Ultra-Wideband Solutions for Last Mile Access Network

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INTRODUCTION

Ultra-wideband (UWB) is an alternative wireless communications technology that offers high bandwidth wireless communications without the constraints of spectrum allocation. Fundamentally different from conventional radio frequency communications, UWB relies on a series of narrow, precisely timed pulses to transmit digital data. Transmitters and receivers that use UWB can be much simpler to build than their conventional counterparts, resulting in lower cost and higher power efficiency. Moreover, the inherent properties of UWB emissions allow them to potentially coexist with conventional wireless systems on a noninterfering basis.

In April 2002, the Federal Communications Commission (FCC) released UWB emission masks and introduced the concept of coexistence with traditional and protected radio services in the frequency spectrum, which allows the operation of UWB systems mainly in the 3.1 to 10.6 GHz band, limiting the power level emission to -41dBm/MHz. Within the power limit allowed under the current FCC regulations, Ultra-wideband can not only carry huge amounts of data over a short-to-medium distance at very low power (this range can be extended by using ad-hoc or mesh networks), but it also has the ability to carry signals through doors and other obstacles that tend to reflect signals at more limited bandwidths and a higher power (Reed, 2005). At higher power levels, UWB signals can travel to significantly greater ranges.

In March 2005, the FCC granted the waiver request, filed by the multiband Orthogonal Frequency Division Multiplexing (OFDM) alliance (MBOA), in which it approved the change in measurement for the all UWB technologies (neutral approach) (Barret, 2005). The FCC's waiver grants effectively removes the previous transmit power penalties for both frequency-hopping (OFDM) and gated UWB technologies (TH and DS). Hence, they are allowed to transmit at higher power levels and then become idle for some time, as long as they meet the limits for average power density. This new rules allow those technologies to achieve up to four times better performance and double the range.

BACKGROUND

Definitions

The concept of Ultra-wideband communication originated in the early days of radio. In the 1900s the Marconi spark gap transmitter (the beginning of radio), communicated by spreading a signal over a very wide bandwidth (Zhi & Giannakis, 2004). The basic concept is to develop, transmit, and receive an extremely short duration burst of radio frequency (RF) energy, typically a few tens of picoseconds (trillionths of a second) to a few nanoseconds (billionths of a second) in duration. These bursts represent from one to only a few cycles of an RF carrier wave. The resultant waveforms are extremely broadband, so much so that it is often difficult to determine an actual RF center frequency, which is known as "carrier-free." Early methods of signal generation utilized "baseband" (i.e., nonRF) fast rise-time pulse excitation of a wideband microwave antenna to generate and radiate the antenna's effective "impulse" response. More modern UWB systems no longer utilize direct impulse excitation of an antenna because of the inability of such an approach to adequately control emission bandwidths and apparent center frequencies (Ghavami, Michael, & Kohno, 2004).

UWB Attractive Features

UWB possesses some features that are attractive for last mile access:

- **High-speed communication systems:** UWB is advantageous for high-speed, large bandwidth, multiuser, short-to-medium range communication systems. A large number of users can share the same bandwidth for speeds greater than 100 Mbps.
- **Resolve multipath:** UWB radio signals inherently possess very fine time resolution. As a result, it is possible to resolve multipath components down to differential delays on the order of tenths of a nanosecond (corresponding to less than 1-foot path differentials). This significantly reduces fading effects in urban environments and results in fade margin reduction (Rashid, Sabira, Ali, & Khazani, 2006).
- **Secure communications:** UWB signals occupy large bandwidth, can be made noise-like, can communicate at a power spectral density level well below the noise floor of conventional radio-communication receivers, and can communicate with a unique timing code at millions of bits per second. These features result in secure transmissions with low probability of detection (LPD) and low probability of interception (LPI) (August, Lee, & Ha, 2004).
- **Relative system simplicity:** UWB baseband information can be directly modulated using short pulses rather than modulating a sinusoidal wave. In this form of implementation, the UWB transceiver will have no phase-locked loop synthesizer, voltage-controlled oscillator, mixer, or power amplifier compared to the super-heterodyne transceiver (Anderson, Orndorff, Buehrer, & Reed, 2001).
- **Penetration properties:** UWB emissions have good ability to penetrate walls and obstacles and provide high accuracy location determination. These properties would also be useful in Location-based services (LBS) applications in last mile.
- **Low power consumption:** The current target for power consumption of UWB chipsets is less than 100 mW, which make it a good candidate for portable devices.
- **Immunity to interference:** An important feature of UWB systems is their large processing gain, a measure of a system's robustness against interference.

Ultra-Wideband vs. Narrowband

According to the FCC, a UWB system is classified using one of two different measures of bandwidth. A system can either have an instantaneous bandwidth in excess of 500 MHz or have a fractional bandwidth that exceeds 0.20 (by comparison a narrowband signal typically has a fractional bandwidth which is less than 0.01) (Sabira, Rashid, Borhanuddin, & Chan, 2006). Both metrics are defined according to the -10 dB points of the signal's spectrum. Fractional bandwidth (η) is defined as the signal's bandwidth divided by its center frequency or more precisely.

$$\eta = \frac{2(f_H - f_L)}{(f_H + f_L)} \tag{1}$$

These definitions specify that systems with a center frequency greater than 2.5 GHz must have a bandwidth greater than 500 MHz and a system with a center frequency less than 2.5 GHz must have a fractional bandwidth greater than 0.20. Figure 1 below provides an illustration comparing the fractional bandwidth of a narrowband signal and a UWB signal.

UWB TRANSMISSIONS TECHNIQUES

There are two general ways to use the bandwidth available for UWB. Impulse radio (IR) was the original approach to UWB. It involves the use of very short-

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