UWB Wireless Video Transmission Technology in Medical Applications

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Overview

Although wireless equipment and services is one of the fastest growing areas in the healthcare IT segment, wireless technology adoption among healthcare providers lags other major industries. Many industry research reports predict the industry will invest over $9 billion dollars in wireless technology in the US alone by 2010. They also predict that wireless services will surpass wired in the same year*.

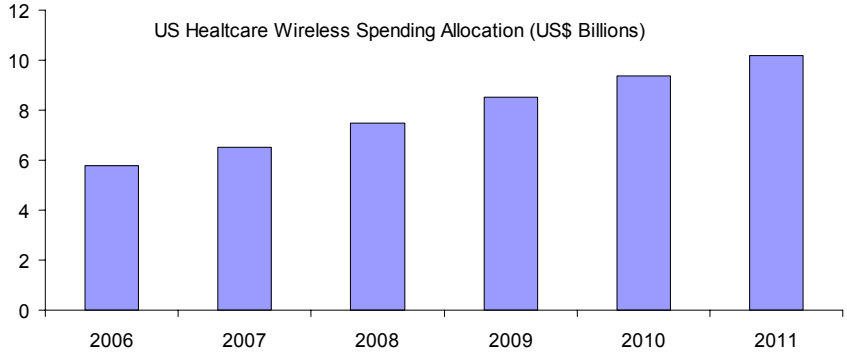

Figure 1.1: US Healthcare Wireless Allocation 2006 - 2011

Decision makers in the healthcare industry are turning to mobile and wireless technology, combined with WiFi networks, to improve the quality of their patient care in critical applications. This results in better, timely healthcare at reduced costs. Integrating mobile medical technology with healthcare enterprise IT infrastructure enables healthcare practitioners to quickly locate a patient's medical information. This allows them to spend more time with the patient, to make informed decisions with fewer errors and reduced costs. To date, wireless networks have been deployed to perform functions such as admission assessments, bedside charting, medication orders, supply inventory, patient records, emergency communication, telemedicine, patient monitoring and alerting, and medical equipment status reporting to name a few. The critical function that wireless technology provides is that it puts data entry and retrieval capability at the point of patient care, adding tremendous value in terms of doctor and nurse productivity and efficiency.

Wireless adoption in the healthcare industry is high and is expected to grow even further. This presents both an opportunity and challenge for the integrated operating room (OR). The equipment in most ORs is connected by fiber optic and /or copper cables pulled through boom arms and conduits in the walls, a time consuming and labor intensive process. In many other cases, cables are just laying on the floor, affecting the safety and efficiency of the OR.

* Source: InStat, In-Dustry Updates, Wireless Trends and Expenditures: US Healthcare

Healthcare OR professionals have long sought a wireless technology to replace wires in the OR as a means to improve the level of efficiency, flexibility and safety. However, due to strict requirements on OR equipment including personnel safety, image quality, operating distance, radiation level, and co-existence with other equipment, so far, this has not become a reality. Most wireless technologies have had bandwidth limitations, interfered with other OR equipment or simply were not robust enough to provide a reliable connection. Recently, FDA and other similar national organizations have approved Ultra Wideband (UWB) based wireless video devices for use in the operating room. They have recognized that UWB is a technology that truly satisfies OR requirements for a medical-grade wireless video system. The figure below shows a UWB wireless video system used with other medical devices in the operating room.

Figure 1.2: UWB Wireless Video System in OR

The scope of this whitepaper is to provide a better understanding of the UWB technology, UWB based products and their powerful features, its fit for OR applications, and an overview of the competitive landscape.

Ultra Wideband Technology- How does it work

UWB is a class of RF technologies that uses a very wide bandwidth to transmit signals via a wireless link. Various implementations of UWB technology differ in frequency band and signal characteristics. The most common UWB technology is based on WiMedia Alliance recommendations[1]. WiMedia's UWB technology is an ISO-published radio standard for high-speed, wireless connectivity. UWB offers an unsurpassed combination of high data throughput rates and low energy consumption utilizing bands within the frequency range of 3.1 – 10.6 GHz in the US and many other parts of the world.

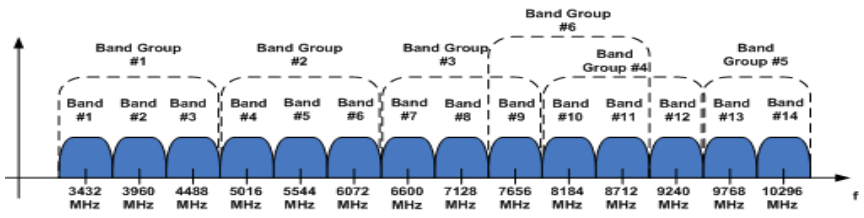

Figure 1.3: UWB Frequency Channels and Band-groups, x-axis: Frequency, y-axis: Power

1. WiMedia Alliance is a 350+ member global nonprofit organization that defines, certifies and supports enabling wireless technology for multimedia applications.

WiMedia defines specifications of a UWB based Physical (PHY) and Media Access Control (MAC) layer. Other technologies including Wireless USB, Bluetooth 3.0 and other proprietary wireless designs can sit at the top of the two layers and take advantage of the larger bandwidth of this new technology calling the combination of the PHY and MAC layers the "common radio platform". The figure below demonstrates the WiMedia Protocol Stack.

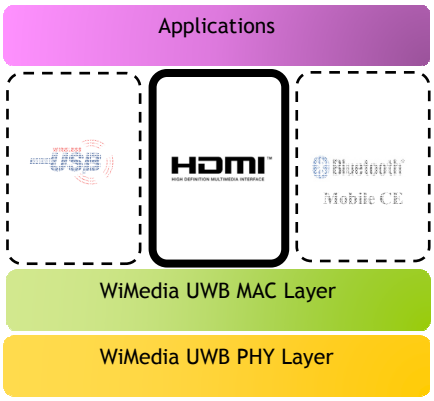

Figure 1.4: UWB Protocol Stack

On the physical layer, the spectrum is divided into 14 bands and 6 band groups (BG) – each band group consists of 3 bands as described in figure 1.3. It also specifies a Multi-band Orthogonal Frequency Division Multiplexing with over 110 sub-carriers per channel (4.125 MHz bandwidth sub-carrier bandwidth), a channel bandwidth of 528 MHz and very low broadcast power that allows same-channel coexistence with narrower band devices such as 802.11a/b/g/n radios. UWB's much higher bandwidth results in higher data throughput, coupled with a very low RF output power; UWB offers a communication range of up to 30 feet (10 meters). Figure 1.5 demonstrates the wide bandwidth of UWB as compared with more traditional narrowband and spread spectrum signals.

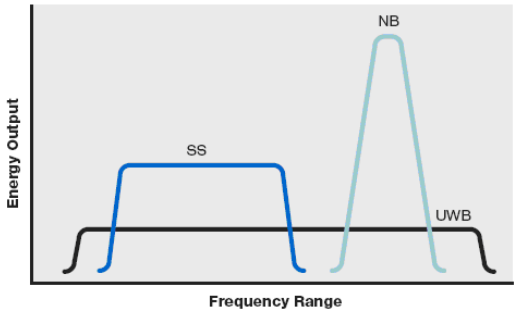

Figure 1.5: Comparison of narrowband (NB), Spread Spectrum (SS) and Ultra Wideband (UWB) signal concepts

In consumer electronics, the low transmission power of UWB is seen as a shortcoming. However, it is less of an issue in operating rooms since most ORs have dimensions similar to 30 feet (10 meter). Furthermore, UWB's lower RF output power allows same channel reuse in adjacent rooms and results in lower radiation levels in general.

The WiMedia MAC protocol defines a Super-frame structure that consists of a "beacon period" and "data period". Beacon frames are transmitted by each UWB device to ensure cooperative behavior among all devices. It provides basic timing information such as super-frame start as well as conveying reservation and scheduling information for medium access. Actual information is transmitted during the "data period".

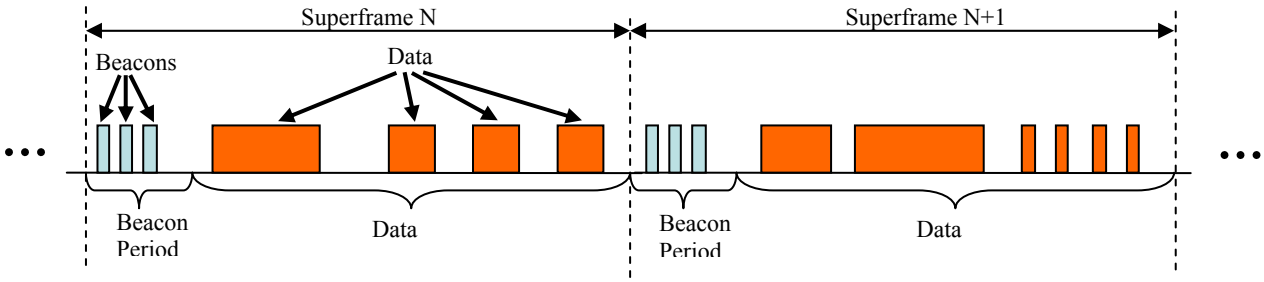

Figure 1.6: UWB Super-frame Structure

WiMedia's security, data path encryption, power management, retransmission, and back-acknowledgement features make the UWB MAC layer reliable for scientific, medical and consumer applications, including video transmission in the operating room.

UWB's extremely wide band allows the transmission of more data in a given period of time than more traditional technologies such as 802.11a/b/g/n and Bluetooth. This is explained more clearly in Shannon's Law which states that the potential data rate over a given RF link – also known as channel capacity C - is proportional to the bandwidth BW of the channel and the logarithm of the signal-to-noise ratio S/N as described in Equation 1.1.

$$C = BW \log_2\left(1 + \frac{S}{N}\right)$$

Equation 1.1: Shannon's Law

As Shannon's Law demonstrates, WHDI, 802.11a/b/g/n, Bluetooth and other narrowband devices in the 900MHz, 2.4GHz and 5GHz bands where each radio channel is constrained to occupy only a narrow band of 20/40 MHz, will be able to offer only a very small channel capacity compared to UWB technology. As a result, narrow band technologies must use complex modulation orders and/or MIMO (Multiple In, Multiple Out) antenna schemes to obtain adequate throughput, and therefore they may not deliver consistent and reliable performance for the multimodality requirements of today's operating rooms. UWB, on the other hand, is in a much better position to do so.

Wireless Video System in the Operating Room – What is needed

Since the year 2000, a concerted effort has been made to increase OR efficiency via OR integration. Integration involves equipping the OR with a central control system that can process information from video and other data sources. It incorporates a pre-planned ergonomic design and includes the ability to electronically send and receive information from the OR. In general, a fully integrated OR usually includes a central router/hub, lighting and

equipment arms, monitors, a video camera system, digital capture devices, insufflators and surgical tables.

Figure 1.7: A typical integrated operating room

One missing element within today's integrated ORs is a medical-grade wireless technology that allows equipment connectivity by means of wireless communication. While most of today's integrated ORs are state-of-the-art in terms of equipment and communication capabilities, they lag every other industry in terms of equipment connectivity – little has changed since the '80s and '90s. This poses a dilemma for cash-strapped healthcare providers who search for every means to improve efficiency and productivity in order to meet their daily and monthly revenue goals per OR.

The purpose of this section is to highlight some of the most important requirements of a medical-grade wireless video system in the operating room including safety, reliability, security, cost, performance, ease of use, flexibility, and compatibility with imaging devices in the OR and other wireless technologies in the hospital environment.

In general, ORs are equipped with multiple surgical displays presenting surgical camera video feeds and procedure-related information to OR surgeons and nurses. Due to smaller weight, higher image quality and overall better performance, most OR displays already have transitioned to HD format displays or are in the process of doing so. Medical-grade wireless video systems must be able to support a mix of HD and non-HD video formats up to 1080p at 60 Hz in a multimodality environment.

Unlike consumer electronics, image sources in an operating room have a variety of non-standard interface/timing parameters including total number of pixels, horizontal number of pixels, synchronization and other parameters that vary from manufacturer to manufacturer and even between models of image sources. Medical-grade wireless video systems must have a very flexible firmware structure that allows interfacing to a wide range of standard and non-standard video signal parameters.

With wireless being a new concept in the OR, wireless devices must be 'Plug-and-Play', easy to use, install, and operate and must provide many automatic features. Additionally, wireless devices in an operating room should provide the flexibility that allows easy cross-connecting to other transmitters and receivers in the same OR.

OR wireless video systems must be safe and must provide robust communication while surgical procedures are in progress. Losing connectivity during procedures can have disastrous consequences for patients and can present a major liability for surgeons and hospitals.

Many wireless communication devices require direct line of sight (LOS) to be able to communicate reliably. However, in an operating room, wireless devices cannot rely on direct line of sight operation and must be designed to operate reliably even if people (doctors, nurses) or equipment stand directly between the transmitter and receiver. At the same time, OR wireless video systems must not cause harmful interference to other medical devices in the OR such as electrosurgical knives, X-Rays, Critical Care Units (CCU), Endoscopic Cameras, Surgical Displays, or Patient Monitoring Equipment. Also, they must co-exist with other wireless technologies such as cell phones, Wireless LAN, Bluetooth, Cordless Phones, and wireless speakers.

Patient safety and privacy regulations require a wireless video transmission system to transmit in a safe manner, without excessive radiation and containing a protection mechanism such as internal encryption so that unauthorized users cannot decode and access a patient's video.

In summary, a medical-grade wireless video system is expected to add value in terms of safety, flexibility and efficiency, and cost less than cabling. UWB technology with its bandwidth of 528MHz per channel, up to 480Mbps speed and low RF power output satisfies all of the above mentioned requirements for a medical-grade wireless video system for the OR and helps improve safety and efficiency in the operating room.

Competitive Landscape – Ultra Wideband vs. WHDI

ZeroWire by NDS Surgical Imaging is a UWB wireless video system operating in the 3.1 – 4.8 GHz frequency band that is protected from other technologies such as mobile phones, cordless phones, Wireless LAN, Bluetooth and other wireless devices that may be found in the hospital environment.

Figure 1.8: ZeroWire UWB wireless video system

ZeroWire has 3 independent channels of 528MHz bandwidth and 128 subcarriers per channel. Its low transmission power of 10 micro watts keeps radiation levels to a minimum and allows same channel re-use in adjoining operating rooms. ZeroWire incorporates a DVI and an HD-SDI port, each of which accepts uncompressed input from HD video sources up to 1080p@60Hz and non-HD video sources. Its Super Low Latency technology reduces the latency of the displayed video to less than 1 frame. ZeroWire's MAC layer features advanced algorithms for reliable video signal delivery that conform to WiMedia Quality of Service (QoS) requirements. Its memory enabled pairing system allows auto connect between the same transmitter/receiver pair whenever they are powered up. A "bonding button" allows connection to a new communications partner. ZeroWire is a 'Plug-n-Play' device that can adjust all of its video parameters automatically to optimize image quality. ZeroWire improves OR efficiency and safety by eliminating video cables, their frequent maintenance and their potential for being a tripping hazard.

ZeroWire incorporates dynamic video and wireless rate adaptation schemes allowing it to adjust its video throughput and adapt quickly to changes in the OR environment. This improves wireless link integrity under high fading and/or blocking conditions.

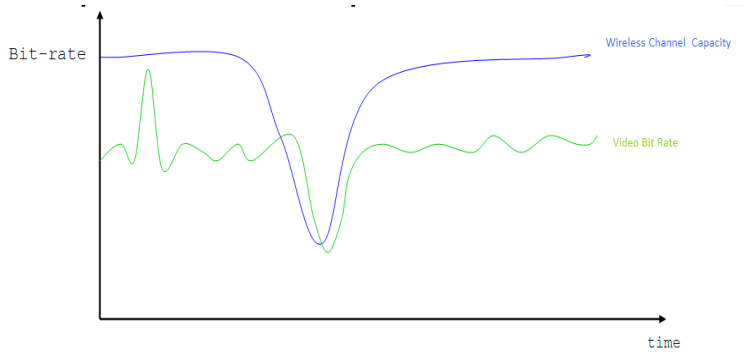

Figure 1.9: Dynamic video and wireless rate adaptation

In contrast to UWB technology, Wireless High Definition Interface (WHDI) technology is a narrow band technology that operates in 4.9 to 5.9 GHz band with a channel bandwidth of 20/40 MHz. Designed primarily for home applications, the technology has had moderate success in the consumer electronics market. However, WHDI's 20/40 MHz narrow bandwidth is simply too small for reliable wireless video transmission and cannot deliver the performance required in the OR.

As shown in figure 1.10, narrow band signals are more susceptible to frequency fading and narrow band interference. Narrow band interference may simply override the WHDI signal and reduce its throughput to zero. Hospitals already have many 5GHz WLAN systems deployed. These can interfere with WHDI systems. The 802.11n WLAN system transmits multiple streams of data in multiple directions that can cause heavy traffic in 5GHz frequency band.

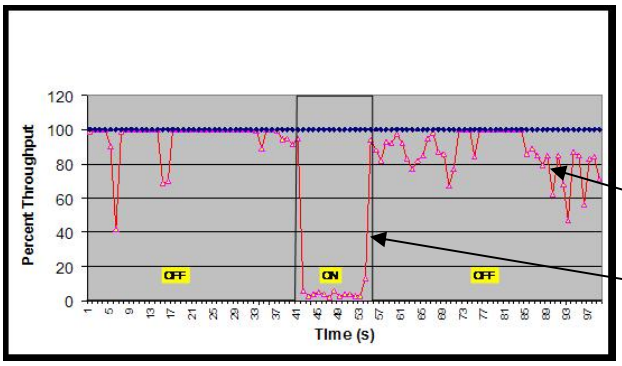

Figure 1.10: Stable UWB vs. Unstable WHDI Performance

WHDI technology uses a proprietary Joint Source-Channel Coding (JSCC) that includes compression, error protection and modulation in a single chip that converts an incoming video to OFDM symbols at its output. ZeroWire on the other hand uses the H.264 compression that is used in high-end video equipment including Blue-ray, HDTV and set top boxes. As H.264 compression is the de facto standard for video compression, its superiority is already proven. JSCC's performance is still an open question and yet to be proven in practical applications.

WHDI technology uses higher order modulations and MIMO antenna schemes to achieve adequate throughput. A MIMO system consists of multiple transmitter and receiver antennas and is able to transmit multiple streams of data simultaneously. In doing so, it can improve channel capacity according to the following equation.

$$C = BW\ Log\ (det[I + \partial\ HH^*])$$ **Equation 1.2: MIMO Capacity Equation**

C: Capacity, ∂: Signal to Noise Ratio, BW: Bandwidth, I: Identity Matrix of dimension N,
H: Channel Matrix of dimension N x M, N/M: Number of TX/RX Antennas,
det[S]: Determinant of the Matrix S

In this equation we see that the capacity increases linearly with the bandwidth and logarithmically with Signal to Noise Ratio. WHDI and WiFi technologies try to make up for their narrower bandwidth by using higher order modulations that require a higher Signal to Noise Ratio. However, higher order modulations add to the system complexity and reduce its reliability. MIMO antenna schemes add even more system complexity. One major disadvantage of a WHDI and WiFi MIMO system is that it utilizes spatial multiplexing that requires a well-conditioned channel matrix H to deliver higher data rates. The inability of the MIMO system to adjust dynamically to the environment of an operating room without requiring an ideal setup of 3 to 4 spatially independent channels prevents WHDI systems from achieving their maximum throughput. As a result, in operating rooms where high image quality is required, they fall back to lower throughput modes and provide only degraded image quality. ZeroWire's extremely large bandwidth eliminates the need for a higher order modulation as well as MIMO antenna schemes and its attendant complexity.

Another shortcoming of the WHDI technology is its high RF output power that prevents same channel re-use in adjoining rooms, as well as increasing the overall radiation level in the operating room. The RF output power of current WHDI systems is 1,000 to 10,000 times greater than ZeroWire. Furthermore, its high RF output power may interfere with 5 GHz WLAN devices that are located a considerable distance from a WHDI device. Most WHDI systems warn to change WLAN frequencies to 2.4 GHz when their system is turned on. Changing WLAN or other wireless frequencies, in hospitals where major wireless investments have been made is not a practical or cost effective option. Market research reports indicate major new investments in Wireless IT including newer 5GHz 802.11n WLAN systems that could further impact the business case for a WHDI based wireless video system in the OR.

Summary

UWB wireless technology uses a very wide bandwidth to transmit information. The wide bandwidth provides sufficient throughput for reliable delivery of high quality video in HD and non-HD formats up to 1080p at 60Hz.

The ZeroWire UWB-based wireless video system improves clinical efficiency and safety in the OR by eliminating video cables on the floor, their frequent maintenance and potential tripping hazard. It can coexist with medical equipment in the OR and other wireless technologies such as WLAN, mobile phones and cell phones.

WHDI and other narrow band technologies are susceptible to frequency fading and narrow band interference. Their performance does not meet the requirements of an operating room. Additionally, WHDI may interfere with WLAN and other wireless systems in the hospital environment. Furthermore, WHDI technology may deliver degraded image quality due to the lack of ideal environment for the MIMO antenna schemes in the operating room.

For these reasons, UWB is the technology to use for wireless video in the OR.

References:

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