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# The Future of In-Building Wireless

Wireless connectivity continues to make meaningful penetration into enterprise networks unlocking performance and transforming the way people work.

# Introduction

Wireless connectivity continues to make meaningful penetration into Enterprise networks. These wireless networks include: connectivity to the Internet via a local area network (wireless-LAN) and cell phone access (wireless-cellular) to the public switched telephone network (PSTN). In the past, these two wireless networks have been separate overlay networks. In the future wireless networks will converge to support both internet and cellular applications, unlocking performance improvements and cost savings. The primary reasons for this significant penetration of both of these in-building wireless applications include:

- The need for higher data rates (up to 10 Gbps) (video applications, teleconferencing, etc.)
- Increased mobility
  - » Proliferation of mobile devices (smart phones, tablets, laptops, watches, etc.)
  - » Adoption of Bring Your Own Device (BYOD) in offices, schools, and other environments (where typically the device has only wireless access)
- Lower cost network infrastructure for wireless systems
- Improved quality of service on the wireless networks
- Improved in-building coverage of wireless
- Ability to maintain a single wireless network to support cellular access, versus multiple vendor-specific DAS systems

Wireless-LAN and wireless-cellular in the enterprise were generally viewed as an overlay network in the past. It is now evolving to be an option as the primary access for voice and data within the facility. This growth of wireless in the enterprise market changes the in-building cabling needs, and changes the equipment needs in the telecommunication closets serving the facility.

This technical paper is intended to validate the following hypothesis:

- In-building wireless-LAN (Wi-Fi based) will continue to evolve and flourish in the enterprise market and grow faster than the base market
- In-building wireless-cellular (Wi-Fi based) will continue to take market share from both DAS and Small Cell, and will eventually dominate wireless access in the enterprise market.

# 1. Background on traditional in-building voice networks based on DAS

DAS (Distributed Antenna System) has been the primary technique for providing cellular access within buildings for the past few decades. DAS networks can be applied in outdoor environments, as well as within buildings. A DAS network replaces a centralized high power antenna serving the facility with a distribution of smaller power antennas covering the same area. This makes a better and more efficient system:

- Higher power efficiency (e.g., less path-loss, less feeder loss)
- Less noise (i.e., primarily from fading and shadowing)
- Higher capacity
- Better managed capacity in certain high density areas
- Better direct line of sight for the antenna’s RF path

The primary reason in-building systems like DAS are being deployed is due to poor cellular indoor coverage supplied by external cell towers. This poor indoor coverage arises due to the following reasons:

- The building acts like an RF shield, blocking the RF cellular signal from cell towers, caused primarily by highly tinted (Low-E) glass windows, and metallic indoor structures, like elevators and metal surfaces
- The building is blocked from cellular tower's signal by other buildings
- The cell tower is too far away (power decreases by the distance squared)
- The cellular service provider's radio frequency (i.e., building penetration is dependent on the carrier's frequency, for example a 700 MHz provider like Verizon will penetrate a building 4x better than a 1900 MHz provider like Sprint)

This applies to signals from all the various cellular service providers that are wanted within the building. Poor coverage within a building can be mitigated by distributing antennas throughout the building (e.g., DAS, small cell, or Wi-Fi), or by building cellular towers (from each service provider) closer to the building, which provides a stronger RF signal capable of penetrating the building.

For some time, DAS has been the most common method to improve coverage and service within a given area. However, newer, more advanced techniques provide better service at a lower cost. The following sections more closely examine DAS and these newer techniques and provide a comparison.

# 2. A comparison of cellular services within a building provided by DAS (passive or active), small cell, and Wi-Fi

There are several ways to bring wireless-cellular services into a building (other than traditional external-to-the-building cellular towers). They include DAS (both passive and active), small cell and Wi-Fi. Each will be subsequently addressed. For each of these techniques to be viable for inbuilding applications, they must provide the following features:

- Serve multiple cellular service providers (e.g., AT&T, Verizon, Sprint, etc.)
- Support emergency first responders
- Support E911
- Have a reasonable installation cost (both initial capital cost and yearly cost of maintenance)
- Can scale up services as needs grow and change
- Support future services

## 2.1 Passive and Active DAS Cellular Networks

Figure 2.1.1 describes a DAS system deployed within a building. Cellular service from multicarriers enters the facility into DAS head-end equipment, where the signals are combined and distributed throughout the building (commonly via coax cable) to an antenna that is appropriately positioned in the building. A single coax cable can support many antennas.

Fiber optic cable can reach remote parts of the building, where a remote active splitter distributes the RF signals to DAS antennas (typically via coax cables). The facility must support two types of emergency service communications: E911 services (provided via the cellular service provider), and first responder services, typically provided over a 700MHz RF external building antenna.

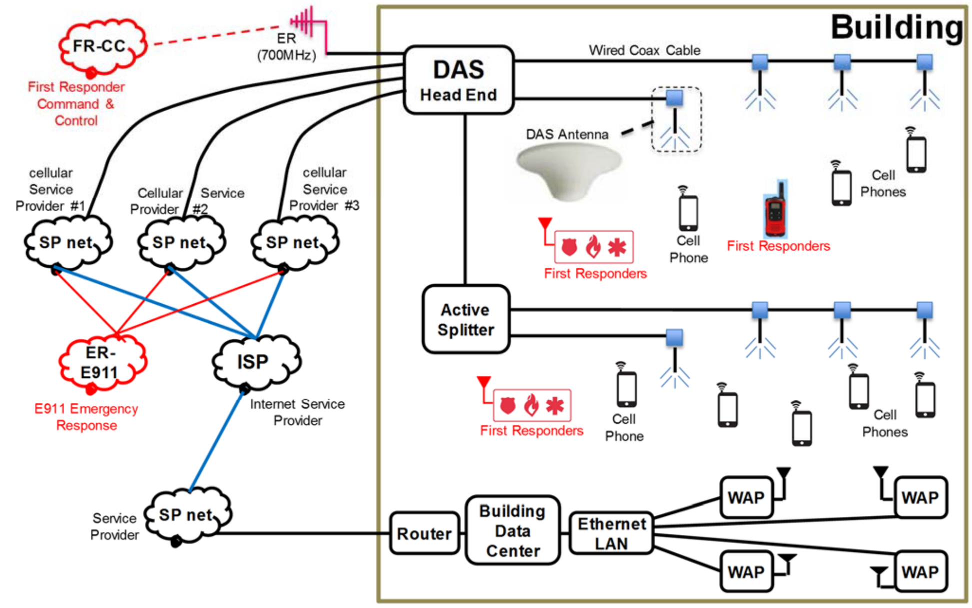


**Figure 2.1.1: Passive/Active DAS Network Architecture for In-Building Cellular, Wireless, and Emergency Services**

Figure 2.1.2 describes in a bit more detail how the DAS head end accomplishes multi-carrier support. DAS cabling within the building simultaneously supports each cellular service provider's primary frequency. Note that AT&T and Verizon are in the low frequency region (~ 700 MHz) while Sprint and T-Mobile are in the high frequency area (~ 1800 to 1900 MHz). Both passive DAS and active DAS are shown in the Figure. With active DAS, services can be distributed to remote distances within the building.

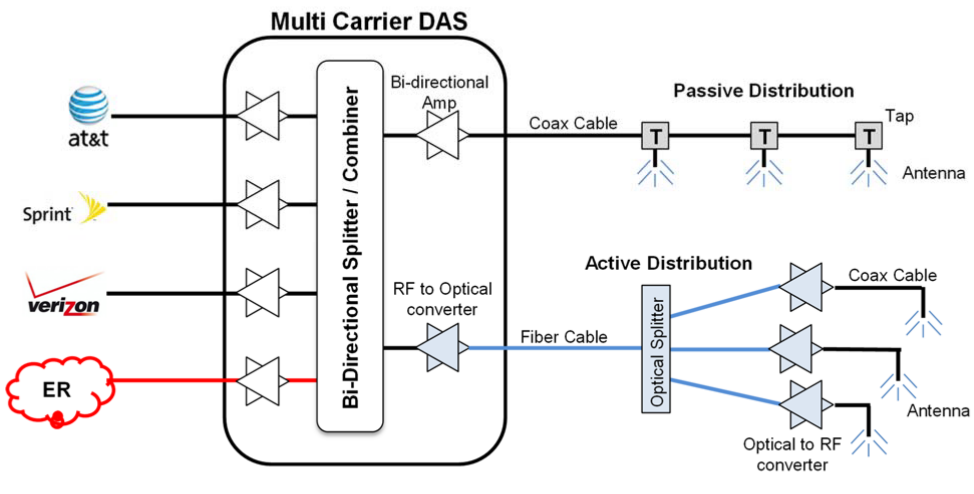


**Figure 2.1.2: Passive/Active DAS multi-carrier support**

Figure 2.1.3 shows from an equipment view, how DAS is implemented at the head end (typically located with a facility's data center) and the equipment used to distribute the RF signals throughout the facility.

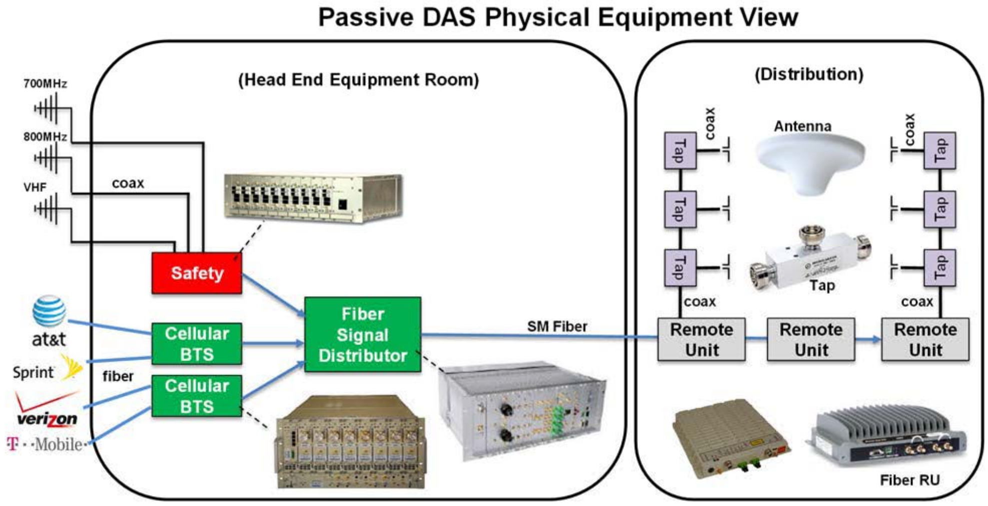


**Figure 2.1.3: A physical view of the equipment used to implement Passive/Active DAS**

Table 2.1.1 summarizes how effectively DAS serves the in-building application. DAS serves the mobile voice needs of a facility, but at a high cost. It does not adequately support the data needs within the facility. For a DAS system to serve the data needs, an overlay Wi-Fi network must be installed.

| TABLE 2.1.1: Distributed Antenna System (DAS) | | |
|---|---|---|
| **Feature** | **Supported Feature** | **Comment** |
| Serving multiple cellular services | Yes | Via RF frequency multiplexing |
| Supporting emergency first responders | Yes | |
| Supporting E911 | Yes | Specific location challenged |
| Installation (initial capital cost and yearly maintenance) | High | A licensed RF frequency is utilized from each service provider, requiring approval by each service provider |
| Scalability | Yes | |
| Future service migration | No | Wi-Fi can be added, but with limited bandwidth due to shared coax media |

## 2.2 Small Cell Cellular Networks for In-Building Applications

Small cells are short-range, compact (the size of a Wi-Fi WAP) cellular base stations that utilize licensed radio spectrums (similar to DAS) and are operated and controlled by a cellular service provider. They are single carrier (e.g., Sprint, AT&T or Verizon only) wireless-cellular access points. For a building to be "covered" by multiple cellular service providers, multiple small cells must be deployed at each location within a building. Small cells look very much like a Wi-Fi WAP and have two connectors associated with them: one for backhaul (Ethernet to work within the building's LAN) and one for power. A business enterprise small cell can handle many simultaneous active calls (e.g., 32 while some can handle up to 128 LTE calls). User cell phones are compatible with the network, and do not need special software (i.e., an app) to operate.

Figure 2.2.1 shows DAS, small cell (SC) and Wi-Fi connectivity for in-building wireless applications. An advantage that small cells have over DAS is that the backhaul media is Ethernet and can utilize the existing LAN network within the building. Additionally, small cell equipment can utilize PoE supplied from the LAN switches. Since the Ethernet connectivity is point to point, the small cell could supply Wi-Fi as well, with the appropriate bandwidth that the facility needs. This makes the installation simpler and the performance better than that of DAS (as compared to a single carrier implementation).

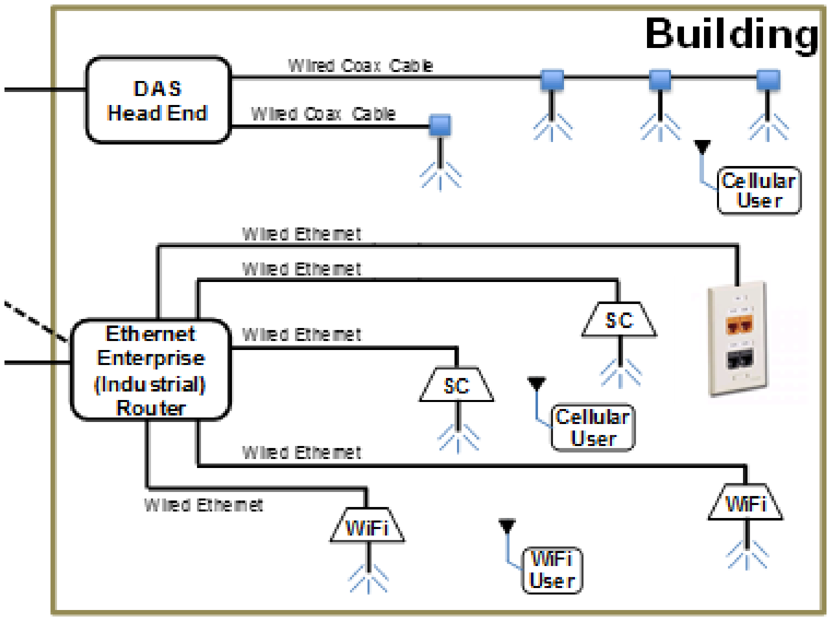


**Figure 2.2.1: DAS, Small Cell (SC) and Wi-Fi distribution within a building**

Table 2.2.1 summarizes how effective small cells are in an in-building application. One of the main challenges that holds small cell adoption back is the fact that it is single carrier only. Additionally, the cost of installing and certifying is not low.

| TABLE 2.2.1: Small Cell | | |
|---|---|---|
| **Feature** | **Supported Feature** | **Comment** |
| Serving multiple cellular services | No | Requires multiple small cells (one or more for each service provider) |
| Supporting emergency first responders | No | Compatible with FirstNet only |
| Supporting E911 | Yes | Provides specific location of user (deterministic) |
| Installation (initial capital cost and yearly maintenance) | Medium | Must be certified by the cellular service provider; for multiple service providers, cost will be high |
| Scalability | Yes | |
| Future service migration | Yes | Will be slow due to the low number of service providers (competition low); Wi-Fi could be supplied and could have adequate bandwidth |

## 2.3 Wi-Fi Networks Supporting In-Building Voice Applications

The primary function of Wi-Fi LAN networks is to support a facility's mobile data network. However, over the past few years, voice over data networks have gained momentum. There are numerous techniques by which voice is being supported over data networks, including Voice over Internet Protocol (VoIP), Google Project FI, and Voice over Wi-Fi (VoWiFi). These techniques will be further discussed in Section 3. Wi-Fi networks are not new for facilities, but wireless access points (WAPs) continue to evolve, offering more and more services.

Table 2.3.1 summarizes how effectively Wi-Fi serves in-building applications. The only drawback for Wi-Fi adoption is support for emergency responders. Wi-Fi will serve the next generation network for first responders (FirstNet), but doesn't provide support for 700MHz RF radio. However, FirstNet is quickly being implemented. (FirstNet is the First Responder Network Authority, an independent authority created by the U.S. Federal government in 2012 to establish, operate, and maintain an interoperable public safety national network; FirstNet's primary objective is to build a nationwide wireless broadband network for public safety, initially integrating the data network, and then integrating into a voice network.) Support for today's 700MHz radio networks can be done easily via an overlay network (i.e., probably an antenna per floor would be adequate). Hence, this should not be a barrier for Wi-Fi to dominate in the in-building market space.

| TABLE 2.3.1: Wi-Fi | | |
|---|---|---|
| **Feature** | **Supported Feature** | **Comment** |
| Serving multiple cellular services | Yes | Required for smart phones and tablets |
| Supporting emergency first responders | No | Compatible with FirstNet only |
| Supporting E911 | Yes | Provides specific location of user (deterministic) |
| Installation (initial capital cost and yearly maintenance) | Low | Powered by PoE, leading to lower installation costs |
| Scalability | Yes | |
| Future service migration | Yes | Via Ethernet standardization |

## 2.4 Comparison Between these Implementations

Table 2.4.1 compares several wireless technologies in terms of initial capital cost, installation time, and some performance metrics. The simple conclusion is that Wi-Fi is the clear winner in terms of overall cost, versatility in supporting different types of market segments, and scalability.

| TABLE 2.4.1: Wireless technology Comparison (reference = ABI research) | | | | |
|---|---|---|---|---|
| **Feature** | **Active DAS** | **Passive DAS** | **Small Cell** | **Wi-Fi** |
| **Capacity & Coverage** | Both | Both | Both | Both |
| **Installation** | 1-3 weeks | 1-3 weeks | Week | Minutes |
| **Neutral Host** | Yes | Yes | No | Yes |
| **Scalability** | Full | Limited | Limited | Full |
| **End Use Case (application area)** | Large Enterprises | Medium to Large Enterprises | All | Small office, Home office (SoHo) |
| **Cost** | $$$$ | $$$ | $$ | $ |



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# 3. In-Building Cellular Voice Protocols

Voice transmission and data transmission have significantly different requirements due to the quality of service needed. Voice traffic packets must arrive in order with minimal delay; data traffic packets do not have to arrive in order and are not as sensitive to delay. These different requirements led to different types of networks for voice (circuit switching over the PSTN network) and data (packet switching). Modern cellular networks (e.g., 4G) are now fast enough that separate networks are not needed, and both voice and data traffic are mostly transported through packet switching networks. Individual packets can have different parameters to let the network know how to support the specific traffic. In these networks, voice and time-sensitive packets are treated differently than data (non-time sensitive) packets. As the cellular network continues to evolve towards a high-performance 5G, all IP-based packet network, the distinction between network architectures and protocols will become less and less.

**TABLE 3.1; Cellular Network Comparison**

| Technology | 1G | 2G/2.5G | 3G | 4G | 5G |
|---|---|---|---|---|---|
| Deployment | 1970/1984 | 1980/1999 | 1990/2002 | 2000/2010 | 2014/2020 |
| Bandwidth | 2k bps | 14-64k bps | 2M bps | 100M bps | > 1G bps |
| Technology | Analog Cellular | Digital Cellular | Broadband / CDMA / IP technology | IP & LAN / WAN / WLAN / PAN | 4G & WWWW (worldwide wireless web) |
| Service | Mobile Telephony | Digital Voice, short messaging | High QoS voice, video & data | IP - Integrated services | IP - Integrated services |
| Multiplexing | FDMA | TDMA / CDMA | CDMA | CDMA | CDMA |
| Switching | Circuit | Circuit | Packet except for ari interface | All Packet | All Packet |
| Core Network | PSTN | PSTN | Packet Network | Internet | Internet |
| Handoff | Horizontal | Horizontal | Horizontal | Horizontal & Vertical | Horizontal & Vertical |

Long Term Evolution (LTE) was added into 4G technology (which displaces UMTS) to increase the data rate. It is not likely to be used when 5G is introduced.

# 4. Voice over IP (VoIP), Google Project Fi, LTE (VoLTE), and Wi-Fi (VoWiFi)

What are the main differences between these protocol technologies? VoIP (a.k.a., OTT, Over-The-Top services) uses the existing IP network for wired or wireless connectivity. Classic examples of this are Skype, Vonage, Lingo, BroadVoice, and Packet8. These service providers (whose network services are being utilized for the VoIP service) have no control, no rights, and no responsibilities. The network carrier only carries the IP packets from source to destination. (Note that the network carrier is anyone who provides Internet access via wired or wireless connectivity. It can be a traditional cellular service provider supplying data access to the Internet, a vendor providing Wi-Fi service to the internet, or a business providing Wi-Fi service to the internet.) These service vendors supply either an application program ("app") to a smart phone, provide an adapter between a wired telephony phone and the internet, or provide an IP phone.



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Figure 4.1 shows the typical architecture of a VoIP service application. The call management is provided over VoIP protocols (e.g., SIP, H.323, Skype, etc.). Some of the disadvantages of VoIP as compared to traditional Plain Old Telephone Service (POTS) are:

- Limited or no service during a power outage (if powered by PoE, power outage is dependent on UPS availability)
- No physical location discovery for Emergency calls
- No internet network reliability
- Low voice quality (QOS)
- Minimal security
- Network access via Internet Service Provider, hence minimal outdoor coverage

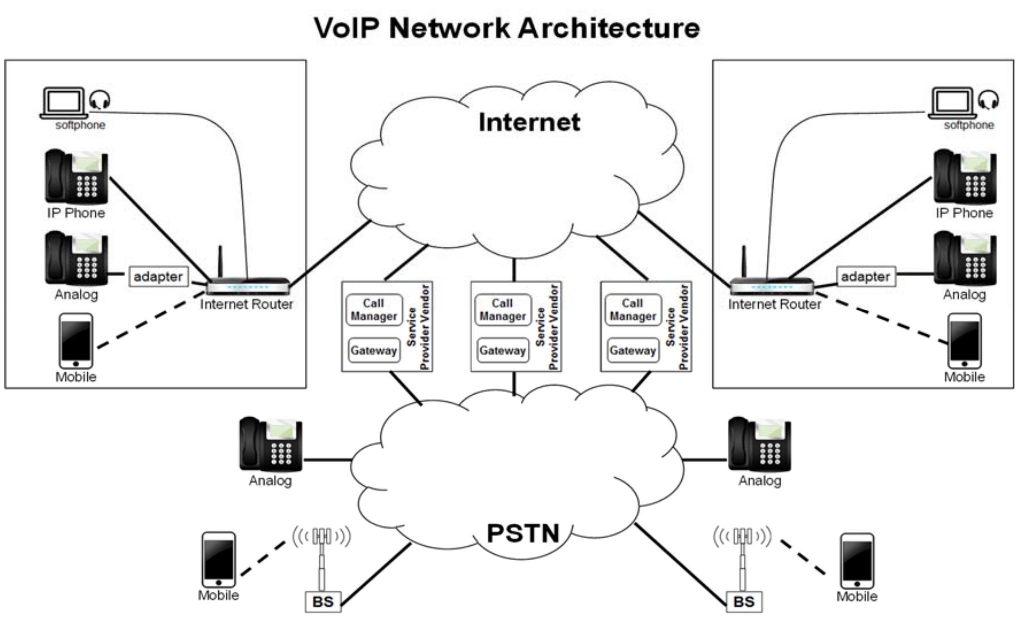


**Figure 4.1: Voice over IP (VoIP) Network Architecture**

A much-publicized VoIP service from Google was launched in 2015 called Google Project FI. It is similar to VoIP architecture, with the following exceptions:

- Limited smart phone support
- Google operates as a MVNO (Mobile Virtual Network Operator). They do not own any cellular network infrastructure, but purchase bulk access to existing network infrastructure (currently T-Mobile and Sprint) and use this to support its services
- Smart phones utilize only the cellular data network provided by the MVNO and Wi-Fi (i.e., not the cellular voice network)
- A smart phone app must be installed, along with a special SIM card

Since the smart phone will have cellular access via the MVNO, the phone will have access within buildings via Wi-Fi, or outside of buildings via cellular service (hence more features than typical VoIP applications). Other companies are also entering this market.

VoLTE (voice over LTE) is an enhanced cellular network that retires the legacy-based circuitswitched network and utilizes the data packet network for both voice and data. For in-building applications, VoLTE utilizes small cell technology for network access. The adoption of LTEbased small cells for residential and enterprise applications has been quite limited. Additionally, network upgrades have been slow and interoperability between VoLTE and cellular calls is still being resolved. Due to these issues, VoLTE has been slow to roll out.

VoWiFi is sometimes erroneously viewed as another form of VoIP. VoWiFi is actually very specific and defined by mobile industry standards-setting organizations, and is increasingly supported as a native feature in many smart phones.

Figure 4.2 shows the VoWiFi architecture.

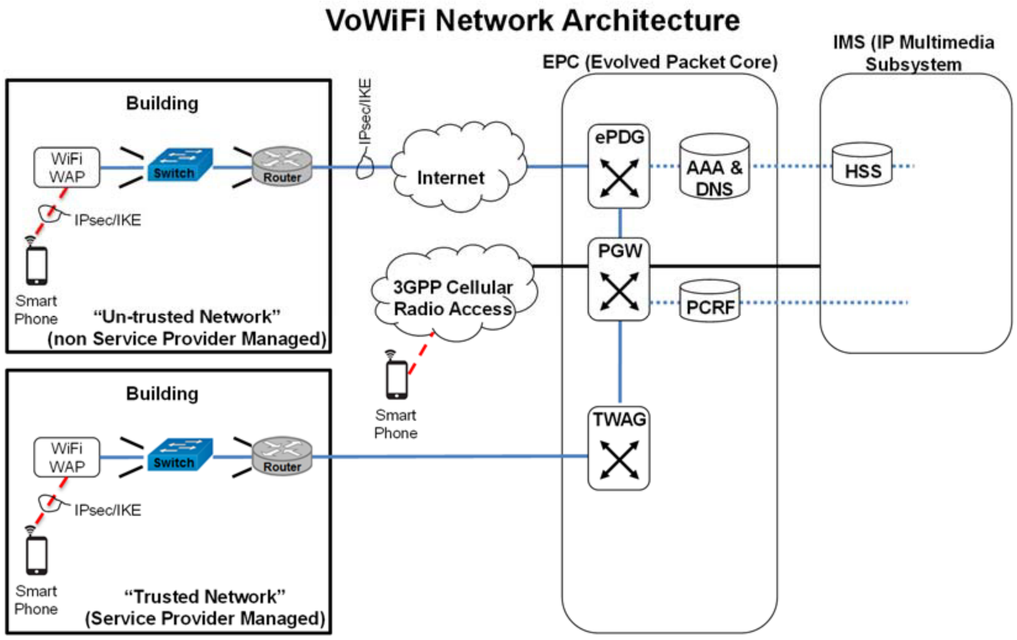


**Figure 4.2: VoWiFi Network Architecture for "trusted" and "untrusted" Wi-Fi networks**

Figure 4.3 predicts the usage of VoLTE, VoWiFi and VoIP. Note in Figure 4.4 that the growth of VoWiFi is more than double that of either VoLTE or VoIP.

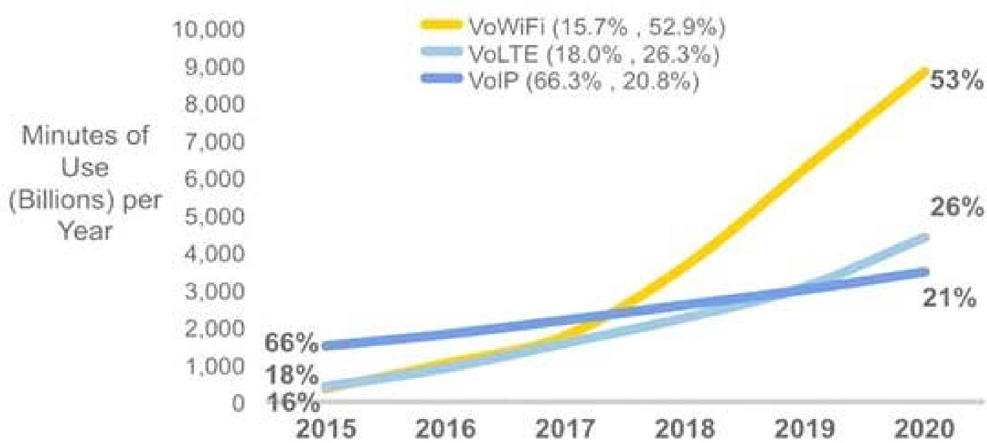


**Figure 4.3: Minutes of Use for VoWiFi, VoLTE, and VoIP. (Source: Cisco VNI Mobile, 2016, percentages in parentheses are 2015 and 2020-time usage)**

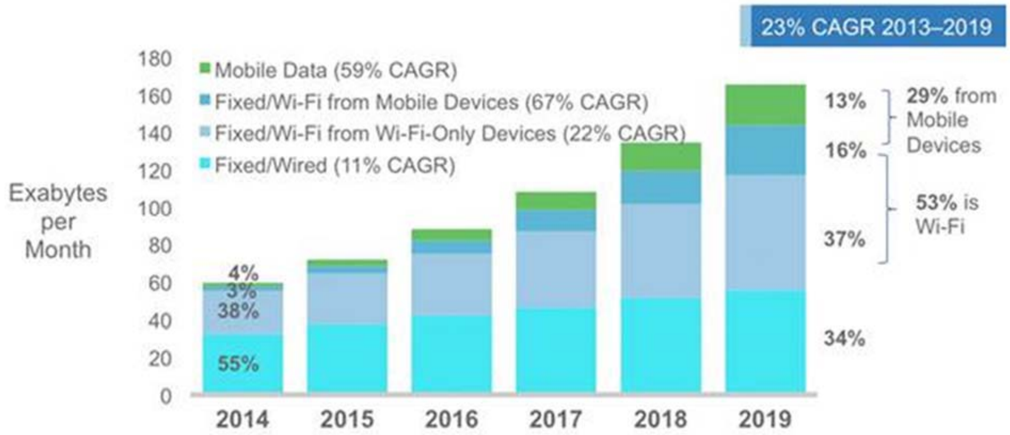


**Figure 4.4: The growth of data needs. (Source: Cisco VNI Mobile, 2016)**

VoWiFi has many benefits to the end user as well as the cellular service provider. Table 4.1 identifies some of these benefits.

**TABLE 4.1: The Beenefits of VoWiFi**

| VoWiFi Benefit to End User | VoWiFi Benefit to Cellular Service Provider |
|---|---|
| Single, uniform voice dialer on their smart phone | Better indoor coverage compared to cellular macro base stations. This solves an increasing problem with the "radio tight" modern building structures |
| Allows for voice services over any Wi-Fi network (home, office, hotspots, ...) | Reduced churn |
| Wi-Fi calling provides better indoor coverage | With indoor coverage, subscribers can give up their landlines. By offering Wi-Fi calling services now, mobile operators can expect higher customer acquisition rates |
| Seamless call transfer support between Wi-Fi and LTE (using VoLTE) and specific support in the device | Operators can get back in the driver's seat making OTT players such as Skype and Viber less important to subscribers. |
| Roaming charges minimized. A call from anywhere in the world is charged as a mobile call in your home mobile network whenever you have access to the Internet over Wi-Fi | Wi-Fi is a low-cost solution to enhance voice service coverage |
| | Operators do not necessarily even have to invest in Wi-Fi footprint. They can instead rely on existing Wi-Fi networks |
| | Wi-Fi calling is sharing similar infrastructure with IMS-based VoLTE |
| | Horizontal |

## 4.1 Wi-Fi Calling – user operation (What must the user do to use VoWiFi?)

One of the main reasons that VoWiFi or even VoIP did not have great usage in the past was due to the complexity of activating and using the services. Currently, these activations are either native to the smart phone or easy to install. Once a smart phone is Wi-Fi calling activated, and a Wi-Fi network is available, then the dialing instructions are the same as traditional calling; the call seamlessly transitions between wireless access points and the cellular network (if the call manager is an LTE mobile service provider).

## 4.2 Wi-Fi technology trends

Table 4.2.1 describes the technology roadmap supporting IEEE 802.11 wireless standards.

| TABLE 4.2.1 Wi-Fi Technology Roadmap | | | | | | |
|---|---|---|---|---|---|---|
| **Wireless Protocol** | **Year Introduced** | **Frequency Bands** | **Data Rate** | **Range** | **Description** | **Targeted Application** |
| **802.11ac** | 2013 | 2.4/5 GHz | < 6.7 Gbps | 100m | Up to 8 spatial streams, 80/160 MHz channels, 256 QAM, MU-MIMO | Office IT infrastructure & Home entertainment |
| **802.11ad** | 2013 | 60 GHz | | 10s of meters | High data rate PAN (aka WiGig) | Docking stations |
| **802.11af** | 2014 | 54 - 790 MHz | 24 Mbps | Several miles | Utilizes unused TV spectrum frequencies LPWAN | Very long range Wi-Fi |
| **802.11ah** | 2016 | 900 MHz | >100 kbps | <1kn | Low power and long range – LPWAN (Low Power WAN) | IoT, Smart building |
| **802.11ax** | 2018/2019 | 5 GHz | 14 Gbps | 100m | 4-MIMO & OFDA streams | Next gen 802.11ac |
| **802.11ay** | TBD | 60 GHz | 20 Gbps | 10s to 100s of meters | High data rate PAN (aka WiGig) | Next gen 802.11ad (short range communications) |

As shown in Table 4.2.1, wireless technology is constantly evolving. Over the next few years, bandwidth is expected to increase by more than double (i.e., 6.7 Gbps to 14 Gbps) and there will be several options for lower bandwidth long-range coverage (i.e., several miles). Ethernet based wireless technologies for LAN communication is evolving as market needs evolve. The IEEE standard body strives to ensure that the right technology is always available.

## 4.3 Security

VoWiFi uses IPsec protocol suite for security between user equipment (e.g., smart phone) and the operator's network (specifically ePDG) and is managed by cellular service providers. The following protocols provide authentication, encryption and data integrity: Authentication Headers (AH), Encapsulating Security Payloads (ESP) and Security Associations (SA).

# 5. Financial Operating Models

There are three prevalent financial operating models that the industry has been employing to roll out wireless-cellular systems within a building. They include carrier-led, third-party neutral host, and venue-led.

## 5.1 Carrier led

The carrier-led model is the most common of the ownership models and typically resides in the enterprise segment of multitenant residential and office buildings. Here the carrier completely funds and operates the network and is typically the only carrier (single carrier).



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### 5.2 Third Party Neutral Host

In the third-party neutral host model, a third-party provider owns and invests in the in-building system, and then leases the system to carriers for a fee. This model is common in public areas or venues with many users, such as sports arenas and stadiums, shopping malls, casinos, and airports. Boingo is one common example of a third-party neutral host, providing cellular and Wi-Fi services for many airports and stadiums.

### 5.3 Venue-led

In a venue-led model, the building owner and/or manager owns and invests in the in-building system. Typically, a multi-carrier system is installed. This model is most commonly used in vertical markets like healthcare and higher education. The investment size limits the use of this model.

## 6. Conclusions and comments on Hypothesis

The hypotheses stated at the beginning of this report were:

- In-Building Wireless-LAN (Wi-Fi based) will continue to evolve and flourish in the Enterprise market and grow faster than the base market.
- In-Building Wireless-Cellular (Wi-Fi based) will continue to take market share from both DAS and Small Cell systems and will eventually dominate wireless access in the enterprise.

The hypothesis that Wi-Fi-based LANs will continue to evolve and flourish in enterprise market has been shown to be true. Wi-Fi technology development is faster and more complex than what the cellular service provider community can provide. This is due to the open standard that it has adopted, the global nature of Wi-Fi, and the competitive market in which Wi-Fi technology resides. We should continue to have high expectations from the Wi-Fi vendor community.

In addition, the hypothesis that VoWiFi will dominate in the in-building enterprise market has also been shown to be true.

- Wi-Fi is already popular (quite pervasive, actually), and consumers have become dependent on it. According to a 2013 report by Deloitte, two thirds of consumers prefer connecting over Wi-Fi rather than a cellular network. This is due to cost reasons, as well as performance reasons (e.g. downloading a YouTube video.)
- Wi-Fi extends coverage. Spotty service is a non-issue when operators employ voice calling over Wi-Fi. In effect, this service extends coverage to areas that cellular signals have trouble penetrating.
- Wi-Fi makes almost any device a communications tool. VoWiFi can be offered as a service regardless of the hardware capabilities of a device. Virtually anything can become a communications vehicle if it's Wi-Fi enabled, even non-SIM devices.
- Wi-Fi is ubiquitous. As stated before, Wi-Fi is virtually everywhere. There will be 5.8 million global hotspots by the end of 2016 (ref = Informa), a 350 percent increase since 2001. It's fast becoming the preferred method of connection, and while it may not yet be as pervasive as LTE, don't be surprised if it gets there – soon.

The conclusion therefore is that Wi-Fi will continue to grow in importance, becoming an even more meaningful mode of connection, and especially voice communication, over the coming years.



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In the future, Panduit expects to see VoWiFi flourish in the in-building environment as consumers become more aware and comfortable with the technology, and as the technology continues to evolve. Associated with this, Panduit expects to see wireless service providers in operator-led financial models switching from DAS to Wi-Fi due to the cost and performance advantages. Panduit also expects to see Wi-Fi networks accelerate in growth in outdoor venues relative to DAS. These outdoor deployments can more efficiently support data and voice applications.

With the rapid growth of Wi-Fi data rates and the rapid growth of Wi-Fi covering new applications, choosing the right cabling infrastructure is of particular importance. This cabling infrastructure should support existing and emerging Wi-Fi applications. Panduit recommends the following infrastructure:

- **Run Category 6A cables to each wireless access point.** Category 6A allows for transmission up to 10GBASE-T, which will soon be needed by these access points
- **Run at least two cables to each wireless access point.** This allows for flexibility for either simply adding additional wireless access points as the number of wireless devices increases, or allows for doubling the data rate to that wireless device if the device allows link aggregation (two 10GBASE-T cables can support the 20Gbps needs of 802.11ay)

The Telecommunications Industry Association, through TSB-162-A, has published "Telecommunications Cabling Guidelines for Wireless Access Points," which offers further guidance for installing cabling systems to wireless access points. This document also recommends Category 6A cabling.

References and in-building wireless organizations

- Market research data (e.g., ABI)
- The HetNet Forum (www.hetnetforum.com)
- Wi-Fi Calling and the Support of IMS Services over Carrier Wi-Fi Networks (http://www.cisco.com/c/en/us/solutions/collateral/service-provider/service-provider-wifi/white-paper-c11-733136.html)
- Small Cell Forum (www.smallcellforum.org)
- FirstNet (www.firstnet.gov)
- Verizon VoWiFi (http://www.verizonwireless.com/news/article/2015/12/verizons-advancedcalling-to-include-wi-fi-calling-beginning-next-week-on-some-devices.html)
- VoWiFi (www.wificalling.net)

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