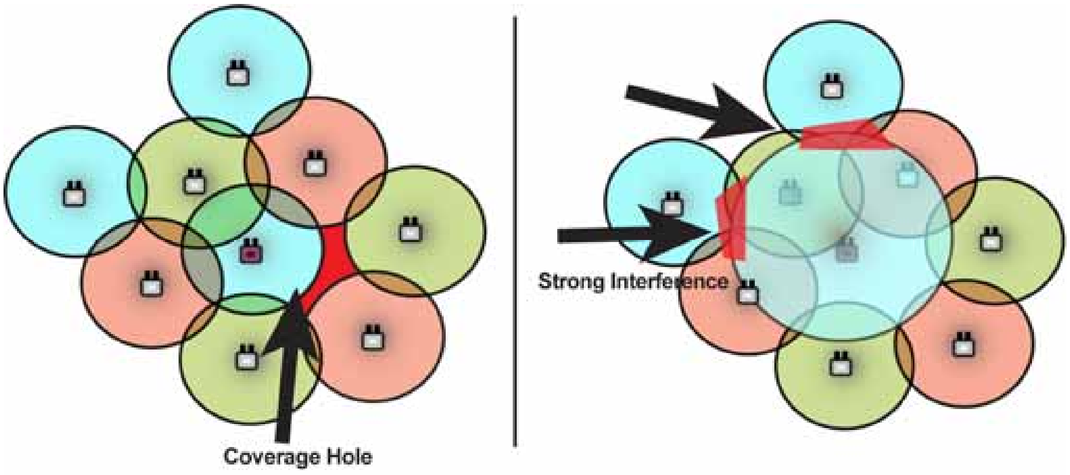


Figure 5 - Both Options Are Bad: Coverage Hole vs. Interference

The microcell architecture results in 20-30% more APs. While it serves the vendors selling this architecture well, it significantly increases the cost of the equipment (more access points as well as bigger controllers), channel planning and design, and post deployment RF channel management issues.

Phase 3: WLAN : Network of Choice

Air Traffic Control: The Solution for Mature Enterprise WLANs

Air Traffic Control addresses the problems that legacy microcell architectures are unable to solve. Air Traffic Control has several elements, each designed to overcome a problem introduced by the microcell deployments.

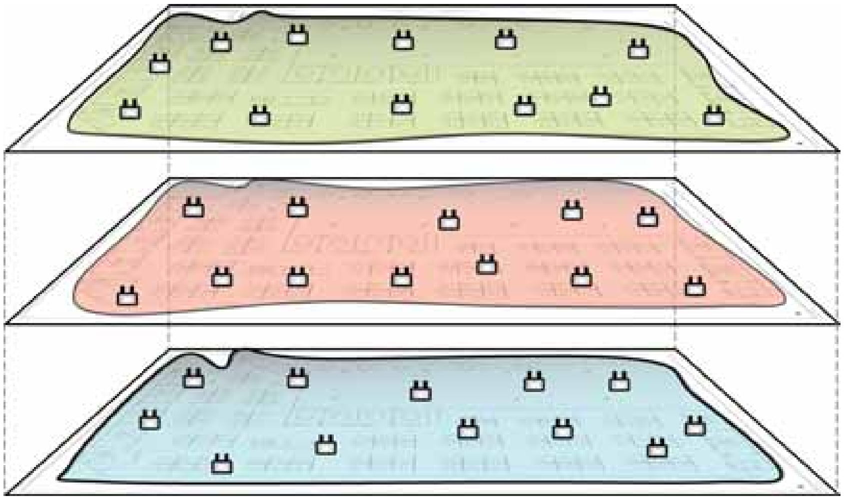


Figure 6 - A Typical Virtual Cell Deployment, Based on Layered Channel Spans

Virtual Cells™

Instead of attempting to avoid co-channel interference between channels as in a microcell architecture, the Air Traffic Control architecture uses the Virtual Cell to eliminate co-channel interference by placing all access points on one channel span and letting the controller control a fully-coordinated, distributed architecture. To a client, all APs appear as one. All APs are placed on the same channel with the same Basic Service Set Identifier (BSSID), as opposed to each AP having its own unique BSSID. With the Virtual Cell, co-channel interference elimination works to negate the effects of the overlap by taking advantage of it instead of avoiding it.

There are several advantage of this approach:

1. <u>No conflict of channel selection</u>
   By virtualizing the identity of the cell, the client no longer has to struggle with the decision to choose among the overlapping APs if it can detect more than one. The client sees only one Virtual Cell and the controller decides which AP should serve the client. Without Virtual Cell, the client must constantly evaluate and possibly hand off.

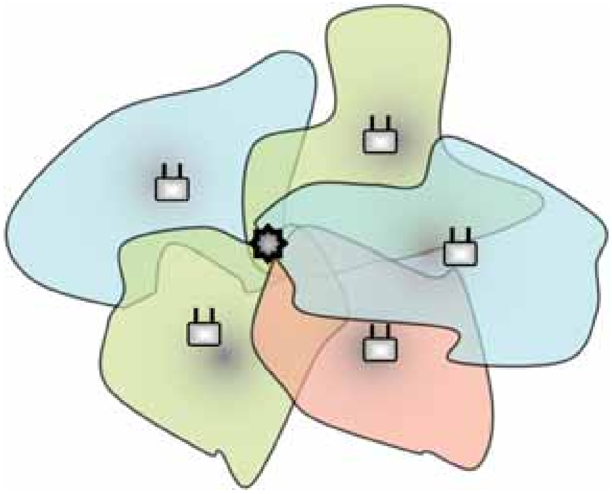


Figure 7 - Without Virtual Cell: Client Sees Multiple Choices per Channel

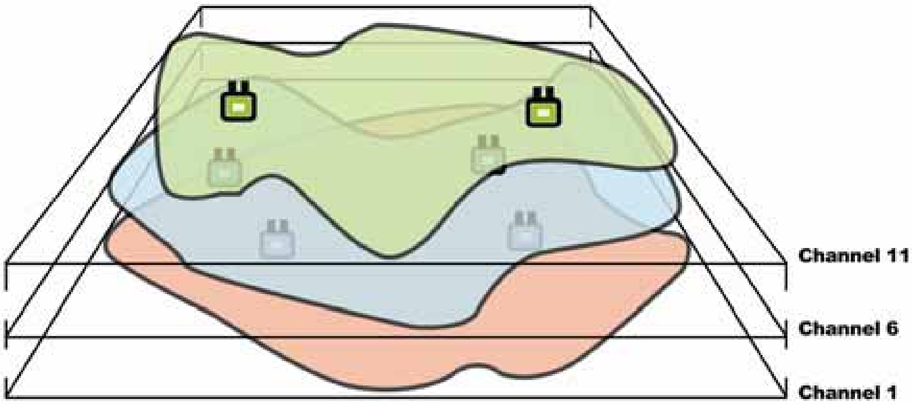


Figure 8 – With Virtual Cell: Client Sees One Choice per Channel

2. Seamless hand-off
   There is no communication break on a handoff, and the client operates smoothly and seamlessly across the entire deployment. This sort of application fidelity is a must for Voice over Wi-Fi networks, as well as most mission-critical applications, such as digital imaging for hospitals, RFID for retail and warehousing, and video conferencing for enterprises.

3. Capacity increases multi-fold
   A single channel spans across all access points creating a Virtual Cell, leaving the remaining non-overlapping channels for adding capacity by layering up more channels. Whereas, in a microcell architecture, all non-overlapping channels are used in the network leaving no extra channels for future expansions.

   The capacity and throughput advantages of channel layering with Virtual Cell, compared to microcell, are evident in the signal-to-noise ratios (SNR) that each technology creates across a deployment. Higher SNR leads to higher capacity, by allowing faster data rates to be used. Low SNR forces the Wi-Fi radios to fall back to the lowest data rates (6Mbps for 802.11a or 802.11g).

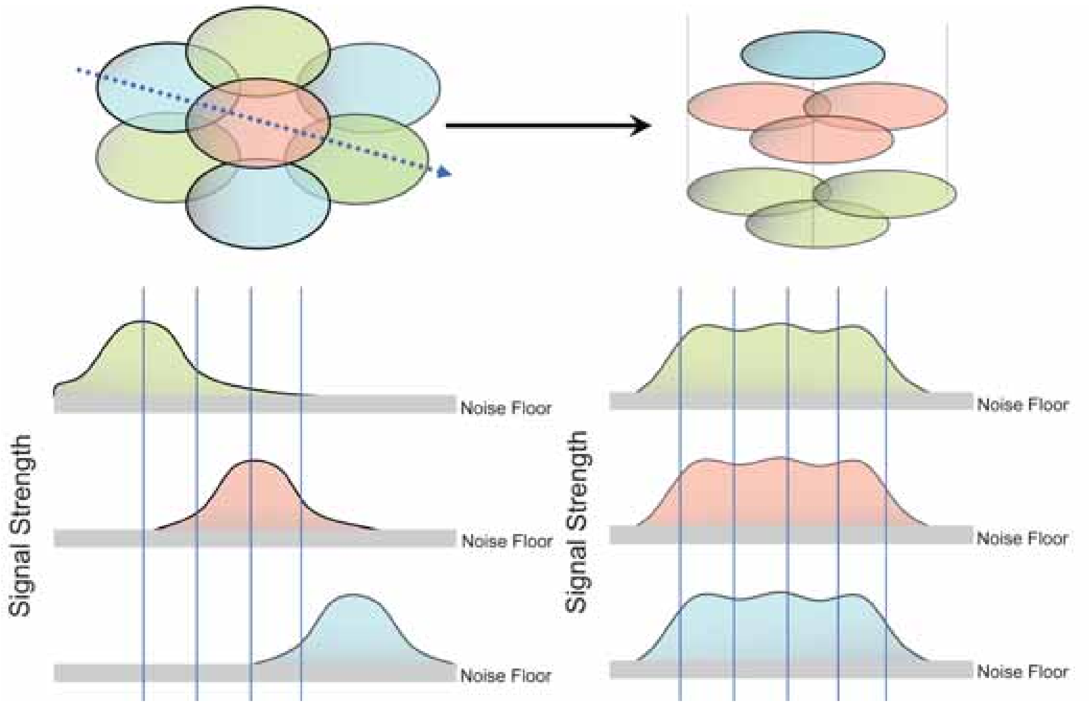


Figure 9 - Signal to Noise Ratios: Microcell (left) and Layered Virtual Cells (right)

In a microcell architecture, hexagonal tiling only provides one channel of good coverage at any given point. Consequently, there can be only one high-SNR AP at any area of the deployment, and many areas that see only low SNR. Whereas, in a layered virtual cell approach, high SNR can be maintained across the entire deployment. The microcell deployment wastes 2/3 of the available capacity to avoid inter-cell overlap. Virtual Cell eliminates this issue by allowing the network to use all the available channels and boost signal quality throughout the coverage area.

4. <u>Effective Load Balancing</u>
As the controller decides which AP speaks to which client—the network is free to choose the best AP to transmit to and receive traffic from the client. In a microcell architecture, the client must choose among all of the APs it can hear, to find one that can handle its load. Unfortunately, clients are unable to gather enough information from these APs to actually know which one can bear the load. Even with load advertisements from each AP and admission control—all a part of the WMM quality-of-service standard—as well as proposed extensions from 802.11k and 802.11v, the industry is still searching for any solution that can work in the case of overlapping cells on a single channel. In other words, the best legacy microcell algorithms today cannot solve the channel overlap problem, and yet, channels always overlap. In contrast, with Virtual Cell, the network knows the resource capacity available on each channel and AP, and using the only fully standards-compliant mechanism available in the industry, the network ensures that the AP with the most available capacity serves the client.

5. <u>Improved Multi-path Performance</u>
Attenuation and signal-to-noise ratios are not the only measures of signal quality. Multi-path effects, or RF echo arising from the bouncing and scattering of multiple versions of the signal off of different objects in the building can cause intense signal distortion. The higher the signal distortion, the more packet loss each station sees, and the lower the rate adaptation algorithm on the station, forcing it to drop the transmit data rate (from 54Mbps downwards) to accommodate.

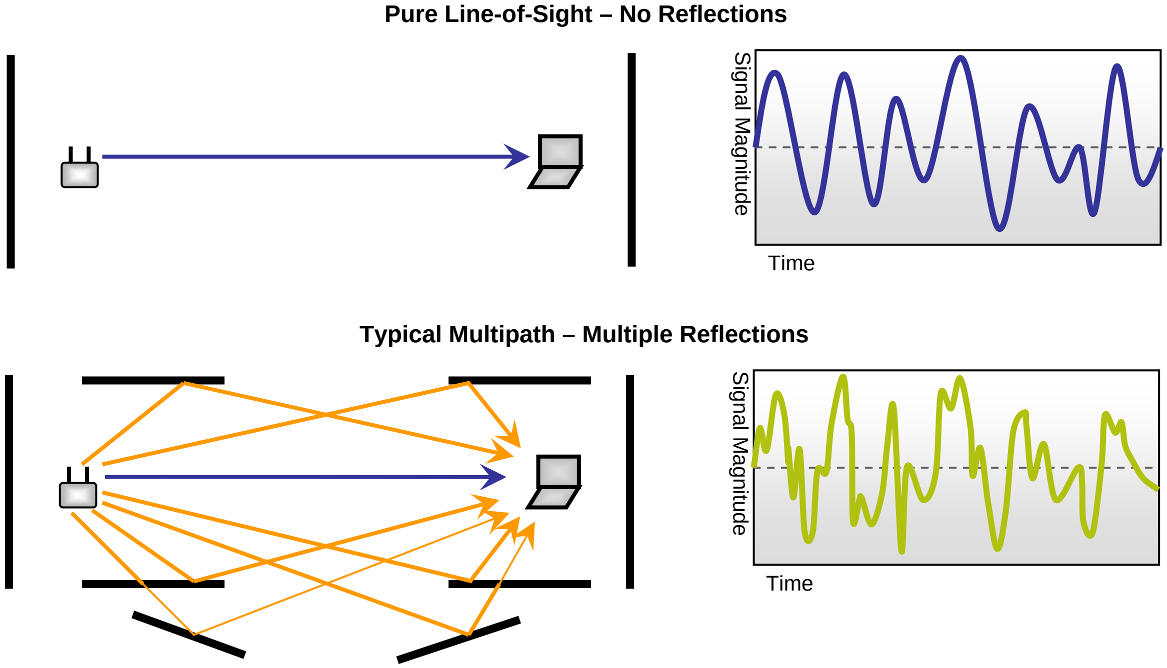


Figure 10 - Multipath Distorts Signal, Even Without Dropping Signal Strength

With Virtual Cell, the network can choose the AP that will always sustain the highest data rates for that client. And by possessing global knowledge about the RF topology, rather than just the localized view that any individual client sees, the network can adapt this decision in real time.

6. Power Savings
   Reducing the power level of wireless devices is tricky—it requires a tradeoff between reduction in battery consumption on each transmission (by transmitting at a higher power) and re-transmition in case of signal loss due to interference. However, no matter what the power setting, legacy microcell deployments require mobile devices to undergo frequent 802.11 handoffs. Furthermore, because of the lack of network control over the client's AP, legacy microcell deployments often stick the client onto cells with lower data rates (the sticky client problem).

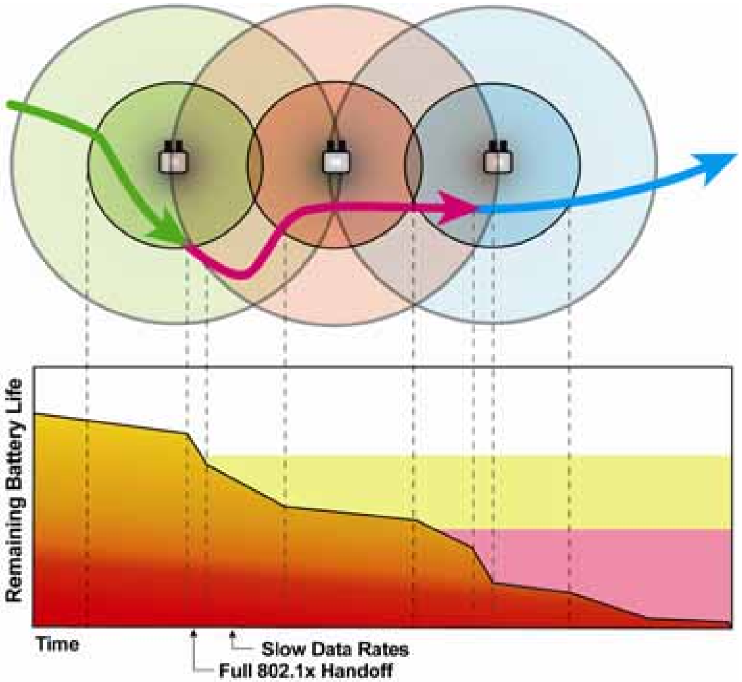


Figure 11 - Power Drops Significantly During Repeated Microcell Events

Lower data rates mean longer transmission times for the client. A 6Mbps transmission rate requires the wireless device to transmit for up to ten times longer than a 54Mbps packet, which translates into as little as one tenth the battery life. Furthermore, full 802.11i handoffs (as seen with WPA or WPA2 networks) require the exchange of up to 20 additional packets on every handoff, and often require that the client exit power save mode to complete the handoff as quickly as possible. For legacy microcell deployments, the more mobile the device is, the more rapidly the battery loses power.

Virtual Cell eliminates both the sticky client and handoff problems, allowing the client to always speak to the AP that provides the highest data rates without requiring the overhead of an 802.11 handoff.

Intra- and Inter-Cell Coordination in the Air Traffic Control Architecture

The key to Air Traffic Control is the concept of coordination, both within a cell and across other cells in the network. The microcell architecture creates individual islands of coverage. Although, together they belong to the same network, and often even to the same wireless controller, each individual microcell operates as a fully autonomous unit at the RF and MAC (medium access control) layer. Think of it as a managed wireless Ethernet hub. A microcell AP generally has no ability to take into account the effects of its neighboring APs, in real time. The controller can change channels or set power levels to manage RF load but it sometimes results in a rippling effect throughout the network. The Air Traffic Control architecture is capable of coordinating all of the individual clients' data streams. Traffic coordination algorithms allow the Air Traffic Controlled AP to ensure independent service fidelity for each client accessing the network. The ultimate objective here is client separation, similar to the way Ethernet switches perform.

Each AP is coordinated, to ensure that the most accurate resource availability is known across every point in the network. Furthermore, the coordination extends across APs and traffic classes, ensuring that the maximum amount of resources are available for voice or mobility applications while ensuring that data applications proceed in a fair and predictable manner. The result is no sacrifice in the network's ability to handle high density data, even when mixed with voice.

Airtime Fairness and Density Control

Wireless LAN's biggest benefit is also its biggest weakness—the signal goes everywhere. The wireless medium is and will always be a shared medium, much like a hub. Thus, the traffic generated by one client can have a profound impact on the others, at the very basics of channel access (such as the contention-based binary-exponential backoff algorithm that is part of the CSMA/CA used by 802.11). Legacy microcell deployments, using basic scheduling and traffic control implementations, must accept this phenomenon. The result is that these systems are unable to maintain any notion of fairness across clients, and even between downstream and upstream channel access for the same client. Here, the key metric is airtime used. To prevent one client from dominating, the network must be built so that each client is apportioned a fair amount of airtime, which it is then free to use however it wishes. The reason why airtime is important is that the amount of air time taken by a packet is entirely dependant on its data rate. Faster packets (54Mbps) clearly take less time than slower ones (6Mbps). Thus, a client can take more than its fair share of air time—eating into the resources of its neighbors—simply by reducing its data rate and transmitting the same number of packets.

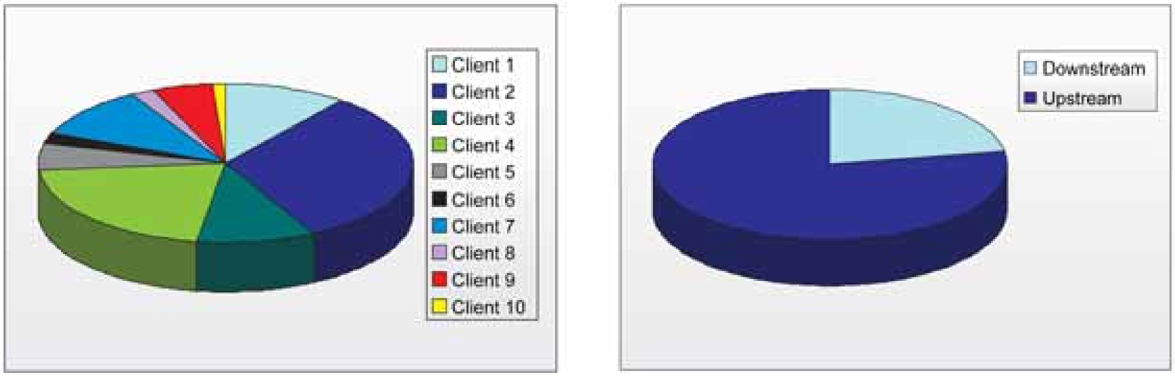
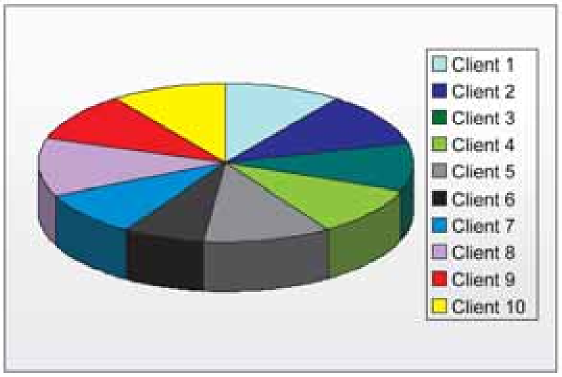


Figure 12 - Microcell Airtime Unfairness: Some Clients Dominate

Meru APs are able to offer air time fairness. Slower clients—those with lower data rates—are unable to dominate the air. As a result, one client is not able to generally interfere with the service of another.



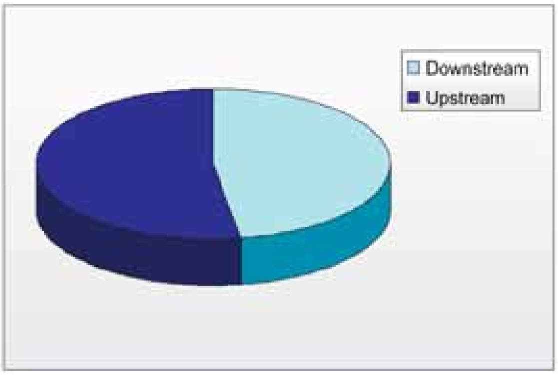


Figure 13 - Air Traffic Control Airtime Fairness

Density Control

As the number of clients accessing a legacy microcell AP increases, each client begins to interfere with its neighbor. The amount of overhead quickly dominates the available throughput for the cell, and the capacity drops dramatically. For example, the typical 22Mbps throughout of an 802.11g cell can drop to the kilobits-per-second range, bringing the network to a nearly-complete stop. This problem is evident in high density environments like auditoriums and conference rooms or briefing centers where the network capacity can't be pre-determined and varies considerably. Air Traffic Control overcomes this problem by intelligently controlling each AP's channel access, ensuring that overhead does not dominate the network and freeing up all of the remaining bandwidth to be returned to each client.

Quality of Service

Quality of Service is important for any WLAN irrespective of the type of applications being run. It is especially critical for voice, video, and mobility-based applications such as recording data while moving. The industry's WMM specification (based on 802.11e) allows traffic to be sorted into classes—best-effort, background, video, and voice—and allows for one class of traffic to be prioritized over another. WMM provides a number of useful mechanisms for providing quality of service. However, implementing WMM does not guarantee quality of service. Because it only provides prioritization, using WMM by itself will only ensure that a voice call is generally better in quality running on the "voice" class, rather than the "best effort" class. It does nothing to actually ensure that the "voice" class gets a high absolute quality of service, and in fact, is unable to provide that quality of service under moderate load, even in a mixed voice-data network. This is called relativistic quality of service. Air Traffic Control takes WMM, and adds to it the notion of deterministic quality of service. Deterministic quality of service ensures a predictable high quality of service irrespective of the amount of load on the network. This determinism is reached by both a more intelligent admission controller, which prevents network overload by providing a busy signal to phone calls in excess of the available capacity. But, more importantly, determinism is reached by coordinating the voice and data traffic within the network, preventing either voice and data, or both, from interfering with each other. This guarantees the quality of every admitted call.

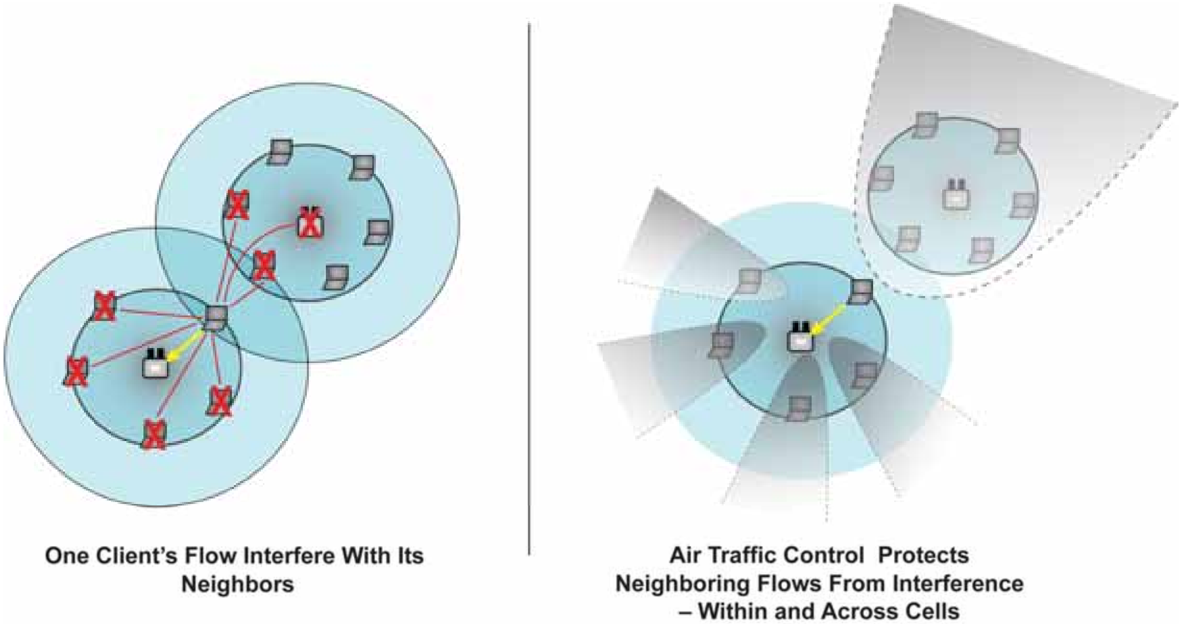


Figure 14 - Air Traffic Control Solves Co-Channel Interference

Air Traffic Control also addresses the issues caused by overlapping cells with Frequency Reuse

Air Traffic Control is able to take advantage of frequency reuse and has the ability to deploy networks with channel spans. With the ability to operate an entire network on a single channel, Air Traffic Control frees up the other channels completely. This allows the other channels to be deployed with their own channel spans. In a microcell deployment, all non-overlapping channels are used and future expansions are only possible by further and further reducing the size of the cell, resulting in increased problems as mentioned above. With intelligent spatial reuse built into Air Traffic Control, not only does the network have three times more capacity to begin with but also allows for capacity increase without having to redesign the network or add more cables for extra APs.

Penalty-Free, No-Compromise Deployments

Meru's Air Traffic Control Architecture provides penalty-free deployments.

These penalties are not the only ones that legacy microcells create. Typical legacy deployments follow the same iterative model. First, an expensive and inaccurate wireless site survey is performed. Second, the equipment is procured and wires are pulled according to the locations specified in the site survey. Third, the equipment is installed and the controller chooses a set of channels and power levels. Fourth, the network quickly hits its constraints. Either coverage holes exist, or worse, areas of high signal strength but low throughput are found. To solve this, more APs are deployed. However, each AP now interferes with its neighbors, and the system reduces power levels and reconfigures channels. The problems emerge: the reconfiguration here to support added throughput causes power levels to drop and channels to change elsewhere, resulting in coverage holes, or worse, areas of high signal strength with low throughput. The cycle repeats. Each AP installation, cable pull, truck roll, and support call takes its toll, and the operational expense of the network begins to far exceed the initial capital expense. The end result is caused by the legacy microcell deployment's fundamental inability to deal effectively with the issues of channel overlap.

Air Traffic Control, in contrast, is the only enterprise-class solution that deterministically breaks this cycle by taking advantage of the channel overlap instead of paying a price for it. Instead of an expensive and inaccurate RF site survey, a basic coverage plan may be performed, using a rule of thumb distance between APs, depending on the target minimum data rate and building materials. Finally cables are pulled and APs are installed. Should the RF environment change or more capacity is required, APs can be added without changing the existing network design and this addition will not cause the action-at-a-distance pain that is inherent with legacy microcells.

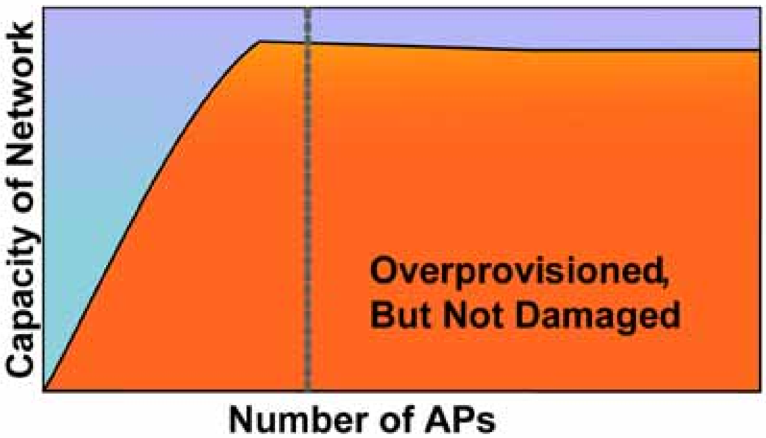


Figure 15 – Air Traffic Control Is Not Subject To Negative Returns

Microcell based wireless LAN solutions limit the returns available because they force IT and users to accept several major tradeoffs that inhibit the organization's ability to assure application delivery; maximize performance and scalability; and minimize the total cost of ownership.

Meru's Air Traffic Control technology, provides the foundation for what the Gartner Group has identified as the industry' s visionary 4th generation WLAN solution enabling companies to fully take advantage of the applications and devices that make them more competitive. The differences over legacy solutions are clear: application delivery is assured; performance and capacity are maximized; and deployment complexity and operations costs are minimized. The key to a more competitive and mobile world is here: enterprise mobility without compromise, only from Meru.