

The Google Muni Wifi Network Can it Compete with Cellular Voice?

Andres Arjona
Nokia Networks
andres.arjona@nokia.com

Sami Takala
Nokia Networks
sami.j.takala@nokia.com

Abstract

Muni WiFi deployments have been widely covered by the media during the last two years. However, the economical feasibility and performance of such deployments as an alternative for voice services has not been proven.

In this paper we measure the voice performance and coverage of the Google network. Then we evaluate the economical feasibility versus cellular deployments. The results show that providing a good service level for voice requires a much more expensive investment. Thus, Google's network is not a competitor for cellular voice. In the current deployment, VoIP is possible only in static scenarios and coverage across the city is not adequate except for the downtown area. For this reason, even though it is possible to use VoIP services in certain locations, the voice quality is far from optimal except for areas with excellent signal conditions. Unfortunately, such areas are rare. Likewise, access points are not densely deployed and lack coverage overlapping. Therefore, it is not possible to provide mobility to VoIP services. In mobility scenarios, voice quality degrades when the wireless link weakens and eventually the call is dropped before reaching coverage from the adjacent access point.

Keywords: Muni WiFi, VoIP performance, evaluation, mesh, Google, Skype

1. Introduction

Multiple Muni WiFi mesh deployments have been implemented or proposed during the last two years, particularly in the United States. However, there are many other countries and cities that have planned Muni WiFi deployments as well, such as a 12 city project in the United Kingdom.

Even though Muni WiFi mesh deployments have been spoken about widely, there are not many feasibility and performance studies that prove that these kinds of deployments are likely to be successful.

A WiFi mesh network is a network that employs one of two connection arrangements, full mesh topology or partial mesh topology. In the full mesh topology, each node is connected directly to each of the others (see Figure 1). In the partial mesh topology, nodes are connected to only some, not all, of the other nodes. Likewise, the network can be based on a single or dual radio solution. In a single radio solution, the same radio is used for access and backhaul. In a dual radio solution, access and backhaul operate at different frequencies, e.g. 2.4GHz for access and 5GHz for backhaul.

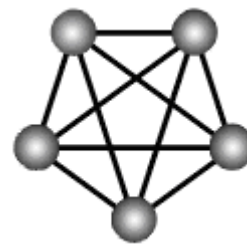


Figure 1. Mesh Network

Current rules of thumb for Muni WiFi deployments state that an average of 30 access points is required to cover a square mile (2.56 square kilometers). Thus, if all access points cover a circle of equal size, and are placed in the plane according to a triangular paving (hexagonal cell coverage) then each coverage disk is about 166 meters, and access points are 287 meters apart.

This research paper discusses the feasibility and performance of voice over IP services in Google's Muni WiFi mesh deployment. The Muni WiFi mesh architecture is evaluated for voice and as well as network coverage. In particular, the paper sets out to technically address whether voice over IP services could work in real-life scenarios using a Muni WiFi mesh as an access network. Based on the analysis of the measurements and performance the implications of whether this technology can compete with cellular voice are concluded.

2. WiFi Mesh Network Architecture

Google's Muni WiFi mesh deployment cost is estimated at roughly one million US dollars [7]. It consists of a network providing coverage to the city of Mountain View, in which Google's headquarters are located (see Figure 2). The network is free of cost and has the objective to be a proof of concept for Muni WiFi mesh deployments. The population in Mountain View is about 72,000 inhabitants. The network provides coverage to about 11.5 square miles (29.44 square kilometers) and consists mainly of the following elements [5]:

- 380 Tropos Access Points mounted on street lamps
- 1 Alvarion Gateway per every 6 access points
- 3 Bandwidth aggregation points connected to Google's Headquarters using GigaBeam equipment.

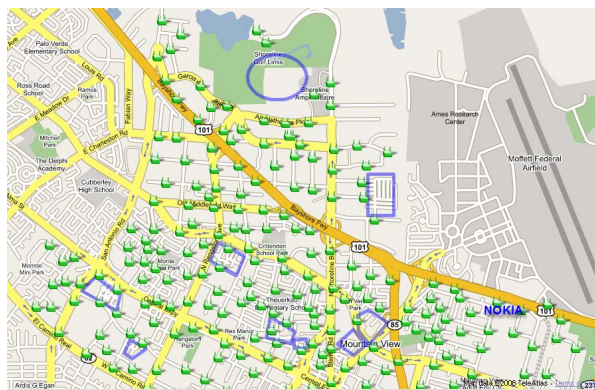


Figure 2. Google's Muni WiFi Network [4]

The network is based on a single-radio architecture in the 2.4GHz band. The deployment consists of small clusters of 6-8 access points connected to a gateway, which most nodes are one hop away. That is, roughly five gateways per square mile. The gateways are connected to an aggregation point using a point-to-point Gigabit wireless links. Such aggregation points support about 20 gateways.

The set of access points connected to the same gateway operate in the same frequency channel. Additionally, the bandwidth is restricted to 1Mbps for both Downlink and Uplink per each user.

Access to the Google network is free of charge and only requires the creation of a user account. By default, encryption is not applied but Google suggests users to download encryption software to protect the data. Likewise, Google encourages users to external adapters in order to access the service indoors.

3. Technical Setup

The goal of the tests was to assure what is the performance level that can be achieved in different common VoIP calls (e.g. Skype). All the scenarios and tests were carried out in outdoor conditions. The performance indoors is expected to be very poor due to propagation and therefore omitted in this study.

A way to define the quality of a location in order to measure performance can be done based on the signal to noise ratio (SNR). The SNR is measured based on the noise floor and the received signal strength from the access point (AP) to the mobile station (MS). Even though unbalance between uplink and bandwidth can result due to the difference in transmission power from the MS (~15-17 dBm) and AP (~20 dBm), the SNR is a relatively good measure of WiFi link condition.

The transmission rate between the AP and the MS is determined by the MS receiver sensitivity. Based on the transmission rate, two scenarios are depicted:

- Excellent Signal Conditions: SNR > 25 dB, providing transmission rates up to 54Mbps
- Medium Signal Conditions: SNR 18 – 24 dB; providing transmission rates up to 36Mbps

Signal conditions with SNR lower than 18 dBm are considered poor and due to packet loss and constant retransmissions are not feasible for VoIP services. However, it might still be possible to achieve connectivity with the AP. The minimum SNR required in order to associate with an AP is roughly 12dB.

3.1. Voice over IP

Voice over IP was measured objectively based on PESQ Mean Opinion Score (MOS) as depicted by Malden Digital Speech Level Analyzer [6]. The tests were carried in static locations selected based on SNR (excellent and medium). Figure 3 shows the VoIP testing configuration.

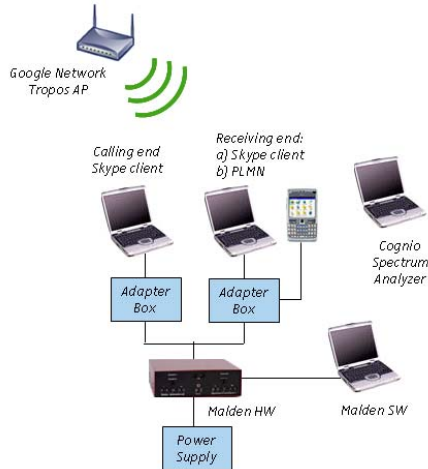


Figure 3. VoIP Testing Configuration

The testing methodology consisted of originating calls with Skype software to a) another Skype user and b) a cellular subscriber. Multiple iterations were carried out with different voice samples. In addition, the unlicensed spectrum was monitored with a spectrum analyzer to look for fluctuations in signal conditions during the tests.

3.2. Network Coverage

Network coverage of Google's WiFi network was measured based on three main types of locations in Mountain View.

- Suburban: Locations with dense foliage, many homes one next to each other, cars parked in front of homes, few people and little traffic. The streets are fairly narrow and most homes are two stories high.
- Enterprise: Locations consisting mainly of enterprise buildings, wide streets, parking lots, regular traffic, few trees and people.
- Urban: Location in the downtown area, constant traffic and pedestrians, mixture of moderate trees, bushes and commerce buildings.

Based on the above characterizations, several surveys were carried out in the three scenarios and coverage maps were generated with AirMagnet Surveyor tool.

4. Measurement Results

The results from the field tests are shown in the following sections.

4.1. Voice over IP

The subjective voice over IP quality tests results are shown in Figure 4 and Tables 1 and 2.

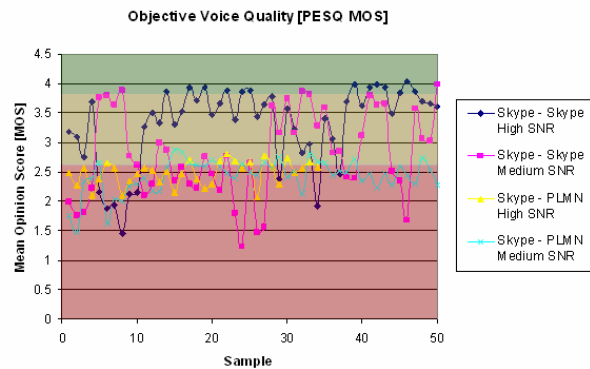


Figure 4. Objective Voice Quality (PESQ MOS)

Table 1. Objective Voice Quality Tests Summary

	High SNR	Medium SNR
Signal-to-Noise Ratio (SNR)	29	20
Noise	-92	-89
Signal Strength	-63	-69
Transmit Rate	54	36
Receive Rate	54	24
Channel	3	9
Skype – Skype MOS	3.3	2.8
Skype – Mobile MOS	2.5	2.4

The results show that good voice quality is possible in the case of Skype to Skype calls. However, the quality is very poor or literally at an unusable level in the case of calls made to cellular phones in the mobile network (see Figure 4 and Table 1). Likewise due the nature of the unlicensed spectrum, signal conditions might not be constant and decrease from time to time due to interferers. That is a possibility for the drops in voice quality during the tests in high SNR where interference from multiple devices was constant (see Table 2).

Table 2. Interferers in the 2.4 GHz Band during Voice Quality Tests with High SNR

Interferer	Avg. Pulse Duration	Avg. Power	Channels Affected
DECT BS	0.317 ms	-60 dBm	1-14
DECT BS	0.282 ms	-85 dBm	1-14
DECT BS	0.369 ms	-72 dBm	1-14
DECT BS	0.256 ms	-64 dBm	1-14

DECT BS	0.251 ms	-82 dBm	None
DECT BS	0.217 ms	-74 dBm	1-14
DECT Handset	0.839 ms	-83 dBm	1-7; 14
DECT BS	0.274 ms	-86 dBm	1-2;5-14
DECT BS	0.245 ms	-82 dBm	None
DECT BS	0.299 ms	-77 dBm	1-14
DECT BS	0.244 ms	-81 dBm	1-14

DECT devices operating in the 2.4 GHz band are widely implemented and available in the United States and therefore a common source of interference.[3]

4.2. Network Coverage

Figures 5 to 10 show the network coverage under the three different environment scenarios, suburban, enterprise and urban. The access points from the Google network are depicted as blue bubbles.



Figure 5: Suburban Coverage



Figure 6: Suburban Coverage (SNR > 25)

The measurement results from the suburban environment show that SNR levels between 15 and 25 dB are available (see Figure 5). However, coverage with excellent signal conditions (SNR > 25dB) is only available in very few areas (see Figure 6). Some of the reasons for this are the distance between each access point and also the dense foliage from the trees in the sidewalks. The access points do not seem to be in

optimal position and in some occasions the tree branches could directly obstruct the access points.



Figure 7: Enterprise Coverage



Figure 8: Enterprise Coverage (SNR > 25 dB)

The measurement results from the enterprise environment show that some areas with excellent signal conditions (SNR > 25 dB) are available (see Figure 7 and Figure 8). This difference when compared to the suburban environment is likely to be due to the wider streets, less trees in the area and parking lots that provide the opportunity to create a line of sight between the mobile station and the access point.



Figure 9: Urban Coverage



Figure 10. Urban Coverage (SNR > 25 dB)

The measurement results from the urban environment show that with an increased number of access points (compared to the previous locations), and the lack of trees and foliage, result in better coverage in the area (Figure 9). Likewise, areas with excellent signal conditions (SNR > 25 dB) are available in most of the downtown area (Figure 10).

5. Evaluation versus Cellular Voice

The measurement results prove that the Google network does not provide an adequate service across the city. Except for the downtown area, the access points are not densely deployed and there are several coverage holes. Our research is based on the assumption that all access points cover a circle of equal size, and are placed in the plane according to a triangular paving (hexagonal cell coverage). As a consequence of the current average of 30 access points per square mile, each coverage disk is about 166 meters, and access points are 287 meters apart. Using a free space propagation model ($\alpha = 2$) and the Friis formula in the 2.4GHz frequency band, the link budget at 166 meters is -84dBm. However, if we use a typical path-loss exponent for mid-density urban areas ($\alpha = 3.3$) [1], the link budget at 166 meters is -113dBm. The receiver sensitivity of an Atheros chipset, which is one of the main WLAN card manufacturers, is depicted by Atheros as follows:

- 802.11g: -90dBm@6Mbps, -71dBm@54Mbps
- 802.11b: -95dBm@1Mbps, -90dBm@11Mbps

The transmission power for the same chipset is:

- 802.11g 18dBm
- 802.11b 18dBm +/- 2dBm

With only 18dBm transmission power for the client, it is evident that transmission is possible for free space propagation, but not an exponent observed in real set-

ups. This can be demonstrated with the following calculation:

$$18\text{dBm} - 113\text{dB} = -95\text{dBm}$$

Furthermore, handheld devices have even less transmission power (usually 15dBm). Therefore, the current network architecture in Google cannot provide good connectivity. This is also a likely outcome in many other deployments based on 30 access points per mile. Table 3 shows other WLAN receiver sensitivity values as given by different manufacturers.

Table 3. WLAN Cards Receiver Sensitivity

Manufacturer	Receiver Sensitivity
Orinoco PMCI Silver/Gold	-82dBm@11Mbps
	-87dBm@5.5Mbps
	-91dBm@2Mbps
	-94dBm@1Mbps
Cisco Aironet 350	-85dBm@11Mbps
	-89dBm@5.5Mbps
	-91dBm@2Mbps
	-94dBm@1Mbps

With a transmission power of 20dBm and a receiver sensitivity of -90dBm, the resulting link budget equals 110dBm. Consequently, using the same typical path loss exponent for mid density urban areas of $\alpha = 3.3$, the cell radius is 130m. For 18dBm, it is 115m, and for 16dBm it is 100m.

In order to address the low transmission power of handheld devices, we assume a radius of 100m. With that cell radius size, 81 access points would be required to cover one square mile without overlapping in the covered areas. Therefore, even a higher number of access points would be required for efficient coverage. Figure 11 show the estimated costs of cellular and Muni WiFi deployments with 30 and 81 access point density per square mile.

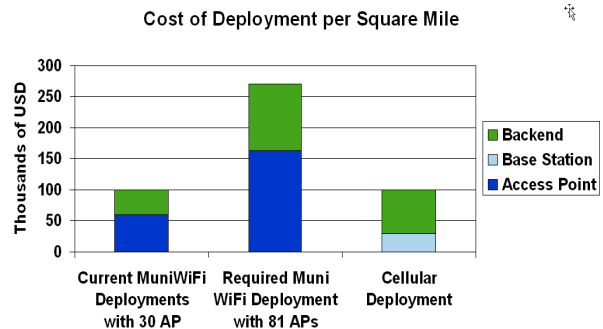


Figure 11. Evaluation of Cost of Deployment between Muni WiFi and Cellular

In contrast, the cost of building a cellular network base station site costs around 30,000 USD [2]. However, macro sites and installation costs can push the cost to 100,000 USD. This shows that the cost of current Muni WiFi deployments is already similar to cellular. The cost of Muni WiFi deployments is not an advantage over cellular deployments. Moreover, the cost of a Muni WiFi network with good coverage would raise the cost up to three times the current cost. Cellular deployments also provide much better coverage (e.g. indoors) where WiFi is heavily handicapped due outdoor-to-indoor wall attenuation. Nevertheless, it is important to note that cellular deployments require an expensive licensed spectrum and relatively expensive sites. Likewise, site acquisition of cellular sites is not always easy or cheap. But in such cases, very small nano base stations similar to WiFi access points can be installed.

The current Muni WiFi rule of thumb of 30 access points per square mile is possibly a consequence of the 100,000 USD cost per mile budget. With an average cost of 2,000 USD per access point, and the cost of a few aggregation nodes, network hardware in the backend and installation, the whole budget is consumed easily. A budget of 100,000 USD per square mile with 81 access points would impose a cost per access point of less than 740 USD.

6. Conclusion

The measurement results prove that the Google network does not provide an adequate service across all areas of the city. Except for the downtown area, the access points are not densely deployed and there are several coverage holes. However, depending on the location, there are indeed many spots available which provide service with a good link quality.

Voice services require an adequate WiFi link and are sensitive to delays and packet loss, thus making outdoor connections difficult. Therefore, due to these requirements, it is even harder to provide mobility, since WiFi coverage should be consistent and have a certain level of cell overlapping between access points. This kind of location was not found in the Google network during the tests. Therefore, whenever the WiFi link is weakened, the voice quality decreases and then the call is dropped. However, if the user is able to find a location with relatively decent WiFi link quality, it is possible to make VoIP calls with an adequate voice quality to other VoIP clients (assuming that the user remains static and the WiFi link in good condition). However, calls terminating in the mobile network had a very poor and often an unusable level of voice quality regardless of the WiFi link conditions.

Furthermore, the voice quality can further decrease due to the nature of the unlicensed spectrum e.g. interference from other WiFi devices, DECT base stations, DECT handsets and PDAs.

The economical feasibility of building Muni WiFi networks for voice is doubtful. With the current access point density, voice services cannot be supported properly. If a network with good coverage is to be deployed, the cost of such a network would be up to three times more expensive due to the large number of additional access points required. Therefore, unless the access point cost drops considerably, building such a network is very expensive and therefore not a real competitor for cellular voice.

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