

A PERSONAL AND INTER-VEHICLE CORDLESS COMMUNICATIONS SYSTEM

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ABSTRACT

The Northrop Grumman Cordless Communications System (CCS) is a state-of-the-art, wireless communications system targeted for tomorrow's armored battlefield. Through a single, hand-held or body-mounted Personal Communications Unit (PCU), the CCS provides the soldier with access to a digital, full-duplex wireless intercom, as well as the capability to simultaneously communicate over a point-to-point digital data link. In addition, through the use of a single Universal Adapter Interface (UAI), the soldier can remotely access the existing analog or digital wired vehicle intercom and the attached wide area tactical radios. Moreover, using a novel protocol and system architecture, the CCS is able to reconfigure itself automatically and seamlessly into various centralized and distributed network configurations as the operational scenario changes. At the core of the CCS is a 20 MIPS, fixed-point Digital Signal Processor, which implements the protocol, control and signal processing algorithms required to achieve robust personal and inter-vehicle communications.

1. INTRODUCTION

This paper describes the Northrop Grumman Cordless Communications System (CCS) [1][2], a wireless system designed for personal and inter-vehicle communications. Initially, the CCS was developed to augment existing analog and digital intercoms used in military ground vehicles. However, it can readily be extended to a host of other wireless applications, including:

- individual soldier radio
- communications systems for military and commercial aircraft
- factory and warehouse communication and monitoring
- construction site communications
- firefighter communications, and
- mobile customer service.

In a conventional intercom system, multiple voice signals are combined into one composite signal that is received by every user of the intercom. If a full-duplex implementation is used, all users are able to talk and hear each other simultaneously. The result is a more natural form of group conversation than "talk-then-listen," half-duplex radio techniques. Conversely, in conventional, point-to-point systems, communications typically involve a directed connection between two parties. Addressing methods are used to establish a network connection between the two parties that is released once communications cease.

Moreover, in many networks, Medium Access Control (MAC) techniques provide many users with access to the same physical medium, allowing multiple, simultaneous point-to-point conversations.

The system described herein utilizes a wireless, digital transmission medium to combine intercom and point-to-point communications into one network. As illustrated by the system specifications provided in Table 1, the functionality supported by the CCS includes:

- voice intercom communications
- multiple virtual channels for digital data communications
- broadcast data communications
- simultaneous digital data communications and intercom voice conversations, and
- automatic switching between centralized and distributed network control.

Personal access to the CCS is achieved through the use of a hand-held or body-mounted Personal Communications Unit (PCU). Vehicle access to the CCS is facilitated by a Universal Adapter Interface (UAI), which also provides system timing and access control in a centralized network configuration.

The remainder of this paper is organized as follows. Section 2 describes the communications protocol used by the CCS. Section 3 provides an overview of the CCS architecture and the various centralized and distributed network configurations supported by the system. Finally, the use of a Digital Signal Processor (DSP) to implement the required protocol, control and signal processing functions is discussed in Section 4.

2. COMMUNICATIONS PROTOCOL

The physical layer protocol designed for the CCS [3] utilizes a Time Division Multiple Access (TDMA) architecture that provides multiple users with simultaneous access to the transmission medium. In addition, the protocol supports digital audio and data transmissions, as well as a Frequency Hopped (FH) Spread Spectrum (SS) radio link.

2.1 Frame Format

In the CCS protocol, time is divided into sequentially occurring frames. Each frame contains a number of TDMA time slots, as shown in Figure 1. Slots *DI* through *DN* and *UI* through *UN* are downlink (transmission from UAI to PCU) and uplink (transmission from PCU to UAI) slots, respectively. Usually, downlink and uplink slots having the same index (e.g., *DI* and

UI) are linked to form a downlink-uplink slot pair. In the centralized network configuration, PCUs use a Medium Access Control (MAC) algorithm to access the available uplink slots. Once a PCU obtains access to an uplink slot, it receives transmissions from the UAI during the corresponding downlink slot. Those PCUs that do not have access to an uplink slot will receive broadcast UAI transmissions during the downlink slot *D0*. Finally, a frame gap is provided so that frames do not overlap due to clock inaccuracies, and for FHSS synthesizer re-tuning.

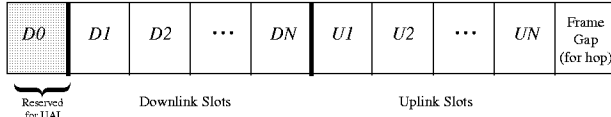


Figure 1. CCS protocol frame format.

2.2 Slot and Header Formats

Each slot in the protocol frame is segmented into a number of fields, as illustrated in Figure 2. Each slot contains a bit sync and slot sync field for radio signal acquisition, a header field for control information, a data field for audio and digital information, a 16-bit CRC field for error detection, and a slot gap to allow for clock inaccuracies.

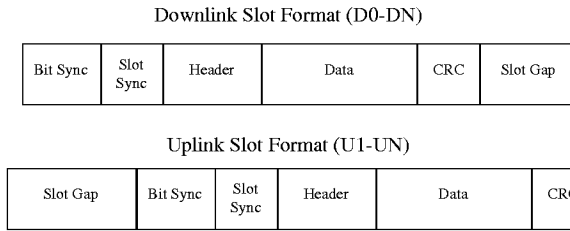


Figure 2. CCS protocol slot format.

The header format for all slots is depicted in Figure 3. The generic format of the header permits protocol layering and the reserved field permits future protocol growth. Finally, the user-programmable ID field permits digital audio and data point-to-point communications.

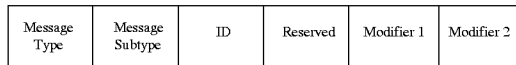


Figure 3. CCS protocol header format.

3. SYSTEM ARCHITECTURE

A typical system architecture for the CCS is depicted in Figure 4. In general, the CCS contains two main components: Universal Adapter Interfaces (UAIs), and Personal Communications Units (PCUs). In its standard mode of operation, a UAI is a device that provides centralized control of the wireless network by receiving, processing and routing incoming PCU transmissions. A PCU is a device that provides an individual user with access to the wireless network. In its standard mode of operation, a PCU that has audio and/or digital data to send will attempt to access the network, and will continue transmitting if access is confirmed by

the UAI. In this mode, messages transmitted and received by the PCU are routed through the UAI. However, PCUs are also capable of forming a network in the absence of a UAI. In this case, the PCUs use distributed control to establish network timing and verify network access. Note that the switch between centralized and distributed control occurs automatically and seamlessly as the network topology changes.

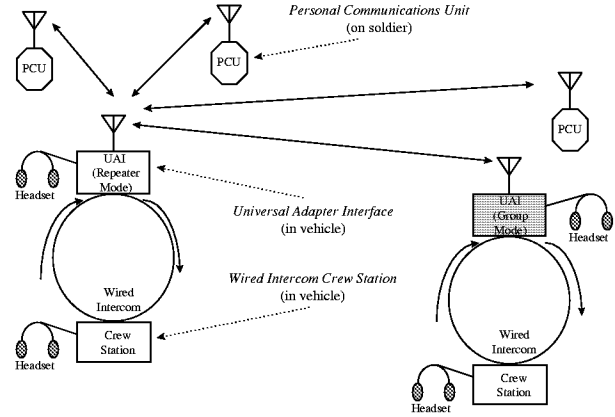


Figure 4. A typical Cordless Communications System architecture.

UAIs in a wireless intercom network may also be connected to a wired intercom. As such, the UAI acts as a bridge between users of the wireless intercom and users of the wired intercom. The UAI sends the composite wired intercom voice signal to the wireless users during its downlink transmissions. Conversely, the UAI combines all uplink wireless messages to form a composite signal that is transmitted to all wired intercom users.

The following sections discuss the system operation and various network configurations for voice intercom and digital data communications. As shown in

Figure 5, the three network configurations described for voice communications are: repeater mode (simple net), autonomous mode and group mode (compound net).

3.1 Repeater Mode

Repeater mode is the standard mode of network operation in which the UAI is the wireless network master. Again referring to Figure 4, in this mode the UAI receives multiple uplink transmissions from a number of PCUs. The UAI then forms a composite audio intercom signal by summing together all of the uplink PCU transmissions received during a given protocol frame. If the UAI is also connected to a wired intercom network, as shown in Figure 4, it can include those conversations in the overall composite audio signal as well. Finally, the UAI transmits this composite audio signal to all PCUs in range. In addition, the UAI may transmit the wireless intercom signals over the wired network, thereby providing a bridge between wired and wireless intercom users.

The paired uplink-downlink TDMA slot architecture provides network robustness and versatility. Specifically, the UAI utilizes slot *D0* to transmit the composite audio intercom signal (sum of

all received PCU and wired intercom signals) to all PCUs in range and not transmitting in the previous frame. Then, the UAI uses slot D_i to transmit a specific signal targeted for the PCU transmitting in slot U_j . This transmission can be an audio intercom signal, control information, digital data, etc. Thus, this architecture supports both intercom and point-to-point digital communications.

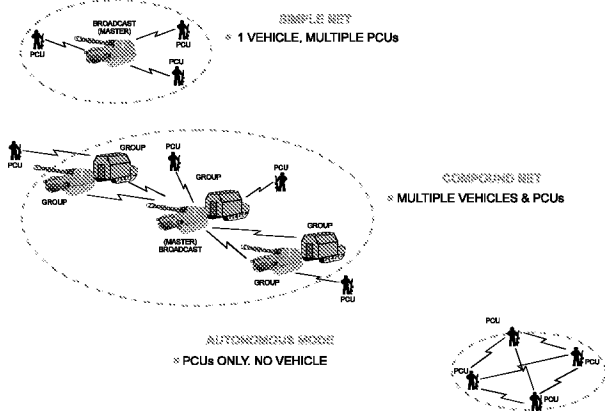


Figure 5. Various network configurations supported by the Cordless Communications System.

3.2 Autonomous Mode

Autonomous mode is the more complex mode of network operation in which PCUs initiate communications in the absence of a UAI. A PCU that is out-of-range of a UAI is called an "autonomous PCU." Note that autonomous PCUs may initiate communications with PCUs already in a neighboring, repeater-based network, or with other autonomous PCUs.

3.2.1 Neighboring Network

Figure 6 depicts a repeater-based network containing a UAI and four (4) PCUs: 0, 1, 2, and 3. An additional PCU, PCU 4, is within range of PCUs 0 and 1, but out-of-range of the UAI and PCUs 2 and 3. To ensure useful, reliable information exchange: 1) PCU 4 should not disrupt the existing repeater-based network, and 2) PCU 4 should be able to communicate with PCUs 0 and 1. These goals are achieved through use of control fields contained in the messages transmitted by each PCU. Specifically, an autonomous PCU (PCU 4) will search for other uplink PCU transmissions that correspond to a PCU or PCUs within listening range (PCU 0 or 1) and part of a repeater-based network. Then, the autonomous PCU will use the network status information included in these transmissions to determine slot availability and system timing in the neighboring network. Finally, the autonomous PCU will begin transmitting in an inactive slot of the neighboring network, and will assert a control bit that indicates that its messages correspond to an autonomous PCU. Thus, PCUs in the neighboring network and within listening range of the autonomous PCU will decode this control information and include the autonomous PCU's audio data in their composite intercom signal.

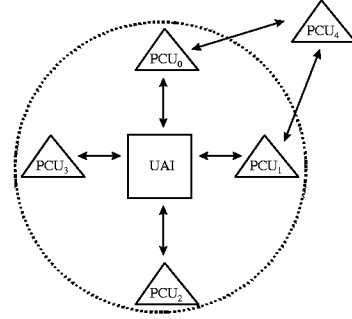


Figure 6. An example of the CCS in an autonomous network configuration.

3.2.2 Autonomous Network

In the event that an autonomous PCU does not detect the presence of other PCUs, the autonomous PCU will begin broadcasting its audio signal after a predetermined search interval has expired. Other autonomous PCUs in the area will obtain network timing from this signal, and will establish a distributed network by periodically broadcasting "beacon" signals.

3.3 Group Mode

The group mode of operation can be used to connect two or more vehicle intercom networks, along with their associated wireless users. Specifically, a UAI in group mode is configured to function as a PCU having the wired intercom as its audio input and output. Since the UAI acts as a PCU, it can communicate with other UAIs and PCUs using the repeater and autonomous modes discussed in the previous sections.

3.4 Point-to-Point Functionality

Point-to-point voice communications in which two users converse privately are also possible within this system architecture. For point-to-point operation, two PCUs would use either a user-programmable identification (ID) number, or a read-only manufacturer ID number to provide network addressing. Also, in a repeater-based system, this conversation can use the same wireless medium as the voice intercom without interference. To achieve simultaneous intercom and point-to-point communications, the UAI uses control information embedded in the uplink and downlink transmissions to route intercom and point-to-point messages to the appropriate PCUs.

3.5 Data Communications

Given that the CCS employs a digital wireless medium, applications requiring digital data communications are supported as well. For example, some of the applications facilitated by this system architecture include:

- reconnaissance (e.g., transmission of images and video from an imaging device located in a concealed position back to a centralized monitoring site)
- remote database access (e.g., for images, maps, etc.)

- remote report filing, and
- user-to-user data transfer.

Moreover, in a repeater-based network, digital data communications can occur simultaneously with voice intercom communications over the same wireless medium without interference. To achieve this simultaneous operation, the UAI uses control information embedded in the uplink and downlink transmissions to route intercom and data messages to the appropriate PCUs.

4. DIGITAL SIGNAL PROCESSING

At the core of the PCU and UAI is a 20 MIPS, fixed-point Digital Signal Processor (DSP) that implements the advanced protocol and signal processing algorithms required by the Cordless Communications System (CCS). In the prototype system, this device is responsible for concurrently processing and combining up to six (6) incoming, 64 kbps digital audio signals, producing two (2), 64 kbps digital audio outputs, managing a full-duplex, 64 or 128 kbps digital data link, controlling the user and radio interfaces, and running a number of signal processing algorithms. Some of these signal processing algorithms include: μ -law companding, audio signal combining, automatic volume control, an adaptive echo canceller, and a Voice Operated Transmitter (VOX).

VOX functionality provides the user with hands-free activation of the radio transmitter during voice communications. Most existing VOX algorithms are designed for low noise environments, and look for large increases in the power of the input audio signal to determine if voice is present (for example, see [4]). In high-noise environments, however, these simple power comparison techniques are unreliable and prone to false activation of the transmitter. Conversely, those existing VOX techniques targeted for high noise applications typically are computationally intensive, and require one or more DSPs for the VOX algorithm alone [5]-[7]. For these reasons, a novel VOX algorithm [8] was developed that incorporates an adaptive noise canceller with a sophisticated detection algorithm to determine the presence or absence of voice. The adaptive noise canceller is a predictive filter that adapts to the input audio signal and suppresses those signal components, for example the vehicle engine noise, whose characteristics are relatively constant over time. By using the output of the noise canceller, the companion detection algorithm provides reliable VOX activation. Moreover, the output of the adaptive noise canceller can be used as the transmitted audio signal to improve speech intelligibility under severe operating conditions.

5. SUMMARY

The Northrop Grumman Cordless Communications System (CCS) is a state-of-the-art personal and inter-vehicle digital communications system. In its present embodiment, the CCS facilitates unprecedented safety and efficiency for users working in high noise environments. These capabilities are enabled through the full-duplex protocol, autonomously reconfigurable network architecture, and the hands-free operation via a high-noise, adaptive Voice Operated Transmitter (VOX). In the future, the flexibility of its protocol and system architecture will

allow the CCS to evolve into a fully integrated, digital audio, video and data network capable of supporting today's, as well as tomorrow's, armored battlefield.

6. REFERENCES

- [1] Collar, S., et al., *Personal Communications System Architecture*, U.S. Patent Pending.
- [2] Jacklin, W., *Personal Communications System*, U.S. Patent Pending.
- [3] Jacklin, W. and Stratmoen, S., *Wireless Communications Protocol*, U.S. Patent Pending.
- [4] Jankowski, J. *Digital Voice Switch*. U.S. Patent, Number 4052568, 04 October 1977.
- [5] Morris, C. F., Morgan, W. C., Shack, P. E. "A New VOX Technique For Reducing Noise in Voice Communication Systems." *Proceedings of Southeastcon 74*, Orlando, Florida, 1974, pages 257 - 259.
- [6] Pencak, J. and Nelson, D. "The NP Speech Activity Detection Algorithm." *IEEE International Conference on Acoustics, Speech, and Signal Processing: Conference Proceedings, Vol.1*, Detroit, Michigan, May 1995, pages 381-384.
- [7] Satoh, H. and Nitta, T. *Speech Detection Apparatus Not Affected by Input Energy or Background Noise Levels*. U.S. Patent, Number 5293588, 08 March 1994.
- [8] Stobba, L. and Jacklin, W., *Voice Operated Switch for Use in High Noise Environments*, U.S. Patent Pending.

Table 1: Prototype CCS System Specifications*

Parameter	Value	Comment
Range	500 m. maximum	Line-of-sight; depends on network configuration
Transmit Power	100 mW typ.	10 mW average with a 10% duty cycle
Data rate	1 Mbps	
Physical layer	Frequency hopped spread spectrum	FCC compliant in the 2.45 GHz ISM band
No. of hopping frequencies	79	Per FCC 15.247 and IEEE 802.11
Operating frequency range	2400 - 2483.5 MHz	Per FCC 15.247
Number of distinct networks	64	Each network is assigned a distinct hopping pattern.
Physical layer frame format	Time division multiple access (TDMA); full-duplex	1 repeater downlink slot; a set of paired uplink-downlink slots
Number of simultaneous talkers	4 PCUs and a wired intercom	Infinite number of listeners
Audio format	8 bit μ -law PCM	

*Values provided refer to the prototype CCS system only. Specifications and features are subject to change without notice.