Technical Issues on Wireless Credit Card Readers

By Dr. Ernie Lin
Nebo Wireless

Two key questions about using a wireless device in the credit card industry are: how far can the device reach and how reliable it is. We will examine each of these technically and explain their ramifications.

To begin with, let's use the popular and well-known cordless phones as a starting point. Technically, when you do the calculation, a cordless phone can reach about 1500 ft in "free space." Free space is a technical term, and it assumes that there are no obstructions between the transmitter and the receiver. But in practice, this rarely occurs. To begin with, you always have the ground, and if you place the base unit on the ground, depending on how wet or what the material of the ground is, your cordless phone may not even work. You will also have problems getting off of the ground if you don't pay attention, because so many items are grounded within buildings. In addition, in a typical environment inside a house or a large building, there are a variety of items (metallic objects, wooden furniture, plastics or even human bodies), which are going to have some adverse impact on electromagnetic wave propagation. It is therefore almost impossible to perform a precise calculation of effective range.

So, how far can a cordless phone reach? Over the years, people have done many tests and experimented with cordless devices in a variety of settings, and have developed some rules of thumb. The rules specify that cordless devices in in-door (meaning in a building) environment, the signal will effectively reach between 200 to 300 ft. In other words, there is a reduction factor of 5 to 7.5 from the theoretical maximum. However, the performance really depends on many factors of the environments. Consequently these numbers only appeared in the literature for a short while, and then they dropped out of sight altogether.

How about 802.11 (a.k.a. Wi-fi) signals? How far can they reach? There are indications that 802.11 also bases 1500ft free space distance as its design rule for its high power version. We have occasionally seen 200 to 300 ft mentioned as its effective in-door range. However, we have not seen any claims to that effect in any official product literature for these devices.

Why would this be? For one thing, with so many litigation lawyers roaming all over the country, manufacturers obviously do not want to get into any claims they can't back up. However, more importantly, there are some well-known problems with the products based on 802.11.

One of the better-known problems for Wi-Fi is the so-called dead spot. No matter where the routers are positioned, there are always spots within buildings where the remote unit cannot connect with a router, or the link gets dropped after a short period of seemingly good communication. For example, I recently visited a relative and stayed in his house for a few days. He had a Wi-fi router installed on the second floor of his house to access his Internet service. However, when I tried to use my laptop to connect to the Internet, I found that I could not establish a connection when I was on the first floor, and I was at most a mere 20 ft away from the router. In practice there are several ways to mitigate this problem (as described below) but each mitigation approach involves additional time and expense to put in place.

What do you do if you run into a dead spot when you try to use a Wi-Fi connection on the go? For a technical person like me, the first thing I would do is to orient the laptop differently. This is because the antenna always favors some directions more than others. If this does not resolve the problem, I would move the laptop around to find a better spot. In the event I still have the problem, I would move the router to a more advantageous position, such as hanging it on the ceiling. However, this approach may not solve the problem even when there is nothing between the remote and the router.

If none of these works, there are still a few options. First, we could get a router with multiple antennas, which would perform “space diversity” or “site diversity”. Second, we could get a high power version of the router, although this is generally a total waste of time and money as will be explained later. Finally, we could use multiple routers like many large companies are doing, which is just another version of “site diversity.” In general, the effective in-door range of Wi-fi is actually much less than the 200 to 300 feet of the typical cordless 915 MHz band telephone.

In general, once one of the resolution steps above is successful, the problem will go away and the user will be happy. So, the use of 802.11 is considered acceptable. But why are there so many problems with using 802.11 (Wi-fi) that we never were aware of when using a cordless phone? Why does the old rule of thumb appear to not be working any more? What would happen if we use Wi-Fi on a portable credit reader?

I’ll explain why there are so many problems first and why they are different from a cordless phone. I’ll then talk about the known problems and unknown problems (I call them unknown problems because I have not seen them discussed in any open literature). Finally, I’ll address what should happen if Wi-Fi is used for a portable credit reader.

Propagation basics

When an electrical signal travels thru the air, what happens?

First, it travels in all directions, even though it does favor some directions more than others. Secondly, it usually travels in a straight line, but not always.

When there is something in the way, what should happen?

There are a few possibilities:

1. The whole signal gets absorbed by the object.
2. The whole signal gets bounced back off of the object.
3. The signal gets partially absorbed and partially bounces back.
4. The whole signal goes around the object.

Let's focus on the last one first. The ability of an electromagnetic wave to go around a subject actually varies quite a bit, depending on many factors. And one of the most important factors happens to be the wavelength, or (inversely) the frequency of the signal. A good real-life example is demonstrated in the differences between AM and FM radios. Most people would agree that FM radios are much better in sound quality etc. But why are we still using AM Radios? The answer is very simple. An AM radio signal is much more capable of going around any obstructions (in addition to bouncing off of objects). If there is a building between your radio receiver and the radio station transmitter, the chances are that an AM radio signal will go around it and an FM signal will be blocked. This is why when you drive for a long distance; you are more likely to turn to an AM station rather than a FM station to reduce the number of times you have to change stations.

For our discussion, a 900 MHz radio does do a better job in getting around any object than a 2.4 GHz radio, but the difference is small (about 2.5 to 1 ratio), when compared to the 100:1 ratio between FM and AM. In any case, the signal may slightly be reduced by the higher frequency, but not substantially. The more important factor is actually the phenomena of bouncing back and its side effects.

Let's look at a simple case. Envision you are sending a signal by electrical wave from point A to point B, and assume that there is nothing in between. What would happen? You may think that if both the transmitter and the receiver are working properly, the signal will be faithfully received and duplicated, but that's not true all the time. As stated before, electrical waves go out in all directions. It is true that if properly designed, it will favor some directions more than others, but it is not just a beam that is confined into a small section. And because the electrical wave travels in all directions, it will hit ground and/or walls and get bounced back. Depending on how the ground and the wall is built (materials and smoothness) and whether there are any objects on the wall, the signal can be bounced back in a nice way such that it hits the receiver cleanly with a strong signal, or in a dirty way that causes multiple strikes on the receiver and with a variety of signal strengths. When the uninterrupted direct wave and the bounced back wave both hit the receiver, the result becomes very interesting. The electric wave in air behaves like the water wave you see in a lake, it goes up and down. So the two waves are actually going up and down. Since the times they take to reach the receiver are different, because they take two different paths, they could reach the receiver in sync or out of sync, or somewhere in between. If the two waves have similar amplitudes, they can cancel out each other when they arrive out of sync. Conversely, they can get added up in sync and become a bigger signal. This type of phenomenon is called multi-path fading, due to the fact that the signal usually gets reduced when it takes more than one-path to reach the receiver.

Obviously, we can design (or orient) the antenna so that the energy flows in the direction we want it to go, and you can see people doing this with cell phones all the time. But for a dynamic in-door use scenario, there are many complications. For example, when someone in a restaurant happens to walk between the transmitter and the receiver, they may absorbs a big chunk of energy and allow only a fraction of the energy of the direct wave to go thru. The direct wave and the bounced back wave can then become similar in amplitude, which would make cancellation possible. In addition, the presence of support structures and walls in between the remote unit and the router can also reduce the energy of the direct wave. And in very complicated structures, more than two waves may reach the receiver at the same time.

Solutions to the propagation problems

Signal reduction by itself is not a very severe problem from a technical perspective, since we can just increase the transmitter power. This, together with some smart circuit design can always fix the problem. These types of wireless systems are called “power limited” systems, and cordless phones are just one of them.

Nationally, around the mid-1970s, we started to covert the telecommunication systems to digital, and we were doing the same for wireless systems too. However, technologists working in this area discovered that when they pumped up the power, they still could not solve the problems caused by the propagation. At that time, most of the technologists were focusing on the fixed transmission problems, meaning both transmitters and receivers are stationary. But the problems for moving remotes are the same or even worse in terms of the propagation. (Other problems associated with moving around will be discussed later.)

After some intense efforts from many people, we finally discovered that the problem is caused by the “dispersive fading” of the signal. Analysis showed that the reduction caused by the multiple paths signals take between the transmitter and the receiver has a non-uniform impact on the signal, and causes more reduction on some frequencies than others. The radios we design don’t usually accommodate this, and it is causing big problems in our wireless systems. Instead of being “power limited”, we discovered that our systems are actually “environment limited”.

Because a cordless phone has a narrow band, it generally does not have this type of broadband problems. As more research was devoted to this problem, a new rule of thumb developed; “**the broader the bandwidth you use, the shorter the distance you can reach”**. Although we cannot express this rigorously in mathematical formulas, there is no question that the broader the bandwidth you have, the more problems you will have, and this is true whether the transmission is wired or wireless. If you apply this principle to our task, then you will find why the two systems are so drastically different. A WiFi system with a 22 MHz (RF) bandwidth will certainly behave differently from a cordless phone, where the total bandwidth is only 200 KHz at most. Since the Wi-fi bandwidth is over 100 times greater than cordless, is it a surprise that you drop the connection with your W-Fi occasionally while your cordless phone is practically always connected?

Why are there different reduction impacts for different frequencies? Again, look at the water waves in a lake. When the wavelength changes, even when the delay between the direct wave and the bounced back wave stays the same, the in-sync or out-of-sync relationship will change. The two waves may be in-sync at a certain frequency, but if the wavelength changes, they may become only partially in-sync or even totally out-of-sync. For the majority of digital signals that consist of multiple frequency components, this creates seemingly insurmountable problems. Once the multiple frequency components of a signal are not able to be added up or reduced in the same fashion, the receivers get confused and can not faithfully duplicate what was originally sent. The signals are like humpy-dumpy; once they fall off the wall, they can never be put back together again. Since analysis proved that we could not totally recover the signal in theory, most researchers quickly gave up on their attempts to design smarter circuits, and instead they tried to “change” the environment.

In 1987, Dr. Adolf Giger and I published a comprehensive paper [1] about how to deal with this problem. In the paper we outlined all the possible solutions from antennae design point view, based on a rigorous theory developed earlier by me. In the paper, we demonstrated how to use this theory to eliminate the effects of environmental limitations, using real life examples of problem resolutions for large dish antennas. Following publication of this paper, a number of researchers employed our theory about how to solve their problems. Even IEEE and other technical societies held special sessions on this subject during the following three to four years. There were an additional 40 to 50 papers published by other researchers along this line, virtually all of which were based on our first paper. It is no overstatement to say that all of the wireless solutions available on the market today are derived either directly or indirectly from these efforts.

At this point I have now summarized most, if not all, possible impacts on wireless communications and their solutions in this article to demonstrate that we know how to deal with this problem already. Why then are there still problems in implementing an effective wireless solution? Well, there are a few issues:

1. Although we know how to solve “environment limited” problems technically, it is only optimal for a stationary solution. While we may be able to solve the problem between one fixed point, and another, no one can predict exactly what will happen as you move to another point. Technically, we can find a solution that is good for most environments, but no one has a universal solution because we don’t know how the environment will change from moment to moment.
2. Some of these solutions look simple, but they are not as trivial as they probably appear to a layman. To give you a simple example; if you don’t know too much about the antennas, hanging the router on the ceiling appears to be a solution that will make the signal available everywhere that has a straight line-of-sight to the router. However, if you happen to stand right directly underneath the router, you may not get any signal at all. This is because the antenna on the router is usually a whip antenna (a.k.a. a dipole antenna, the kind most commonly used for routers), and it will send the electrical wave in all directions, except along the axis of the antenna itself. If the whip antenna happens to be pointing directly toward the remote (in this case downward), the remote does not get any direct signal from the router at all. In other words, implementation of these solutions is for professionals only, not for a layman, since some technologies (such as 802.11) are actually very user-unfriendly.
3. The most severe problem is related to moving around. When the portable unit moves with a user, the environment gets changed. It may be OK at one location, and not at the next location. Assuming you are employing one of the most sophisticated solutions found, you will use two or more routers to have better coverage. Let’s say one of these two routers will pick up the communication at one point and the second at the next. The algorithm for dynamic switching from one router to the other either manually or or as a built-in function for the remote unit may not be that trivial. When you lose the connection with one router and try to re-connect with the second one, it may take up to several minutes. To begin with, the remote may struggle to hang on to the connection with the first router. In general, a Wi-Fi adapter will lower its connection speed (say from 56 Mb/s to 11 Mb/s) and try again. If it doesn’t work, it then drops the connection speed further and tries again. This goes on until the connection is either established or the connection speed tries to drop below an acceptable level. If dropped, the remote will pause for up to a minute and then makes a new attempt at the connection. This goes on for a few tries (3-7), before it gives up and searches for a different router. If a new router connection is established, the user now will have to resend the signal manually. While this may be acceptable for Internet browsing with your laptop, but how about for credit processing?

Summary

The solution must be related to our need: we want to have a portable unit that can move around. It has to work in all environments. But this is only feasible in a narrow band environment, especially when we cannot tolerate disconnection/reconnection delays, or any interruption of more than 10 to 20 seconds in the process. Technically speaking, there is simply no way to achieve this unless you do it with narrow band. Since we really don't have much data to send to process a credit card transaction; the small data rate of narrow band will suffice for this application, particularly when we do not artificially add unneeded network protocol layers to the communication, such as either Wi-fi or ZigBee. Why do we have the challenge the physics - **the broader the bandwidth, the shorter the distance**?

Last Note: For those who want to explore the technical issues in greater detail, please examine the book written by my partner, Dr. Giger [2].

References:

1. E. H. Lin, A. J. Giger and G.D. Alley, "Angle Diversity on Line-of-Sight Microwave Paths Using Dual Beam Dish Antennas,' ICC 1987. This paper was published again by IEEE in *IEEE Transactions on Communications* a few months later.
2. A. J. Giger, *Low-Angle Microwave propagation: Physics and Modeling*, Artech House, 1991