

RECENT ADVANCES IN ULTRA WIDEBAND COMMUNICATIONS SYSTEMS

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1. ABSTRACT

The last compilation of ultra wideband (UWB) communications systems is nearly two years old [1]. This paper is intended as an update and illustrates recent trends in UWB communications for multi-user networking applications. More specifically, the paper describes three recent system developments – an *ad hoc* wireless UWB communications network for tactical voice and high-speed data communications; a long range UWB system for over-the-water and non line-of-sight voice, data and video communications; and a wireless UWB communications network for support of both tactical and strategic (long haul) communications.

2. INTRODUCTION

Within the past two years, military and government applications of UWB communications have demanded the accommodation of larger numbers of users, each with ever increasing bandwidth requirements. Often, a number of network "users" are simply remote sensor nodes (e.g., video, seismic, acoustic, etc.) whose data streams must be made accessible at will to other users within the network. Data requirements have ranged from low bitrate audio (e.g., 10's of kb/s CVSD voice) to real-time video (several Mb/s) applications. Both tactical (1-2 km) and strategic (>100 km) applications are of importance, with low probability of detection (LPD) a primary requirement in most government applications.

This paper provides an overview of three recently developed UWB systems which were designed to meet tactical, strategic and mixed-mode requirements for LPD multi-user communications. The first such system, *Draco*, utilizes an unique frequency division multiplex (FDM), time division multiple access (TDMA) UWB physical layer (PHY) and provides for true mobile *ad hoc* wireless operation within a tactical environment. The second system, *HFUWB*, was designed to provide for extended range operations (>10 miles) in non line-of-sight (non-LOS) environments utilizing surface or ground wave propagation of the UWB electromagnetic signal. The last system, *Orion*, is a composite tactical, short range UWB

network with an additional strategic, long haul (non-LOS) capability accommodated via frequency diversity. While each of these systems has been implemented in hardware; only the first two have been field tested to date.

3. DRACO, AN AD HOC UWB NETWORK FOR TACTICAL COMMUNICATIONS

DRACO is a proof-of-concept, high-speed, multi-channel UWB network incorporating both communications security (COMSEC) and transmission security (TRANSEC) capabilities. COMSEC is achieved through the use of Type 1 encryption; while TRANSEC is accomplished through the use of an unique UWB waveform design. The configuration of a single DRACO transceiver node is illustrated in Figure 1 below.

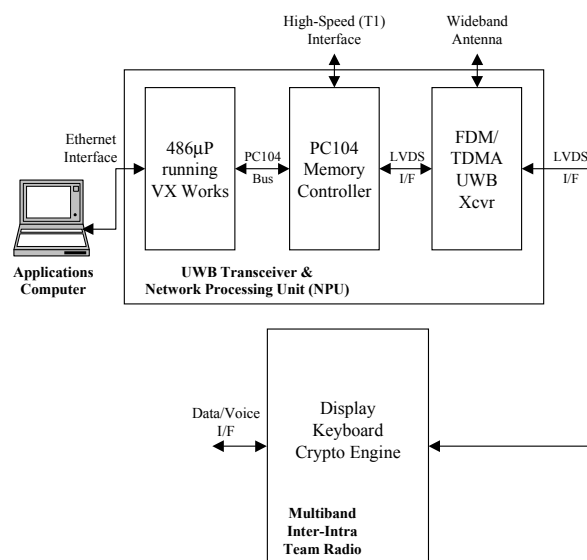


Figure 1. Draco UWB Transceiver System Block Diagram

Each DRACO node (cf. Figure 2 below) consists of a handheld user interface (consisting of a modified Thales Multi-band Inter/Intra Team Radio, MBITR); FDM/TDMA UWB transceiver and Network Processing Unit (NPU). The external MBITR electronics includes

Control and Crypto Interfaces, digital voice vocoder, RS232 serial data interface, keypad control, and liquid crystal display (LCD). All modes of operation for the DRACO Transceiver are controlled via the MBITR front panel keypad.



Figure 2. Draco UWB Communications Node
MBITR handheld interface on right,
UWB transceiver with NPU unit on left.

DRACO nodes support full network functionality using either encrypted voice or data (12/16 kb/s), or unencrypted medium to high-speed data at rates from 115.2 kb/s to 1.544 Mb/s (T1). A DRACO transceiver node can be operated as an unattended communications relay; originating sensor (e.g., video, seismic, acoustic, etc.) communications node; reachback packet node; or destination terminal.

DRACO UWB Electronics include a VHF/UHF multi-channel UWB Transmitter, companion multi-channel UWB Receiver and Digital Processor. DRACO hardware modules are illustrated in Figure 3 below.

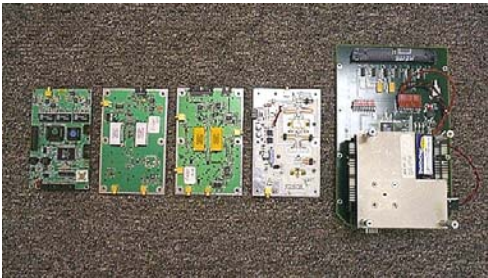


Figure 3. DRACO UWB & NPU Electronics
(Left to right: UWB digital processor, FDM T/R electronics,
UWB receiver front end, UWB transmitter and PC104 memory
controller with 486-based NPU stack)

The FPGA-based Digital Processor implements all high-speed UWB transceiver functions including RF control, timing recovery and synchronization, and Reed-Solomon forward error correction (FEC). The PC-104 based Memory Controller manages the interfaces between the UWB transceiver, the Thales MBITR electronics and the Rockwell-Collins Network Processing Unit (NPU). NPU electronics consists of a 486 microprocessor running VxWorks[®] and a 10baseT Ethernet Interface. VxWorks[®],

a registered trademark of Wind River Systems, Inc., Alameda, CA, provides an open architecture, high-performance, real-time operating system (RTOS) with sophisticated networking facilities

Unique to DRACO's UWB electronics is an ultra wideband, frequency division multiplex (FDM) architecture which provides an adaptive physical layer for Rockwell-Collins' Orthogonal Domain Multiple Access (ODMA) networking protocols. The use of orthogonal UWB frequency channels, implemented via a patented technique for generating spectrally-confined UWB emissions [2], significantly increases network throughput by enabling simultaneous transmissions of network management and data packets from units in close proximity without mutual interference. DRACO also utilizes a single pulse, UWB detection capability (i.e., one bit per UWB pulse), which permits high data rate (T1) communications without an excessive increase in pulse repetition frequency (PRF). Such low burst rate transmissions are effective in maintaining a low probability of detection [3].

The ODMA multimedia wireless networking protocol, running under VxWorks[®], implements a modified version of Rockwell Collins' *SoldierPhone* architecture [4]. The software automatically and adaptively configures the DRACO system to maintain communications among all nodes, even in the event that a signal path is degraded due to weak signal, interference, or node failure. The NPU implements a fully distributed, peer-to-peer, multi-hop networking system without the need for a centralized controller. All nodes distributively synchronize themselves and enter the network after power up.

The NPU software uses USAP (Unifying Slot Allocation Protocol) [5] and heuristics to determine RF connectivity, and then allocates RF resources. Each node uses a broadcast management channel to exchange routing and link state information. In DRACO, the management channel is implemented as a separate, orthogonal UWB RF channel. The routing scheme for the NPU uses a system of distributed routing tables to provide point-to-point routing for up to 50 nodes with a maximum of six hops between source and destination. Each node periodically transmits its routing table information to a neighboring node; and a dynamic, up-to-date topological image of the network is created with each node having a view from its own perspective. This method uses a combination of node distance and total link qualities to create tier classes. These classes are then ranked from best to worst, and the neighbor with the best tier class to a particular destination becomes the next hop along the route.

The NPU protocols use a cell-based communication architecture similar to ATM. Both raw, digitized voice and packetized data, which are stored in data buffers by

the Memory Controller card, are divided into small cells by the NPU to which are attached a management header. Because of its ability to adapt to ever-changing RF conditions while providing reliable multimedia communications, DRACO is a very flexible wireless, multi-hop, network.

A set of eight DRACO nodes was tested in field demonstrations at Ft. Campbell, KY. Ranges in excess of 1 km between nodes, with full *ad hoc* wireless connectivity, were demonstrated.

4. A UWB TRANSCEIVER FOR NON-LOS LONG-RANGE COMMUNICATIONS

Historically, UWB communications systems have operated in frequency ranges well above a few hundred MHz, and often above 1 GHz. Since the dimensions of an antenna suitable for handheld transceiver operation are usually quite limited, the direct impulse excitation of such antennas naturally gives rise to UWB emissions in the upper UHF through microwave frequency bands. However, at these higher frequencies, transmission range becomes severely limited by the effects of signal cancellation from the out-of-phase, reflected (multipath) signal from the earth.

For example the differential path length Δ_{path} between the direct and reflected paths to an intended receiver is given by the expression

$$\Delta_{path} = \sqrt{d^2 + (h_T + h_R)^2} - \sqrt{d^2 + (h_T - h_R)^2}$$

where d is the distance (range) to the receiver, h_T is the height of the transmit antenna above ground, and h_R is the height of the receive antenna. For distances d large relative to the individual antenna heights, the path time differential in seconds is approximately

$$\tau_{path} \approx \frac{2h_T h_R}{cd}$$

where c is the speed of light. Thus, for a 1 kilometer range between 2 handheld UWB transceivers whose antennas are 2 meters above ground, $\tau_{path} \approx 26.7$ picoseconds. Since the reflection coefficient is nearly -1 for low grazing angles [6], these small subnanosecond time differences between direct and reflected waves can result in substantial signal cancellation, even for short nanosecond pulses. Furthermore, for propagation distances appreciably beyond the "turnover point" defined as

$$d = \frac{4}{\lambda} h_T h_R$$

(e.g., 53 meters for the above handheld example at a 1 GHz center frequency) the received power is approximately given by

$$P_R \approx \frac{(h_T h_R)^2}{d^4} G_T G_R P_T$$

which exhibits a 4th law dependency with range, essentially independent of the operating frequency.

Now, from the physical properties of electromagnetic propagation over dielectric materials [7], an electromagnetic wave also has a natural tendency to propagate along the earth/atmosphere boundary as a result of earth currents induced by the transmitted signal's magnetic field. This action produces a surface wave propagation of the RF field which can extend over fairly large distances. Signal losses using surface wave phenomenon are considerably less than those encountered with direct wave transmission in which multipath cancellation from the ground reflected signal essentially cancels the direct path. However, surface wave propagation is essentially a low frequency phenomenon which becomes increasingly inefficient for electromagnetic propagation as the frequency exceeds the HF band (i.e., above 30 MHz).

Based upon the above discussion, one frequency band of particular interest is that currently used by the military for VHF tactical vehicular broadband communications systems, i.e., 30 to 88 MHz. While somewhat higher in frequency than optimum for strong surface wave propagation, this band has the unique feature that a large number of ruggedized, broadband antennas are available from a wide range of manufacturers.

Under a recent development effort for the U.S. Navy, Multispectral Solutions, Inc. (MSSI) developed a spectrally-confined [2], high-power UWB transceiver which operates over the 30 to 50 MHz portion of this band (i.e., 50% fractional bandwidth). These VHF UWB transceivers were designed with sufficient peak power output to achieve a communications range of 60 nautical miles over water. The transceivers operated at a data throughput of 850 kb/s, utilizing an average power of 6 Watts and a peak power output of 120 Watts. The high DC-to-RF efficiency of the transmitter design permitted extended field operation on rechargeable batteries.

The *HFUWB* transceiver is illustrated in Figure 4 below; with spectral densities and time domain waveforms shown in Figure 5.



Figure 4. Modular HFUWB UWB Transceiver
(Transceiver shown with RF front end module)

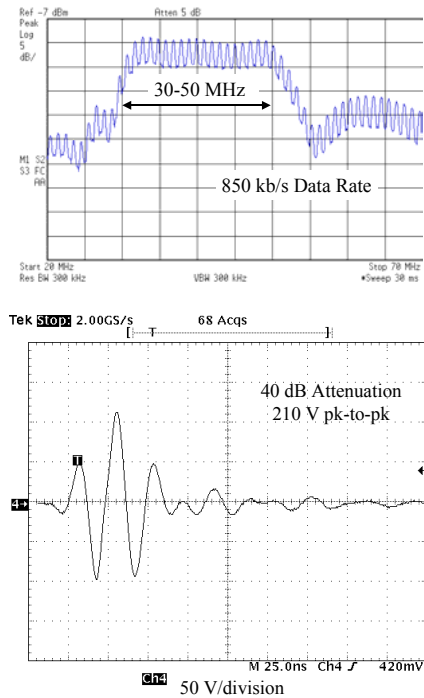


Figure 5. Power Spectrum and Time Domain Waveforms for HFUWB Transceiver

The transceivers were operated with both standard Single Channel Ground & Airborne Radio System (SINCGARS) 30-88 MHz whip antennas and a custom 30-50 MHz "fat" dipole (Figure 6) originally developed for shipborne applications.



Figure 6. HFUWB "Fat Dipole" for 30-50 MHz Coverage

5. ORION, A UWB NETWORK RADIO FOR BOTH TACTICAL & LONG RANGE COMMUNICATIONS

The final system to be discussed merges a UWB network designed for small group operations with a long range, back haul capability.

Unlike DRACO, the short range communications portion of ORION operates in the L-band region (1.3 to 1.7 GHz) with a 27% fractional bandwidth. Peak power

output at L-band is 0.8 watts. With the units operating at the maximum continuous burst rate of 2 Mpps, a worst case average power of 4 mW and a worst case average power density of 10 pW/Hz (-50 dBW/MHz) are observed. With 0.8 W peak output power and short stub antennas, the units have a demonstrated operational range of 1 km (line-of-sight). Designed for full duplex digital voice and data at rates up to 128 kb/s CVSD voice and 115.2 kb/s RS-232 data, transmissions are packet burst with average pulse repetition frequencies (PRFs) comparable to the transmission rates (single pulse per bit decisions). The L-band ORION radios are shown in Figure 7 below.



Figure 7. ORION L-band UWB Radio Transceivers

For short range tactical communications, system operation relies upon the use of a single "master" unit which has RF coverage to all other ("slave") units. Slaves communicate through the master in a star topology. Once granted channel access by the master, a slave unit continues to transmit either voice or data packets through the master to its ultimate destination. The communications channel established through the master node is symmetric in that both source and destination can communicate in full duplex fashion once the link is established.

A system level block diagram of the ORION radio is shown in Figure 8 below.

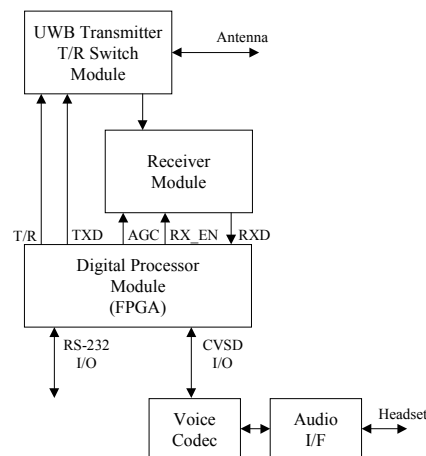


Figure 8. ORION System Block Diagram

The unit is modular in construction and consists of a motherboard and 3 plug-in daughter cards including UWB

transmitter and transmit/receive (T/R) module, UWB receiver module and Digital Processor Module (cf. Figure 9 below).

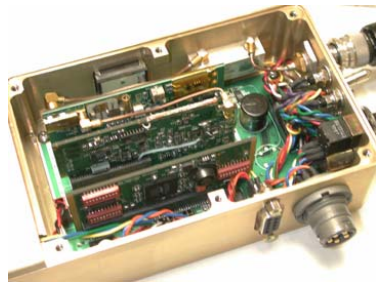


Figure 9. Modular ORION Architecture

(Top-to-bottom: Receiver, Transmitter and Processor Modules)

The Digital Processor Module is implemented in a single field programmable gate array (FPGA) and performs the following tasks within the radio:

- Clock and Timing Recovery
- RF Gain Control (AGC)
- Bit stream processing for CVSD voice
- RS-232 data generation and recovery (only level shifting is done by external chip)
- Forward error coding (FEC) encoding and decoding
- Burst interleaving and randomizing of data
- All formatting and sequencing logic.

A block diagram of the ORION FPGA architecture is shown in Figure 10 below.

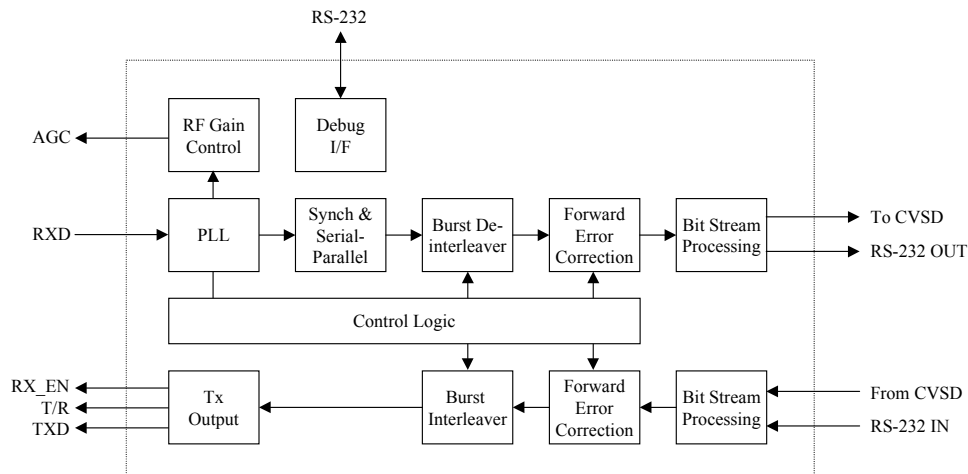


Figure 10. Digital Processor Module FPGA Block Diagram

The UWB Digital Processor was implemented using an Altera 20K100E (with 100,000 available gates).

In addition to an L-band, LOS capability, ORION also incorporates an additional long haul, or backbone capability. This is accomplished by using a set of modified *HFUWB* transceivers where the first in the chain interfaces to the L-band system via a high-speed serial interface, and the remainder can perform either point-to-point or digipeater (digital repeater) functions. The VHF portion of ORION can also accommodate up to a 2 Mb/s data rate; however, only 115.2 kb/s data and 128 kb/s voice were used in this application.

6. REFERENCES

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