

Ubiquitous Wireless Broadband with City-wide WiFi Infrastructure

1. Background

Getting connected has become a norm for enterprises and consumers. People prefer to access information and to stay tuned-in via Internet applications whilst they are on the move. With the increasing market requirement of multiple play, both handheld devices and networks are emerging to support converged communication services anytime, anywhere. Wireless infrastructure plays a crucial role to achieve ubiquitous connectivity in campus and metropolitan areas. As a result, City-wide wireless infrastructure is gaining momentum with numerous worldwide deployments.

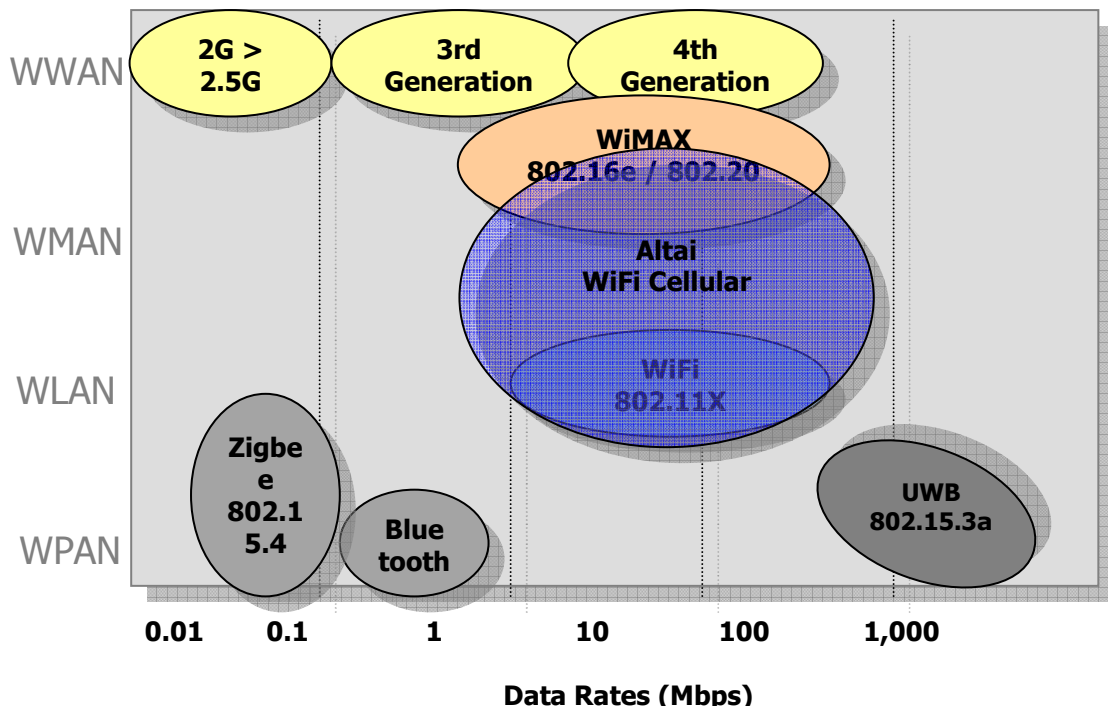
There are a number of alternative wireless infrastructures for a city-wide deployment, and the most popular one nowadays is the third-generation cellular network (3G). The 3G network can have wide area coverage and the key application is voice. In addition, 3G can support data applications such as mobile TV and web browsing. The current technology can support data rates up to 3.6Mbps per station. WiMAX is a hot topic in the industry and is strongly advocated by Intel, Motorola and Samsung. Mobile WiMAX is often regarded as the fourth-generation network (4G), but it is expected that WiMAX will take some time to become popular, especially in client devices. Comparatively, WiFi is the readily available technology for wireless connectivity. WiFi has high penetration into client devices and is commonly found in notebook computers, PDAs, and mobile phones. It can deliver true broadband connectivity with the 802.11g standard which provides data rates up to 54Mbps.

However, the inherit design of WiFi creates different challenges for city-wide deployments. The initial application for WiFi was for WLAN coverage, with a typical coverage radius of 100m. This implies a large number of WiFi access points would be required for large area coverage. In urban or densely populated areas, the WiFi coverage would be spotty due to the low penetration power of the WiFi signal, so it is difficult to achieve ubiquitous coverage. Moreover, WiFi has conventionally been used to support data applications for nomadic users. It is a challenging task to support multimedia applications at mobile speeds with the presence of delay-sensitive traffic. In particular packet latency can vary greatly in the air interface.

In view of these challenges and the readiness of various wireless technologies, proponents of ubiquitous wireless applications such as municipal governments and service providers are eager to find out what is the best technology for city-wide wireless deployments today.

Altai WiFi cellular system is the first proven solution in the market that can address the stringent requirements of city-wide wireless infrastructure. The Altai WiFi cellular network provides the capabilities of handling real-time applications whilst providing high bandwidth for bandwidth-hungry applications. In addition, the Altai smart base station can overcome the limited coverage of traditional WiFi equipment and provides metropolitan coverage with a minimum number of base stations and physical backhauled. Figure 1 illustrates the positioning of Altai WiFi cellular solution amongst other wireless technologies.

Figure 1: Comparison of Wireless Technologies



2. Altai WiFi Cellular System

The design of our Altai WiFi Cellular System provides a cost-effective city-wide WiFi network that supports real-time multimedia applications such as voice, streaming video, network gaming and Internet surfing for both nomadic and mobile users. Our ultimate goal is to enhance peoples' experiences in getting connected. The Altai system is developed based on the following criteria:

- Coverage – to achieve micro-cellular coverage
- Capacity – to provide sufficient user capacity in urban areas
- Mobility – to support users in driving speed
- Quality of Service – to support real-time applications
- Manageability – to simplify operations and maintenance of WiFi network

To meet the above-mentioned criteria, the system components comprising the infrastructure of Altai WiFi Cellular System include:

- Altai A8 WiFi Base Station
- Altai A0 Wireless Bridge
- Altai Pico Base Station
- Altai Wireless Management System (AWMS)

The cellular architecture of Altai system is similar to a 3-layer cellular network. The pico-cell is used to increase the system capacity in densely-populated areas. The micro-cell provides large area coverage with integrated wireless backhaul connecting to the hub site where a

wireless bridge is used for point-to-point or point-to-multipoint connections. The Altai Wireless Management System (AWMS) provides management of all the network elements.

Altai A8 WiFi Cellular Base Station

Altai A8 base station (as shown in Figure 2) is the flagship product in the Altai WiFi Cellular System. It is the World's first WiFi cellular base station optimized for micro-cellular coverage. Altai A8 has been designed from the ground to be an outdoor base station for city-wide WiFi network. Comparing with standard outdoor access point that has a non-line-of-sight (NLOS) radius of 100-150m, the A8 can achieve a non-line-of-sight (NLOS) radius of 300-500m, which is 10 times better in coverage area. Altai A8T (as shown in Figure 3) consists of the same base station but with a 4-sector tube antenna matching with the street environment such as lamppost.

Figure 2: Altai A8 WiFi Cellular Base Station with Standard Smart Antenna



Figure 3: Altai A8T WiFi Cellular Base Station with 4-Sector Tube Antenna



Limitation on WiFi Coverage

To achieve a 300 to 500m NLOS range is challenging for 802.11 WiFi networks due to the following reasons:

- The transmitted power, or more precisely the Electrical Isotropic Radiated Power (EIRP) is restricted by regulatory authorities in different countries, e.g. the FCC in the US restricts the EIRP to a maximum of 36dBm
- The power of WiFi terminals are low and non-adjustable, typical terminals transmit at 16-20dBm
- WiFi operates in un-licensed spectrum
- As with all wireless systems, the coverage with WiFi is affected by the environment

Each of the above factors restricts the range of a WiFi network, and the first two factors are the major inhibitors for an extended access range of a WiFi network.

For example, in the US, the EIRP (transmit power of the base station plus the antenna gain) is restricted to 36dBm, whereas the EIRP restriction in the cellular network world is about 55dBm. General speaking the coverage of a WiFi base station will be less than the cellular base station. Another critical point is WiFi operates at a higher frequency band than cellular networks, and therefore the penetration capabilities of WiFi by its nature will be lower than a cellular network.

The term, coverage, is for bi-directional means downlink (from base station to client terminal) and uplink (from client terminal to base station) direction. The base station EIRP is the summation of transmit power and antenna gain. Through the increase in transmit power doesn't help the uplink performance and so the coverage. On the other hand, increase the antenna gain can help the coverage since antenna gain is applicable to both downlink and uplink traffic. Thus the antenna gain can help to improve the uplink performance of client terminals.

Smart Antenna Design to Increase Coverage

Higher gain antenna often require longer antenna dimension. To be realistic in deriving an optimal antenna gain, the transmit power of the base station can be set at 21dBm which is close to the transmit power of a terminal device; the antenna gain should be about 15dBi to give a FCC EIRP limit of 36dBm. As in the WiFi operating frequency at 2.4GHz, a 15dBi antenna gain means an omni-antenna of 4m long. Not only this sounds impractical with this long antenna, but also the vertical beam-width is much affected with long antenna.

The question is how to design an antenna system to provide 360-degree coverage and give a high gain of 15dBi. Altai applied the idea from cellular network experience in which sector antennae are used to give 360-degree coverage but each sector antenna operates in different frequency channel. In applying to WiFi base station, Altai uses the sector antennae as an antenna array system operating in one channel only, thus providing adaptive WiFi transceiver system utilizing directional antennae. The adaptive nature of WiFi base station is of absolute importance in ever-changing and noisy RF environment, especially for WiFi signals operating in un-licensed band. In RF propagation environment, the received signal strength at the client terminal is a combination of microscopic multi-path fading and antenna gain factor of the base station. In order to improve the robustness of the communications link between the client terminal and base station, the base station needs to equip with a high gain antenna system and antenna diversity feature to optimize the signal reception. The design of Altai A8 base station utilizes smart antenna algorithm to increase the overall network capacity and coverage. A8 has cross-polarization antenna elements inside each sector antenna to facilitate selection diversity; hence the A8 base station has a total of 8 antenna elements. Figures 4 shows the antenna system connected to the base station with RF cables.

Figure 4: A8 Antenna System Configuration



The A8 base station is to be mounted in pole at the roof-top or along the street. Adjustable mounting kit is provided to adjust the antenna orientation and its down-tilt angle to adapt to the covered environment. The antenna elements are connected to the base station with RF

cables. There are multiple radio modules inside the base station to pass the signals up for further processing, and the intelligence of the base station resides in embedded software to determine the best antenna beam for each client terminal under interference and multi-path fading, to closely monitor the link performance with beam tracking technologies, and to perform beam switching among the antenna elements to ensure optimized signal strength. All in all, the patented advanced signal processing algorithm as implemented in embedded software is the technology core of Altai smart base station, to increase the coverage through the optimization of signal strength under noisy RF environment.

With the 4-sector antenna that provides 360-degree coverage, the antennae are mounted evenly around the pole such that one antenna is perpendicular to the adjacent one in order to give a coverage area as in Figure 5.

The horizontal beamwidth of each sector antenna is 70-degrees and the vertical beamwidth is 11-degrees. The coverage of an A8 base station is estimated in a square shape as shown in Figure 6.

Figure 5: Signal Coverage of 4-Sector Antenna

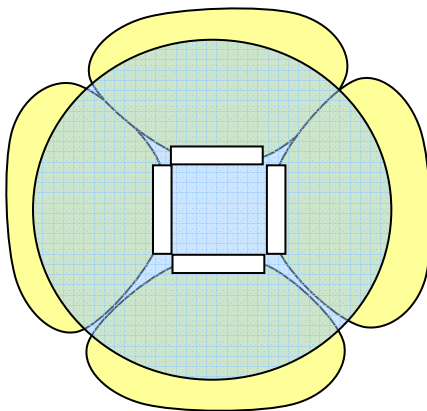
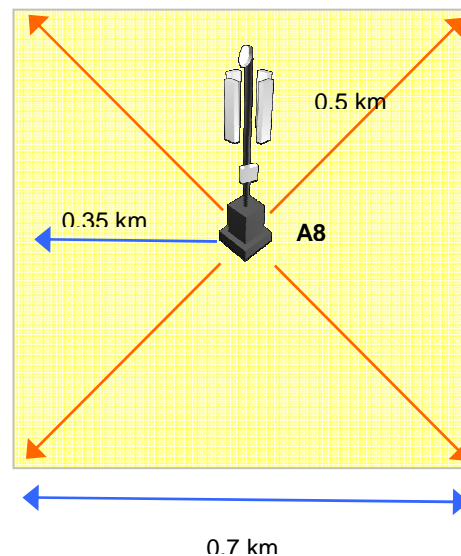


Figure 6: A8 Coverage Area

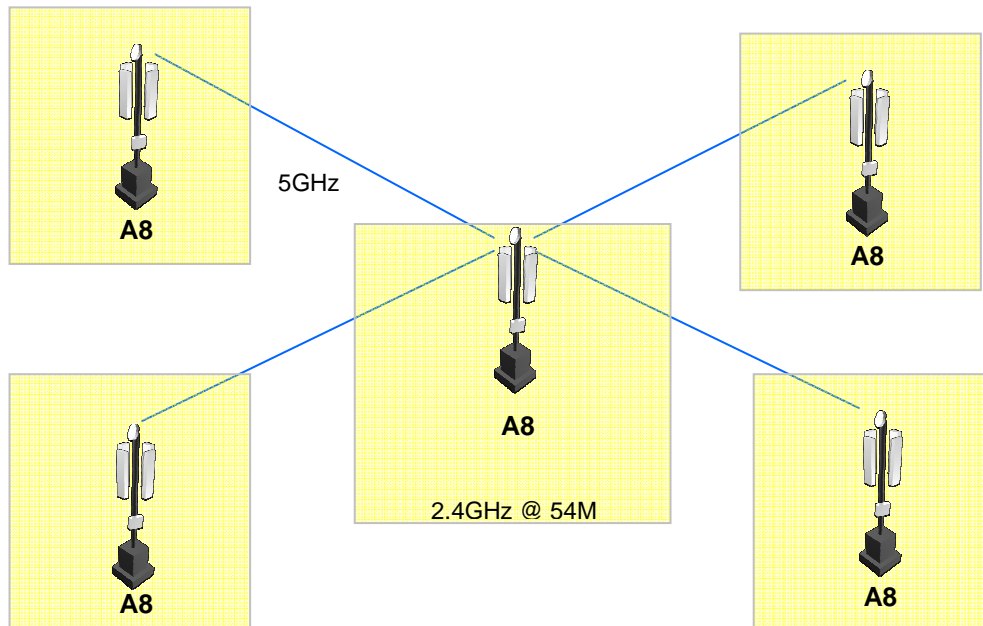


Since the A8 base station can provide a NLOS radius of 300 to 500 m or 0.3 to 0.5 km to match the footprint of micro-cellular deployment in urban area, this is equivalent to a coverage area of maximum 0.5 square km. In general, for an area of 1 square km in urban environment would require 2 A8 base stations. The number of required base stations will be less than other available base stations in the market so the upfront investment will be significantly lowered. Due to smaller number of required base stations, the associated costs like site acquisition & construction, and physical backhaul will be reduced as well.

The sector antennae of A8 base station operate at 2.4GHz to provide access coverage to the client terminals, and the A8 station has both a physical Ethernet and a 5GHz wireless backhaul for connection to the backend network. In the case using the physical backhaul, this requires T1/E1 based leased line from the fixed carrier and will incur monthly subscription charge on the leased circuit. To save the physical backhaul costs and in some cases the leased circuit cannot be made available in rural area, wireless backhaul is widely deployed in

city-wide wireless network. Several A8 base stations can form a cluster to cover a large area as illustrated in Figure 7.

Figure 7: Typical A8 Cluster Structure



The A8 base stations are interconnected via the 5GHz backhaul, the central A8 acts as a master which can connect up to 4 A8 base stations. Each A8 will provide a local coverage area of 0.5 square km, making a total coverage of 2.5 square km (1 square mile) per cluster.

As the A8 base stations will be used to support multimedia applications of different client terminals, A8 supports WiFi Multimedia (WMM) which is the implementation of a subset of IEEE802.11e features. It defines 4 access categories or QoS level to prioritize different user traffic. Therefore real-time applications such as voice, video streaming and interactive gaming can be supported.

Altai A0 WiFi Bridge

Deploying a wireless network often requires point-to-point or point-to-multipoint link communications for network interconnection and the Altai A0 WiFi bridge (Figure 8) is built to serve this purpose. Operating at the 5GHz ISM band, the A0 bridge extends the network coverage by forming a point to point link with another bridge. This could be another A0 bridge or the 5GHz radio integrated in the A8. The A0 bridge can act as a root with up to 4 other slave bridges when operating in point-to-multipoint configuration. It has a built-in antenna and the A0 supports the 802.11a standard, offering data rates up to 54Mbps. The A0 bridge can also support the Turbo-A mode with up to 108Mbps data rate. The A0 can provide an extended range up to 28km with an external antenna

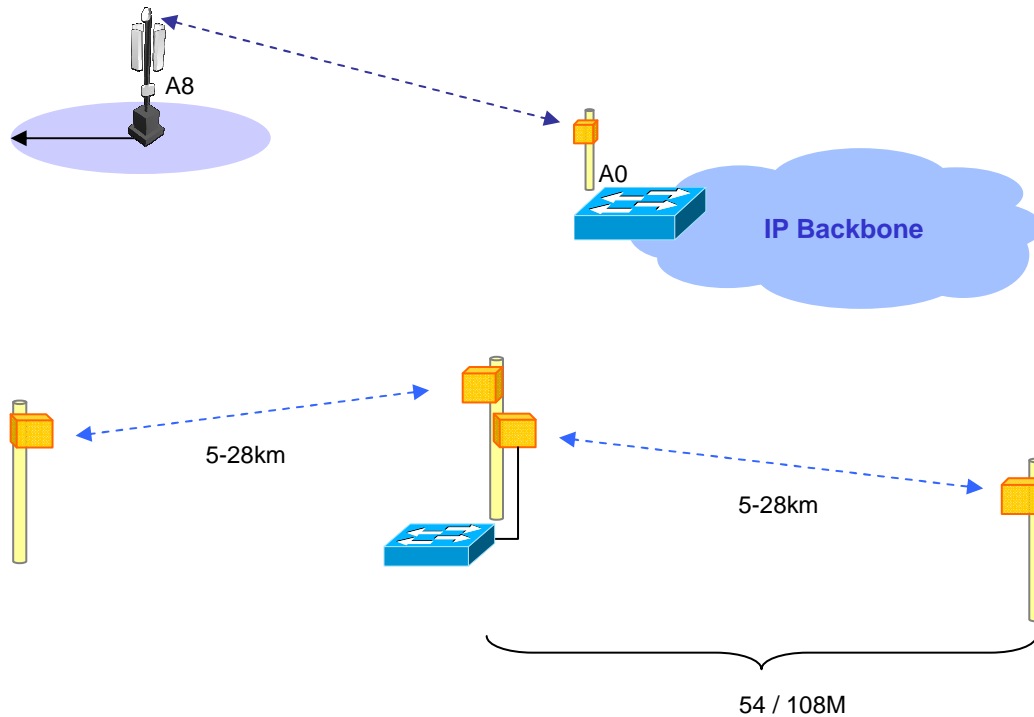
Figure 8: Altai A0 WiFi Bridge



option (14 km in turbo mode).

The A0 bridge has a 100BaseT Ethernet interface for interconnection to the wired network. In most cases, it is installed at the hub site where the physical network connection exists (Figure 9).

Figure 9: A0 Bridge Deployment Scenarios



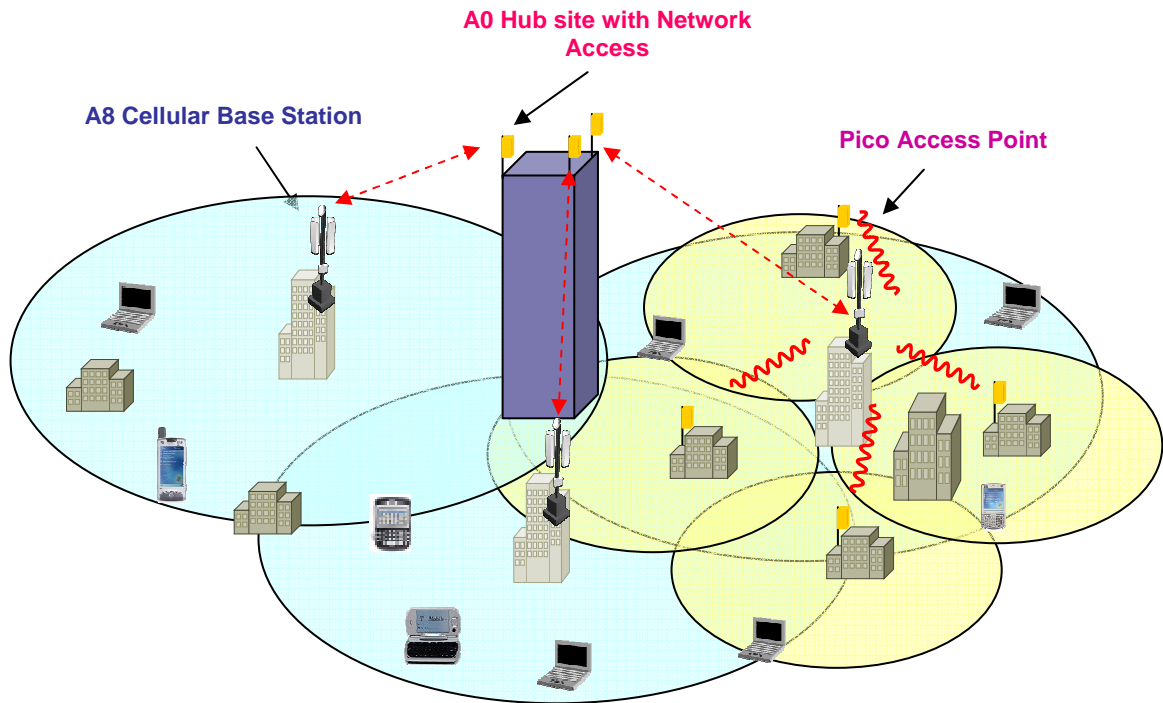
Altai A2 WiFi Pico Access Point

As mentioned above the A8 base station can provide large area coverage similar to the footprint of a micro-cellular network. There are increasing requirements in capacity and data speed in the urban area where there is high user density. The deployment of the Altai A2 pico access point (as shown in Figure 10) within the coverage of the parent A8 can increase the overall network capacity. In addition, with the large coverage area of the A8, the A2 pico access point is targeted to enhance the coverage in more challenging RF environment, for example in the vicinity of high-rise buildings, narrow streets or urban areas with neighboring signal interference. As a result, the A2 pico access point complements the A8 base station to form a 2-tier network hierarchy to provide both capacity and coverage optimization. The deployment scenario of A2 pico access point is depicted in Figure 11.

Figure 10: Altai A2 WiFi Pico Access Point



Figure 11: Altai A2 WiFi Pico Access Point Deployment Scenario



The A2 pico access point has 2 omni antennae for access signal coverage and it has a built-in 5GHz antenna to form the backhaul link with its parent A8 base station. The non-line-of-sight (NLOS) radius of the Pico base station is around 100m. An A8 base station can connect with up to 4 A2 pico access points under its coverage area.

Altai Wireless Management System (AWMS)

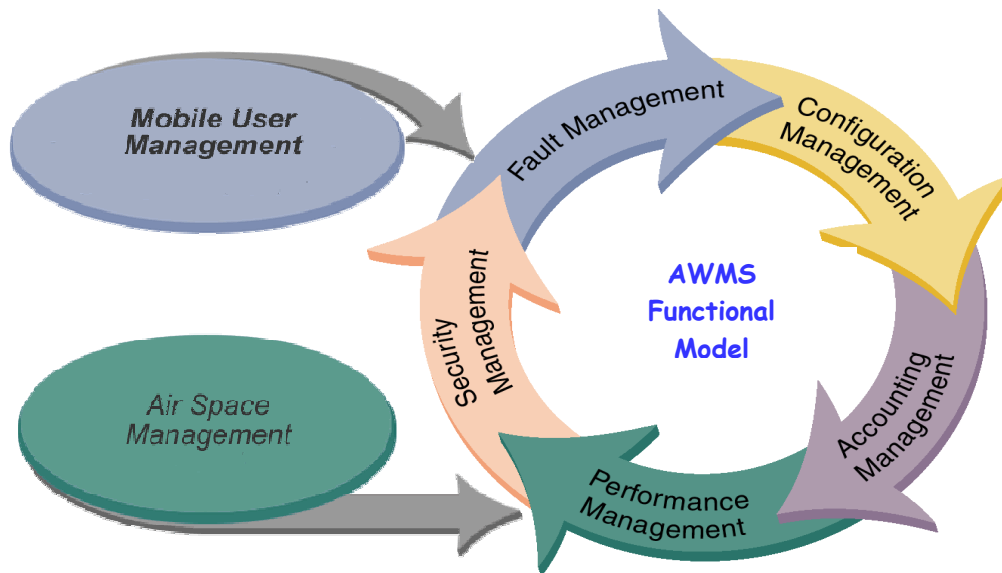
AWMS provides the network operator a full suite of element and network management functions for City-wide WiFi networks. It can help the network operator significantly reduce the complexity of network provisioning and facilitate operations and maintenance process through remote and centralized administration of WiFi network elements. This will save the effort of providing on-site support to configure and manage the network equipment in the field.

The functionalities of AWMS (Figure 12) include fault management, configuration management, accounting management, performance management and security management. Some of the key features are listed as follows:

- Network map support
- Automatic AP detection and provisioning;
- Template-based multiple AP configuration
- Automatic firmware upgrade
- Rogue AP detection
- Real-time network monitoring and proactive fault handling

- Dynamic frequency selection
- Multi-layer security management
- WDS link management: inventory, connection status and performance monitoring
- Performance monitoring and analysis: network wide traffic load and parameters tracking
- Mobile user tracking and reporting: client session notification and tracking

Figure 12: AWMS Functionalities



AWMS consists of 3 sub-systems, namely a proxy, a server and a user client. The proxy is the agent between a server and a group of base stations and it is used to manage a group of base stations. The server is the core component of AWMS and it controls the flow of instructions and results in the entire system. Lastly the user client provides a user-friendly graphical user interface (GUI) for network administrators and IT managers to manage and operate the WiFi network. There are different AWMS versions for different network sizes. For smaller networks, the proxy is integrated into the server component.

3. The Ideal Network Architecture of City-wide WiFi

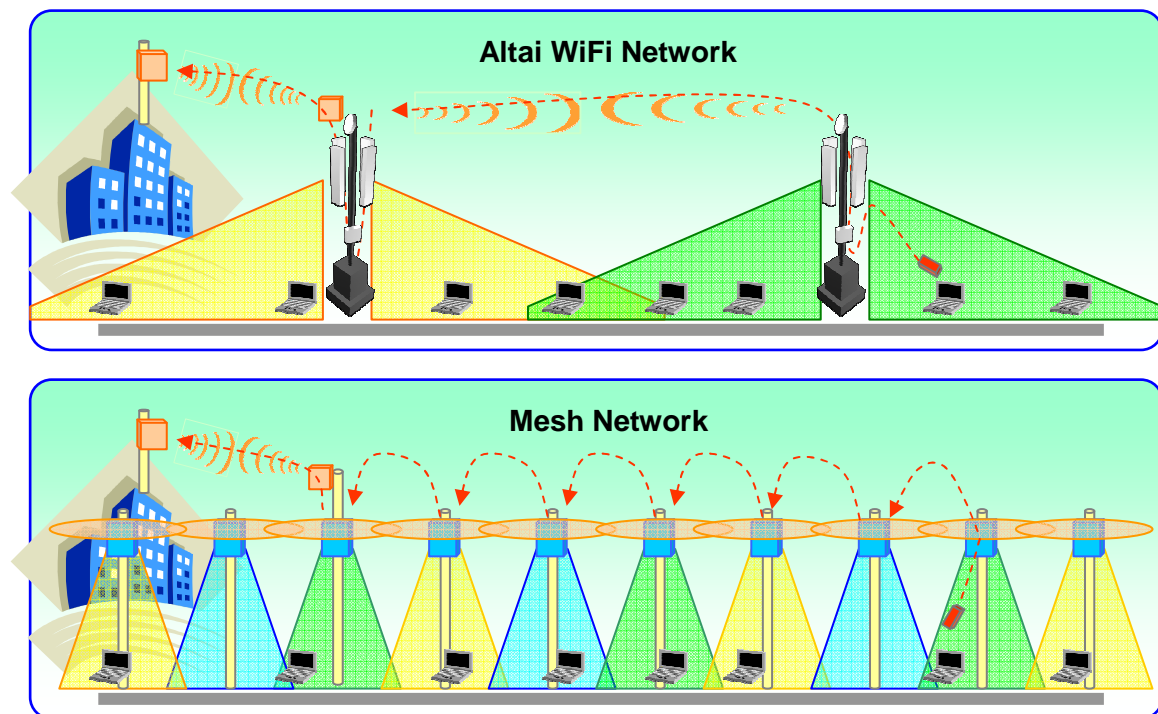
City-wide WiFi deployments across the globe are primarily using the mesh architecture, so the term “Metro Mesh” is commonly known nowadays. Mesh networking is a way to route the traffic between wireless nodes, the packets are transferred by hopping from node to node until the destination is reached. The reason of the mesh popularity is because of the ability to use one backhaul for a large number of APs, and also the site locations of the APs need not to be accurate enough as the APs themselves can self-organize to form a mesh network. However, there are high prices to pay for these simplicities.

Mesh technology is originated from military applications. This technology is developed to provide peer-to-peer connectivity on an ad-hoc basis, but it is not designed for multiple client terminals communicating with a serving radio in a client server mode.

Most Mesh APs are equipped with dual-radio system for access and backhaul connectivity. The mesh backhaul radios operate at the same frequency band and compete for bandwidth among them; this reduces the aggregate network capacity. In mesh architecture, the APs have to hear each other so the packets can be routed from one to another. There will be more overlapping area between adjacent APs. This scenario requires more mesh APs to be deployed to cover an area. On the other hand, apart from the capacity and coverage issue, there is another performance issue with the mesh architecture. The mesh routing algorithm requires the data stream to pass through a number of nodes to reach the end user. The hop count problem will give rise to the high latency issues which create problems in supporting delay-sensitive applications.

Altai has created the WiFi cellular architecture such that the backhaul is at most 2 hops away from the end user by forming bridge links, base station clusters and Pico-cell overlays for wide area coverage. This architecture can support real-time VoIP and video streaming applications. The network architecture difference is shown in Figure 13.

Figure 13: Altai WiFi Cellular vs. Mesh Architecture



4. Conclusion

Altai's WiFi Cellular Solution is well proven in the field that it can support the sophisticated requirements in a city-wide WiFi deployment. With its advanced technologies to breakthrough the conventional WLAN coverage area and all the necessary features to support real-time secure communications in an un-controllable RF environment, it provides a cost-effective network solution to address the growing city-wide WiFi market.

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