**Dynamic Backbone Subnets - DBS/802.11**

*Access Point-to-Access Point Routing for 802.11 Infrastructure Networks*

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**Background**

Work to develop distributed, dynamic routing protocols for broadcast wireless networks began at the Naval Research Laboratory (NRL) over 20 years ago [1-4]. The Navy’s original interest was born from a desire to provide intratask force communication for naval battle groups at sea using networked HF radios and spread spectrum signaling [5-6]. NRL demonstrated the first implementation of the DBS routing protocol in 1990 as part of the Unified Networking Technology (UNT) project [7-8]. Later, in the mid-1990s, another advanced technology demonstration, the Data and Voice Integration ATD, added quality-of-service (QoS) capability that could support both differential and integrated services across multi-hop networks[9-10].

The most notable feature of the DBS architecture is the distributed protocol that periodically probes node connectivities and uses this information to maintain a dynamic backbone for the subnet. This backbone approximates a spanning tree that connects all nodes and over which all broadcast traffic is routed. In addition to user broadcast and multicast traffic and other control traffic, node connectivity information is sent over the backbone in order to develop unicast routing tables. Thus, unicast traffic is not constrained to use only backbone links, but is free to use shortest path routing. Because the backbone can be reconfigured in a known, fixed length of time (approximately 1 to 3 seconds), this architecture is well suited to dynamic topologies. In particular, we have used this architecture to implement an ad-hoc, 802.11 Extended Service Set (ESS), which, at the IP layer, behaves like an ordinary Ethernet subnet. Thus, we are able to combine the features of ad-hoc networks (i.e., all nodes can be mobile) with the control features of 802.11 infrastructure networks (e.g., Point Coordination Function and Hybrid Coordination Function).

At present, with funding from the Office of Naval Research (ONR), NRL has developed a DBS/802.11 implementation with the following features:

- Single channel operation with Access Point (AP) and Distribution Service (DS) functions supported by single 802.11 transceiver
- Wireless AP-to-AP routing proactively maintained by DBS protocol
• Self synchronizing, i.e., no need for external time sync, e.g., GPS
• Multiplexing of AP-to-AP communications that enables optimization of transmitted packet lengths and has potential to support multi-hop virtual circuits
• Creation of a fully mobile, auto-configurable, Extended Service Set (ESS)
• Data driven (i.e., reactive) discovery of current station (STA) associations enabling efficient traffic delivery to STAs roaming within the ESS

From a military perspective, DBS/802.11 is a type of highly mobile, untethered, networking technology essential for the implementation of network-centric war-fighting doctrines that cannot rely on fixed infrastructure. From a commercial perspective, DBS/802.11 provides automatic, dynamic range extension for 802.11 infrastructure networks via in-band AP-to-AP routing with the added benefit of potential for QoS support.

Overview of DBS/802.11

DBS/802.11 implements routing underneath the IP Layer. This decouples DBS routing from IP routing, thus, making DBS routing invisible to the IP Layer. From IP’s vantage point, all interfaces attached to a DBS/802.11 subnet appear to be one hop away although, in reality, DBS may route traffic through multiple relays to deliver it to the destination interface. Since DBS supports broadcast as well as unicast traffic delivery, standard protocols such as ARP, RARP, DHCP, and other service discovery mechanisms can work in their normal fashion. This distinguishes the DBS method of implementation from that of the mobile ad hoc network (MANET) protocols developed by the Internet Engineering Task Force (IETF), which perform routing at the IP Layer. MANET protocols, because they implement routing at the IP Layer, can route via a heterogeneous mix of links and networks, although much MANET experimentation is done using a homogeneous set of 802.11 radios operating in ad hoc mode as illustrated in figure 1. However, service discovery mechanisms do not work in the normal fashion within a MANET routing domain since queries typically sent as local subnet broadcasts are not normally forwarded by IP routing.

Figure 1. 802.11 components
Figure 1 shows the 802.11 components used to create 1) a DBS/802.11 extended service set (ESS) operating in infrastructure mode and 2) a MANET independent basic service set (IBSS) operating in ad-hoc mode. 802.11 stations (STAs) use the 802.11 wireless medium to provide MAC service data unit (MSDU) delivery and, optionally, authentication, deauthentication, and privacy services. In general, a basic service set (BSS) is formed by STAs that are able to directly communicate with one another. However, there are a couple of caveats. Firstly, a MANET, because of its IP Layer routing capability, does not require all nodes in an IBSS (called independent because it has no AP and, therefore, no access to distribution system (DS) services) to be directly connected. The IP routing function enables nodes that are not directly connected to communicate via intermediate relays. Secondly, in infrastructure mode, each BSS contains an AP that provides both STA and DS services to the member STAs associated with the BSS and also serves as the communications hub for the BSS. All STAs within the BSS must be directly connected to the AP, but need not be directly connected to other STAs within the BSS. The AP can serve as a relay within its BSS for member STAs that may not be directly connected to each other. The DS services offered by an AP are association, disassociation, reassociation, distribution and integration. The first three DS services are used to define BSS membership while the distribution service enables the formation of an ESS by interconnecting multiple BSSs. This is the place where DBS fits into the 802.11 architecture, i.e., by providing an automatically configured, dynamically maintained, multi-hop distribution service that enables the formation of a completely mobile ESS. Finally, the portal, shown in figure 1, supports the integration service.

Figure 2 depicts the dynamically created DBS broadcast backbone used for routing of broadcast and multicast traffic. The backbone also disseminates global topology information which is used as input to Dijkstra’s Shortest Path Algorithm for computation of point-to-point routes. The maximum number of APs in a single DBS subnet is bounded since the DBS protocol requires participating APs to follow a specified transmission schedule that has a length directly proportional to this maximum number. To explain further, DBS nodes send one protocol transmission per frame, each node transmitting in turn in ascending order by node number. A sequence of six frames, called an epoch, is sufficient for each node to determine its one and two hop neighbors and determine whether or not it is a relay node in the DBS broadcast backbone. When integrated with 802.11, DBS uses a self synchronization technique similar to that of an 802.11 BSS by broadcasting a time stamp as part of the Frame 1 transmission. If a node receives a time stamp from a neighbor that is later than its own clock, it advances its clock to the later time. Thus, DBS nodes eventually synchronize to the most advanced clock in the DBS system with accuracy more than sufficient to send DBS frame transmissions in the proper order.

Although the number of APs in a DBS/802.11 subnet does not scale (~30 for 802.11b), the number of STAs is limited only by the 802.11 address space and the anticipated channel utilization of STAs and APs. Further scalability can be achieved by bridging or by adding additional subnets in the usual fashion with routing among subnets being managed by IP – perhaps by OSPF or a MANET routing protocol depending on the degree of dynamics. If there is a possibility that nodes may migrate from one subnet to
another, then use of an end user mobility protocol, such as Mobile IP (MIP), would be highly desirable. Since IP routing protocols have their own scalability issues, there could be a synergistic relationship between DBS/802.11 and IP routing depending on the design parameters and requirements of a particular mobile architecture.

![DBS Mobile APs](image_url)

**Figure 2. DBS/802.11 Extended Service Set (ESS) for Station Roaming and AP-to-AP Routing**

**Implementation**

NRL’s DBS/802.11 implementation is made possible by the existence of the host AP mode of operation currently available in the Intersil Prism chip set firmware. Host AP mode disables management layer operation in the firmware and permits the driver to take over the management function. Ultimately, our desire is to implement the entire DBS/802.11 protocol suite in firmware, but that avenue of development was not available to us for our initial implementation. In the meantime, we have implemented DBS as a process running in Linux user space. Figure 3 shows the functional partitioning of a DBS/802.11 AP configured for outdoor mobile experiments conducted at NRL. The Reliawave 802.11b PC card firmware handles the control messages (RTS, CTS, ACK, …) associated with the Distributed Coordination Function (DCF) and the time critical management messages (Beacons and Probe Responses). Less time critical management messages (Association, Authentication, …) are handled by a modified version of the Absolute Value Systems, Inc., (AVS) driver, which runs as a Linux kernel module and communicates with the DBS daemon.
**Experimental results**

NRL conducted a series of DBS/802.11 field tests in early September 2002. The purpose of these initial tests was not to probe the limits of the network’s capacity; rather, it was to demonstrate 1) a working implementation and 2) the operation of both unicast and broadcast routing across a dynamically changing topology. To this end, ten vehicles were outfitted as mobile nodes (see figure 2) using the configuration shown in figure 3. An eleventh node served as a fixed command post. The northwest quadrant of NRL’s main site provided sufficient range and transmission blockages due to buildings and trees to create a dynamic, multi-hop topology as vehicles transited a pair of counter-rotating loops as shown in figure 4. During the final day of experimentation (9/11/02), the command post (Xcom) sent broadcast traffic to all the mobile nodes while each mobile node transmitted position locator information (PLI) back to Xcom as unicast traffic. The DBS/802.11 network delivered better than 90% of the broadcast traffic despite the malfunction of one of the mobile nodes with an antenna connection problem. The lower success rate for the point-to-point traffic is explained by the fact that the 802.11 packet retry count was set to zero for this test.
Xcom sends relayed broadcast traffic to 10 mobile nodes (7 pkt/s – 328 bytes/pkt)
- Each mobile node sends relayed point-to-point PLI traffic to Xcom (1 pkt/s – 100 bytes/pkt)
  - PLI includes the mobile node’s current position and traffic stats
- 5 minute rotation period
- ~ 191 Kbps aggregate network load
  - Broadcast load per node: 18,368 b/s
  - Point-to-point load per node: 800 b/s
  - Aggregate for 10 nodes: 191,368 b/s
- ~ 174 Kbps aggregate network throughput
  - PLI: 74.08%
  - Bcast: 90.67%
- No DBS daemon failures during full day of experimentation on 9/11/02
- One mobile node had faulty antenna connection during initial 1/3 of test

**Future Work**

Our DBS/802.11 work is now in its final year of ONR funding. We hope to make significant progress both in the area of additional protocol development and in standards development. Protocol development will focus on transmission scheduling, which can provide solutions for 1) the hidden terminal problem encountered by AP-to-AP transmissions and 2) the bandwidth reservation requirement for supporting AP-to-AP virtual circuits. We believe that an adaptation of the hybrid activation multiple access (HAMA) protocol [11] can provide a solution for the hidden terminal problem while DBS itself contains a virtual circuit mechanism. The challenge then, for our current host AP mode of implementation, is to sufficiently control scheduling without direct access to the firmware. Implementation directly in firmware would be a more attractive approach that would undoubtedly be expedited by adoption of an 802.11 AP-to-AP subnet routing standard. To that end, the authors are active members of the IEEE Standards Association.

**References**


