The Future of Wireless Technology
Achieving Gigabit Data Rates

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As the need for high quality multimedia, voice and data services rises, so do the communications technology requirements, pointing toward an approaching need for gigabit speeds and longer range connectivity. How do we get there? In conjunction with motivated regulatory agencies in North America, the European Union, and across the Asia-Pacific region that are providing new approaches for spectrum use, new radio systems will evolve which will require significant optimization at the architectural, circuit and algorithm levels. While some approaches such as IEEE 802.11n are improving data rates through increasing efficiency by evolving existing standards, other approaches, such as Ultra Wideband (UWB) and Cognitive radio, are taking much more aggressive strategies, such as sharing spectra with other users. Another approach that will be pursued is to take the time honored strategy of moving to higher, unused frequencies such the 60 GHz millimeter wave band.

Increasing efficiency to reach gigabit per second levels is quite difficult, and 802.11n only promises a modest increase in wireless bandwidth, though robustness is no doubt improved. The sharing strategy of Ultra Wideband is accomplished by severe restrictions of the transmit power while Cognitive radios will likely not have such a limitation, but constantly sense the spectral environment and then alter their characteristics as necessary to avoid interference. On the other hand, millimeter wave radio technology can use conventional radio techniques at high power levels in the new unlicensed bands, but require new design methodologies if CMOS is to be used to yield cost-effective solutions. This article will compare and contrast each of these new approaches, which will likely be at forefront of the next generation of wireless designs that address gigabit wireless networking.

IEEE 802.11n

802.11n is an extension of the popular, 802.11 family of wireless local area networking technologies. Originally intended as an enhancement to improve actual data network throughput to over 100 Mbps, it now includes a compendium of technologies to support devices and applications ranging from single antenna, low-power Voice over IP (VoIP) telephone handsets, to four antenna, high performance graphics workstations. All of the major chip companies that have been shipping 802.11a, b and g products have 802.11n technologies under development. In addition, Airgo has recently arrived on the scene with a different approach to MIMO. The IEEE currently expects 802.11n to be an official standard some time between March and September 2007.

802.11n uses a wide variety of digital and analog techniques at both the medium access control (MAC) and physical (PHY) layers of the networking stack to support these applications. MAC techniques range from multiple receiver aggregation to increase efficiency and decrease power consumption for VoIP systems, and jumbo frame support for bulk data transfers. PHY techniques range from 256-quadrature amplitude modulation (QAM) to increase the spectral efficiency of wireless links, to 40 MHz channel bonding, to single and multiple antenna spatial multiplexing to support single input/output and multiple input/output (MIMO) systems with one to four antennas – the key advantage of 802.11n systems. All of this will be delivered along with legacy support for previous generations of 802.11a, 802.11b, and 802.11g systems.

The comprehensiveness of 802.11n is also its biggest limitation. In order to support a variety of applications as well as legacy protocols, an 802.11n system must support a mix of features that significantly increases the complexity and cost of implementation. Spatial multiplexing and MIMO systems significantly increase the amount of silicon necessary to process signals such that an increase from one to the four antennas supported in the emerging standard increases processing complexity of some parts of the wireless system by 64-fold.

Supporting the maximum data rates of over 500 Mbps provided by the 802.11n standard without accessing significant new amounts of spectra requires pushing the limits of Shannon's Law by increasing spectrum capacity from a reasonable 2 bps/Hz of today's 802.11a and 802.11g systems to over 16 bps/Hz. This will constrain the range and achievable error rates at higher data rates. As such, most 802.11n systems are expected to eventually only support 100 – 200 Mbps of actual data throughput.

Ultra Wideband

Ultra Wideband (UWB) includes a set of technologies that are allowed by the FCC to transmit a very low power signal over the 7 GHz of spectrum from 3-10 GHz that is shared with other users. The challenge for UWB radio implementation is to fully exploit this wide bandwidth to provide high data rates in a solution less costly than provided by techniques such as 802.11n. There have evolved two competing approaches, one of which is based on frequency hopping OFDM which has many of the same characteristics as 802.11a/g systems, while the other is a fundamentally new approach using impulses instead of sine waves to transmit the data. A major challenge of the OFDM approach is that the overall complexity is on the order of present 802.11 systems, which means the opportunity for dramatic cost and power reductions is unlikely. On the other hand, an impulse radio uses a simple pulser to drive the antenna, and radiates a passband pulse shaped by the response of the wideband antenna and potential bandpass filters. This direct sequence scheme uses antipodal signaling or pulse position modulation, which has much lower linearity requirements, but has been rejected by large industry consortia such as the WiMedia Alliance because of concerns including lack of scalability. This competition between approaches has posed IEEE standards challenges that have significantly delayed availability of UWB products.

While the potential to deliver hundreds of megabits of throughput with simple radios is attractive, the extremely low transmission power provides a severe range limitation if gigabit/second links are desired. While efforts are in progress to relax regulations and this technology is strongly supported by many companies, UWB is only usable in the United States, and for short range, "USB-type" connections. As such, UWB is beginning to show significant promise with a range of viable application considerations. Also as more is learned about impulse radio implementations, a path to scalable, low-cost implementations may be discovered.

Cognitive Radio

The Cognitive radio concept is to share spectra by sensing the spectral environment in frequency, time and spatial domains and then to transmit in the unused dimensions. This new radio functionality will involve various new analog and digital signal processing techniques to accomplish the time varying spectral sensing, wideband frequency agility, and spatial discrimination. To fully exploit this approach, it would be desirable to allow such operation over the same 3-10 GHz that is used by Ultra Wideband, but the decision to do this by the FCC is no doubt relatively far in the future. However, there is hope that such a decision may ultimately be made as the FCC is going through the rule making process which might allow some limited form of cognitive radio operation in the digital TV bands from 400-800 MHz.

While there is much in common in implementation of UWB and Cognitive radios, the advantage of using wide bandwidths with reasonable power levels, could ultimately provide an approach which could achieve gigabit per second data rates. Just as there is a lack of knowledge of the best way to implement impulse radios, there is much to learn in how to implement Cognitive radios that can avoid the primary users in a shared band with sufficient reliability such that the secondary users are not impaired. The first conference focused on this type of radio is DySPAN 2005, which is being held this fall in Baltimore by the IEEE. This, no doubt, heralds the beginning of a new approach to spectrum usage.

Millimeter Wave Radio Technology

While there is much to be done in the regulatory domain for Cognitive radios, the work has already been done in the millimeter wave bands. In particular, there is an essentially unused unlicensed band from 57 to 66 GHz. Partly because of an oxygen absorption peak at 60 GHz, various regulators across Asia, Europe, and the Americas allow for 10's to 100's of Watts of Equivalent Isotropic Radiated Power (EIRP) for wireless transmissions. The wide bandwidth and high allowable transmit power potentially enable multi-gigabit wireless transmissions, though several key issues must be addressed before low cost gigabit per second links will become a reality.

Historically, millimeter wave electronics components have only been feasible in expensive and bulky compound semiconductors such as Indium Phosphide (InP) and Gallium Arsenide (GaAs) that are used in radios costing hundreds to thousands of dollars. In order to achieve widespread adoption of this technology, it is necessary to implement these circuits in the lowest-cost technology, namely CMOS. Recent results at the Berkeley Wireless Research Center have shown that not only does 130 nanometer CMOS have sufficient performance to be used for an integrated radio solution at 60 GHz, the use of on-chip transmission lines yields a design methodology that is highly reproducible.

Many people also believe that the characteristics of millimeter wave present a much more difficult propagation environment for high data-rate wireless communications. While the oxygen absorption causes a 15 dB/km loss, this translates to only 1.5 dB loss at 100 meters, so, for indoor applications the absorption loss from oxygen is negligible. There is also a belief that there is another loss that is proportional to the frequency squared, which comes from the Friis path loss equation. This "loss" actually comes from the fact that if omnidirectional antennas, such as half wavelength dipoles, are used then as the frequency goes up, the effective area of the antennas decreases as frequency squared. If on the other hand, the areas of the antennas are kept constant, then there is no increase in path loss, and in fact there is a "gain" which increases as the frequency squared, since an antenna that has an area greater than a half wave dipole is directional and will have a passive gain. For example, a 60 GHz antenna, which has an effective area of 1 square inch, will have a gain of approximately 25 dB. However, this gain comes at the expense of being highly directional. This would mean that millimeter wave radios need a solution for precise aiming to be used at their full potential.

Conclusions

In aggregate, advances in radio technologies bring the promise of extremely high data speeds with increased reliability and better use of wireless spectrum. While each of the technologies described above has its performance advantages, each also has its own unique limitations, which must be overcome. It is clear, however, that the application demand for higher data rate links, which will ultimately range over gigabits per second will result in solutions using some or all of the above approaches to achieve this goal.