802.11a Wireless Network Issues in Warehouses & Distribution Centers (vs 802.11b)
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Introduction
A number of 802.11a products have begun to appear in the marketplace. The availability of these products has caused wireless network managers to wonder if it is now time to begin considering deploying 802.11a products.

This paper attempts to present some of the issues that still surround 802.11a wireless network deployments, particularly in automated data collection (ADC) environments – typically warehouses and distribution centers. In many cases, the issues are just that – issues. Because of immaturity of these products, there still are no definitive answers to many of the questions that arise. The goal of this paper is to present the issues, along with the best relevant information available today. This paper also presents some ‘educated guesses’ about the impact of these issues. Finally, this paper concludes with a forecast of how radio frequency technology is likely to play out for warehouse applications.

Background
802.11a provides for maximum wireless signaling rates of up to 54 Mbps using frequencies in the 5 GHz band. This compares to a maximum signaling rate of 11 Mbps in the 2.4 GHz band with 802.11b.

The Institute of Electrical and Electronics Engineers (IEEE) ratified the 802.11a specification in 1999 – about the same time as the 802.11b specification was ratified. 802.11a products are only just now appearing on the market because of the technical difficulties of implementing the 5 GHz radio and encoding techniques required by the standard.

Data Collection Clients (Terminals) for 802.11a
Perhaps it is best to start with the data collection clients currently available to use 802.11a networking: They don’t exist! The current crop of 802.11a radios all use a 32-bit I/O interface. 32-bit interfaces have been common on laptop computers for several years now. However, they do not exist on data collection clients. All of today’s data collection clients are based on microprocessors designed for 16-bit interfaces. This includes even the latest Windows CE devices based on StrongArm and Xscale microprocessors. LXE anticipates that it will be at least a year before any data collection computers are capable of integrating 802.11a radios.

Note that this limitation is not confined to industrial mobile computers. Consumer mobile computers, such as personal digital assistants (PDAs) are also constrained to 16-bit interfaces. None of the current market of PDAs is capable of 802.11a networking.
Indoor Applications Only
The 5 GHz frequencies used by 802.11a are referred to as the Unlicensed National Information Infrastructure (UNII) bands. There are three separate UNII bands defined by the FCC. The majority of 802.11a radios on the market today operate in the UNII-1 and UNII-2 frequency bands. FCC regulations restrict unlicensed transmitters in the UNII-1 band to indoor applications only. Therefore, today’s 802.11a radios can be used indoors only.

This situation, like many of the other disadvantages of 802.11a, will be overcome in time. Radio manufacturers will produce some UNII-2 only radios that can be used outdoors – but with only 4 channels to choose from, not 8 as with the current UNII-1/UNII-2 radios. The UNII-3 band will also be used for outdoor applications – most likely wireless bridging. There currently are no radios that operate in the UNII-3 band.

Incomplete Worldwide Adoption
As of this writing, the 802.11a standard is applicable only in the Americas and in the Asia/Pacific regions. The frequency bands used by 802.11a are not approved for unlicensed use in the European Union. Until this issue is resolved, multi-national organizations will be unable to standardize on the 802.11a technology. In contrast, 802.11b technology is compatible with all regulatory domains.

The IEEE 802.11h task group is now working on the issues required for European adoption of the 802.11a frequency bands. Task Group h has not yet completed its work. (Once it does, expect a new radio designation: 802.11h. 802.11h radios will fundamentally be the same as 802.11a radios but will implement the new features required for compliance with European regulations.)

Higher Data Rates
802.11a products can transmit at 54, 48, 36, 24, 18, 12 or 6 Mbps. By contrast, 802.11b signaling rates are 11, 5.5, 2 or 1 Mbps. In addition, 802.11a protocols are slightly more efficient than 802.11b at the highest signaling rates. Effective throughput with 802.11a is approximately 28.3 Mbps at the 54 Mbps signaling rate, whereas 802.11b delivers only about 5.2 Mbps at the 11 Mbps signaling rate.

<table>
<thead>
<tr>
<th>Signaling Rate</th>
<th>802.11a Throughput</th>
<th>802.11b Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>28.3</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>26.2</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>21.5</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>15.8</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>12.4</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>4.6</td>
<td></td>
</tr>
<tr>
<td>5.5</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.8</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: 802.11 data rates and approximate throughput (in Mbps)
Increased Non-Overlapping Channels

802.11a allows for 8 channels whose frequencies do not overlap. While 802.11b defines up to 14 channels, these channels overlap in such a way that only 3 non-overlapping channels can be selected. The advantage to non-overlapping channels is that they allow more flexibility in access point placement and network configuration.

Overlapping channels create interference, which reduces the effective throughput from both channels. Non-overlapping channels do not interfere with each other, and allow full throughput on both channels. 802.11b networks can be installed to avoid overlapping channels, as illustrated below, but this arrangement allows little flexibility to provide redundant coverage or co-located wireless networks.

The eight non-overlapping channels available in 802.11a allow additional network configurations. An 802.11a wireless network can be installed to maximize separation between adjacent channels, as shown in Figure 2.
An alternate layout for 802.11a might be to provide more than one channel of coverage in each location. This can be done to provide additional bandwidth to support increased numbers of clients, or it can be done to segment wireless users into different workgroups. (This last is the real purpose of the 802.11 service set identifier.) The configuration illustrated in Figure 3 will deliver an aggregate signaling rate of 108 Mbps.

**Fewer Sources of Interference**

The 2.4 GHz frequency band occupied by 802.11b is shared with a variety of other equipment. Microwave ovens, some auto paint curing facilities, some outdoor lighting and Bluetooth personal area networks are examples of equipment that generate 2.4 GHz radio waves capable of interfering with 802.11b networks.

At present, the 5.2 GHz band used by 802.11a does not suffer from as many sources of interference. Some radar equipment uses 5.2 GHz, but otherwise the band is fairly empty. This situation may change as other RF enabled products are developed.

**Decreased Range At Maximum Throughput**

Prior to real product shipments, there was a lot contradictory speculation regarding the range of 802.11a products compared to 802.11b. 802.11a chip makers and those attempting to stimulate the market for 802.11a products claimed that the range of 802.11a products would be equal to or exceed 802.11b ranges at equal data rates. Others stated this could not possibly be so because physics indicates that both an increase in frequency and increased data rates (more complex encoding schemes) contribute to reduced ranges.

There are now some 802.11a products shipping, so we can examine some of these claims with real data. The data below comes from the data sheet of one access point that is capable of using both 802.11a and 802.11b radios. The data given is for indoor environments. (Whatever an indoor environment means to this manufacturer, we assume it was consistent across all their tests. The ranges here are not meant to reflect what another user might achieve, but are useful for comparing 802.11a and 802.11b performance.)
Table 2: Example indoor range data

<table>
<thead>
<tr>
<th>Signaling Rate</th>
<th>802.11a</th>
<th>802.11b</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>60 ft</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>130 ft</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>130 ft</td>
</tr>
<tr>
<td>6</td>
<td>170 ft</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>350 ft</td>
</tr>
</tbody>
</table>

The following paragraphs use these distances to illustrate different installation configurations.

**Doing a Facilities Analysis for 802.11b, adding 802.11a later.**

Using the example data given above, the 802.11b radio covers 53,000 sq. ft. at 11 Mbps. The 802.11a radio, at full bandwidth, covers 11,300 sq. ft. If the goal is to cover the entire area at 54 Mbps, then, in general, it can take almost 5 times as many 802.11a access points to cover a given area compared with the number of 802.11b access points required for 11 Mbps coverage. Figure 4 shows a hypothetical installation in a facility measuring 370’ by 560’. This area can be covered by six 802.11b access points, but requires thirty 802.11a access points to cover the same area.

![Figure 4: Maximum data rate coverage for 802.11a and 802.11b](image)

In Figure 4, the 802.11a access points were located independently of the existing 802.11b access point installations. In this case, it turns out that none of the 802.11a access points are located in
exactly the same places as the 802.11b access points. In reality, some of the 802.11a access points could be shifted to take advantage of existing 802.11b locations. The figure is unrealistic in a number of other ways:

- It assumes there are no obstructions to interfere with the RF coverage patterns
- It assumes no sources of RF interference
- It assumes there are no reflective surfaces to distort the shape of the coverage patterns

Figure 4 does illustrate that upgrading an existing 802.11b installation is going to require work and expense nearly equivalent to doing a brand new installation with no existing RF. The 802.11a access points will require a new site survey, new Ethernet cable runs and new power cable runs (if not using Power over Ethernet). In other words, there is very little that can be leveraged from the existing 802.11b installation.

**Co-locating 802.11a and 802.11b access points**

Another option for enterprises looking to install 802.11b access points now and add 802.11a coverage at a later date is to simply reuse the 802.11b access point locations. In this scenario, it is not expected to get the maximum 802.11a data rates throughout the coverage area. It is expected that in areas most distant from an access point, the 802.11a data rates will fall back to a lower rate.

This scenario works only if the original 802.11b facilities analysis was done for 11 Mbps coverage. However, data collection installations are typically surveyed for only 1 or 2 Mbps. The coverage range for 2 Mbps is not provided for the radios in Table 2, but based on the data given, and on LXE experience, it is expected that a comparable 2 Mbps range would be approximately 250 feet. Unfortunately, the 802.11a access point drops the data rate to only 6 Mbps and at 170 feet loses coverage altogether. In this situation, the 802.11a user would find large gaps in the coverage area.

![Figure 5: 802.11a coverage (6 Mbps) using a 2 Mbps 802.11b FA](image)
Antenna Limitations

As mentioned earlier, current 802.11a radios are implemented in the UNII-1 and UNII-2 frequency bands. In addition to limiting the UNII-1 band to indoor applications, the FCC limits transmissions in the UNII-1 band to 50 mW. They also stipulate that radios operating in this band must not allow end-users to change antennas. The result is that all 802.11a radios on the market today are equipped with antenna that cannot be removed.

In response to this limitation, the radio manufacturers have deployed new antenna technology that provides some flexibility. For example, at least one access point radio is equipped with an antenna that acts as an omni-directional antenna when mounted in one orientation and as a patch antenna when mounted in a second orientation.

These advances in antenna technology still do not provide the flexibility required to effectively cover warehouse or storage yard locations. In those applications, LXE has found that antenna selection varies according to the facility and the available access point mounting locations. In some locations, it is appropriate to use omni-directional antennas that provide a good deal of down-tilt. In other locations, higher gain omni-directional antennas work better. Still other locations call for highly directional antennas.

Decreased range plus limited antenna effects in the warehouse

The range data in Table 2 applies to office environments – not a data collection location. In office environments, access point antennas are typically located at the ceiling level, about 9 to 10 feet above floor level. In this environment, client devices are generally located on a desk or table, about 3 feet above the floor or 6 to 7 feet below the access point antenna.

In a warehouse, access point antennas are typically mounted on the roof trusses, anywhere from 30 to 45 feet above floor level. Client devices are either held in the hand or mounted on fork trucks or lifts. In this environment, client devices may be anywhere from 5 feet to 40 feet below the access point antennas.

It takes a good deal of energy just getting the RF signal to the floor in a warehouse. And since omni-directional antennas tend to radiate energy much further horizontally than vertically, it may turn out that 802.11a coverage at 54 Mbps does not extend to the floor level at any point in the warehouse.

Figure 6 below shows a hypothetical coverage pattern for an access point radio in a warehouse. This figure does not represent measured data – rather, it is a projection of typical 2.4 GHz antenna patterns and modified somewhat to account for metal shelving, a metal ceiling and RF-absorptive content on the shelves. 2.4 GHz antenna patterns were used because elevation plane range data for 5 GHz antennas is not yet available. Figure 6 is not intended to represent what will happen with 802.11a in the warehouse. It presents only another issue that LXE believes might become a factor when deploying 802.11a products for automated data collection.
Increased Power Consumption

It has long been predicted that power consumption will be a significant problem for 802.11a radios. Until there are 802.11a enabled mobile devices, it is not at all clear what the reality of battery life will be. For example, Table 3 represents the current requirements of one pair of 802.11a and 802.11b radios from the same manufacturer.

<table>
<thead>
<tr>
<th></th>
<th>802.11a</th>
<th>802.11b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Power</td>
<td>520 mA</td>
<td>450 mA</td>
</tr>
<tr>
<td>Receive Power</td>
<td>580 mA</td>
<td>270 mA</td>
</tr>
<tr>
<td>Sleep Mode</td>
<td>20 mA</td>
<td>15 mA</td>
</tr>
</tbody>
</table>

Table 3: Current requirements for 802.11a and 802.11b client radios

However, since the 802.11a radio is powered by 3.3V and the 802.11b radio is 5V, it is not quite so clear the 802.11b radio will provide better battery life. Table 4 converts the current requirements of Table 3 to power consumption.

<table>
<thead>
<tr>
<th></th>
<th>802.11a (3.3V)</th>
<th>802.11b (5V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transmit Power</td>
<td>1.7 W</td>
<td>2.25 W</td>
</tr>
<tr>
<td>Receive Power</td>
<td>1.9 W</td>
<td>1.3 W</td>
</tr>
<tr>
<td>Sleep Mode</td>
<td>.07 W</td>
<td>.08 W</td>
</tr>
</tbody>
</table>

Table 4: Power requirements for 802.11a and 802.11b client radios

The implications of these figures are not clear. The 802.11a radio actually uses less power to transmit than does an 802.11b radio, but it uses substantially more power to receive. The typical data collection application uses the Telnet protocol and a terminal emulation on the client device. In this setting, more data is received by the client than is transmitted. The higher power consumption of the 802.11a client on receive may cause it to use more power than the 802.11b
client in this environment. On the other hand, the 802.11a client will operate for a shorter time to send the same amount of data, so its battery consumption may not be worse than the 802.11b client.

**Higher Cost**

At the present time, 802.11a radios are significantly more expensive than 802.11b radios. The table below provides a couple of current examples:

<table>
<thead>
<tr>
<th></th>
<th>802.11b</th>
<th>802.11a</th>
<th>Premium for .11a</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer ‘C’ access point</td>
<td>$899</td>
<td>$1249</td>
<td>$350</td>
</tr>
<tr>
<td>Manufacturer ‘C’ client adapter</td>
<td>$169</td>
<td>$229</td>
<td>$60</td>
</tr>
<tr>
<td>Manufacturer ‘P’ client adapter</td>
<td>$179</td>
<td>$229</td>
<td>$50</td>
</tr>
</tbody>
</table>

**Table 5: Cost comparison of 802.11a and 802.11b technologies**

It should be noted, however, that the price of 802.11a radios today is similar to the pricing of the first generation of 802.11b radios. These prices will undoubtedly fall as the technology matures.

**The 802.11g Factor**

802.11g is a pending standard that will deliver the same data rates as 802.11a, but using the 802.11b frequency bands. As of the fall of 2002, the 802.11g standard has not yet been ratified. Ratification of 802.11g is predicted within the next two quarters.

Because the standard is not yet defined, there are currently no 802.11g radios on the market. However, several vendors are currently working on 802.11g radio designs. Many of these vendors (and probably eventually all ‘enterprise’ caliber vendors), intend to develop dual band radios that support both the 802.11a and 802.11g standards. It is expected that 802.11g radios will start appearing in the marketplace near the end of the second quarter of 2003.

Because of the imminent availability of 802.11g radios, many network managers are now faced with the dilemma of deploying 802.11a radios now or waiting six months to deploy 802.11g equipment.

802.11g products will share some of the drawbacks and advantages of both 802.11a and 802.11b.

**802.11g Advantages**

- Same data rates as 802.11a
- Seamless roaming between 802.11b and 802.11g
- Existing 802.11b clients will be supported by 802.11g access points
- New 802.11g clients can connect with existing 802.11b access points (max 11 Mbps)
- Better range than 802.11a at comparable data rates
- Current worldwide adoption

**802.11g Disadvantages**

- Same interference issues as 802.11b
- Increased power consumption
- Current lack of client support
- Higher cost initially
The primary advantage to 802.11g is that it will provide the ability to roam from areas of high bandwidth requirement to areas of low bandwidth requirement. A client device equipped with an 802.11g radio will be able to move from a carpeted area covered by an 802.11g access point into a warehouse covered by an 802.11b access point without any interruption in network service. Similarly, a client device equipped with an 802.11b radio will be able to operate in areas covered by 802.11g access points (at signaling rates up to 11 Mbps) as well as in the areas still covered by 802.11b access points.

The Future of 802.11a in ADC

Typically, the primary consideration driving the adoption of 802.11a in any environment is the increased throughput potential it offers over 802.11b solutions. In ADC environments, these throughput requirements do not exist.

A Bit of History

LXE has been supporting ADC customers through many generations of hardware products. The first data collection systems relied on 400 MHz narrowband transmissions that delivered a maximum of 9600 bps. Bandwidth was truly limited with those products. However, as the technology migrated to the 900 MHz frequency band, bandwidth increased to around 64 Kbps. At this data rate, most data collection customers found they had adequate bandwidth. However, all 900 MHz solutions were proprietary to the specific vendor.

When 2.4 GHz technology hit the scene the 802.11 standard was adopted. The first version of 802.11 offered a maximum data rate of 2 Mbps. This provided a little ‘cushion’ in terms of throughput for data collection customers. The standard also offered interoperability of different vendor products at the air interface level.

Round 2 of 802.11 – the 802.11b standard – finally brought data rates that were interesting to horizontal markets. This drove demand up, production volumes increased and prices fell. Production of the earlier 2 Mbps products ceased. It was natural for data collection markets to migrate to the 802.11b standard to take advantage of the new competitiveness in the marketplace. But, even the 11 Mbps that 802.11b offers is more than LXE customers require. Most wireless networks installed by LXE are still surveyed for 2 Mbps.

Why 802.11a?

In spite of the fact that data collection applications still require a network throughput of only 2 Mbps, there are a number of factors that will drive the adoption of higher data rate radios into ADC environments.

- **Insurance for future applications:** Many of LXE’s customers believe that while the traditional “green screen” application currently serves their data collection needs, new applications are pending that will bring additional functionality to their data collection activities. Today, few LXE customers have implemented more demanding applications. But, the emergence of new data collection terminals running Windows CE has certainly increased the potential for more capable applications.
• **Complementary applications:** There is gathering momentum to provision additional applications in the warehouse not directly connected to data collection. Voice applications are the most common example. Voice applications will work over 802.11b networks, but the number of simultaneous conversations possible is limited. Installing a higher bandwidth wireless network can provide additional flexibility for these applications.

• **Homogeneous networks throughout the enterprise:** As wireless networks have made inroads into horizontal applications, IT managers are increasingly involved in provisioning the wireless networks in the warehouse as well as in the carpeted areas of the business. Network maintenance and administration is simplified if the same equipment can be used in all areas. If 802.11a bandwidth requirements exist in the carpeted areas, this same infrastructure may be implemented in the warehouse as well.

• **Roaming users:** Data collection activity is typically confined to the warehouse or yard areas. However, there may be a few users, such as supervisory personnel, who require network connectivity both at their desk and while in the warehouse. If these users move frequently from one location to another, it benefits the company to provide compatible network connectivity in both locations. If office applications require higher bandwidth, then it may make sense to install 802.11a access points in the warehouse as well.

• **Interference avoidance:** Although rare, LXE has run into situations where coverage with an 802.11b network is made difficult by the presence of microwave ovens or other equipment that radiates in the 2.4 GHz band. Because 802.11a operates at a higher frequency, these same sources of interference do not affect it.

**The LXE Prediction**

It appears likely that the early part of 2003 will see some adoption of 802.11a backbone products in data collection spaces. These products will take the form of dual radio access points capable of supporting both 802.11a and 802.11b radios. Client devices will continue to deploy with 802.11b radios throughout 2003 due to the lack of 32-bit radio interfaces on those platforms.

The availability of 802.11 a/g radios beginning in late 2003 will limit the adoption of the 802.11a-only radios, and they will fade quickly from the data collection environment. By early 2005, it is expected that main-line data collection devices will have incorporated the necessary 32-bit interfaces. At this point, the 802.11 a/g combination radios will become the radio of choice for most data collection applications and the 802.11b radios will begin to fade. It does not appear that the 802.11g-only radio will ever make much of a mark on the industry.
Figure 7: Radio technology adoption forecast for ADC