MAC at issue for low-rate UWB nets
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Ultrawideband radio is, in principle, a physical transmission technique suitable for all kinds of applications. Given the strong power emission constraints imposed by the regulatory bodies in the United States — but likely to be adopted by other countries as well — UWB is emerging as a particularly appealing transmission technique for applications requiring either high bit rates over short ranges or low bit rates over medium to long ranges.

For the moment, the industry's attention is on the work being carried out by the IEEE 802.15.3a task group, which is defining a short-range, high-rate physical layer that will be paired with the 802.15.3's coordinated, time-division multiple-access (TDMA) media-access control (MAC). However, in the case of lower-rate transmissions, this MAC may not in fact be optimal for impulse-based UWB. Instead, an uncoordinated MAC derived from the modeling of pulse collisions of multiple asynchronous users may be the better option.

The high-bit-rate, short-range case for UWB includes wireless personal-area networks (WPANs) for multimedia traffic, cable replacement such as wireless USB and wearable devices like wireless high-fidelity headphones. The low-bit-rate, medium- to long-range case applies to long-range sensor networks such as indoor-outdoor distributed surveillance systems; nonreal-time data applications like e-mail and instant messaging; and in general all data transfers compatible with a transmission rate in the order of 1 Mbit/second over several tens of meters. A recent release of the IEEE 802.15.4 standard for low-rate WPANs (IEEE 802.15.4-2003, 2003) has increased attention for the low-bit-rate case.

The scenarios of applications mentioned above refer to networks that commonly adopt the self-organizing principle — that is, distributed networks. Examples of these networks are ad hoc and sensor networks, such as groups of wireless terminals located in a limited-size geographical area, communicating in an infrastructure-free fashion, and without any central coordinating unit or basestation. Communication routes may be formed by multiple hops to extend coverage. This paradigm can be viewed as different in nature from the cellular-networking model where, typically, nodes communicate by establishing single-hop connections with a central coordinating unit serving as the interface between wireless nodes and the fixed-wired infrastructure.

With respect to media-access control, the IEEE 802.15.3 standard (IEEE 802.15.3-2003, 2003) defines a MAC protocol for the high-bit-rate case (11 to 55 Mbits/s) and distances up to 50 meters. The TDMA-based protocol was originally developed around a traditional, narrowband (15 MHz on-air bandwidth) physical layer in the 2.4-GHz unlicensed band. The sudden and strong interest in UWB caused a rushed adoption of the IEEE 802.15.3 MAC standard for the UWB physical layer also, although this MAC is neither tailored nor optimized to UWB peculiarities.

Boost for innovation

Ultrawideband's typical features, such as the need for operating at low power vs. a rather accurate ranging capability, may have a significant impact on the design of the MAC and of routing algorithms and strategies. The optimization of MAC and network modules in ad hoc networks is a topic that currently occupies research attention worldwide.

The impulse-radio (IR) principle, in particular, may boost innovation in designing efficient algorithms for resource sharing and management because of the impulsive nature of the transmission. IR intrinsically partitions time in a peculiar way, because of the short and limited duration of the pulses. The spectrum of the IR signal is usually shaped by encoding data symbols using time-hopping pseudorandom sequences that may also serve as users' signatures, and ensuring access to the medium by multiple users. This resource-partitioning scheme is called time-hopping multiple access (THMA).

At first glance, it may appear that THMA falls into the code-division multiple-access (CDMA) category, where different users adopt different codes. As in CDMA, each code modifies the transmitted signal in such a way that a reference receiver is capable of isolating the useful signal from other user signals, which are perceived as interferers. The possibility of removing these unnecessary contributions mainly depends upon the characteristics of the codes used for separating data flows, and upon the degree of system-level synchronization.

In the ideal condition of perfect system synchronization, ideal channel and orthogonal codes associated with different data flows, the receiver is not affected by the presence of multiple transmissions. In a realistic scenario, however, where devices do not achieve ideal synchronization, and codes lose orthogonality because of different propagation delays on different paths, the receiver may not be capable of removing completely the presence of the undesired signals, and as a consequence system performance is affected by multiuser interference (MUI).

MUI in continuous-transmission vs. IR systems may substantially differ in nature, especially when in IR the number of pulses in the air is not sufficiently large to fill up the time dimension. A reduced number of pulses traveling over the air interface can be associated to scenarios where one or more of the following characteristics are present:

A reduced number of transmitters over a given geographical area (that is, low user density);
Transmitters characterized by low data rates; and
A low number of pulses per bit.
Examples of those application scenarios are sensor networks that are typically characterized by low data rates and sparse topologies.

In the IR low-rate framework, MUI can be better modeled following the concept of pulse collision rather than, as is common practice in conventional systems, as an additive Gaussian noise with uniform power spectral density over the range of frequencies of interest. The time occupied by a single pulse — that is, the time interval in which most of the energy of the received pulse is concentrated — lies between about 70 picoseconds and 20 nanoseconds, depending upon pulse shape and channel behavior. Pulse duration is thus rather short, and as a consequence, for low global-system bit rates, pulse collision might be a rather rare event. Moreover, since information bits are usually grouped into packets by the MAC before being sent over the air interface, it is on those packets that the effect of interference should be evaluated. MUI can be revisited under this perspective, by observing that interference is truly perceived as such in the event of both packet collision and pulse collision within the collided packet.

Uncoordinated transmission

Based on this approach, we have proposed in an upcoming paper ("UWB2: Uncoordinated, Wireless, Baseborn, medium access for UWB communication networks," to appear in Mobile Networks and Applications in the second quarter) discussing a UWB-IR-tailored MAC design for asynchronous UWB networks in which asynchronous UWB users are allowed to transmit in an uncoordinated manner. Network simulation results showed a fairly high probability of successful packet transmission for uncoordinated transmission of a reasonable number of users, leading to the conclusion that a UWB-tailored MAC for low-bit-rate applications may adopt a pure Aloha approach.

Aloha is a multiaccess approach in which each node transmits packets without waiting for a slot boundary. If collision occurs, the packet is retransmitted. This technique is a classic and is considered by many to be the simplest and best decentralized access policy. (The main reference is Norman Abramson, "The Throughput of Packet Broadcasting Channels," IEEE Transactions on Communications, Vol. 25, No. 1, January 1977, 117-128.)

The other side of the coin is an increased overhead required by the presence of a synchronization trailer in each transmitted packet. That said, this drawback may be an acceptable price to pay for low-bit-rate applications, while an additional advantage offered by the proposed approach is the possibility of collecting distance information between transmitter and receiver during control packet exchange. This information can enable the introduction in the MAC of new functions, such as distributed positioning.

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