Municipal wireless systems – RF ekistics

Charles I. Cook
Qwest Communications
Charles.Cook2@qwest.com

Thomas Schwengler
Qwest Communications
Thomas.Schwengler@qwest.com

Gilman R. Stevens
Qwest Communications
gil.stevens@qwest.com

ABSTRACT

A number of municipalities have studied opportunities to build large wireless networks at fairly low cost. In particular, the use of Wi-Fi is promising because of the low cost of hardware, license exempt spectrum, and the wide availability of customer equipment. On the other hand power limitations, interferences, and operations reliability are a concern for these networks.

This document focuses on the Municipal Wireless RF Ekistics. It reviews fundamental aspects of wireless communications from experiments and technical documents and applies the business due diligence basics. The document considers general wireless communications principles and presents aspects that must be considered for wireless systems such as Wi-Fi for coverage on the order of a municipal scale or a fairly large residential area.

INDEX TERMS

Muni Wi-Fi, Municipal wireless, Residential propagation models

I. INTRODUCTION

Wireless coverage provides an important asset both for voice and data communications. Voice services have been traditionally provided by cellular systems that focused on providing wide coverage, and they have subsequently evolved to provide higher data rates. Smaller wireless local area networks (LANs) have also provided good data services and have evolved toward greater range and voice services. Wi-Fi access points have become the standard in wireless local area networks, and their success is such that some recent applications are expanding their use to wider area networks, even for coverage of entire cities. These applications, however, are not always successful. This paper analyzes some of the fundamental principles required to design successful wireless systems.

Understanding the fundamentals of the unlicensed 2.4 GHz band and the Wi-Fi standard is, of course, important to design and build a reliable Wi-Fi network, and several more steps need to be considered for a successful large coverage area deployment. The first step is good RF (Radio Frequency) propagation planning; the second step is good urban planning; the third step is understanding consumer behavior for use of a wireless data service; the fourth step is business modeling using all the above information. This document provides insights into these points and addresses in particular:

1. RF planning and the need to outline a set of simplified general rules and associate business rules for basic municipal build out of a Wi-Fi network.
2. Wi-Fi signal, wavelength, and power as it relates to the basic square mile RF engineering and how to handle Wi-Fi RF engineering as it applies to residential zoning.
3. Basics of Wi-Fi capacity and performance engineering in a mesh configuration.
4. Complex Wi-Fi issues with angle of incidence, reflection, and refraction that affect performance in the outdoor-to-indoor and indoor and outdoor communication path in order to provide Internet service.
5. Take rate analysis for the different use models for Muni Wi-Fi as applied to meteorology of an outdoor area and human psychology of the mass market consumer.
6. Business model comparison to understand

the trends for outdoor wireless deployment for data services only without voice services.

Several different types of Wi-Fi designs exist: access points may be placed outdoors on street light poles or indoors; coverage may be designed for indoor areas or larger outdoor areas. Wi-Fi has proven to be an excellent technology of choice for indoor placement and indoor use. Wi-Fi has also proven to be a good technology choice for indoor placement and small area outdoor use. Some more robust equipment (albeit more expensive) also allow outdoor placement and outdoor use such as in a campus environment. The industry has been interested in expanding these successful models to the outdoor large-area placement model for either indoor or outdoor use. We will consider these expansions in this document and examine why–in some cases–such expansions might not necessarily be successful.

We will examine RF propagation characteristics along with other key parameters that are required for an outdoor large-area Wi-Fi deployment model to be successful. The primary focus of this document is large-coverage-area outdoor placement for indoor use and outdoor use. Large-area coverage is defined as where the coverage target exceeds one square mile.

II. BACKGROUND

A. *Summary of Simple RF Reference Points*

Wireless services are difficult to design, deploy, and optimize well, because of the many factors involved in wireless services and the complexity of the technology. The examples provided in this document are meant to represent data that fall into the bell curve 1-sigma of accuracy [1]. In other words, 68% of the time the example provided will be applicable, but there will be special conditions where the example data may not apply.

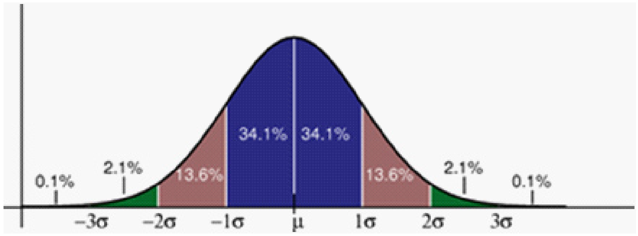


Figure 1. Normal distribution curve

The goal of establishing these examples is to illustrate the complexities of RF engineering to set the appropriate level of expectation with those who install Wi-Fi or other wireless services.

B. *RF Issues to Consider*

Wireless RF systems have many factors that can affect the ability for the signal to connect between two points and for the information to be sent correctly. Some, but not all, of these variables include:

- Weather (temperature, humidity, rain, snow, wind)
- Terrain and building conditions (and vegetation)
- RF parameters and their tradeoffs

Important parameters of any radio system are traded off for others: coverage, capacity, throughput, latency, availability, and reliability. Many radio system parameters are considered: wavelength or frequency ⇔ transmit power ⇔ distance ⇔ angles of incidence ⇔ number of materials going through ⇔ antenna gain ⇔ refraction by material type ⇔ material dielectric constants ⇔ material permittivity ⇔ interference.

These factors allow radio system designers a wide range of parameters to optimize based on different applications, from mobile cellular networks to fixed high-capacity systems. The many combinations of variables make precise predictions difficult; therefore, scientific measurements, lab tests, and field trials are conducted to derive general engineering guidelines. These guidelines are typically used for initial radio designs over large areas and provide some degrees of uncertainty; they may be refined at later stages with more extensive field measurements.

Expertise in wireless operations shows that careful initial planning for RF coverage will provide good estimates, but it should be emphasized that these rules may not be valid in all situations, and some variability is inevitable. Overly conservative estimates may limit risks of bad coverage, but are too costly and overly optimistic designs appear much cheaper but will result in poor network performance.

III. RF PROPAGATION ANALYSIS

Wi-Fi products are based on the IEEE 802.11b/g/a standards. These products rely on radio air interfaces defined for use in unlicensed bands in the US. They mostly use orthogonal frequency multiplexing, a very efficient technique designed to support high data speeds. Key elements of radio communications, such as basic propagation characteristics and probability of sufficient signal strength, are still of the utmost importance and must be carefully analyzed. These other factors must also be considered when estimating the distance placed between the transmitter and receiver in a wireless network to ensure a quality customer experience

A. Propagation Models

Between transmitter and receiver, the wireless channel is modeled by several key parameters. These parameters vary significantly with the environment, rural versus urban, or flat versus mountainous [2], [3].

Different propagation models are used in the industry depending on terrain data available. A handful of empirical models have been widely accepted for cellular communications, their success being mostly due to their simplicity and their fairly good prediction for first order modeling. Some of these models have been extended to Wi-Fi frequencies and are used to predict propagation path loss as a function of distance. In many cases these propagation models provide a good path loss estimate for general coverage prediction.

One-Slope Empirical Models

One-slope Empirical Models show linear trends with distance logarithms using parameters derived from extensive data measurement campaigns typically between 900 MHz and 2.5 GHz.[2]. Figure 2 is an example of a One-slope Empirical Model used to demonstrate wireless signal loss vs. the distance between the transmitter and receiver. These models show a good first estimate for signal strength estimation as a function of distance in a given environment, but they are imprecise since they do not take into account details such as terrain types, building types, and trees or other obstructions.

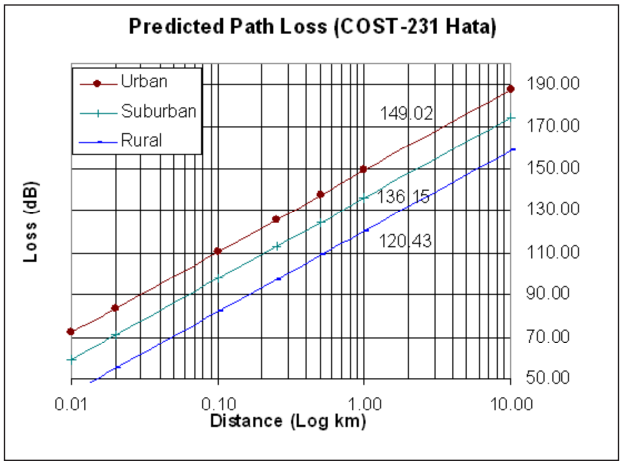


Figure 2. Path loss prediction with one-slope models, example using COST 231- Hata model extended to 2.4 GHz, with access points placed 30-feet high

Ray-Tracing Models

Ray-tracing is a general technique of modeling the path taken by radio waves by rays of light as they interact with optical surfaces. Much like a light source emits a ray of light, which eventually comes into contact with a surface interrupting its progress. Radio transmitters emit a similar signal that encounters various obstacles on its path [3]. The frequency of signal as well as the type of obstructions have a major impact on the type of reflection, refraction, and absorption by an obstacle. A surface generally reflects part of the ray, in one or more directions; it may also absorb a portion of the ray, resulting in a loss of intensity of the reflected and refracted light [4].

Ray-tracing models may be used in urban corridors and residential neighborhoods because they take into account reflections off the ground and off neighboring buildings, which are typical in urban areas. The ray-tracing model uses optical-like rays measured from the transmitter to the receiver. Ray-tracing models have the advantage of providing more detailed information of the effects of obstructions, reflections, and refractions in the path and are largely used by commercial software for detailed coverage maps.

For instance, a simple model may be derived that takes into consideration several rays bouncing off the ground and off buildings to show the following approximation in a typical suburban area. (See the lines in blue and red in Figure 3. The green line is added for comparison of a one-slope model as shown in Figure 2.)

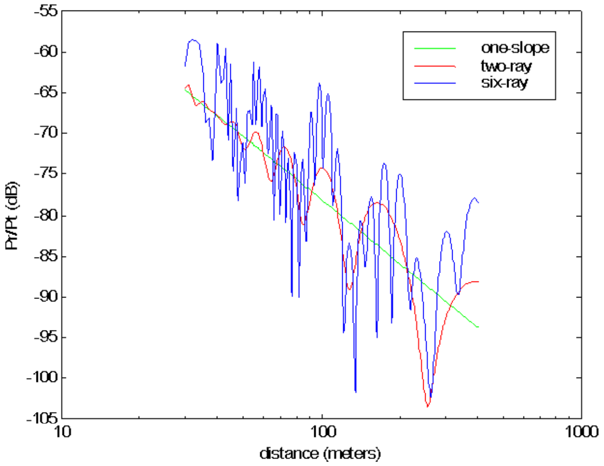


Figure 3. Signal strength prediction with one-slope, 2-ray, and 6-ray models

The above is an example of a chart created using a ray-tracing model for a typical suburban neighborhood with average residential street widths and home separations. Figure 3 helps to demonstrate the difficulty to predict reliable Wi-Fi coverage; the figure shows that one home may have low signal strength, whereas another home may have good signal strength. This is one of the many RF dilemmas that service providers must work through to provide consistent performance and service among the customers. This signal strength change is not intuitively obvious and can cause customer confusion and complaints.

Ray-tracing models also help illustrate that wireless coverage does not degrade in a linear fashion. There are many nulls that are the result of reflections adding and cancelling signal strength at various distances. A drawback for the ray-tracing model is that detailed descriptions of the Wi-Fi coverage area are required for precise predictions. The cost and time involved for establishing accurate prediction tools are not negligible. Generally, the predictions become more accurate with precise building data.

Empirical Measurements

In all cases, empirical measurements and extensive drive tests are made in the last design phases and used to adjust the above models. Many commercial software packages allow these measurements to be added into models for improved results.

B. Important Propagation Parameters

Propagation models give a good median prediction for distance versus signal strength, which in turn allows for good throughput vs. distance predictions for Wi-Fi deployment. It should, however, be emphasized that many parameters come into play for more reliable predictions; they are reviewed in more detail in this section.

Wavelength and Frequency

The wavelength of the Wi-Fi signal is smaller than that of more commonly used cellular and TV band frequencies. Wi-Fi operates at 2.4 GHz for 802.11b and 802.11g products and at 5.8 GHz for 802.11a products. The 2.4 GHz signal has a wavelength of 4.9 inches, and the 5.8 GHz frequency has a wavelength of 2.8 inches. As a comparison the cellular frequencies in the US operate at 900 MHz, which has a wavelength of 13.1 inches. The highly sought-after TV bands operate at 700 MHz with a wavelength of 16 inches.

The practical significance is that the Wi-Fi signal is attenuated by a wide range of obstructions. Higher wavelength cellular and TV bands can penetrate most walls, whereas higher frequencies are likely to suffer a higher degree of transmission loss as the thickness of the wall increases. This makes lower frequencies more valuable for reasons such as:

1. Varying weather conditions have less of an impact on transmission loss on the lower frequency TV-band signal;
2. Lowering frequencies tend to scatter better around objects thus allowing for non-line-of-sight communications; and
3. Lowering frequencies tend to penetrate better through vegetation and into buildings.

Power

Wi-Fi signals have low power strengths, which vary depending on the access points but are regulated by FCC rules, part 15 [5]. Outdoor Wi-Fi units are typically limited to 4W (36 dBm) effective isotropic-rated power (EIRP). Indoor client devices' EIRP may range from 17dBm to 18 dBm depending on the wireless LAN products.

A typical wireless CDMA EVDO handset (with support up to 3.1Mbps of data transport) may have a power output of 24dBm, and a cellular base station (GSM, CDMA, UMTS or WiMAX) may transmit up to 60 dBm; the cellular handset and base station combination is much more powerful than a Wi-Fi indoor router and outdoor router, and thus, along with longer wavelength, has much better performance than an outdoor-to-indoor Wi-Fi model[6].

Antenna directivity and gain are also restricted for use with Wi-Fi. Cellular networks make extensive use of these antennas that provide higher gain in a specific direction.

- Outdoor antenna gain.

Larger antennas may be used to increase power in certain directions. These antennas are typically larger and more expensive but can achieve higher gain.

- Indoor antenna gain.

Most client-device antenna gains are very low (a few dBi) because of the fairly small sizes required, as well as the fact that these antennas must be capable of receiving a signal from any direction because of the mobile or portable aspect of the client.

Antenna gain is an important design parameter: the cost of installation, placement, orientation, and down tilt need to be carefully engineered for optimum signal propagation as well as interference mitigation.

Distance

Wireless signal strength decreases as the distance from the wireless access point increases. Simple radio propagation models typically estimate power loss as an inverse power law of the distance. For instance, free space loss occurs as 1/d2, and empirical models show power loss in 1/dn with the path-loss exponent n between 2.6 and 4 depending on terrain conditions and obstructions[3].

With these simple models, signal path calculators can be derived [7]: at 2.4 GHz a simplified engineering rule for business analysis for reliable outdoor signal strength is between 1000 feet to 1500 feet radius. For indoor use, the simplified rule is approximately a 300-foot radius. These numbers are based on power levels within and at or near the upper bound of allowable power as specified by FCC rules [5].

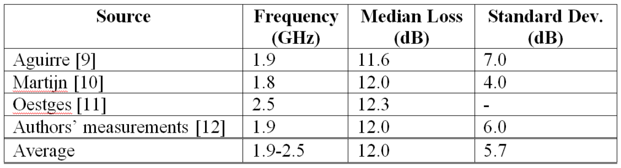
It is important to have a good signal loss calculator accurately account for the power and angle of incidence along the block from where the outdoor access point is located and the building where the indoor penetration is required. The farther away the building is from the wireless access point, the lower the power level will be to penetrate the wall, resulting in a poor customer experience.

Wall Obstructions

The loss of signal strength due to a wall obstruction is difficult to measure because outside and inside measurements must be made; the two environments are very different since the indoor environment has many more multiple paths. The amount of multipath is very large. For example, from an outdoor unit to an indoor unit; since the signal may propagate through the wall, through windows, first reflect off the neighbor's external wall across the street, or even scatter and reflect through the roof line and down from the ceiling. Therefore, wall penetration losses reported in the literature vary greatly [8].

The mean and standard deviations of indoor penetration loss vary with frequency, types of homes, and the environment around the homes. Variations also depend on the location of the wireless indoor unit within the building (near an outside wall, a window, or further inside). Precise characterization of in-building penetration is, therefore, difficult. Nonetheless, an approximation of an average penetration loss around 12 to 15 dB and a standard deviation between 5-8 dB seems to be the norm in published studies (references listed in the Table 1). Table I summarizes examples of published results demonstrating outdoor-to-indoor penetration loss for suburban areas.

Table I. Median and standard deviation for outdoor-to-indoor penetration loss in surburan areas



Source	Frequency (GHz)	Median Loss (dB)	Standard Dev. (dB)
Aguirre [9]	1.9	11.6	7.0
Martijn [10]	1.8	12.0	4.0
Oestges [11]	2.5	12.3	-
Authors' measurements [12]	1.9	12.0	6.0
Average	1.9-2.5	12.0	5.7

Penetration loss also strongly depends on angle of incidence. A direct line of sight perpendicular wave penetrates an obstruction much better than obliquely incident waves (see also section on Angle of Incidence and Refraction).

Finally, overall probability of wall loss may be summarized by a distribution function showing the amount of fade margin required to provide indoor coverage as represented in Figure 4 as obtained from measurements in a typical Denver residential neighborhood. Note the chart does not consider additional penetration losses contributed by angle of incidence.

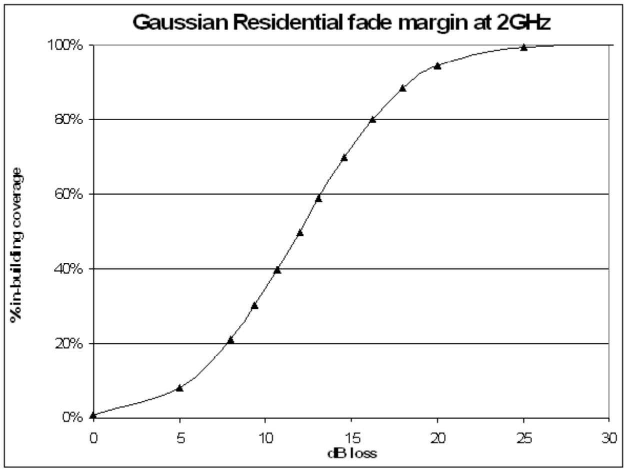


Figure 4. Percentage building coverage as a function of building penetration loss as measured in a residential area

Tree Obstructions

Vegetation and foliage causes severe radio attenuation. [14],[15] The added difficulty of prediction for foliage comes from the fact that propagation losses vary with the position of the transmitter with respect to the tree; they also vary with seasons (especially in deciduous trees), with the amount of rain, and even with wind conditions. [16] They also vary relative to the length of conifer needles with respect to wavelength.

From the information above, the following conclusions may be drawn:

- Coniferous trees: cause an average attenuation of 10 dB.
- Deciduous trees: cause an average attenuation of 6 to 12 dB (depending on the season).
- The information in Figure 4 leads to the simplified engineering rule for business analysis that 1 external wall and 2 deciduous trees are the limit for minimal service, or 1 external wall and 1 coniferous tree is the other limit for minimal service.

Environmental Factors Such as Snow, Rain, Fog, Smog, Temperature, and Humidity

At Wi-Fi frequencies, direct rain attenuation is not noticeable. Rain, however, may affect vegetation signal loss and indoor penetration, since wet materials change permittivity and may lower the amount of power reaching indoors.

- Rain on trees, moisture, and humidity have an effect on signal strength. Tests show that wet trees cause an average 16 dB loss.
- Wind blowing through the leaves creates many problems for signal strength, thus a general rule for wind and trees is that a five-mile-per-hour wind will create a greater dispersion of signal loss, which can increase dropped packets and thus overall performance. Higher winds will have a higher dispersion of the signal and thus an increase in the problems in achieving a given performance [16].
- Angle of Incidence and Refraction

Power loss is greater at acute angles [8], [11]. Figure 5 uses an example of a 10-degree angle as the maximum angle to engineer along the homes or buildings of a particular street. The power loss at 10 degrees is roughly 22% and at a 5-degree angle represents roughly a 47% power loss [17], [18].

Figure 5 illustrates the impact of angle of incidence using a view down the street, the top view and then the angles from the Wi-Fi placement.

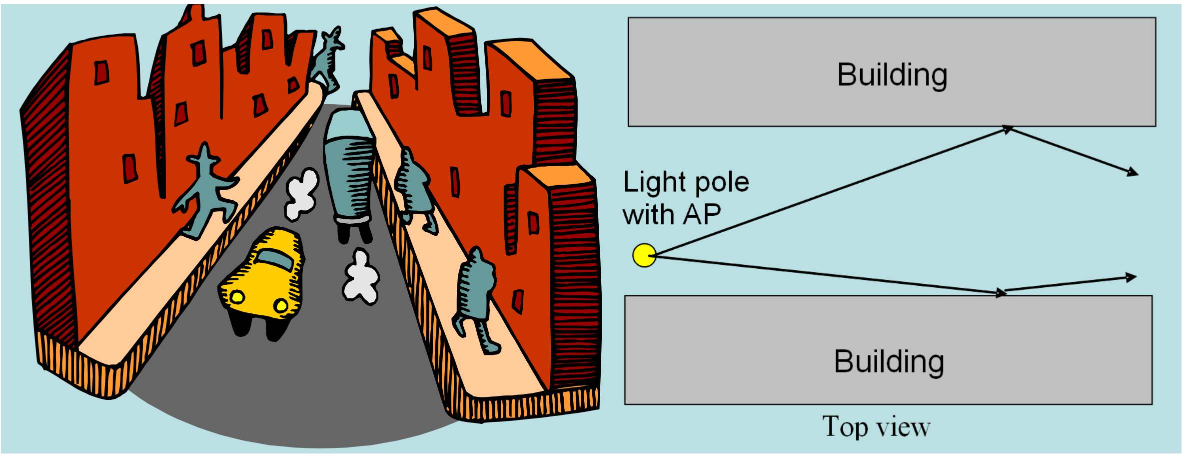


Figure 5. 2 Panel view for angle of incidence

- The left frame is an example of a downtown corridor with a Wi-Fi access point attached to a streetlight.
- The right frame shows the street top view and angles of incidence. The important item to note is that angles of incidence will cause differences of indoor coverage between street sides.

Dielectric Constants vary with the type of building material; therefore, the portion of power penetrating in homes varies with the types of homes ([4] Table 3.1, p. 55). In typical residential streets, angles of incidence of the nearest direct path can be as low as 4 to 11 degrees. For these acute angles, a large portion of power is reflected, and the portion of power actually entering buildings is approximately 10-40% depending on building materials as tabulated below ([3, p. 35], [17], [18]).

Table II. Typical oblique angles around 10 degrees down a street will cause the following attenuation for penetration into buildings

Wall	**Relative permittivity**	**Percent power penetrating wall**
Glass	3.8 - 8	10-20%
Wood	1.5 - 2.1	30-40%
Gypsum board	2.8	23%
Chip board	2.9	22%
Dry brick	4	18%
Dry concrete	4 - 6	14%
Aerated concrete	2 - 3	20-30%
Limestone	7.5	13%
Marble	11.6	10%
Ground	15	8%
Water	81	3%
Snow	1.2 - 1.5	40-50%
Ice	3.2	20%

Models and empirical experiments show the large variations between indoor coverage characteristics and outdoor coverage characteristics. In some cases, such as a typical residential area, where access points are placed on streetlight poles, outdoor coverage is adequate, but waves impinging on the residences have a low angle of incidence and penetrate poorly.

Figure 6 illustrates a typical suburban neighborhood with homes made of bricks and wood and light poles alternating on every side, every three homes. It illustrates that for some homes, although outdoor power levels are satisfactory, indoor levels are insufficient.

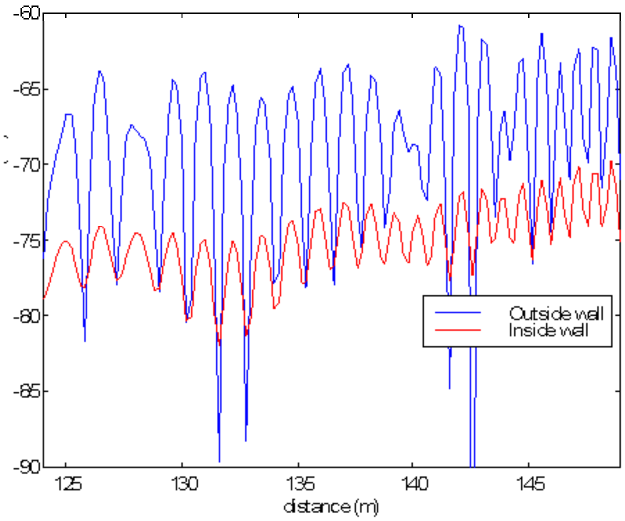


Figure 6. Indoor and outdoor power levels (in dBm) for a typical Wi-Fi system covering a residential home, AP placed 400 feet from two light poles, one on each side of the street

The distance between access points causes, of course, additional propagation power loss, but also has the effect of making angles of incidence on homes more acute and, therefore, lowers power actually penetrating indoors. This is better explained in the section on zoning and homes per acre and the corresponding front-yard-to-pole placement and the distance along the row of homes before the angle of incidence becomes small enough to create a refraction problem for penetrating indoors.

IV. COVERAGE AND CAPACITY PLANNING

All the above characteristics are summarized by a system link budget, which is used to design and plan a radio system for coverage and capacity.

A. *Coverage Planning*

The link budget of a radio system allows radio planners to predict performance versus range in various environments. A Wi-Fi system has different possible modulations with different throughput. Typical throughput versus distance depends on propagation characteristics as outlined above and also on other sources of interference. Link budget analyses can predict concentric areas in which certain performance is expected, but other sources of interference are often unknown, variable in time, and difficult to predict.

Radio Planners start from expected coverage estimates based on system link budget (mainly system power, antenna gain and receiver sensitivity) and take into account some modeling for the environment to cover (residential or urban, indoor or outdoor). In this phase, an excess margin is also added to the link budget to provide a given service reliability; typically chosen to provide in excess of 90% service reliability within advertised coverage [2],[3].

Initial planning is then modified further after field measurements and includes interference measurements. Frequency use and reuse patterns are determined with access point placement proposed. Actual placement often depends on many other parameters, such as real estate considerations. The resulting design is then used for initial roll-out and is still regularly optimized as the environment changes. In unlicensed operations, such as Wi-Fi, perform such verification often due to external interference sources.

B. *Capacity Planning*

All network architectures have what are called choke points or bottlenecks. Understanding these bottlenecks is critical in order to meet the busy-hour-high-use time periods.

Wi-Fi 802.11b/g may use 11 different channels in the US; however, only three channels are non-overlapping and thus only these three can provide a full channel of capacity. So typical Wi-Fi systems use three channels (1, 6, and 11) to cover the area (although four-channel reuse with some overlap have been used as well).

Wi-Fi access by 802.11 b/g is often advertised at speeds up to 54 Mb/s. Practically, only 25-30 Mb/s may be achieved (in the best lab conditions). Also, although the number of 802.11b client devices is decreasing, the presence of these older cards may have an impact: they can, of course, access an 802.11g Wi-Fi network, but they will cause that access point to operate in 802.11b mode at lower modulation and lower throughput.

For a Wi-Fi mesh configuration [19] and multiple radios where one radio is used for access and another for backhaul, an 802.11a/g 54 Mb/s backhaul link has less than 50% usable bandwidth. Some equipment tested in the lab showed a 75% throughput degradation from the root node to the next node. To reduce cost, some access points use the same radio for access and backhaul, which further reduces multihop capacity.

Careful analyses and tests must be performed to identify bottlenecks of a meshed system. A Wi-Fi Mesh network may be designed with a ratio of 30 nodes per backhauled (or root) node (30:1), but providing reliable service on the order of 1 Mb/s requires fewer hops and more backhaul in recently conducted tests. For the purposes of this document, we use a simplified engineering rule to business analysis and derive that a 10:1 and no more than a two-hop configuration will be used to engineer the Wi-Fi mesh network. This is an important number for determining operating costs, since the access points (where you have the interconnection to a fixed wireline service) require at least a 25 Mb/s or higher connection for every 10 Access Points in the network.

If Voice over Wi-Fi is planned, fewer hops and more backhaul are required, leading to an estimated 5:1 or 3:1 Mesh ratio. The human ear has a very low tolerance for delays. Mean opinion scores (MOS) for voice quality degrade significantly beyond 400 ms delays, while the human eye for Internet surfing can easily tolerate several seconds delay for information coming from the Internet [20]. Multiple simultaneous users in the same Wi-Fi hotspot need to be tested to truly assess the quality of VoIP.

C. *Interference Considerations*

Coverage and capacity predictions are only the first step for sizing a Wi-Fi system. When licensed spectrum is used, that spectrum is cleared prior to roll-out. This usually provides sufficient guarantees that no unwanted interferer will disrupt service. In unlicensed operations, such as Wi-Fi, however, the consideration of interference is often dominant.

Solving Wi-Fi interference presents two challenges, including:

1. Interferences vary with usage patterns, time of day, and seasonal variations.
2. Interferences may appear unpredictably with new or modified wireless systems upon which a service provider has no control.

Dense urban cores use Wi-Fi frequencies heavily, and complete reliable coverage is a challenge and requires a fairly high density of access points. Luckily, suburban area studies and drive tests have shown that many suburban areas see fairly low levels of interferences [21]. Nevertheless, these drive tests show peaks in most areas reaching or exceeding -70 dBm in the 2.4 GHz ISM band (also some increased activity in the 5.8 GHz UNII band); these peaks may be caused by a variety of devices and may have an impact on Wi-Fi systems.

Some cities have seen significant interference increases in such levels in the last year, and drive tests repeated at 12-month intervals show significant differences in dense areas. Suburban areas are beginning to see a similar trend. Other tests made at fixed locations over several days also show strong daily variations. In one instance industrial microwave ovens caused repeated high-level interference nearly every day around lunch time.

Although these interferences are in most cases manageable, they cannot be ignored and have a strong impact on long-term operations. In particular, they cause difficulties in spectrum reuse patterns for contiguous coverage and strongly encourage remote and even dynamic methods to change and optimize RF channel selection.

The indoor environment is somewhat more shielded and benefits from better SNR in an indoor-to-outdoor coverage solution. Indoor coverage from outdoor systems is, therefore, more unreliable due to weaker indoor signals and increased likelihood of multiple outdoors sources of interferences.

Outdoor coverage is inherently unreliable, but may be sufficient for citizens' use. It is, therefore, not recommended to rely on outdoor Wi-Fi coverage for emergency responses. Licensed spectrum such as 700 MHz to 900 MHz (including 800 MHz cellular) and 1900 MHz (cellular PCS) are much better suited for reliable, ubiquitous, first-respondent support. The new 4.9 GHz band unfortunately suffers from poorer propagation properties and requires specific devices that have yet to reach good economies of scale. The 4.9 GHz frequency is also limited by low power similar to Wi-Fi frequencies and thus has similar radius coverage limitations to those found in Wi-Fi. The FCC recognizes these facts and proposes to allocate a portion of 700 MHz for public safety [22].

V. CONCLUSION

Wi-Fi is a wonderful standard that achieves industry-wide acceptance, good economies of scales and speed of deployment in unlicensed frequency bands. Consequently, Wi-Fi deployments offer well-proven models for local area networks. Yet these models for Wi-Fi hotspots may not necessarily extend into a successful, economical, large-area outdoor Wi-Fi coverage model.

Wi-Fi as a large-area-outdoor-coverage technology has different technical challenges and brings cost factors to new businesses. Thus, the sum of the complexities can result in difficult initial build out, as well as very costly operations to support acceptable service levels. Wi-Fi products are geared toward small-area coverage, but can be costly in comparison to wireless technologies like EVDO, HSPA, and WiMAX, that are specifically designed for large-area coverage.

Wireless cellular systems have typically started by covering large-outdoor areas and have more recently focused on smaller footprint and higher data rates for better indoor coverage. Wi-Fi deployments are well suited for these indoor services but face significant problems for outdoor use over a large area as compared to other cellular data technologies.

Wireless technologies need extensive analyses for new wireless service offerings: one must start with the basics of wave propagation and then factor in complex analysis and modeling. The set of key preliminary issues that must be considered include all the items in this document, and each of these areas must be thoroughly understood for reliable coverage, capacity, resulting operations and customer service. In the case of Wi-Fi, in the 2.4 GHz frequency block, the model is excellent for small-area indoor placement and indoor use, very good for small-area outdoor placement and limited-area outdoor use, but based on the existing available results, a potentially costly and poor service for large-area coverage in outdoor-to-indoor placement and use or large- area outdoor use models.

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CHARLES I. COOK is with Qwest Communications, Denver, CO (phone: 303-896-5652; FAX: 925-281-0662. He holds an M.E. from Cornell University, Ithaca, NY, holds more than 20 patents, and is a senior member of the IEEE.

DR. THOMAS SCHWENGLER is with Qwest Communications, Denver, CO (phone: 303-896-1291; FAX: 303-896-7040. He holds a PhD and M.S. from the University of Colorado, Boulder. He teaches at the University of Colorado Interdisciplinary Telecommunications Program. He holds a dozen patents and is a senior member of the IEEE.

GILMAN R. STEVENS is with Qwest Communications, out of the Dallas, TX office (phone: 972-855-7575; FAX: 972-720-2912. He holds a BA from the University of Colorado in Math and Computer Science, Boulder, CO. He holds eight issued patents.