Network-Centric Warfare and Wireless Communications

Modern warfare is increasingly network centric

Civilian society has moved from the industrial age focus on automation and scale to an information age economy based on computing and communications. Warfare is also moving towards an information age paradigm based on information sharing, situational awareness, and distributed points of intelligence, command and control. A widely-networked fighting force is better able to share information about tactical situations that may be geographically widespread, asymmetric, and rapidly changing. Commanders must be able to better assess situations across broad theaters, with extensive data, voice, and especially video feeds as strategic inputs. Thus, network-centric warfare improves effectiveness at both the tactical "point of the spear" and in the achievement of broader strategic goals.

Broadly disseminated knowledge assets enable fighting forces that must self-synchronize, even as they physically disperse to address dynamic battlefield conditions. The speed of decision has increased and command decisions must be rapidly relayed and implemented, to improve battlefield outcomes. Information superiority has become as important in today's battlefield as air superiority was in the past in increasing mission effectiveness.

Information superiority has become critical as needs of both warfighters and commanders have broadened to include real-time video, high-speed data, and voice. Data and intelligence sources include terrestrial forces and sensors, satellites, UAVs (Unmanned Aerial Vehicles), and a wide variety of centralized and distributed information assets.

Network-centric warfare "cornerstone" technology requirements

The vast majority of these information assets, command, communications, and control must be delivered wirelessly, with seamless connections to wired networks for intelligence resources and other data. Further, these wireless technologies must support data, voice, and increasingly, video traffic flows. Beyond those basic capabilities, four key cornerstone capabilities must be incorporated in the networks designed to support modern warfare: mobility, high performance support of real-time protocols, distributed frequency agility, and distributed topologies and network formation.

- *Mobility*

In the network-centric warfare environment, mobility implies more than just the motion of individuals and vehicles in relation to one another and to other fixed locations. High performance must be maintained in motion, which includes rapid reconfiguration of network topology as units and individuals re-orient themselves in pursuit of battlefield objectives. To achieve this, networking hand offs between communicating devices must be coordinated to minimize data outages and/or a reduction in performance while in motion. These hand-offs must be transparent to communicating units, maintaining session connectivity while in motion. Location awareness, both in relation to other communicating devices and space (such as GPS) may also be key to high performance in motion.

- *High performance for real-time protocols*

With streaming and stored video an increasingly important part of modern command, communications, and control, the ability to deliver high bandwidth streams with low latency and low jitter is critical. This is not just at headquarters command locations, from a variety of video sensor platforms but increasingly to individual vehicles and war fighters. In many cases, these video streams must be delivered expeditiously across multiple hops (node-to-node connections) without loss of performance. Similarly, voice communications across many hops and in motion with high performance is a challenge demanding low delay and jitter at each network device.

- *Distributed frequency agility*

The dynamic and unpredictable nature of modern warfare and the peculiarities of the Radio Frequency (RF) spectrum environment place a high premium on the capability of individual devices to independently choose frequencies, locate and connect with peer devices, and rapidly shift frequencies in an automated, coordinated fashion without centralized oversight. This capability permits units to be brought on-line quickly in a hastily-formed network as well as to deal with inadvertent or malicious interfering and jamming signals in a deployed situation. Ideally, communicating devices will choose and manage frequencies and channels independently, for maximum flexibility in responding to mobility or interfering sources. In addition, these devices should continuously monitor the RF environment to allow for ongoing automated and coordinated optimization of the available RF spectrum.

- *Distributed topologies and network formation*

Relationships between organizational units, vehicles, and individual warfighters may change rapidly, bit in terms of command and control and in terms of physical proximity. In earlier eras, battlefield superiority depended on masses of contiguous units, but today the focus is on efficiency in achieving mission objectives. In order to deal with these changing relationships, communications devices must dynamically monitor and reconfigure network topologies. With thousands or hundreds of thousands of devices deployed in a single operation, it would be physically and logically impossible for network topologies to be defined and managed centrally. Instead, each device must independently find the best path for interconnection, choosing from available connections based on rules-based criteria. Topology flexibility combines with frequency agility to permit networks to form, change, and reform automatically, without client awareness or intervention.

Third Generation Mesh Architecture

In development for more than five years, MeshDynamics Wireless Mesh Technology meets these four cornerstone requirements with two foundational technologies, Third-Generation multi-radio architecture and Dynamic Distributed Radio Intelligence. The following sections highlight these two technologies, then describe four unique capabilities of the MeshDynamics solution for military mobility: channel and topology agility in motion; fully dynamic ("rootless") topology support; hybrid topologies for tactical network extension; and location and relationship capabilities in support of the network-centric warfare cornerstones.

Mesh networking began in military applications with a simple topology often referred to as "ad hoc" Individual single-radio nodes provided connections to adjacent nodes (and potentially to wireless client devices) by switching between bridging functionality and client service functionality. While effective in low-demand environments and inherently mobile, the constant "turnaround" of radios and reliance on a single channel throughout the network greatly diminishes the potential performance of the network. Network-centric cornerstone requirements for high performance of real-time protocols (including higher data rates and video streams) led developers to create later generations of more sophisticated mesh networking topology.

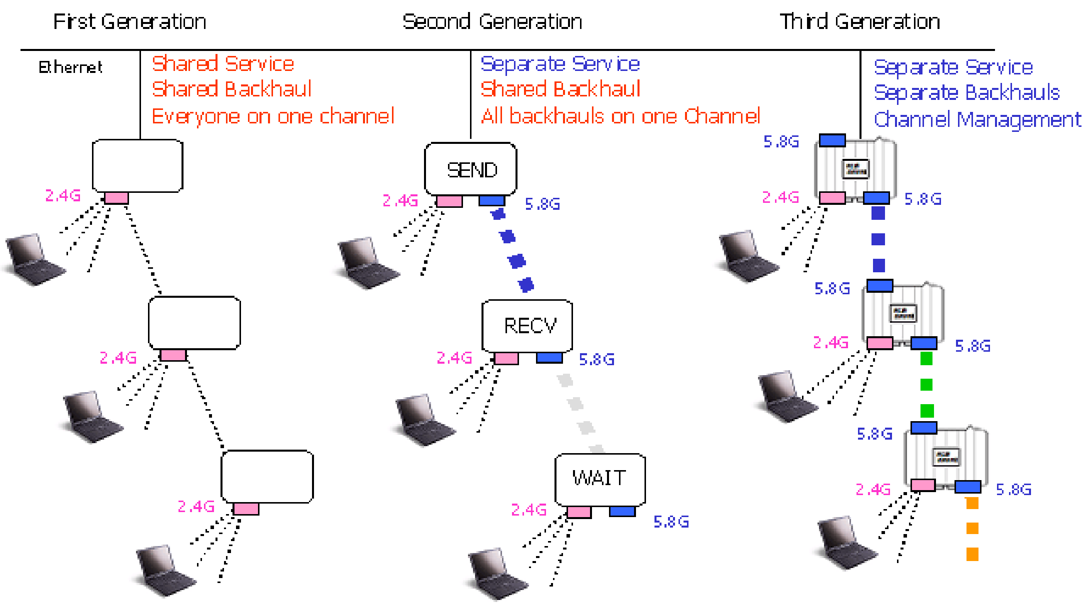

Figure 1: (L-R): Ad Hoc, 1-Radio Meshed Backhaul, MeshDynamics multi-radio Mesh Backhaul

Three generations of evolving mesh architectures are depicted above. They are (Left to Right):

First Generation: 1-Radio Ad Hoc Mesh (left). This network uses one radio channel both to service clients and to provide the mesh backhaul. The ad hoc mesh radio, marked AH, provides both services – client access and backhaul. This architecture provides the worst services of all the options, as expected, since both backhaul and service compete for bandwidth.

Second Generation: Dual-Radio with Single Radio Ad-Hoc meshed backhaul (center). This configuration can also be referred to as a “1+1” network, since each node contains two radios, one to provide service to the clients, and one to create the mesh network for backhaul. The “1+1” appellation indicates that these radios are separate from each other – the radio providing service does not participate in the backhaul, and the radio participating in the backhaul does not provide service to the clients. Performance analysis indicates that separating the service from the backhaul improves performance when compared with conventional ad hoc mesh networks. But since a single radio ad hoc mesh is still servicing the backhaul, packets traveling toward the Internet share bandwidth at each hop along the backhaul path with other interfering mesh backhaul nodes - all-operating on the same channel. This leads to throughput degradations which are not as severe as for the ad-hoc mesh, but which are sizeable nevertheless.

Third Generation: Multi-radio Structured Mesh (right). The last architecture shown is one that provides separate backhaul and service functionality and dynamically manages channels of all of the radios so that all radios are on non-interfering channels. Performance testing by military organizations indicates that this provides the best performance of any of the methods considered here. Note that the two backhaul radios for the 3-radio example shown in Figure 1 are of the same type - not to be confused with 1+1 so-called dual radio meshes where one radio is for backhaul) and the other for service. In the 3-radio configuration, 2 radios are providing the up link and down link backhaul functionality, and the third radio is providing service to the clients.

The power of distributed dynamic radio intelligence

The major challenge in Third Generation architectural implementations is avoiding co-channel interference from the multiple radios operating in a given band. This is an obvious problem when operating in the non-licensed public spectrum, but can also limit performance in licensed

military frequencies used by custom radios. Earlier Third Generation implementations often restricted this interference by using directional sectored antennas. But this technique is useless in the mobile environment.

MeshDynamics' instead allocates channels dynamically, listening for adjacent nodes as well as competing, interfering, or jamming sources, addressing the third cornerstone of distributed frequency agility. Channel maps are selected and reselected as necessary to provide optimum performance and to maintain connectivity, no matter how the RF environment may change nor how individual nodes may move in relationship to one another. This would not be possible with traditional centralized RF channel management through a single controller, as changes in location and RF environment may isolate sections of the network from the controller. Instead, a unique MeshDynamics technology distributes the channel and topology selection to independent but coordinated functions in each node. This is Distributed Dynamic Radio Intelligence.

The combination of multi-radio Third Generation capabilities and Dynamic Distributed Radio Intelligence maintain a high degree of connectivity in motion, ensuring that the MeshDynamics network delivers high performance at speed. In the military environment, this provides for the maximal utility of tactical networking, as data, voice and video may be shared no matter the physical relationship of the communicating units to one another of fixed bases.

Hybrid topologies for tactical network extension

Although the Third-Generation wireless mesh architecture has been proven to provide much higher performance than ad hoc First Generation architectures, there are tactical deployment situations where a combination of the two capabilities may be useful in achieving the mobility and distributed topologies and network formation cornerstones. In particular, small footprint (minimal size, low weight, low power) single-radio peer-to-peer ad hoc nodes carried by individual personnel may be desired in many tactical situations.
MeshDynamics has pioneered a unique bridging technology between the Third Generation high performance multi-radio network and widely distributed individual peer-to-peer ad hoc nodes that allow the individual ad hoc nodes to join the higher performance network directly when in range, but to hop peer-to-peer across the ad hoc network if necessary to connect to the Third Generation high performance network.

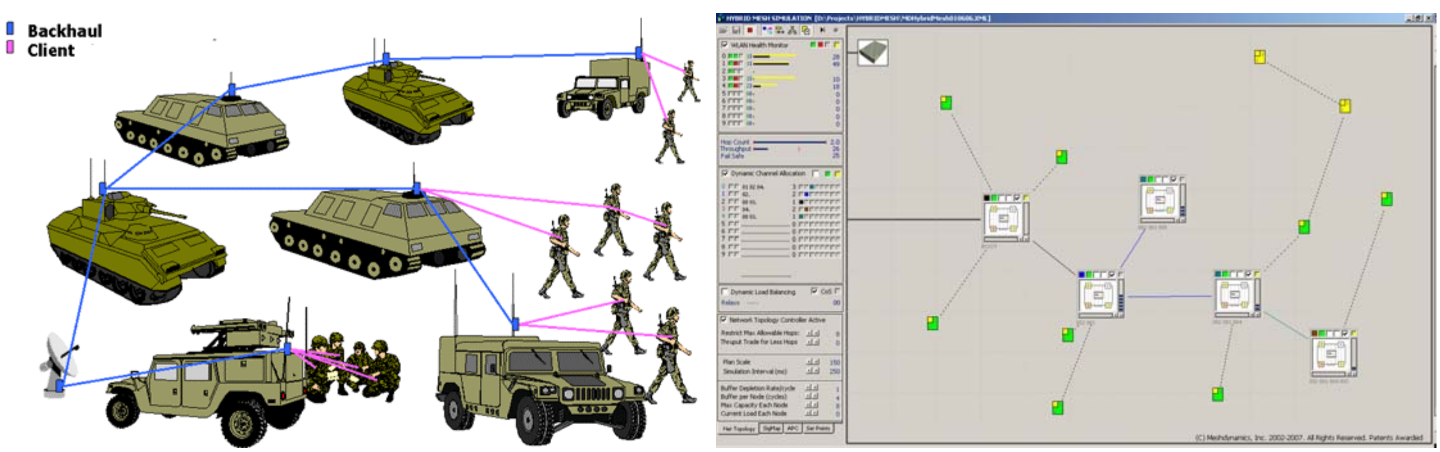

Fig 2: Hybrid Mesh is a high performance multi-radio meshed backhaul that supports both standard and ad hoc mesh clients.

In a typical deployment, higher performance multi-radio mesh nodes might be deployed on supporting vehicles, with body-carried nodes deployed with each individual. As individuals move farther from the supporting vehicle, their connection will shift automatically and dynamically between a direct connection to the vehicle-mounted network and a peer-to-peer bridge when too distant or obscured from the vehicle.

The Third Generation multi-radio mesh provides bandwidth and low latency for mission critical voice/video involving wide areas (and consequently many hops). The ad hoc mesh provides the connectivity to the multi-radio backhaul and can coexist with it with minimal modification: the ad hoc mesh views the multi-radio backhaul as an Ethernet link substitute. This extended combined network is now auto-configurable and scalable under a unified control layer. Note that the infrastructure mesh supports both “standard” clients – those that connect to the Access Point but do not have any ad hoc mesh functionality and “ad hoc mesh” clients.

Radio-Agnostic Technology

MeshDynamics' patented and patent-pending Third Generation implementation is not limited to any particular number of physical radios, or indeed to the concept of separate physical radios at all. Instead, the MeshDynamics networking algorithm treats multiple physical and/or logical radios as a pool of available connections to be dynamically managed for optimum performance in a mobile environment. MeshDynamics' powerful networking algorithms have been designed to work over a variety of civilian and military radio bands. Current production products serve WiFi 802.11 a/b/g at 2.4 and 5.8 GHz and public safety nets at 4.9 GHz. Support for 900 MHz, 700 MHz, and WiMAX bands is in development. Custom development capabilities are also available for military radios operating in a broad range of bands.

Location and relationship capabilities

Because of the efficient, yet extensible, node-to-node management information path provided by the MeshDynamics network, additional functionality is available for monitoring and reporting of location information in support of the mobility cornerstone technology requirement. Individual nodes may be fitted with GPS (Global Positioning System) receivers and real-time information on the nodes' locations (fixed or in motion) may be provided to administrators or to other applications using standard data protocols.

In addition, each node maintains a listing of the MAC IDs of every associated user device. This information may be interpolated by an external application to indicate with which nodes individual client devices are currently associated. Combined with the known fixed or GPS-derived location of each node, this provides a rough approximation of end user location and distribution.

Channel and topology agility in military environments

In order for the MeshDynamics network to continually and dynamically respond to a changing tactical environment, each node is designed to periodically and momentarily "listen" to its surroundings. This brief activity does not appreciably diminish data capability, but allows each node to constantly be aware of a changing environment. In hastily-formed networks, newly deployed units can rapidly discover (and be discovered by) adjacent units already operational in the network. No site survey or channel pre-configuration is necessary: the distributed dynamic radio intelligence in each node manages the complete network set-up process.

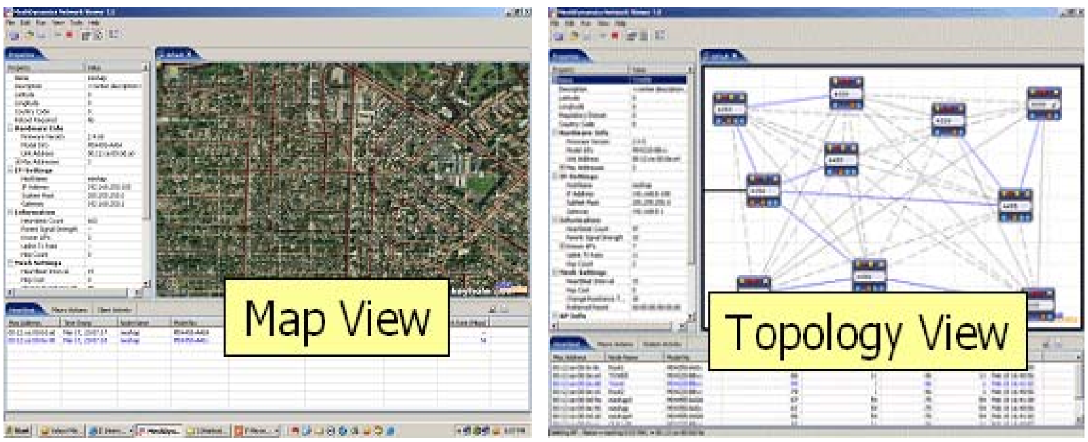

Fig 3: Node Heartbeats provides GPS updates for the map view. It also provides node connectivity information for the topology view.

This capability is provided by a constant exchange of an informational heartbeat between nodes. This efficient datagram delivers information about adjacencies to permit each individual node to make independent but coordinated decisions regarding channels and topologies. In high-speed mobility environments, an additional dedicated "scanning" radio may be incorporated into each node to provide the smoothest and most rapid adaptations of channel and topology for near instantaneous node-to-node switchover as required. A recent successful trial involved transmission of real-time video from a moving vehicle connecting through a series of roadside fixed nodes. Video transmission was maintained without dropouts, as the dedicated scanning radio allowed the mobile node to continually connect in turn to the best fixed node.

Network start-up is automatic and immediate when power is applied to the nodes. MeshDynamics units are compact and rugged, making for minimal transport cost and weight in hastily-formed and mobile applications.

Complete Data Security and Performance Features

Extensive data security capabilities are provided, including WEP, WPA, WPA2, 128 bit AES encryption, 802.11i, and FIPS 140-2. Extensive VLAN and performance-tuning features are standard, including 802.11e, protocol-based forwarding, and hidden SSIDs.

About MeshDynamics

Founded in 2002, MeshDynamics began shipping production units late in 2005 and has customers in many applications areas: municipal (metro) networking; homeland security/defense; transportation (e.g., rail and air); military; and public safety. Customers are worldwide; sales are direct and through resellers. Military organizations and defense contractors have performed extensive tests confirming MeshDynamics' industry-leading performance. In addition to these sales of the standard products, MeshDynamics maintains substantial custom development activity with key defense agencies. The technology pioneered for these demanding customers has been utilized in MeshDynamics' products.

The MeshDynamics design is radio manufacturer independent, allowing the rapid addition of new radio frequencies, radio system suppliers, and new technologies such as WiMAX and other emerging technologies. MeshDynamics' technology is patented and patent-pending, developed by teams of engineers in the USA and India. For more information please visit us at www.meshdynamics.com