Mobile Ad Hoc Networking

Since BBN helped build the world's first ad hoc network over 30 years ago, we have earned widespread recognition as the world's leader in mobile ad hoc networking, both in research and in mission-critical tactical systems. The BBN routing engine runs in every major tactical ad hoc network around the world. BBN has designed and implemented tactical ad hoc networks for the United States, United Kingdom, and Canada. Export versions of our routing engine run in a number of nations around the world, including the Netherlands, Finland, Italy, Croatia, Germany, Singapore, and Sweden.

Beginning with fundamental network research in applicability and scalability, BBN has applied its deep networking expertise to deploying networks—often with government or academic partners—that exemplify the capacity of modern mobile networks to adapt to challenging environments and requirements.

Much of this effort is focused on realizing the DoD's vision of a ubiquitous network that performs seamlessly from foxhole to satellite and across a variety of nodes in between. BBN is uniquely suited to this problem. Our staff has over 1,000 man-years of research experience working with wireless, wireline, and satellite networks. Our experts are well-positioned to architect smart, scalable networks with the ability to direct traffic efficiently, wake up nodes as needed, and minimize power usage, all while maintaining the highest levels of network integrity and security.

BBN Software in Mission Critical Wireless Networks

The United States Government, its allies, and large systems integrators rely on BBN for the secure tactical communications networks of today and tomorrow.

- BBN software implements the self-organizing, self-healing networks in the Joint Tactical Radio System (JTRS) Wideband Networking Waveform (WNW), and BBN is responsible for networking in JTRS Cluster 1 and JTRS AMF.
- BBN is designing the worldwide DoD satellite network and its management system in the Transformation Communications (TC, TMOS) systems currently in procurement.
- BBN routers provide the self-organizing, self-healing features of the IRIS system, the main tactical communications system for the Canadian Army.
- BBN has provided the router software for two next-generation tactical networks for the United Kingdom's BOWMAN system; the High-Capacity Data Radio (HCDR) and the Local Area System (LAS).
- BBN routers provide secure IP communications for the US Army's Mobile Subscriber Equipment (MSE) and Near-Term Digital Radio (NTDR) networks.
- Many US friends and allies—including the United Kingdom, Canada, the Netherlands, Finland, Italy, Croatia, Germany, Singapore, and Sweden—use export versions of BBN routers.

Technology Leader

For over 50 years, the BBN name has been synonymous with technical innovation. Since providing the acoustical design of the UN General Assembly Hall in 1948, BBN has expanded its expertise into a wide range of technical disciplines with impressive results. BBN implemented and operated ARPANET, the forerunner of the Internet. We created TENEX, one of the early multi-user operating systems, and the first person-to-person network email system, establishing the @ sign as an icon for the digital age. We have been a long-time leader in underwater acoustics technology for the military. Today BBN operates the first metro quantum cryptography network, the first real-time foreign broadcast monitoring system, the first stereoscopic digital mammography system, and has developed the world's leading system for real-time detection of snipers in noisy urban environments.

BBN's Mobile Ad Hoc Networking Publications

"Ad Hoc Networking with Directional Antennas: A Complete System Solution," R. Ramanathan, J. Redi, C. Santivanez, D. Wiggins, S. Polit, IEEE Journal on Selected Areas in Communications, Vol. 23, No. 3, Mar. 2005.

"Challenges: A Radically New Architecture for Next Generation Mobile Ad Hoc Networks," R. Ramanathan, Proceedings of ACM Mobicom, Aug. 2005, Cologne, Germany.

"Effect of Overhearing Transmissions on Energy Efficiency in Dense Sensor Networks", Basu, P. and Redi, J., International Conference on Information Processing in Sensor Networks 2004.

Ad Hoc Networking

Ad hoc networking provides robust, self-organizing, self-healing communications over multiple nodes without fixed infrastructure and allows a distributed, auto configuring routing architecture that can adapt to change—capabilities that are most valuable in situations where energy is a constrained resource. BBN has designed an ad hoc network protocol stack that provides cross-layer optimizations from the transport layer all the way down to the radio, providing the best performance without the constraints of layering or pre-existing networking traditions. Furthermore, our solution uses only off-the-shelf parts for its ground-breaking operation and can utilize new advances as they become available and cost-effective.

Our approach is characterized by utilizing and often creating new ways to think about problems in wireless networks. For example, BBN:

- Developed the first routing protocol that supports mobile nodes with directional antennas
- Developed a variety of innovative methods for dynamic clustering of ad hoc nodes and for using clusters to improve network performance and connectivity
- Developed hazy-sighted routing, which limits the distribution of routing information within a wireless network while preserving connectivity and enabling wireless networks to scale to far larger size
- Designed wireless sensor networks that use orders of magnitude less power than previous networks while meeting a variety of strict performance requirements for responsiveness and reliability

WiroKit

The vision of integrated communications across an ever increasing number of nodes in mobile wireless networks is a **network** problem (rather than a software or hardware problem) that requires a revolutionary approach to handle bursty data, mobility, scalability, and Quality of Service. In anticipation of these emerging needs, BBN invested in an internal R&D project called the Wireless Router Kit, or WiroKit, which can solve many military communication problems.

WiroKit is a software toolkit containing the software base of an ad hoc router and implementing two different routing algorithms; a full peer-to-peer link-state router and an extremely lightweight, many-to-one (or many-to-few) routing algorithm for sensor networks with a large number of sensors but a limited number of monitoring points. It is highly portable, highly adaptable, and efficient in both processing and memory requirements. It can be integrated into an IP network between IP and the MAC layer, or may run stand-alone. WiroKit code has been proven in large (~10,000 node) sensor network simulations with realistic parameters for RF connectivity based on terrain and foliage, sensor types, sensor algorithms and their distributed architectures, target types, density and movements, refresh rates, alarm-time requirements, and battery exhaustion rate. WiroKit is now available from BBN as licensed technology.

BBN's Mobile Ad Hoc Networking Publications

Roaming in the Global Wireless Internet," C. Elliott in Emerging Location Aware Broadband Wireless Ad Hoc Networks 2004.

Distributed Applications for Mobile Ad Hoc Networks Using Attributed Task Graphs, P. Basu, W. Ke, and T. Little, "Modeling in Mobile Computing Handbook, 2004.

Movement Control Algorithms for Realization of Fault-Tolerant Ad Hoc Robot Networks," P. Basu and J. Redi, *IEEE Network*, July/August 2004.

Antenna Beamforming and Power Control for Ad Hoc Networks," R. Ramanathan, in Mobile Ad Hoc Networking, 2004.

Explicit Transport Error Notification (ETEN) for Error-Prone Wireless and Satellite Networks, R. Krishnan, J. Sterbenz, W. Eddy, C. Partridge, and M. Allman, Computer Networks, vol. 46, 2004.

"Exploiting the Interactions Between Robotic Autonomy and Networks", Redi, J. and Bers, J., 2003 NRL Symposium on Multi-Robot Systems,Kluwer Press.

A Brief Overview of Ad Hoc Networks: Challenges and Directions," Ram Ramanathan, Jason Redi *IEEE Communications Magazine*, May 2002.

"Experimentation and Modeling of HTTP Over Satellite Channels," H. Kruse, M. Allman, J. Griner, and D. Tran, *International Journal of Satellite Communications*, Jan-Feb 2001.

"A Survey of Energy Efficient Network Protocols for Wireless Networks," C. Jones, *Wireless Networks*, August 2001.

"Energy-Conserving Access Protocols for Identification Networks," Imrich Chlamtac, Chiara Petrioli, and Jason Redi, IEEE/ACM Transactions on Networking, 1999.

"A Unified Framework and Algorithm for Channel Assignment in Wireless Networks," S. Ramanathan, Wireless Networks, 1999

Directional Antennas in Ad Hoc Networking

In the late 1990s, BBN revolutionized the field of ad hoc networking by demonstrating the immense advantages of using directional antennas and Multiple-Input Multiple-Output (MIMO) transceivers in ad hoc wireless systems. BBN followed up by developing and demonstrating a suite of mechanisms for taking full advantage of directional antennas in ad hoc networks. This work was the first to combine ad hoc networking technology with directional antenna technology and exploits the unique possibilities that this combination allows. The chief innovations include directional-antenna-based medium access control, neighbor discovery using directional antennas, and topology control using antenna pointing to guarantee the communication connectivity and survivability of FCS/C4ISR.

Networked Teams of Autonomous Robots

Robots require collaborative problem solving abilities, which means they need continuous communications capabilities that deliver self-organizing, self-healing, adaptive information in highly volatile and restrictive mobile environments. BBN has developed, delivered, and demonstrated an Energy Conserving Stack for Robot Teams, mechanisms at different layers of the protocol stack to provide significant energy savings, collaborative architecture, enhanced networking through intra-robot interaction, operational and environment mode adaptation, an interactive learning approach to network enhancement, pro-active network feedback, RF and link views to other modules, and asynchronous prediction of future network events. BBN protocols have dramatically cut the battery power needed for ad hoc networking while maintaining the network performance needed for real time tactical robots. This is enabling technology that can be applied across a variety of robotic ad hoc networking solutions.

Next Generation (XG)

Under funding from DARPA's neXt Generation Communications (XG) program, BBN Technologies has developed an architecture and technology for policy-agile opportunistic spectrum sharing. This technology is aimed at increasing spectrum utilization by enabling devices to utilize spectrum opportunistically whenever and wherever it is available, when authorized by policy. Our key contribution is the development of a machine-readable policy language framework and protocols that will enable XG-capable radios to adhere to relevant policies as they dynamically choose where and how to use available spectrum. An additional benefit is the ability to define "temporary" policies to which radios would conform, thus encouraging experimental use of spectrum. Our Policy Conformance Reasoner (PCR) software demonstrates how a radio system can check whether its intended emissions conform to policy (as specified in the defined policy language) and can search the policy constraint space for allowable opportunities.

BBN's Ad Hoc Mobile Networking Patents

System and Method for Testing Protocols for Ad Hoc Networks U.S. Patent No. 6,922,395

Distribution of Potential Neighbor Information through an Ad Hoc Network U.S. Patent No.6,456,599

Cluster Head Resignation to Improve Routing in Mobile Communication Systems U.S. Patent No. 6,493,759

System and Method for Scheduling and Rescheduling the Transmission of Cell Objects of Different Traffic Types U.S. Patent No. 6,526,062

Energy Conserving Network Protocol U.S. Patent No. 6,512,935

Cell Discard Scheme for IP Traffic over a Cell Relay Infrastructure U.S. Patent No. 6,567,378

Systems and Methods for Networking Radar Detectors U.S. Patent No 6,567,035

Systems and Methods for Collision Avoidance in Mobile Multi-hop Packet Radio Networks U.S. Patent No 6,556,582

Method and Apparatus for Asynchronous Reservation-Oriented Multiple Access for Wireless Networks U.S. Patent No 6,577,613

Asymmetric Orthogonal Codes for Wireless System Receivers with Multiplication-Free Correlators U.S. Patent No 6,574,269

Asymmetric Orthogonal Codes for Optical Communication U.S. Patent No 6,574,268

Self-Organizing Mobile Wireless Station Network U.S. Patent No.6,594,468

Band Manager for Use in Multiple Channel Networks U.S. Patent No.6,621,795

Systems and Methods for Routing Packets on Alternate Paths U.S. Patent No. 6,671,819

Store-and-Forward Packet Radio System and Method U.S. Patent No. 6,671,804

Store-and-Forward Packet Radio System and Method U.S. Patent No. 6,665,722

Cluster Head Resignation to Improve Routing in Mobile Communication Systems U.S. Patent No. 6,662,229

Adaptive Antenna System U.S. Patent No.6,720,936

System and Method for Facilitating Communication between Dissimilar Radio Voice Devices U.S. Patent No. 6,693,899

Space Virtual Private Networking

Space Virtual Private Networking (SpaceVPN) is a multi-Satellite Virtual Private Network for space-based applications. BBN is developing architectures and building experiments to test concepts for networks that allow researchers to access and control instruments on satellites in space from their desks. These architectures can be used as part of NASA's Earth Sensor Web, as well as on robotic and human missions for detailed investigation of planets, moons, and small bodies in the solar system. Building on the Distributed Spacecraft Network, or Hi-DSN, and security protocols such as IPSEC, BBN provides an integrated set of radio transceiver capabilities and network protocols for establishing and maintaining communications among diverse spacecraft in multiple orbits, and for connecting orbiting satellites to aircraft and terminals on the ground. Through NASA's Advanced Systems Technology Program (AIST), BBN is helping to extend VPNs to space, and providing authentication, access control, integrity, and confidentiality for space communications in new and innovative ways.

Connectionless Networks

The DARPA Connectionless Networks program was established to drastically reduce the amount of energy required for mesh or ad hoc networking and communication. In phase one, BBN reduced the energy used for delivering information in a tactical wireless multi-hop network by over 300 times, resulting in battery powered radios working hundreds of times longer. Furthermore, these reduced energy requirements will potentially reduce the cost of operating radio networks while increasing military effectiveness. Our low-duty radio multi-hop networking schemes will lead to smaller batteries with increased battery life for use in battlefield communications devices. These devices range from data-collecting sensors placed in remote locations to radios that soldiers use to communicate with each other. More efficient networking and communications protocols will allow remote sensors to transmit important information over longer durations and allow soldiers to carry fewer batteries and replace them less frequently during missions.

Talk to Us!

To learn more about mobile ad hoc networking technologies at BBN Technologies, please call or write:

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BBN's Ad Hoc Mobile Networking Patents

System and Method for Facilitating Communication between Dissimilar Radio Voice Devices U.S. Patent No. 6,693,899

Node Belonging to Multiple Clusters in an Ad Hoc Wireless Network U.S. Patent No. 6,711,409

Packet Loss Service-Level Guarantee Monitoring and Claim Validation Systems and Methods U.S. Patent No.6,795,400

System and Method for Logging Computer Event Data and Physical Components of a Complex Distributed System U.S. Patent No.6,789,182

Message Routing Coordination in Communications Systems U.S. Patent No. 6,775,709

Systems and Methods for Antenna Selection in an Ad-Hoc Wireless Network U.S. Patent No. 6,816,115

Methods and Systems for Performing Frame Recovery in a Network U.S. Patent No. 6,804,316

Personal Area Network with Automatic Attachment and Detachment U.S. Patent No. 6,804,232

Systems and Methods for Generating Customized Bundles of Information U.S. Patent No.6,801,936

Sliding Scale Adaptive Self-Synchronized Dynamic Address Translation U.S. Patent No.6,826,684

A System and Method for Conserving Energy in Wireless Devices U.S. Patent No. 6,859,135

Distribution of Potential Neighbor Information through an Ad Hoc Network U.S. Patent No. 6,456,599

Self-organizing Mobile Wireless Station Network U.S. Patent No. 6,418,299

Bandwidth Allocation in a Wireless Personal Area Network U.S Patent No. 6,272,140.

Method and System for Connectionless Communication in a Cell Relay Satellite Network U.S Patent No. 6,310,893.

Wireless Personal Area Network with Automatic Detachment U.S Patent No. 6,314,091.