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A White Paper
Signal Distribution Systems Using Waveguide Technology

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Executive Summary

I was contacted several months ago by a company that claimed to have answers to widespread problems in the design and deployment of Wi-Fi systems in large industrial and public facilities, such as warehouses, offices, and hospitals. If correct, they have accomplished a large step in improving the performance, reliability, and security of WLAN systems.

It looks like their approach could significantly reduce the present mutual interference that's running rampant in industrial and commercial buildings throughout the country while reducing capex and opex costs. Today the typical way to try and increase coverage and capacity is to simply throw another Wi-Fi access point into the area and hope for the best.

Wireless Expressway (*WE*) appears to have a much better and far more economical approach. Their simple answer is to "take the signal to the user." They do this by employing *waveguides* – more on these later. For example, using their technology, a typical 40,000-to-50,000 square foot warehouse can be covered very well with only ONE Access Point as opposed to the 8-10 APs recommended by others in the field. Not only is the cost of all the extra APs saved, but the additional UTP cables, switch ports, wireless controller ports, recurring software licenses, and ongoing maintenance aren't needed.
An industry report by Honeywell® places the cost of bar code read errors by pickers in a warehouse with signal dead spots at about $60 per event. Bad bar code reads caused by poor signal coverage disappear in a facility covered by a Wireless Expressways system.

Their claims sounded somewhat unbelievable. After reviewing the backgrounds of the principals in the company, however, I was encouraged to stop and listen to what they have developed and how their technology is making a positive change. They claim to have modeled, designed, built, field-tested, and patented hardware solutions for the following problems in the Wi-Fi industry:

- Dead and erratic signal spots in large buildings, especially warehouses with multiple aisles and changing contents on rack shelves.
- The unreliability of wireless system designs based on "*site surveys".*
- Slow data rates caused by the addition of *too many* access points in an attempt to solve the dead spot problem that results in channel-clogging interference between and among access points.
- The difficulty of getting consistent, high speed, reliable MIMO data rates from 802.11n, or ac to multiple clients operating at 5GHz.

A Few Wi-Fi Bits of History

Although the 900Mhz (.900GHz) unlicensed band had preceded it with some notable success, the 2.4GHz ISM band quickly became the preferred band to use for serious, high-speed, data communications in commercial operations. However, signals in the then-new 2.4GHz frequencies behaved differently in indoor spaces than its lower frequency cousin. The higher-frequency acted more like *light* and was not as forgiving as 900MHz. How to cover areas with signals at 2.4GHz, when it first came out, was unsolved by the customer support group of a major wireless LAN hardware provider and others in the field. They were forced to advise their VARs to first "guess" at a location in a building to place an access point radio in the middle of, for example, a warehouse, office, or hospital, etc. to gain familiarity with the indoor propagation characteristics of 2.4GHz. The VAR was then advised to walk around the facility noting the signal strength readings on a notebook computer at different locations, and add more access points where signals were weak or non-existent. Thus, the “site survey” was born and became a “standard” that is still used today in designing even major, expensive, WLAN systems. There are now numerous software programs that are available to determine coverage, but again they continue to recommend the addition of more Wi-Fi access points to solve coverage issues because that’s been the only tool available to solve the problem. Wireless Expressways provides a new *box of tools* for the WLAN designer by using waveguide-based signal distribution.

Later, Multiple-Input-Multiple-Output (MIMO) technology came along that employs encoded, multiple “spatial streams” in the same operating channel. This type of signaling system was relegated to the 5GHz band to gain more bandwidth to support higher data throughput. It’s very sophisticated. Unfortunately, the signals from separately transmitted spatial channels, in order to deliver a high data rate, had to “get lucky” with a good reflection from the right place to allow the attainment of anything close to maximum speed. Like most reflected signals, recovered data speed can vary wildly if you move the receiver, e.g. a handheld bar code reader, tablet, notebook computer, etc., a few inches one way or the other. The process is “hit and miss.” *WE* has a solution for this problem too.

The company that claims to have answers to all these problems, Wireless Expressways, Inc. is based in San Antonio, Texas. The principals in the company are Charles Becker and Michael Fischer.
I wouldn’t consider them to be “newbies.” They have worked in the wireless and computer industries for a total of over 90 years and hold a combined list of over 80 patents in communications and computer topics, 30 of which are registered to “*WE”*. Becker started and ran a very successful communications integration company for 25 years and also founded a separate, successful, advanced modem and multiplexer manufacturing company that went public. Fischer architected chip sets for the first 100 million Wi-Fi devices sold. He is often called the *father of Wi-Fi*, having served on the seminal IEEE 802.11 committees for 10 years that developed the core specs for the wildly successful Wi-Fi industry. *After hearing this, I listened even more carefully.*

Extensive claims require extensive proof. So I gathered the following information from them to explain how they have solved the stated current problems in commercial Wi-Fi systems. It appears that their solutions are based on low-cost, company-designed *waveguide,* unique waveguide signal couplers, and unique antenna technology to provide full, high-speed Wi-Fi coverage in buildings of 20k square feet to a million square feet or more.

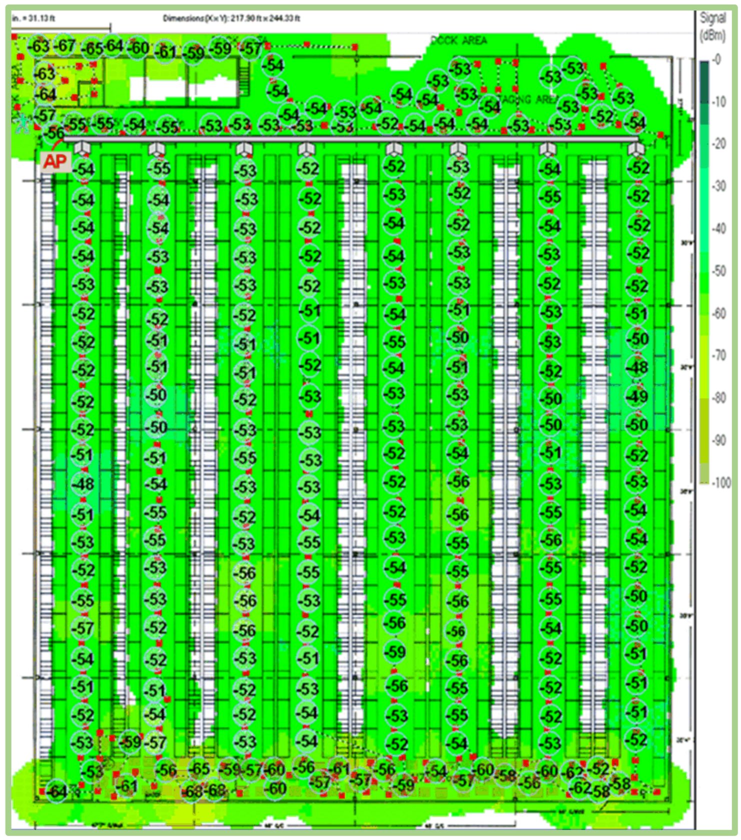
If all of their claims prove out, *WE’s* technology will go a long way in cleaning up very inefficient indoor Wi-Fi operations that are limping along with *too many* APs that are causing poor performance, low reliability from intermittent dead spots, and high maintenance. At the same time, *WE* technology will significantly increase data security by reducing the escape of signals *to* other buildings and reduce inbound interfering signals *from* neighborhood APs.

During my research into these solutions to major wireless signal problems, I asked a number of questions and spent time reviewing Wireless Expressways’ documentation and success with their warehouse installations that are up and running using their technology today. Below are the questions I sought to have answered that are centered on their claims. The answers were provided by Charles Becker, the CEO and co-founder of Wireless Expressways, Inc:

Claim 1: Complete signal coverage (no dead spots) in large buildings.

The problem: Warehouses and Distribution Centers (DC's), in particular, are one of the most difficult indoor venues to thoroughly cover due to their long rows of racks containing shelves that may contain literally any kind of signal-reflecting or absorbing products from pills to paint cans to pickles.

Present wireless distribution systems don't overcome the problem of blocked signals caused by objects in warehouses such as racks and products on them, machinery, ducts, and dock offices. What's needed is to provide consistent, high-strength signals to floor-level aisles and to docks where workers are operating handheld Wi-Fi -configured bar code readers and other Wi-Fi –configured devices.



If one steps back and takes a serious look at this problem, it becomes evident that the present method of mounting access points *above* the racks, e.g. in the "red iron" in the ceiling of a warehouse *will not* provide reliable coverage to aisles in the facility. Most warehouses have large numbers of racks with *frequently changing contents* on their shelves. It's a seriously flawed approach to rely on signals from scattered APs in the ceiling using small vertical antennas to "look through" the contents of shelves and provide reliable signals to personnel working in aisles and on docks.

An access point per aisle could be used, but that's expensive from not only the number of APs and UTP runs required, but this glut of APs would cause very unacceptable co-channel interference and system slowdowns. It's also easy to see that no amount of *beam forming* from a single, or a few APs will reliably solve the problem. Like in a game of pool, it isn't always possible to get the right *bank shot* from a fixed location.

The ONLY way to assure full coverage is to *illuminate each aisle with beam-formed high-level signals* and not try to illuminate aisles by going *through* rack shelves and their changing contents. See *WE* 40k square foot, 1 AP, warehouse system above.

The Solution is to place a very low-loss, hollow, passive, metallic *waveguide* along one end of the aisles and feed it with signals from ONE access point at the waveguide's end or middle. The waveguide span is then provisioned with ports for variable signal couplers inserted into the waveguide adjacent to the *ends* of each of the *aisles*. Note the high and consistent signal levels above. They are *measured*, not simulated levels.

Each coupler was set to sample a predetermined signal level from the RF energy traveling down the waveguide's length that feeds beam antennas pointed down each aisle. Using this configuration, typically 8-10, 175ft+, aisles can be illuminated with high-level signals from ONE access point mounted near ground level. A site survey is NOT needed, or desirable. The signal level transmitted down each aisle is precalculated using an XL program and set into each signal coupler in the waveguide that feeds each aisle. If necessary, aisles of different lengths, dock offices, cooler rooms, work areas, etc. can be illuminated with signal strength that's adjusted for each area. The resulting *minimum* signal level in any aisle at 2.4GHz is VERY HIGH, typically -54dBm at the *far ends* of *all* the aisles and it's *designed* to remain constant, *regardless of the changing content on rack shelves*.

A receive level of -54dBm is approximately 20dB = 100 times the minimum receive power needed by a typical handheld bar code reader for consistent, reliable, full-speed operation when running 802.11g, 54Mbps, the most popular warehouse signal standard. Also noteworthy is the fact that ONE AP per 8-10 aisles creates a single-channel "zone" in a warehouse that's highly isolated in the 2.4GHz band from the other two high-speed channels possibly used in adjacent zones. This offers a significant advantage in large warehouses. It allows frequency *reuse* along the facility, very few co-channel holdoffs, almost no roaming, and a *minimum number* of APs to cover the entire facility.

A typical 250k warehouse having primarily paralleled product racks can be completely covered with only 5-6 access points instead of 40-50 APs in typical current designs.

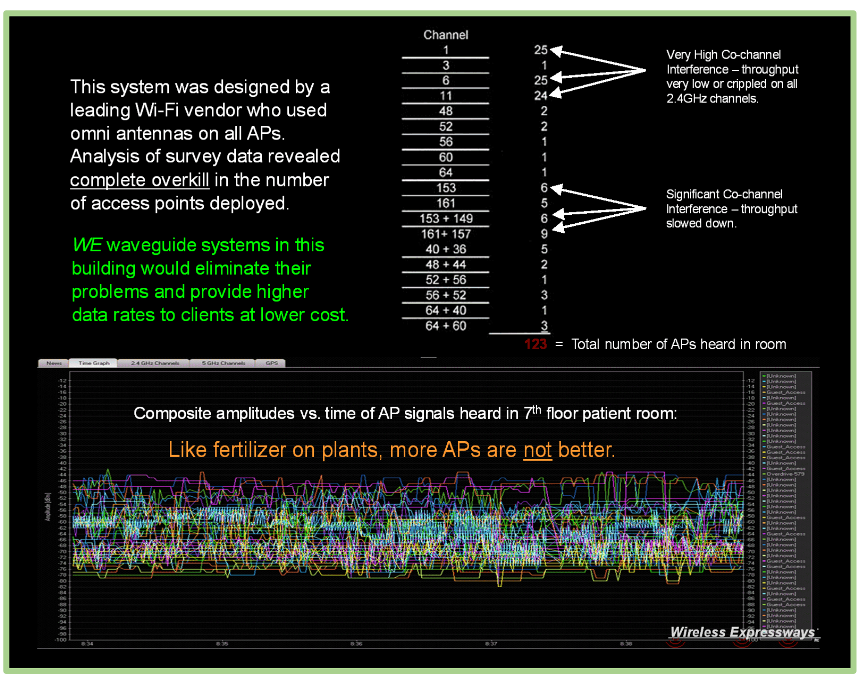
Another advantage of using this coverage method in an isolated zone is its lower susceptibility to 802.11b signals from visiting cell phones carried by visitors. These "b" phones can cause a "g"-configured AP in a zone to downshift to slower "b" (11Mbps maximum) data rates when the cell phone is close to a zone, but only one AP is affected. Also note that the average data traffic per bar code reader is low, easily allowing a single AP to cover an entire zone where 20 or more pickers and dock workers are operating simultaneously, and will support additional devices that require high data volumes. A *redundant AP* can be connected to the same *WE* waveguide array, set to a separate channel, and configured to provide immediate backup when the primary AP fails, and/or it can be used for an online, additional, separate channel for VOIP, video, or backup.

Any zone access point can be easily serviced when it is *mounted close to ground level -- usually on the end of a rack in a WE system*. No lift is needed. And the RF loss in the cable from the AP up to the waveguide array is typically 3dB or less, a loss that is easily absorbed into the total signal budget in a *WE* system. If an AP becomes defective, it can usually be replaced in minutes at ground level, and automatically receive a configuration off the local network or cloud by the supervisory WLAN control system or from the company's IT department. Quick accessibility is a welcomed feature for most remote locations.

The systems described here eliminate erratic signal behavior in warehouses and eliminate dead spots. Getting rid of dead spots in wireless coverage is not just "nice to have" but is a necessary goal in Warehouse Management Systems using software that can't tolerate an interruption of Wi-Fi signals to a client operating on their WMS system. The problem is caused by a fragile communications protocol between the client and CPU on the far end of the link. If the wireless signal in the link is dropped for even a short time, the lost link will lock the current files on the far-end CPU that usually can't be reset by a picker on the floor. Instead, an authorized IT person must reset the application to reestablish connectivity to the picker. The total lost picker production time, plus lost IT personnel time in these types of events is cumulatively large and expensive. A Wireless Expressways system protects this from happening by a no-dropout design. Complete signal coverage is provided in all areas the client is to operate, even within docked trailers, if required.

Our scorecard: *WE* field tested its technology in 5 locations that have WMS systems prone to having the problem detailed above. All 9 *WE* systems installed in these locations have logged a perfect "no dropout" record for **11 total years** since their installations.

Claims 2 & 3: The unreliability of designing Wi-Fi systems by "guess and try" site survey methods can be avoided by using the *deterministic* method of *WE* waveguide-based design.

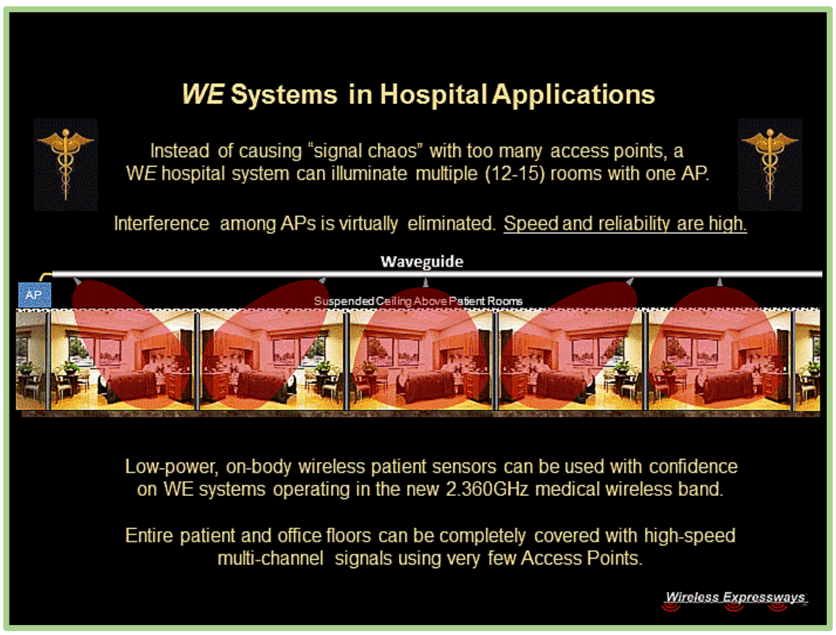


Many Hospitals that were designed by site surveys are good examples of how NOT to design Wi-Fi systems. An example is shown in the RF data recorded (left) in a patient room in a large healthcare facility.

Hospitals are a key application for *WE* waveguide systems. Most large hospitals were early adopters of Wi-Fi to provide communications to portable devices for nurses, doctors, and others who directly or indirectly treated patients. Unfortunately, most of these systems were designed by "site survey" methods that prescribed large numbers of access points throughout all areas in a hospital's facilities. The result was severe signal overcrowding that caused low performance, low data rates, and low availability. These systems are now out of date and need replacement.

In addition to the need for their general Wi-Fi systems to be overhauled, hospitals need to gear up for new applications, such as RF-based patient-worn monitoring devices that require more reliable, full-time data retrieval from patients.

A new hospital patient monitoring band at 2.36GHz has been approved and is starting to be deployed. Using present techniques of attempting to send signals through walls, metal studs, conduits, and the like, isn't a good idea for this new band (or any other application.) A new, more reliable method of intimately connecting to bedridden patients wearing on-body telemetry radios is envisioned by *WE*. It can be designed and deployed to cover many multi-patient rooms with highly stable and reliable signals. (See the graphic below.)



A *WE* waveguide system installed above the ceiling in a row of typical patient rooms is ideal for feeding each room. Like warehouse systems, appropriate *beam antennas* are connected to the waveguide to feed signals into each patient area and *exclude* signals from external sources. All antennas are pointed *downward* and are less than 25 feet from any patient in a typical multi-patient room. The signals that reach the floor below are low level and set to channels that will not interfere with neighboring APs. The APs on the lower floor are set to non-interfering channels, where possible. Other areas, e.g. ward hallways, are also easy to implement in a *WE* system for those patients who are ambulatory. The combination of these two techniques yields complete, reliable, coverage for patient-worn telemetry.

If desired, a separate, independent channel in the 2.4GHz ISM band adjacent to the medical 2.36GHz medical band can be multiplexed onto a patient-monitoring waveguide-based system. It can be used for general purposes by staff or a guest channel for visitors.

Offices have a wide variety of layouts and plenty of walls to absorb and reflect signals. These effects can be seen in the scale model below that uses light to depict RF signals in a simulated office environment. The model was built to simulate, visualize, and display RF effects. It was constructed with clear plastic "wall" panels and strips of aluminum foil at the same scale as standard metal studs and door frames. The metal objects are fully reflective to light to simulate RF signal interactions. The shadows shown are in *back* of the furniture, studs, and door frames. A radiating AP is shown mounted at the left end of the row of offices and uses an omni antenna. Several things are noted. *First*, the room where the AP is mounted is *over-illuminated* with excessive signals that are *wasted*. *Second*, the antenna is radiating signals out the corner of the building to the adjacent office's neighborhood – *an unnecessary security risk*. *Third*, the portion of the signals that are propagating down the line of offices meets a number of *absorbing and reflecting objects.*

Both free space loss and in-path absorption by sheetrock walls, furniture, people, etc. and reflections from metallic objects attenuate the signals to almost unusable levels at the far right end of the row of offices. The *WE* method of employing waveguide-based signal distribution systems in offices solves the problem illustrated above by *transporting* signals from an AP through a low-loss waveguide *above* a typical suspended ceiling.

Antennas feed each office area with high-level signals. (See graphic below). Note that the waveguide signal illumination in all offices is directed *downward* to limit signals to only the *inside* of the rooms. It even avoids room clutter. Greater security is provided by isolating signals from/to "unfriendlies" that may be outside this office group, maintains high data rates, and decreases co-channel interference from other APs.

The same waveguide distribution techniques shown here for offices can also be applied to schools to decrease the losses of intervening walls between classrooms.

Claim 4: *WE* has developed a method of deploying 802.11n and 802.11ac MIMO connectivity in offices, schools, hospitals and other venues. High speed wireless communications with multiple, distant, clients are supported. MIMO signal strength and signal quality are preserved by transporting spatial streams from an AP to user devices via low-loss waveguides.

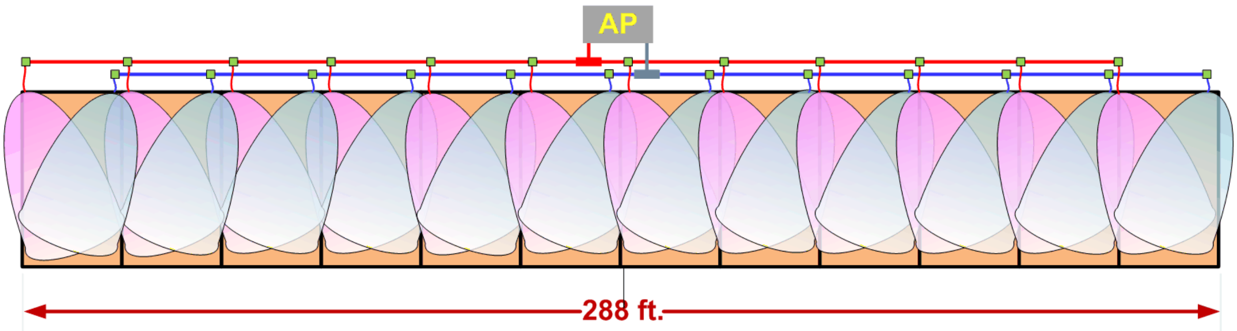
The Problem: Impressive gains in Wi-Fi communications speeds are possible using 802.11n, ac technology that incorporates multi spatial-channel radios. The requirements for attainment of these higher speeds are, unfortunately, the conditions that 1) two or more separate spatial signals arrive at the client receiver with good differential characteristics in two or more antennas and 2) high receive strength from the receive antennas. When processed, they allow decoding of the separate streams that are then *summed* to provide a higher aggregate data rate. In practice, however, this is difficult to obtain and sustain reliably in the field.

Solution: *WE* has solved the problem of unreliable MIMO data rates caused by low signal strength, free space loss, loss in walls, and insufficient reflections from near-path clutter. A waveguide is placed in the ceiling and OVER the walls. It bypasses the physical clutter with highly efficient RF transmission lines, then presents spatial streams directly to each user area. The antennas placed in user rooms are adjusted to optimize MIMO effects. *WE* has developed and patented inexpensive wireless distribution systems based on multiple runs of low-cost, 5GHz waveguide to distribute *controlled* multi-spatial streams of MIMO signals to clients. GUIDED MIMO™ systems, operating at 5GHz, are totally passive (access point not included) and are designed to occupy HVAC plenum spaces.
A *WE* GUIDED MIMO™ waveguide system, typically 100-200 ft. in length, is assembled from multiple, parallel runs of 5GHz low-cost, low-loss waveguides capable of transporting separate spatial streams originating from an AP to local *and* distant indoor user areas. Free space loss at 5GHz, at 100ft. is 77dB. In comparison, a 100ft. section of *WE* waveguide is less than 2.5dB with "flat" response across the 5GHz band.

The waveguide essentially "shorts out" free space. *WE* waveguides (2 or more used in GUIDED MIMO™ systems) incorporate adjustable signal couplers that can be varied over a 40dB range. They are attached along the waveguide, where needed, to feed spatial stream antennas installed in user areas.

Each waveguide in a *WE* GUIDED MIMO™ system can be fed by one or more APs at either end, or in the middle of the system using appropriate adapters. A typical group of 10-12 user zones, each of 1k-2k square feet, can be illuminated with multiple spatial streams using only a *single* access point. Each signal port on the waveguide is designed to produce a *minimum* of approximately -62dBm received signal strength at *each* user location for client receivers to decode high VHT, MCS levels. (See the two-channel graphic below.)

12,000 Square Feet of 12, 42X24ft Rooms. All Rooms covered With 802.11ac.
Every Room is Illuminated by Two or Three Spatial Channels Using Room-optimized Antennas.
A two spatial stream system is shown. ALL Rooms Driven by Only ONE AP.



The output of the couplers on the waveguide connect through short cables to inexpensive, specially designed 90-degree beamwidth spatial stream directional, room antennas – *one antenna per spatial stream per* room or area in a system. Two or more SS antennas illuminate *each* room to provide ideal, local, MIMO signals. Note the physical separation of spatial signal antennas in each room to create a *fixed, stable, time differential*.

Each area in a building (offices, conference rooms, hallways, etc.) is illuminated with *WE* antennas that have the correct pattern and gain for a particular location. The signal power to each area is adjusted to provide the calculated signal level needed for that size area. The antennas are attached to signal couplers on the waveguide. Each coupler is set to the needed output level to illuminate an area. Each antenna carrying a spatial stream can be Az-El adjusted for optimized "cross-fire" room illumination by the system installer to maximize MIMO data rates and MIMO reliability. The users in EVERY room or area see signal strengths that appear like signals "local" to the AP, but are, in fact, carefully derived from ONE AP a distance away, to cover separate rooms in client locations.

Each spatial stream transmitted to a user area is high quality compared to variably attenuated and selectively faded signals that have passed through, or have been reflected by, changing in-path objects in a conventional free space "hope for the best bounce" MIMO system. Wasteful "signal overkill" in any illuminated area is avoided by radiating only the correct amount of power into each area, including the location of the AP, if required, plus an additional 4-6db of safety margin.

A user-friendly XL simulator for *WE* waveguide system design has been developed to allow the use of floor plans to configure single-channel and multi-channel GUIDED MIMO™ systems. System design usually requires only the floor plan and a walk-through, on-site visit, or images from the site, to determine placement of antennas and mounting hardware.

Unlike the legacy, expensive "guess and try" site survey approach to designing indoor wireless networks, *WEs* waveguide signal distribution method of design accounts for all signal levels down to ~ 0.1dB and presents excellent, consistent signals to all clients. Antenna patterns and directions to minimize interference are determined at the time of system design. Several 802.11n, or ac channels can be *multiplexed* onto a single 5GHz GUIDED MIMO™ system for higher simultaneous bandwidth to ALL user locations illuminated by the same multi-waveguide backbone. *WE* GUIDED MIMO™ systems are completely passive (no electronics) and need little or no maintenance once installed.

Please note that Wi-Fi was used as the example RF subject in this paper due to its ubiquitous nature around the world. *WE's low latency transmission* technology is, however, also applicable to cell, Bluetooth, LTE, LTE-U, and other IIoT data formats. Any RF signaling bandwidth that falls within the bandpass of a specific *WE* waveguide is acceptable. Waveguide systems designed to operate in new bands, such as 2.5GHz and 3.5GHz, etc. can be provided by *WE* relatively quickly.

Consider *WE* systems as the "missing link" needed in IIoT systems.

The Market for *WE* Products

Wireless Expressways' technology is *DISRUPTIVE* and applies to many markets.

WE's waveguide-based antenna systems are designed for communications integrators, VARs, and large end users who have been looking for ways to design and implement high quality general coverage and MIMO-based, lower cost, WLANs using *deterministic designs* instead of presently used "guess and try" methods. It's the next generation of WLANs.

WE's core method of signal distribution yields a bounty of excellent results, including:

- *WE's* SYSTEM DESIGN METHOD employs RF engineering, *not* guesswork.
- ONE AP can cover a very large floor zone with reliable, high-level signals and high data rates delivered to every user, regardless of location.
- FLOOR ZONES on adjacent high-speed channels allow channel reuse with little or no co-channel interference in large facilities.
- LIMITED RADIATION to/from outside areas improves data security.
- ACCESS POINTS in warehouses can be mounted at ground level in *WE* systems for easy maintenance and rapid AP replacement without a lift.
- MIMO APs on *WE* waveguides provide high data rates to all users.
- LOW CAPEX AND VERY LOW OPEX costs.

Conclusion

The above paper discusses the many facets of new, inventive, solutions for in-building wireless coverage. As mentioned, these implementations are well beyond the drawing board stage. They have been field proven in installations in a number of warehouses throughout Texas. While they do require installation by someone with technical skills, once a system is installed, it is basically trouble free.

The advent of 5G and unlicensed spectrum in the 5 GHz band as well as the spectrum sharing agreement with Federated Wireless and cell users in the 3.5 GHz band simply mean that there will be more and not less pollution of the radio spectrum as the noise floor across a broader range of the spectrum continues to move higher. It appears from what I have seen and read about Wireless Expressways' RF distribution solutions, they are far more impervious to most increases in the noise floor as well as other devices which may be co-located in the same or nearby facilities. In fact, if more wireless users in warehouse industrial parks, businesses, schools, and hospitals, for example, were to implement their wireless systems using *WE's* approach, there would be a large reduction of interference in and among buildings, resulting in much higher average data rates, greater systems' reliability, and higher data security in every facility.

It isn't often in the technological world of today that one can find a company that has encountered problems that are plaguing many customers, review the issues, and then identify solutions that will solve the problems at a reasonable cost. Wireless Expressways is one of these companies. It is always great when I find a company that develops technology to fix existing problems rather than a company that invents a new technology and then looks for a problem to solve.

Andrew M Seybold
Charles D Becker

About *WE*:

Wireless Expressways, Inc. is a privately held Texas-based corporation that has designed, developed, and field tested most of the configurations in this white paper.

WE is seeking funding to commence full-scale manufacturing of its proprietary, *disruptive* technology to solve the current pervasive problems in Wi-Fi distribution systems in industrial, commercial, and public venues.

The company has received 30 US and International patents on its technology. More are filed and planned. *WE* was the CTIA2013 Innovator of the Year In Indoor Networking.

Interested parties should contact: Charles Becker
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