DARPA NetCentric Radio Demonstration

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ABSTRACT

The objective of the DARPA Network Centric Radio System[1] (NCRS) Program was to design, develop, integrate, and demonstrate the enabling communication technologies and system capabilities required to enable network centric warfare. NCRS is a First Generation Mobile, Ad Hoc Network (MANET) designed to enable ground and airborne vehicle based on-the-move and on-the-halt network centric connectivity. It demonstrated a gateway architecture that offers interoperability among various current, future, coalition and first responder communications radios, via the network, not the radio. This capability illustrated a new dimension for military communications interoperability.

INTRODUCTION

The after-action analysis of the command and control systems from many of the conflicts since Vietnam indicated a consistent inability to communicate between the services during joint operations and exercises. After Grenada, a GAO report [1] indicated that air support operations between the Army ground forces and Marines were hampered due to the incompatibility of their radios. These shortfalls continued though to the 1990 Persian Gulf War as described in a 1992 report to Congress [2],[3] that described the problems in establishing an interoperable network across disparate communications systems. Interoperability enables information to be exchanges among the services directly and satisfactorily. These same issues are also prevalent in the non-DoD communications systems used for public safety organizations as seen during the response to the terrorist attacks of September, 2001.

Early in the 21st Century, the focus of many of the DoD efforts was on how to enable Network-Centric Warfare (NCW). In particular, NCW was to allow warfighters to take advantage of all the available information within the Battlespace in a rapid and flexible manner. One example is the enabling of an effective the sensor-to-shooter process. The key enabler to this process was development of the Global Information Grid (GIG) [1]. The GIG is the network fabric for which to build a "Systems of Systems". Mobile networking is one piece of the GIG and is built upon the use of the proposed interoperable Joint Tactical Radio System (JTRS).

This paper describes the field demonstration of one capability that had been plaguing the department for the past few decades interoperability at the tactical level. The NCRS has demonstrated a MANET gateway architecture whose envisioned performance is comparable to that of the anticipated JTRS WNW operating within the lower tiers of the Transformational Communications Architecture (TCA) [5] augmenting the GIG, but with one added capability. NCRS now was a TCA-compatible gateway architecture that offered interoperability among various current, future, coalition and first responder communications radios, via the network, not the radio.

TRANSFORMATIONAL COMMUNICATIONS ARCHITECTURE

The Department of Defense is extending the Global Information Grid to interconnect all military forces and facilities world wide. This extension is called the TCA and is illustrated in Figure 1. This figure is taken from Reference 5 and the various acronyms can be found in that reference [5].

[1] NCRS was formerly known as the Future Combat Systems Communications

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Here we see a tiered architecture. The lowest tier is the realm of tactical sensor-shooter networks implemented with small tactical radios and mobile ad hoc networking technology. The upper tiers provide the world wide/theater backbone implemented with high capacity space and air based platforms as well as terrestrial fiber-optics. In the middle, is the critical Tiers 1 and 2 – the mobile backbones? In our opinion, the answer is yes. For Tiers 1 and 2 to be truly mobile wireless backbone networks, they must fill the gaps between the upper tiers that employ a fixed terrestrial and space based infrastructure with the fluidly mobile lower tier comprised of ad hoc tactical networks and legacy radios, e.g., SINCGARS, HAVE QUICK, EPLRS, LINK 16. None of the latter map well into the system proposed for the upper tiers.

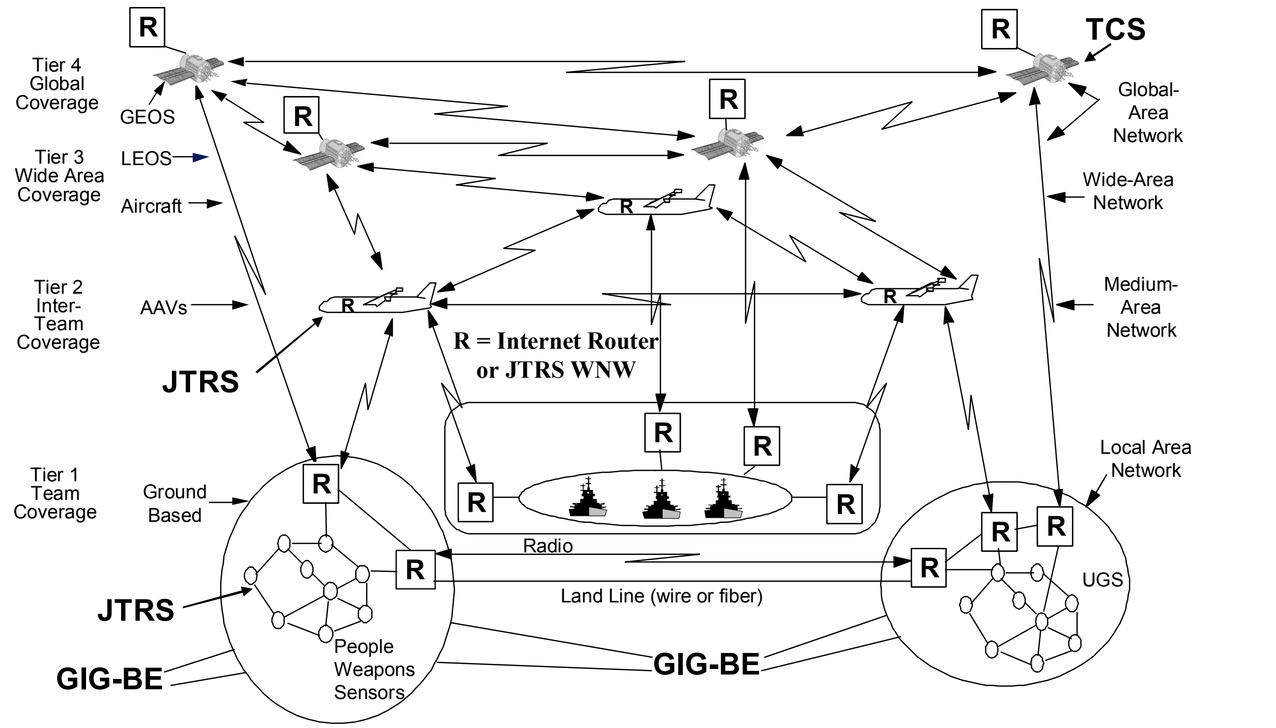

Figure 1: DoD GIG Architecture

NETWORK CENTRIC RADIO SYSTEM

The objective of the NCRS Program is to design, develop, integrate, and demonstrate the enabling communication technologies and system capabilities required to enable network centric warfare. The NCRS networking systems is a First Generation Mobile, Ad Hoc Network (MANET) designed to enable ground and airborne vehicle based on-the-move (OTM) and on-the-halt (OTH) network centric connectivity. Its dual operation would be comparable to the (1) anticipated Joint Tactical Radio System (JTRS) Wideband Network Waveform (WNW) vehicle-to-vehicle data connectivity (Low Band), and (2) JTRS Near-term Data Link/Warfighters Information Network-Tactical (WIN-T) for Above Brigade Communications (High Band).

The virtues of the FCS-C network capabilities compared to current deployed tactical communications systems are as follows:

- The *flexibility* it offers to support a wide range of deployment scenarios, applications, and traffic types. Preliminary studies of current Force XXI Battle Command, Brigade-and-Below (FBCB2) network planning suggests potential improvements to eliminate up to 12 of 13 database tables and upwards of 150,000 entries. Inherent to MANET protocols is a high level of adaptation to the dynamics of topology, network membership, and link conditions.

- Dynamic multi-mode rate *adaptation* on a per-link basis continually maximizes multi-megabit data rate for given link and network utilization conditions. Assured network connectivity upwards of 150 km for air-to-air and air-to-ground line-of-sight is achieved using extended range waveform mode for wide area missions including ISR.
- Quality of service techniques applied at both Channel Access and Routing components ensure *prioritization* of critical traffic flows and reliable delivery under both nominal and congested network states in changing battlefield conditions. Unicast and multicast routing protocols rapidly adapt to changing topologies for effective traffic dissemination in support of existing and emerging user applications.

The FCS-C network system has been tested and matured in five (5) field test events using a test-fix-test process. They are:

- Low Band Go/No-Go Demo (Demo 1 – Feb 02)
  - **20 ground mobile nodes with COTS/NDI low band radios and directional antennas at Lakehurst (NJ) NAS**
- Low/High Band Go/No-Go Demo (Demo 2 – Oct 02)
  - **20 mobile nodes (19 ground/1 air) with COTS/NDI low/high band radios and directional antennas at Lakehurst (NJ) NAS**
- LSI Demo (Mar 03)
  - **14 mobile nodes (13 ground/1 air) with COTS/NDI low/high band radios and COTS/NDI directional antennas at Ft. Dix, NJ**
- Relevant Field Environment Operational Demo (Demo 3 – Aug 03)
  - **20+ mobile nodes including 2 airborne nodes with objective low/high band radios and COTS/NDI/objective directional antennas at Boise, ID (OTA IDNG)**
- AAEF Spiral A Ft. Dix & Ft Benning Demos (Sept 2004)
  - **2.45 GHz FCS-C low band OPS in Complex Terrain w/o Airborne Relays for Connectivity**

Below find a summary of the DARPA Go/No-GO Testing From Idaho field trials:

FCS C Demo 3 Go/No-Go Results - 8/2003

FCS Communications Go/No-Go Metrics	Demo 3 Criteria	Raytheon (FCS-C)
20 Node Average Network Aggregate Throughput (Goodput) Low Band High Band	**AJ/LPD HDR** **200 Kbps 10 Mbps** **1 Mbps 70 Mbps**	**AJ/LPD HDR** 203 Kbps 10.3 Mbps 24 Mbps 50 Mbps
LPD/AJ Spatial - Low Band (3 dB beamwidth) Spatial - High Band (3 dB beamwidth) Processing (PG, nulling, etc.) Low Band High Band	 **45°** **3.5° x 12° *** **40 dB** **14 dB * (19.4 dB)**	 39° 3.5°x12° 41.6 dB 19.4 dB
Latency Type 1 (10% of the avg sys load) Type 2 (30% of the avg sys load) Type 3 (60% of the avg sys load) (Retrans 3x)	 **90% < 200 msec.** **90% < 1 sec.** **90% < 30 sec.**	 90.0% 88.8% 98.9%
HB/LB Transition	**<1 sec.**	1 sec.
Packet Delivery Type 1 (10% of the avg sys load) Type 2 (30% of the avg sys load) Type 3 (60% of the avg sys load) (Retrans 3x)	 **90%** **90%** **90%**	 75.0% 73.6% 88.3%
20 Node Network Initialization Time	**<6 min.**	2 min.
Node Entry Time	**<30 sec.**	10 sec.
Detect Node Exit Time	**<10 sec.**	5 sec.

Live Test under operational conditions - User level performance

NOTE: Items in Red corrected upon return to lab and GO/NO GO validated in Raytheon Parking Lot

NCRS MANET GATEWAY DEMONSTRATION

In January, 2006, a culminating unscripted operational demonstration was performed at the McKenna MOUT Site, Ft Benning, Georgia, by US Army Signal Officers in the Ft Gordon Signal Center. The demonstration consisted of operating up to 14 mobile network elements, or nodes, with a variety of communication systems and user applications. The nodes were deployed as a Mechanized Infantry Battalion, with Battalion and Company units. The communication systems included tactical "stub-nets" which operated at lower tactical echelons (e.g. Intra-Company links), a high data rate primary Tier-1 "back-bone" communication system which provided connectivity between higher echelon elements (e.g. Battalion-Company links), secondary/back-up Tier-1 "back-bone" communication systems, and Tier-2 communications that provided connectivity to echelons above the Battalion. All of these communication systems were interconnected using the USMC Condor system in which IP routers automatically routed application data between the various elements using the most efficient routes and radio systems. Applications that were supported by the DARPA NC Network included: CPoF (Command Post of the Future) and C2PC (Command and Control Personal Computer) for Situational Awareness and Battlefield Command and Control; Video Data Streams from IP Cameras on selected network elements (both airborne and ground simultaneously); IP Chat; Voice Over IP (VOIP); and Network Maintenance Data (CenGen Network Manager).

The operational exercises at Ft Benning utilized all 14 nodes operating in 6+ hour exercises which spanned operational ranges up to 100 kilometers, the distance from the Battalion Forward Command Post to the Objective.

During these tests, the soldiers operated unscripted through cities and down roads lined with trees to simulated communications under realistic complex / urban terrain. The following results were typical from air-to-ground experiments conducted on tree-lined roads. US Army Signal Officers operated all equipment, and directed the exercises using CPoF/C2PC, Chat and VOIP. The Signal Officers also directed placement of the Airborne relays to maintain the Tier-1 backbone network. Here is a summary of the key demonstration capabilities:

- Demonstrated rapid autonomous mobile ad-hoc network formation and maintenance during tactical mobility scenarios (self-forming and self-healing)
- Demonstrated Link ranges in excess of 60 km at full 5 Mbps data rate (Terrain / geometry dependent)
- Demonstrated Maximum link range at lower, but operationally useful data ranges demonstrated to over 120 km (e.g., 800 kbps at 150 km during one test)
- Demonstrated Adaptive Data Rate (ADR) shifts between link data rates to maintain reliable data transfer under changing link conditions
- Demonstrated low latency, multi-hop relay capability with adaptive throughput under changing link conditions, including arbitrary airplane, helicopter and vehicle speeds

Figure 2 shows a summary graph of typical link operations:

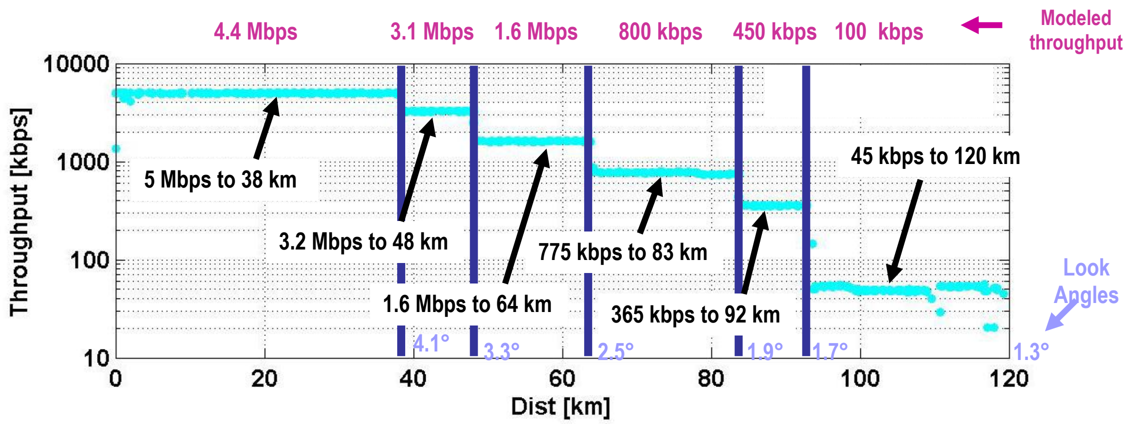

Figure 2: Typical Measured FCS C Air-to-Ground System Throughput versus Range

During all training and simulated operations tests, the soldiers operated through cities and down roads lined with trees to simulated communications under realistic complex / urban terrain. The following results were typical from air-to-ground experiments conducted on tree-lined roads. The reddish numbers at the top is the expected data rate performance for the test series using Raytheon FCS C models using rudimentary environment models. The aqua lines are measured FCS C throughput during the test and the black numbers are averaged results from each segment. Given the variability of propagation loss by the FCS C signal traversing real tree environment at low grazing angles, the measured and modeled results agree pretty well.

In addition, the new FCS C capability demonstrated was a TCA-compatible gateway architecture that offered interoperability among various current and future communications radios, via the network, not the radio. Specifically, interoperable communications was demonstrated among the following digital and analog systems: CPoF's VoIP, the ITT Soldier Radio, the Enhanced Position Location Reporting Systems (EPLRS), HAVEQUICK I/II (PRC-117), the Single Channel Ground and Airborne Radio System (SINCGARS/PRC-119) and the High Frequency MAN-PACK Radio (HFMR/PRC-150). In other words, we did not need physical layer interoperatability to have a set of dissimilar radios talk to one another. Like the commercial world where a DARPA PM can send a voice/text message from his Verizon CDMA cell phone to the DARPA Director's GSM Blackberry/GPRS Blackberry, the demonstration had current and future tactical radios talking to themselves and more modern systems. DARPA believe this new dimension offer a potentially more affordable route for military communications interoperability. Figure 3 shows a simplied view of the Ft Benning NCRS demonstration.

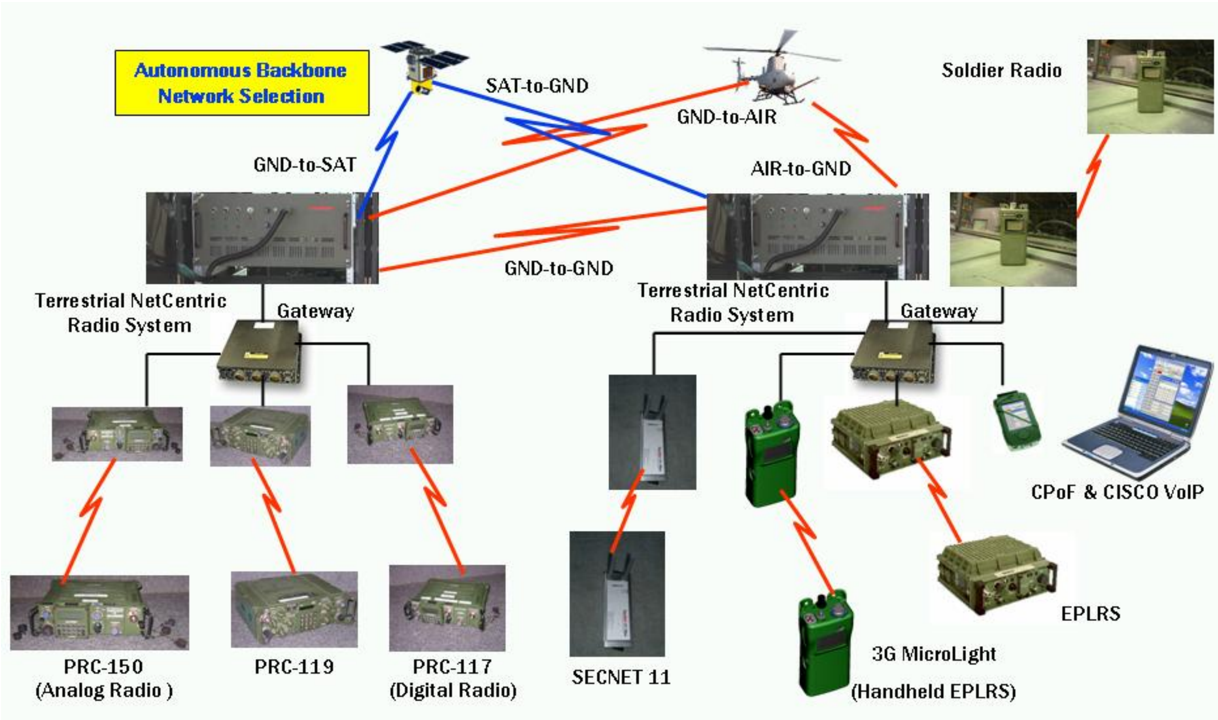

Figure 3: Simplied NCSR Communications Architecture

In addition to the above, DARPA communicated with

- Ku Satellite Radio: Ku On-The-Move (OTM) was deployed on the Battalion TAC, providing a Tier-2 Network connection and/or a backup to the primary Backbone; Ku On-The-Pause (OTP) was deployed at the Battalion TOC, and also provided a Tier-2 or Backup Tier-1 network connection.
- Inmarsat Satellite Radio ---- The Inmarsat radios were used as a backup to the Primary Tier-1 backbone, and were deployed on the Alpha and Bravo company headquarters.
- Boeing Satellite Radio System --- The Boeing Satellite Radio System interfaced two of the lower echelon company nodes to the network via Tier 2 routing.
- SECNET11 --- Two SECNET11 radios formed a "Stub-Net" in Bravo Company, and were deployed on the Bravo Company headquarters and one lower echelon Bravo Company node.

Finally, each node was equipped with one or more radio systems that connected directly to a "black" Cisco router. The "black" Cisco router connected to a "red" Cisco router via an Encryption Device. Crypto emulators (PC operating emulator SW) were used in lieu of an actual KG-250, which would be the NSA-certified Type 1 Network Encryptor (also has been demonstrated with equipment previously in checkout portion of program). The applications (CPoF/C2PC, Chat, VOIP, Video, etc) interfaced to the network via the "red" Cisco router.

Figure 4 is a comparison of FCS C Ft. Benning Results with reported JTRS WNW results [5]:

Characteristic	Wideband Network	FCS C MANET / Gateway [2]
Demonstrated Max Data Rate at Max line-of-sight, point-to-point mode	• 1 Mb/s @ ~14 miles (Expansion to 2 Mb/s is planned for summer of 2008) [1]	• 5.5 Mb/s @ 23,6 miles • 1.6 Mb/s @ 39 miles • 775 Kb @ 51.6 miles
Demonstrated Radio Interoperability with Networking	• Demonstrated hardware running WNW simultaneously with a JTRS version of a legacy signal, which proves the feasibility of key JTRS concepts, waveform portability and simultaneous waveform operation [1]	• Simultaneous demo at Ft Benning of MANET/Gateway communications among the following digital and analog systems: CPoF's VoIP, the ITT Soldier Radio, the Enhanced Position Location Reporting Systems (EPLRS), HAVEQUICK I/II (PRC-117), the Single Channel Ground and Airborne Radio System (SINCGARS/PRC-119) and the High Frequency MAN-PACK Radio (HFMR/PRC-150) and various SATCOM Links.

Demonstrated FCS C Performance at Ft

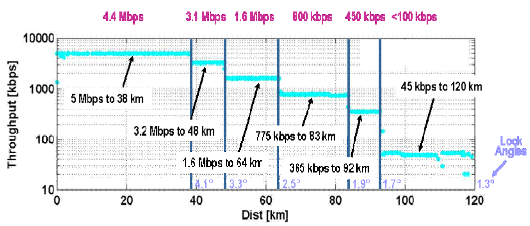

Figure 4: Comparison of JTRS WNW & FCS C Performance

SUMMARY

The objective of the DARPA Network Centric Radio System Program was to design, develop, integrate, and demonstrate the enabling communication technologies and system capabilities required to enable network centric warfare. NCRS is a First Generation Mobile, Ad Hoc Network designed to enable ground and airborne vehicle based on-the-move and on-the-halt network centric connectivity. It demonstrated a gateway architecture that offers radio interoperability among various current, future, coalition and first responder communications radios, via the network, not the radio. This capability achieved reliable data transfer under dynamically changing link conditions and node topologies while maintaining prioritized quality of service. Link ranges in excess of 60 km were demonstrated at the full 5 Mbps peak user data rate with connectivity maintained to distances over 120 km using airborne relays performing a "comms-primary" mission.

ACKNOWLEDGEMENTS

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