An Evaluation of In-Building Wireless Coverage

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900 East Hamilton Avenue • Suite 230 • San Jose • California • 95008 • **t** 408.583.0011 • **f** 408.583.0031

www.infonetics.com • Silicon Valley, **CA** • Boston, **MA** • London, **UK**

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I. The Rise of Mobile Data and Smartphone Use

Mobile phones have been a global phenomenon for over a decade now, with worldwide mobile subscribers now over 2 billion. In developed countries, 3G networks started widespread rollout several years ago, offering broadband-like speeds of 1M and above to the handset. Though cellular data services are still largely based on simple communications such as e-mail or SMS, 3G adoption is increasingly driven by the need for high speed data, for instance using a 3G network card inserted into a laptop.

According to the January 2007 edition of our biannual *Mobile and WiFi Phones and Subscribers* worldwide market share and forecast service, total mobile service subscribers reached 2.5B in 2006, with 7% of these being 3G subscribers. The total figure is forecast to reach 3.6B by 2010, with 11% being 3G users. In developed markets such as North America, Western Europe and parts of Asia-Pacific such as Japan, South Korea and Hong Kong the proportion of 3G users is much higher.

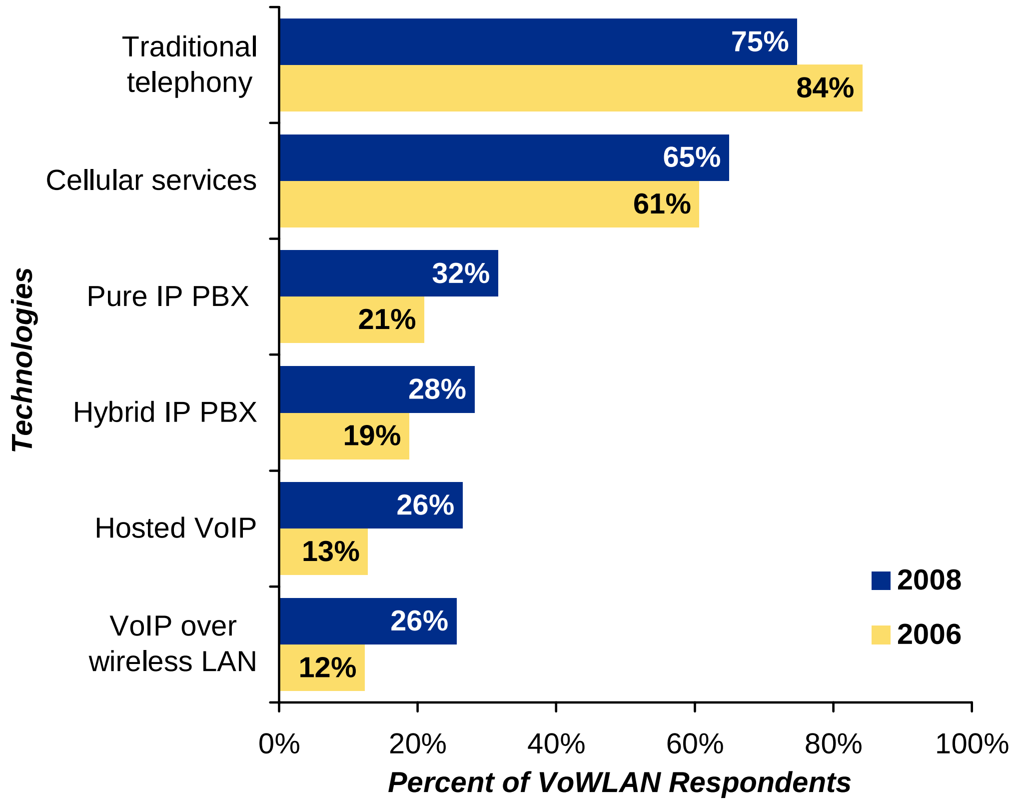
3G adoption is being increasingly driven by the need for high speed data—using a 3G network card inserted into a laptop, for instance—as well as new content-rich multimedia services, including high quality streaming video, fast downloads of high resolution images and other large files, and interactive services and applications such as advanced gaming.

In many organizations, mobile phones, smartphones, and other cellular devices are becoming primary communication devices—employees move around throughout the day attending meetings, and large organizations often host visiting customers or employees. In our study published in October 2006, *User Plans for Wireless LANs and Mobility: North America 2006*, we interviewed 240 IT and network managers from small, medium, and large organizations across a range of vertical sectors about their use of wireless technologies and mobile services.

Exhibit 1 below shows that cellular is the most popular voice call technology, second only to desk-based land-line phones (which decline in usage from 2006 to

2008), with the percentage of organizations using cellular services rising to 65% by 2008. Employees need to be constantly connected while they are mobile, but lack of coverage impedes cellular phone use.

Exhibit 1 **Voice Technologies Used**



Source: *User Plans for Wireless LANs and Mobility: North America 2006, Infonetics Research*

II. Why In-Building Coverage is Essential

Mobile connections rely on coverage from macrocells, which are deployed on masts or high buildings to provide coverage to an area of several kilometers. When a mobile subscriber is inside a building, however, building materials such as concrete and steel attenuate (weaken) cellular signals—although coverage from the macrocell does penetrate the building, the signal strength is reduced and can be nonexistent in some areas.

In many locations within a building, the cellular signal quality may also be degraded because of conflicting signals from multiple macrocells. (This can be especially problematic in high-rise buildings.) In addition, because macrocells provide coverage for a wide area that may house numerous high user-density buildings, there could be capacity limitations in any given building due to demand from other users in the area. This can lead to longer call setup times, and calls being blocked or even dropped altogether.

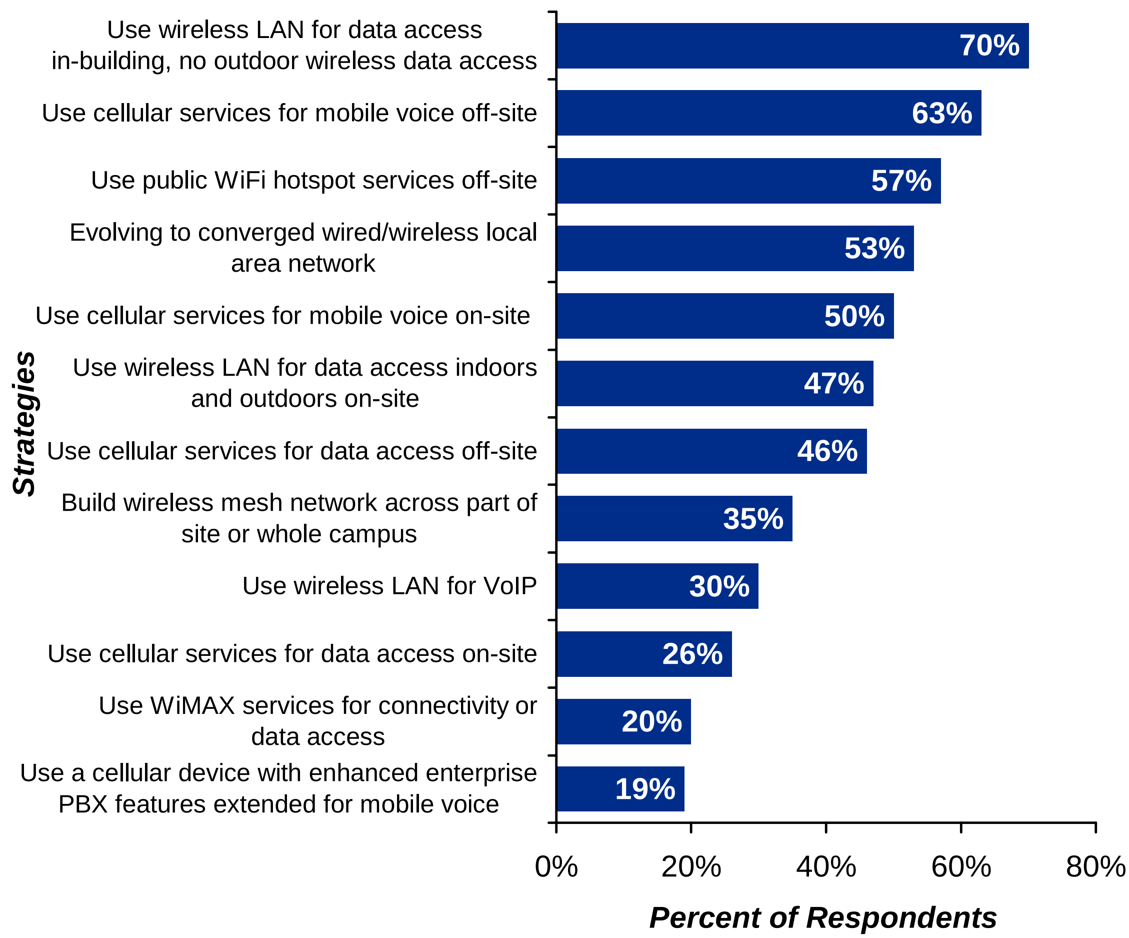
Mobile operators are investing significantly on network upgrades for 3G services. In the 4Q06 edition of our *Radio Access Network Equipment and Subscribers* quarterly worldwide market share and forecast service, we tracked the W-CDMA radio access network equipment market—including NodeBs and radio network controllers at $8.3B in 2006, rising to $12.2B by 2010.

Unless mobile operators reinforce macrocellular investment with an effective in-building coverage strategy, they will inhibit their opportunities to grow their 3G subscriber base and generate next-generation service revenue for high speed services. Rising deployment of 3G-based data services will require wireless operators to boost coverage in large commercial and multi-tenant buildings because of the need to provide low latency, high speed access networks for 3G services.

In addition, sole-tenant enterprises and multi-tenant building owners are increasingly choosing to deploy their own in-building coverage solutions to facilitate employee or tenant communications.

In *User Plans for Wireless LANs and Mobility: North America 2006,* we asked survey respondents to choose from a series of possible mobility strategies those that describe the approaches their organization is taking. Exhibit 2 below shows that using cellular services for mobile voice on-site is rated by 50%. Using cellular services for data on-site, a strategy for 26%, is likely to grow over the next few years, driven by the desire to carry a single device for both voice and data as far as possible.

Exhibit 2 **Mobility Strategy**



Source: *User Plans for Wireless LANs and Mobility: North America 2006, Infonetics Research*

3G services are not necessarily voice-oriented, and as such tend to be used in a pedestrian or stationary mode (users, though wireless, are mostly static). This reinforces the need for pervasive coverage, as the user does not want to have to move around to achieve a reliable connection to the network.

In-building coverage is crucial to user acceptance of 3G services, because a high proportion of cellular traffic originates from inside buildings. Despite many cellular users being frustrated with less-than-perfect coverage inside buildings, more and more people continue to choose cellular as their sole form of telecommunication.

This creates a quality of service need, because simply providing coverage in itself is not enough—the coverage must deliver high performance in terms of capacity and consistency, not just availability.

III. In-Building Coverage Challenges

Macrocellular radio signals attenuate as they pass through the fabric of a building, resulting in dead zones, where there is no coverage at all or only intermittent coverage, so the primary challenge is to provide consistent, robust signal strength throughout the building to maximize the performance of handsets and devices attached to the network.

To achieve this, there are several key considerations. It is necessary to determine exactly where the coverage is weak—it may be in several isolated areas or across the building or campus. Also, interference can be a significant problem, often caused by electronic instruments located within the building. Not all in-building wireless systems offer control over the amount of radio energy delivered at each internal antenna; however, some can control this energy, limiting interference and loss of signal strength.

The first step is to do a professional site survey, identifying coverage deficiencies, determining the impact of outside interference, and outlining the amount and type of equipment needed to establish a robust link budget (measurement of the quality of the network connection) throughout the building.

Technical choices for in-building systems range from a simple band-aid that will fix a coverage issue in a specific area, to a complete, campus-wide, multi-technology architecture. Aside from technical considerations, deployment of in-building wireless coverage can be disruptive and expensive, depending on the choice of system. Systems vary in their scalability (a consideration if future expansion is planned)—some may not be flexible when it comes to being upgraded to enable future services to be delivered. Some only need upgrades to centralized electronics, and others require fundamental alterations to antennas.

While indoor coverage is a challenge for all cellular services, supporting pervasive 3G services indoors is even more challenging. Most 3G services, such as HSDPA and EV-DO, are currently being offered in higher frequencies, so operators can re-utilize the lower, cellular frequencies to support high-QAM W-CDMA based protocols. Also, newly available spectrum is mostly in higher frequencies, with the trend being a shift from 800/900Mhz to 1800/1900 to 2100Mhz. These higher frequencies are more easily attenuated by building materials. This can be a greater challenge for multi-level buildings, and it is not feasible—or sometimes legal—for operators to simply ratchet up the power to overcome signal dissipation.

Fundamentally, there is a need for a better link budget to support data applications. (The link budget represents the relationship between power transmitted and signal strength, and is reduced as the data rate goes up.) HSDPA in particular suffers from poor in-building penetration, and brings an additional challenge for coverage, namely the reduction of the link budget.

Finally, it is increasingly important that improving cell phone coverage in an office complex is achieved with an appropriate commercial arrangement for the mobile operator and the user organization. Several business models exist specifying which party bears the cost of that infrastructure:

- Operator pays: the operator will deploy an in-building solution in exchange for a commitment of *x* number of handsets for *x* number of years; this is by far the most common arrangement
- Shared cost #1: the operator and user organization share the costs of the solution; the user organization allows access to its existing in-building cable infrastructure (fiber, for instance), and the operator pays for the system hardware and the RF source
- Shared cost #2: if the user organization is unwilling or unable to commit to the necessary number of handsets required for the operator to pay for the entire solution, the user organization could pay for a portion of it
- User organization pays: if the user organization requires a solution for multiple operators, it will generally have to bear the costs of the entire solution

IV. High-Level Technology Comparison

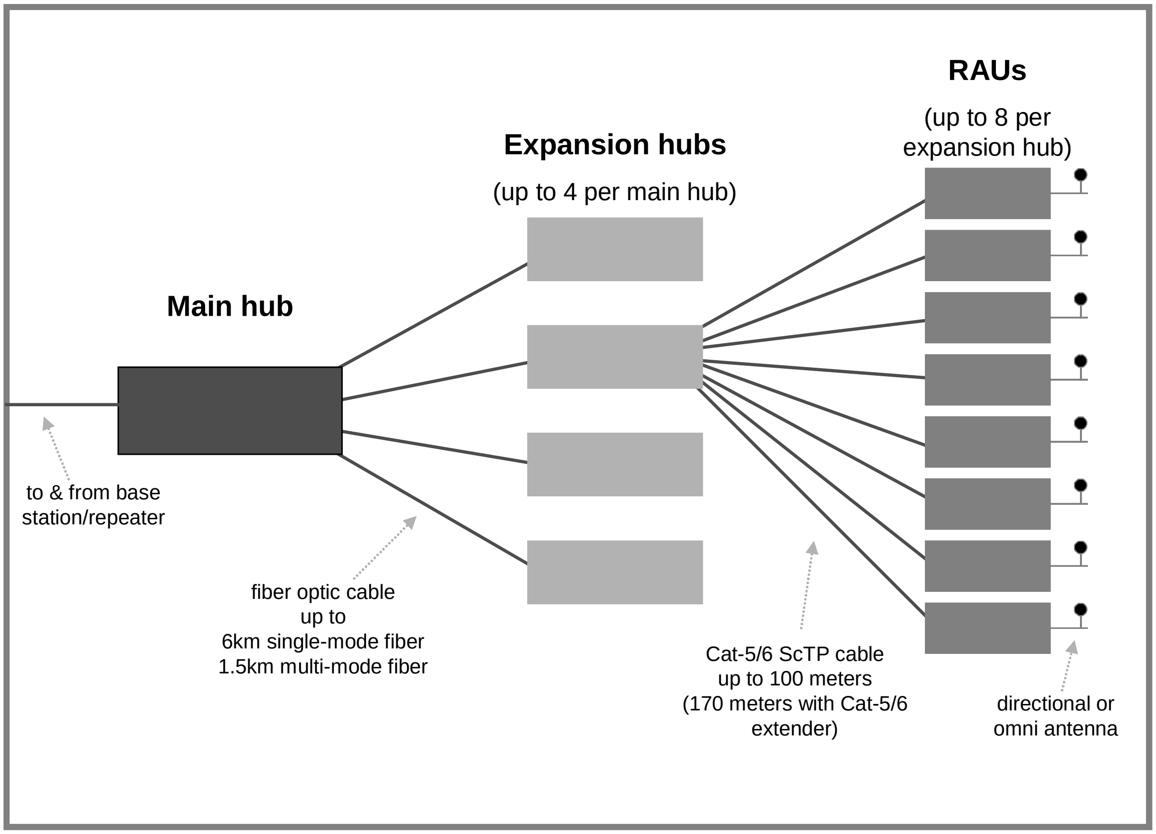
A. Active and Passive Distributed Antenna Systems

Distributed antenna systems (DASs) have one primary advantage in that they are based on technology that is proven as scalable: the mobile network itself. These systems operate by using one centralized radio source—and extending its signal to multiple antennas deployed at specific points within a building.

Some DASs use large coaxial cable to distribute the signal through a facility. These systems are considered passive because they do not use managed electronics in the distribution network. They are generally used for small coverage applications where the length of a coaxial cable run is not an issue. Length is an issue because the signal in a passive system attenuates over longer cable runs, leading to inconsistent signal strength and making system engineering difficult. Each antenna's coverage area will vary depending on the length of coax to which it is attached, which could mean that the whole system will need re-engineering if more capacity or coverage areas are added. In addition, passive DAS is often expensive and time-consuming to install because of the specialist requirements of installing heavy coaxial cable.

Active distributed antenna systems use Cat-5/CATV and fiber cabling and combine active electronic hubs, fiber optics, and active radio access units to distribute the signal from a single, centrally located radio source, as shown in Exhibit 3 below.

Exhibit 3 **Active Distributed Antenna System**



Because the signal does not degrade, it has the same strength at every antenna point, regardless of the distance from the central radio. Since every antenna is simply an extension of the centralized radio source, there is no interference among antennas and no limit on the number of antennas that can be deployed within a building, or where they can be located. The signal consistency means there is no need to traffic engineer the system at the individual antenna level to deliver pervasive coverage for high user-density areas.

Some active DAS systems support optimum signal strength throughout the interiors of buildings that span hundreds of thousands of square feet. To increase capacity, additional radios can be added to the macro base station. DAS antennas themselves are relatively small and inexpensive, and can deliver maximum output power to support voice and high speed data. Also, active DAS uses standard cabling to connect hubs to RAUs and remote antennas, reducing deployment costs and time when compared with passive DAS—unlike passive systems that require specialized cable installation, regular IT staff can easily roll out the infrastructure with commonly used wiring.

Sizing is another criterion for delivering effective in-building wireless coverage; the size of the building, the capacity of the base stations (number of radio channels), the number of services (cellular operators, WiFi, WiMAX, public safety, etc.), and the quality of the signal—the average signal strength throughout the building—must all be factored in.

Historically, in-building wireless systems were deployed using large half-inch coaxial cables. Because RF signals attenuate as they pass through the cable, the longer the coax run, the weaker the signal coming from the antenna. Though it is possible improve the performance of passive cable to an extent by using a larger diameter cable, this is often impractical.

Adding active amplifiers in the system boosts the signal in both directions. Placing the amplifier next to the antenna has been imperative, due to:

- The introduction of services at higher frequencies, particularly AWS spectrum in North America and UMTS in Europe and Asia
- Data-specific protocols like HSDPA and EV-DO, which require a much more robust link budget to deliver their advertised data rates

However, placing an amplifier behind 150 meters of coax has significant impact on HSDPA being delivered in the UMTS (2.1GHz) band, so the ultimate iteration of active system technology places the amplifiers at the end of Ethernet type cabling (fiber and Cat-5) so cable attenuation essentially disappears as an issue.

A middle ground solution also exists—hybrid fiber / coax systems. These systems offer some of the advantages of active systems (and are generally classified as active systems because they use electronics), in that they have a fiber link (connecting the head-end unit with the remote unit), which provides good performance and extra reach.

Conversely, hybrid fiber / coax systems still have many of the drawbacks of passive systems, because they use coax cabling to distribute the RF signal from their remote units (generally placed in wiring closets) to the antennas in the ceilings. This means that the final amplifier in the system is located some distance from the antenna point, and the coax used to get to that antenna introduces performance issues such as signal loss and uplink noise.

Both active and passive DAS can support multiple carriers in a single antenna system, with a straightforward centralized or hub electronics upgrade required to support new carriers or services. Deployment of multi-carrier distributed antenna systems is being driven by the need for dual 2G/3G support, multi-tenant and enterprise demands, so it is an increasingly important capability to support.

Historically, passive DAS systems based on RF over coaxial cable dominated the market, but this has changed rapidly. Now, active systems using RF over fiber and Cat-5/CATV cable are leading the market because they offer a more economical, better performing alternative, and are also much more flexible in terms of meeting future needs, such as more operators, more channels, high bandwidth for data applications, etc.

B. Picocells and Femtocells

Picocells are a small form factor base transceiver station with a range of several hundred feet that can be deployed to create in-building cellular coverage where macrocell signal strength is insufficient to support high user-density. IP-based picocells support a flat 3G network architecture by integrating multiple network elements—including radio network controller functions—into a single device. To increase in-building system capacity with picocells, it may be necessary to add more radio resources at every picocell location in the building to support more users—a costly and time-consuming undertaking.

Femtocells are smaller home base stations that allow wireless users to communicate across any IP access network using a standard mobile handset. Some of the potential benefits of using femtocells for indoor coverage include: the ability to provide capacity that scales in line with subscriber demand, a reduced requirement to deploy additional macrocells to support indoor users, and an operational expenditure requirement that is kept in check by IP backhaul paid for by the customer.

To provide adequate coverage in large buildings, it might be necessary to use multiple picocells or femtocells. However, because each cell uses the same frequency, a large area within the building will receive multiple picocell or femtocell signals with similar signal strengths, causing local interference issues and prohibiting high data rates.

Each picocell or femtocell requires backhaul connectivity. Femtocells enable mobile operators to route traffic through the IP network and significantly reduce opex requirements for backhaul, and at the same time reduce the load on the BSC or RNC—susceptible failure points in the mobile access network. However, the location of a picocell or femtocell may be determined by the need for backhaul connectivity for each cell, and may not be the optimal location to provide the best coverage. In contrast, DAS installations place the radio source in a convenient location for backhaul—typically the communications room or data center—and the antennas may be placed as needed for optimum coverage.

The management of multiple small radio base stations in a network could create interference issues with the macro network, and this problem is not helped by the fact that femtocells are currently proprietary.

Both technical and economic challenges must be overcome before femtocells can be widely deployed. On the radio access side, equipment suppliers still need to prove that these devices can coexist with the macro network without negatively affecting its performance. Integration with core network infrastructure is also critical, yet there is uncertainty about how best to achieve this

In summary, picocells and femtocells are:

- Newer technologies that reduce the complexity of the components that need to be installed
- Architected for small spaces like homes or small offices, not for large enterprise buildings or campuses
- Single band, single operator
- Not really scalable building blocks

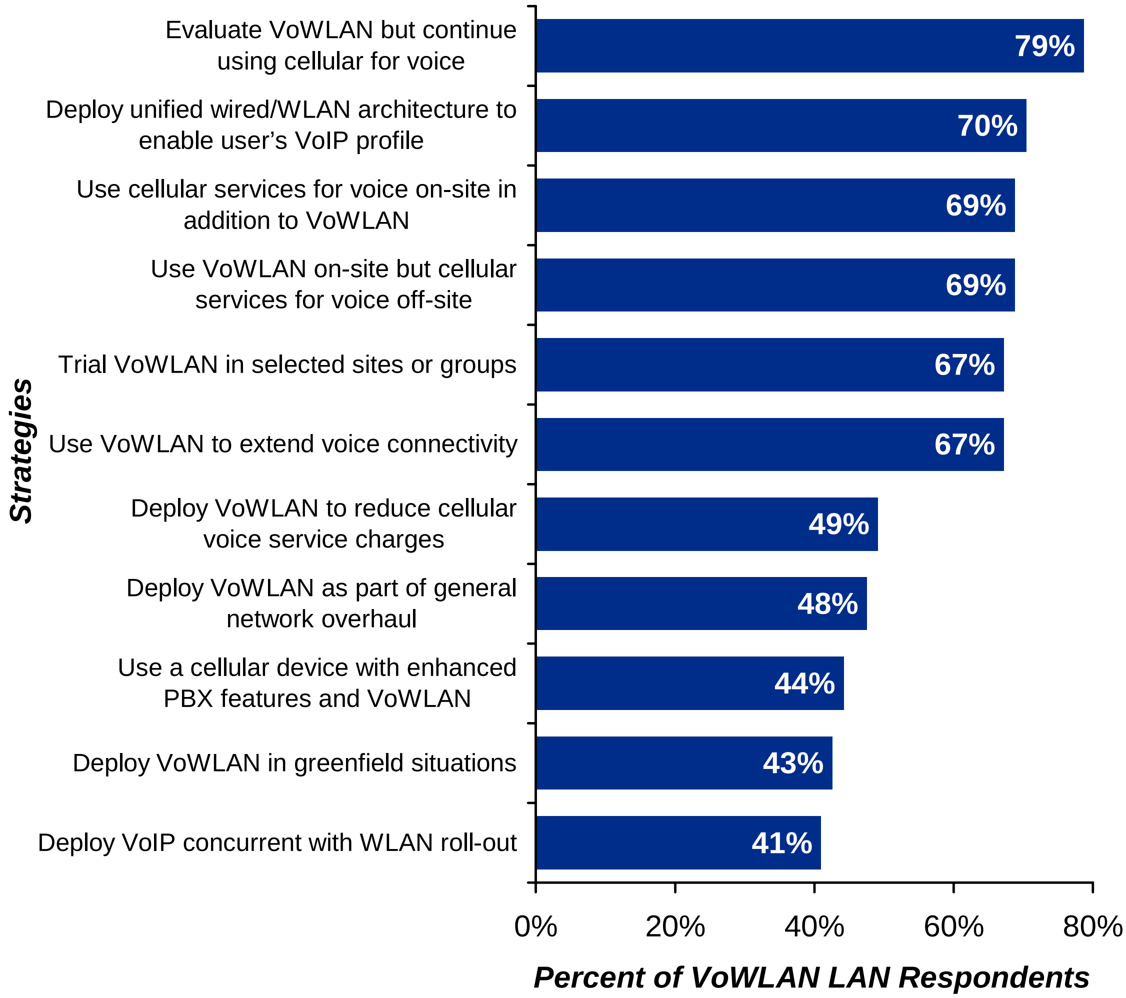
In the future, it is highly likely that picocells will be used in combination with DAS systems to cover larger venues

C. Voice over IP over Wireless LAN

VoIP is an increasingly significant application driver for wireless LAN adoption, as voice capability cements the case for mobile networking; the reverse is also true: voice becomes a more powerful tool when enabled across a wireless platform, and this potential symbiosis has generated much interest and activity in the VoIP over wireless LAN (VoWLAN) space, with IP PBX, wireless LAN infrastructure, and IP handset vendors all pitching in to build out the wireless VoIP ecosystem.

In *User Plans for Wireless LANs and Mobility: North America 2006,* we asked survey respondents intending to deploy voice over wireless LAN (VoWLAN) to choose among a list of strategies the ones that best describe their approach to VoIP over their wireless LAN. Exhibit 4 shows that the top two responses are cautious: evaluate it but continue using cellular, or eventually deploy it to replicate the user's VoIP profile across both the wired or wireless LAN. Many respondents still regard VoIP as a future technology, an attractive idea but not ready for prime time—and in the meantime cellular, albeit more expensive (in terms of "air-time" charges), works fine. (Please see chart, next page.)

Exhibit 4 **Strategy for VoIP over WLAN**



Source: *User Plans for Wireless LANs & Mobility, North America 2006, Infonetics Research*

It is worth noting that VoWLAN is not free of charge (though many organizations perceive it to be), as it incurs significant deployment and management costs. In addition, VoWLAN requires the replacement of the handset, either with a single-mode WiFi-only device, or a dual-mode WiFi/cellular handset. Neither of these are cheap options, particularly when having to supply many hundreds of employees with new phones.

Upgrading an existing data-centric WLAN infrastructure to support voice requires four to five times as many access points as originally deployed, significantly impacting total cost of ownership for wireless VoIP.

On the handset side, user organizations have two choices for in-building wireless VoIP:

- Single mode WiFi-only phones; this means keeping cellular phones for wide area communication, which in turn means employees have to carry two phones
- Dual-mode WiFi/cellular phones: these are currently very expensive with limited handset choices, and it is unclear when volumes will be sufficient to drive costs down to parity with mobile phone prices

End-user organizations certainly question whether or not WLAN architectures are ready to fully support VoIP, which is not what they were designed for. VoWLAN is not standardized. Also, VoWLAN has not proven that it has overcome the scalability challenges of only supporting a dozen or so users per access point, and though protocols are being developed, there is currently no QoS guarantee, so calls are subject to drop-out, and roaming does not always work seamlessly. Because 802.11 uses unlicensed spectrum, interference can be a problem and can be subject to contention issues if there are multiple users or networks—or microwave ovens—in the same vicinity.

VoWLAN represents two technologies—VoIP and WLAN—that are still maturing and converging. End-users are beginning to understand that they need a harmonious deployment of both technologies to leverage the full benefits of each. It is likely that the technical challenges faced by VoWLAN will be overcome in the future, but it is not yet a challenger to cellular as the primary mobile voice technology used by organizations today.

V. Integration of Multiple Technologies

Active DAS uses electronics to deliver wireless signals from an RF source through hubs in the campus communications center, and from there via fiber to expansion hubs in each building, which are linked via standard Cat-5/CATV cabling to the remote antennas. On a fundamental level, they represent a combination of wireless and wired technologies. The RF source could be a standard base station, a microcell, a repeater/BDA, or on some occasions a picocell.

But the technology integration can be taken farther. Some active DAS systems are a good example of how multiple technologies can be integrated to deliver improved in-building wireless coverage, because they support multi-frequency coverage—such as GSM and W-CDMA frequencies—and can be upgraded to improve capacity, coverage, or support future services without changing antenna placements. By supporting multiple frequencies in a single in-building system, building or facilities owners can support multiple carriers, and tenants retain a choice of service provider.

DAS can also be combined with picocells, leveraging the benefits of each, to provide an in-building solution that delivers the highest performance and lowest interference while minimizing network integration requirements. The active DAS system enables a higher load of the picocell by expanding its coverage area. If the building is modestly sized, and the macrocellular signal is not dominant within the building, a single standalone picocell base station would be adequate to provide pervasive coverage. However, buildings of several thousand square feet would require a higher output power of the pico base station, which could result in interference with macrocellular signals. Using an active DAS in combination with a picocell addresses this problem, because the DAS effectively distributes the picocell's radio signal throughout the facility without requiring higher output power.

VI. Public vs Private Mobile Networks

There are multiple markets for in-building wireless solutions, including private buildings and campuses, public buildings, and facilities such as subway stations. Mobile operators are leading efforts with building owners, suppliers, and enterprises to unlock the in-building market—a major strategic change from only a few years ago.

Providing in-building coverage is not just a technology issue but a business issue. Although the value proposition for improving in-building coverage for tenants is well understood, the revenue model for the mobile operator has not been as clear. Mobile operators often face an increasing tightening of their capital expenditures and must evaluate every potential installation from an ROI perspective. They may have different strategies for providing coverage to a particular building or facility, but all mobile operators base their evaluations on the same fundamental criteria—reducing risk of churn.

Generally, operators fund the equipment and installation costs in return for the promise of an extensive, extended service contract. The main thrust is to prevent a significant customer from going to a competitor, and therefore the ROI is analyzed against the cost of reacquiring that customer. However, operators will demand some type of monogamy, and will exclude other operators from deploying equipment for the duration of the contract.

By deploying capacity indoors, where it is most needed, mobile operators are in effect extending the public network into the private domain. They share or absorb the cost of deploying the in-building coverage system and retain responsibility for operations and maintenance. In the immediate term, they gain greater flexibility to introduce disruptive pricing and bundling strategies, allowing them to accelerate capture of wireline voice minutes and increase the number of subscribers and the revenue from the building tenants. Over the longer term, there is the opportunity to develop revenue from high speed 3G services, potentially selling upgraded mobile devices to the customer, and lock-in usage for outdoors also.

Multi-carrier coverage solutions allow for improved coverage within large buildings and across-campuses without tying the resident enterprise or organization to one particular cellular operator. For large public facilities such as airports or convention centers, there is a clear benefit for the operator in providing pervasive, multi-carrier in-building coverage—there is a constant flow of people, many of whom will use their mobile devices to communicate. This potentially generates significant revenue that is worth the investment. Usually such facilities are carrier-neutral, so in such circumstances an active DAS system is a logical solution.

When deployed appropriately, in-building coverage is more about providing for people, rather than physical space. By providing better coverage inside a building where there is high use density and thus high demand, the operator could be offsetting the need to boost coverage at the macro level, which would be a more expensive means of making provision for the high traffic volumes generated by a user base concentrated in a specific location.

In terms of owner-funded coverage systems, the building owner can offer a tangible amenity to tenants and / or employees while retaining full control over which carriers and services are offered.

VII. Conclusions

- Mobile phones are the most widely used wireless connection, and the number of applications is increasing rapidly; users are becoming more reliant on their mobile device, not just for voice, but for an increasing range of data applications; in addition, the value of voice over mobile has increased; high value individuals (corporate executives, doctors, technical specialists, etc.) need to remain in contact with their colleagues and maintain mobility

- In-building wireless coverage is often poor; macrocellular radio signals attenuate as they pass through the fabric of a building, resulting in dead zones, where there is no coverage at all or only intermittent coverage

- Despite the buzz about VoWLAN and dual-mode phones, cellular extension is still the main technology used to improve indoor mobile coverage

- Active and passive DAS can support multiple carriers in a single antenna system, with a straightforward centralized or hub electronics upgrade required to support new carriers or services

- Active distributed antenna systems, which use Cat-5 or fiber cabling, combine active electronic hubs, fiber optics, and active radio access units to distribute the signal from a single, centrally located radio source, and then propagate it through multiple remote antennas throughout the building; active systems offer clear advantages for larger buildings, campus environments and for the distribution of new, data-centric protocols such as EV-DO and HSDPA

- Picocells or femtocells can also improve in-building mobile coverage, but for larger buildings it might be necessary to use multiple picocells or femtocells; because each cell uses the same frequency, multiple cell signals with similar signal strengths will be produced, causing local interference issues and prohibiting high data rates; these are effective single-unit solutions, but they are not good building blocks for wide-area deployments

- DAS can be combined with picocells, leveraging the benefits of each, to provide an in-building solution that delivers the highest performance and lowest interference while minimizing network integration requirements; however, this may not be appropriate for all installations; mixing picocells does not work on passive DAS because picocells have insufficient power to effectively drive a passive DAS

- By enhancing in-building cellular performance, mobile operators can persuade some enterprises NOT to use VoIP over wireless LAN in the future

- The need to improve the quality and reliability of indoor voice and data connections will drive mobile operators to invest heavily in systems that boost wireless coverage within large commercial buildings and multi-tenant dwellings, to protect against churn by major customers

- Multi-carrier coverage solutions allow for improved coverage within large buildings and across-campuses without tying the resident enterprise or organization to one particular cellular operator

Appendix: References

- *Mobile and WiFi Phones and Subscribers* worldwide market share and forecast, Infonetics Research's biannual service tracking unit shipments and revenue for mobile phones, and single-mode (WiFi only) and dual-mode (WiFi/cellular) VoIP handsets, and mobile subscribers

- *User Plans for Wireless LANs and Mobility: North America 2006*, for which Infonetics Research interviewed 240 small, medium, and large organizations about their adoption plans for deploying wireless LANs by August 2006, published October 2006

- *Radio Access Network Equipment and Subscribers*, Infonetics Research's quarterly worldwide market share and forecast service tracking unit shipments and revenue for RAN equipment, including base transceiver stations, NodeBs, base station controllers, and radio network controllers

About Infonetics Research

Infonetics Research (www.infonetics.com) is the premier international market research and consulting firm specializing in data networking and telecom. We provide a complete view of the market through constant interaction with equipment manufacturers, service providers, end-users, chip and component manufacturers, sales channels, and the financial community. We offer quarterly market share and forecasting, end-user survey research, service provider survey research, and service provider capex analysis. We are respected in the industry for being objective and accurate and for delivering on time all the time.

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Contact Information

US Headquarters
900 East Hamilton Ave #230
Campbell, CA 95008
United States
t +1 408.583.0011
f +1 408.583.0031

Boston Metro Office
3 Baldwin Green Common #307
Woburn, MA 01801
United States
t +1 781.933.9649
f +1 781.933.9659

London Office
P.O. Box 672
Orpington, Kent BR6 6WS
United Kingdom
t + 44 1689.851.618
f + 44 1689.851.618

Sales

Larry Howard, Vice President
larry@infonetics.com
t +1 408.583.3335
f +1 408. 583.0031