Radio Aware Routing:
Enabling Communications on the Move

Introduction

Relief workers, soldiers, public safety personnel, and others need the right information, in the right place, at the right time, wherever they are located. Mobile ad hoc networks are emerging to address these needs. A new IETF request for comment, RFC 4938, defines a PPP-over-Ethernet (PPPoE) based mechanism for integrating IP routers and mobile radios in ad hoc networks, enabling faster convergence, more efficient route selection, and better performance for delay-sensitive traffic.

The Paradox of Mobile Networking

Mobile networking evolved as a way to deliver the benefits of information sharing and communication to workers on the move. In the beginning, "mobile networking" was simply a way for remote workers to connect back to an enterprise campus, and it comprised technologies such as dial and broadband access and virtual private networks. Today, wireless access points and broadband connections are nearly ubiquitous, and remote workers can reach those "home" networks from airports, hotels, and even coffee shops. Even mobile phones have morphed into "digital assistants," enabling users to check email messages, send attachments, exchange photographs, and browse the Internet while on the go.

Although mobile networking technology has untethered us from our desks, we typically remain very much leashed to stationary communication resources. Most on-the-move users still require access to fixed telecom and networking infrastructure and centralized services, application programs and data. For some users, these limitations are not serious. In an increasing number of environments, however, reliance on a fixed infrastructure and reach-back to central services is at best inefficient, or worse, impossible.

Consider relief workers in the aftermath of a natural disaster, where the network infrastructure may be impaired or destroyed; soldiers in the field, deployed beyond the reach of a fixed infrastructure; police, fire, or emergency medical services (EMS) responding to a complex, multiagency emergency scene in which traffic has overloaded available resources. For these "disadvantaged" users the need to communicate is acute; sharing the right information at the right time can be a matter of life or death. These scenarios require direct wireless IP networking between local peers that will work even when fixed networks and central services are unreachable.

The great paradox of the mobile networking revolution is that those with the most critical information needs too often have the least access. Consequently, there is a burgeoning demand now for solutions that will deliver the right information, in the right place, at the right time, wherever users are located.

This white paper describes how mobile ad hoc networks are evolving to support peer-to-peer, "infrastructure-less" networking among highly mobile users, and how routers and mobile radios can be enhanced to optimize IP networking in wireless environments.
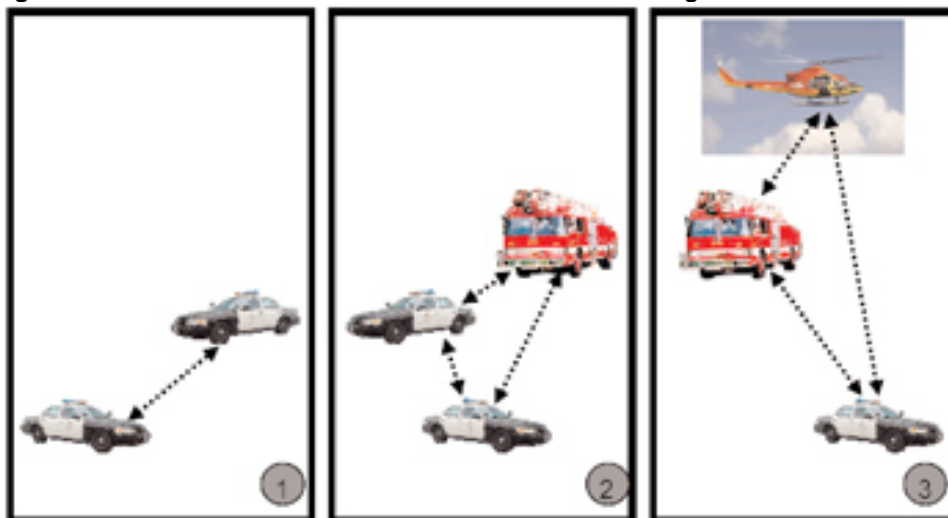
Mobile Ad Hoc Networking

Mobile ad hoc networks are emerging as a means for delivering the benefits of IP networking to users operating beyond the reach of a fixed network. In ad hoc networks, mobile nodes associate on an extemporaneous or ad hoc basis (refer to Figure 1). Ad hoc networks have numerous distinguishing characteristics when compared to conventional networking solutions:

- Self-forming: Nodes that come within radio range of each other can establish a network association without any pre-configuration or manual intervention.
- Self-healing: Nodes can join or leave rapidly without affecting operation of the remaining nodes.
- No infrastructure: In an ad hoc network, mobile nodes form their own network, and essentially become their own infrastructure.
- Peer to peer: Traditional networks typically support end systems operating in client-server mode. In an ad hoc network, mobile nodes can communicate and exchange information without prior arrangement and without reliance on centralized resources.
- Predominantly wireless: Historically networks have been mostly wired, and enhanced or extended through wireless access. The ad hoc environment is essentially wireless, but can be extended to support wired resources.
- Highly dynamic: Mobile nodes are in continuous motion and ad hoc networking topologies are constantly changing.

Collectively, these characteristics will enable ad hoc networks to deliver timely information to a new and underserved class of users. Ad hoc networking solutions can be applied to virtually any scenario that involves a cadre of highly mobile users or platforms (which may include stationary devices as well), a strong need to share IP-based information, and an environment in which fixed infrastructure is impractical, impaired, or impossible.

Figure1   Ad Hoc Networks Form as Nodes Come Within Range

Benefits of Ad Hoc Networking

Ad hoc networks deliver a compelling advantage wherever highly mobile users, unsupported by fixed infrastructure, need to share IP-based information. Specific benefits include:

- Superior information sharing at all levels, enabling improved situational awareness, a clearer understanding of leader's intent, and the ability for remote users to self-synchronize.
- Self-forming, self-healing operation, which facilitates deployment and minimizes the need for manual configuration and intervention.
- Multi-hop networking, which extends network coverage and provides redundant paths for increased resilience.
- Ability to operate with or without connectivity to a centralized network.
- Key enabler for new applications, such as vehicle-to-vehicle networking, intelligent transportation systems, sensor networking, telemetry monitoring, and more.

Challenges of Ad Hoc Networking

Ad hoc networking poses numerous challenges when contrasted with most currently deployed mobile networking solutions. For example, many TCP/IP applications are based on a client-server model in which a centralized manager controls operations. In an ad hoc network, access to centralized resources is likely to be unavailable at the precise moment it is needed. Therefore, ad hoc network applications must operate on a self-configuring, peer-to-peer basis.

In addition, many network services, such as authentication, authorization, and accounting (AAA), security, Domain Name System (DNS), and application acceleration (to name a few), also rely on centralized or strategically concentrated servers or appliances. In an ad hoc network, such services must be virtualized and distributed, so that each mobile node has access to required functions without the need for reach-back to remote servers.

Ad hoc networking also poses hardware and platform challenges, because many of today's networking devices must be optimized from a size, weight, and power (SWaP) perspective. In the peer-to-peer world, anybody or anything that moves can potentially be a wireless networking node. Ad hoc networking then requires a variety of platforms ranging from traditional rack-mount to vehicle-based, to hand-carried or wearable, with all offering equivalent network services.

Routing and scalability are critical factors in ad hoc networks. Concerns about the speed with which mobile nodes can join or leave the network, the prospect of large numbers of peers and link updates, and the overhead associated with different protocols have led to the development of both new protocols—such as Optimized Link State Routing [OLSR] and Dynamic MANET On-demand [DYMO]—and ad hoc-related optimizations to existing and proven protocols—such as Open Shortest Path First Version 3 (OSPFv3) and Enhanced IGRP (EIGRP).

But the most fundamental problem facing those who develop, deploy, or use ad hoc networks has been how best to merge two very different worlds—IP routing and mobile radio—while taking advantage of the strengths of each. In ad hoc networks, mobile nodes typically communicate over wireless radio networks, where bandwidth is at a premium. Radio link quality can vary suddenly and dramatically because of factors such as noise, fading, interference, and power fluctuation. In such dynamic environments, Layer 3 IP routing issues such as network convergence, route-cost calculation, and congestion avoidance can become highly problematic.

The seven-layer architectural model used in traditional networking assumes that each layer is unaffected by, and essentially blind to, whatever happens at any other layer. However, in ad hoc networks the efficiency of Layer 3 processes is directly related to lower-layer events. Consequently,

the notion of using cross-layer feedback mechanisms has gained significant momentum. For example, cross-layer feedback can enable Layer 1 and Layer 2 intelligence to influence and optimize Layer 3 routing decisions.

Radio Aware Routing: Cross-Layer Feedback for Router-Radio Integration
Radio Aware Routing takes advantage of the functions defined in RFC 4938, which Cisco authored. RFC 4938 is an IETF standard that defines PPPoE extensions for Ethernet-based communications between a router and a device such as a mobile radio that operates in a variable-bandwidth environment, and has limited buffering capabilities. These extensions provide a PPPoE session-based mechanism for sharing radio network status such as link quality metrics and establishing flow control between a router and an RFC 4938-capable radio.

An RFC 4938 radio initiates a Layer 2 PPPoE session with its adjacent router on behalf of every router and radio neighbor discovered in the network. These Layer 2 sessions are the means by which radio network status for each neighbor link is reported to the router. The radio establishes the correspondence between each PPPoE session and each link to a neighbor (refer to Figure 2).

Figure 2 RFC 4938 PPPoE Sessions
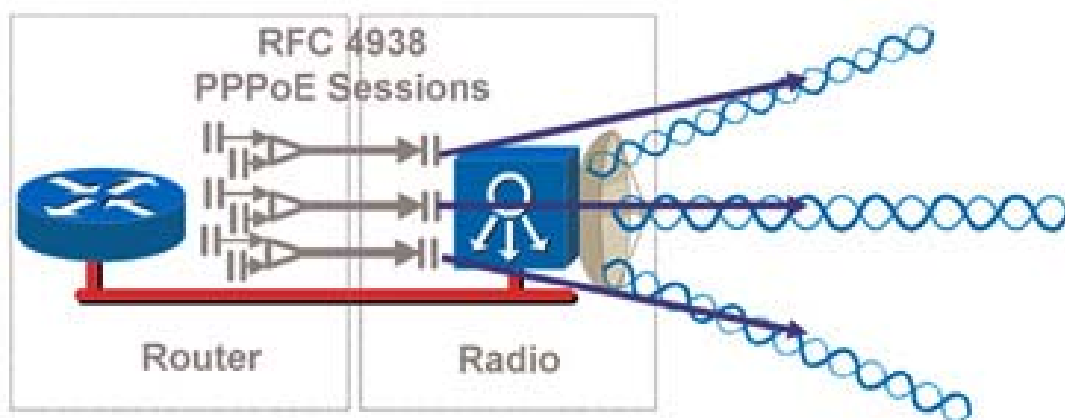
Whenever a PPPoE session is established, the router opens a Point-to-Point Protocol (PPP) Link Control Protocol (LCP) session with the corresponding neighbor to negotiate PPP options (refer to Figure 3). When the PPP LCP process is complete, the PPP IP Control Protocol (IPCP) initiates an exchange of Layer 3 parameters between neighbor nodes. After the IPCP exchange, PPP data starts to flow from router to router.

Figure 3 PPPoE Session Establishment
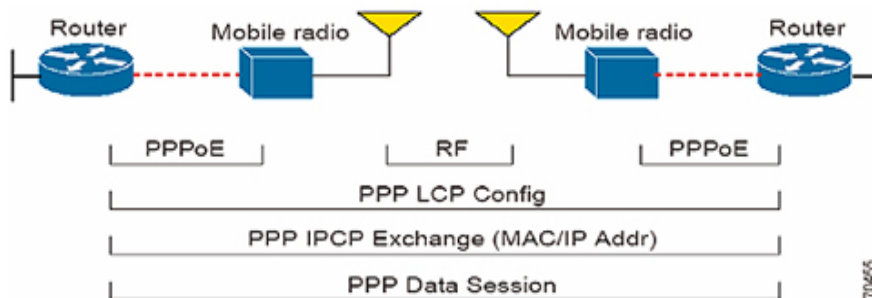
Taking Advantage of RFC 4938 for Ad Hoc Networking

Effective networking in an ad hoc network environment requires mechanisms by which routers and radios can interoperate efficiently, without impacting operation of the radio network; radios can report status to routers for each link and each neighbor; routers can more readily recognize topology changes; and routers can use radio link information to optimize routing decisions. To address these needs, the Cisco RFC 4938 implementation incorporates the following features:

- PPPoE Credit-Based Flow Control: This extension to the PPPoE protocol allows a receiver to control the rate at which a sender can transmit data for each PPPoE session, minimizing the need for queuing in the radio.
- Neighbor Up/Down Signaling: Cisco routers can use PPPoE session establishment or termination signals from the radio to update routing topologies.
- Link Quality Metrics Reporting: This PPPoE protocol extension enables a radio to report (or a router to query) link quality metric information. Cisco routers have been enhanced in order that OSPFv3 and EIGRP routing protocols can factor RF link quality metrics into route cost calculations.

PPPoE Credit-Based Flow Control

The carrying capacity of each radio link can vary due to location changes or environmental conditions, and many radio transmission systems have limited buffering capabilities. To minimize the need for packet queuing in the radio, Radio Aware Routing employs a credit-granting mechanism that enables the radio to control the rate at which its partner router sends traffic.

When the PPPoE session is established, the radio can request a flow-controlled session. If the router acknowledges the request, all subsequent traffic must be flow-controlled. If a flow-control session has been requested and cannot be supported by the router, the session is terminated. Typically, the radio initially grant credits during session discovery. When a device exhausts its credits, it must stop sending until additional credits are granted. Credits can be added incrementally over the course of a session. Implementing flow control on the PPPoE router-to-radio sessions also allows the use of fair queuing for each session.

Neighbor Up/Down Signaling

Ad hoc networks are highly dynamic environments. Nodes may move in or out of radio range at a fast pace. Each time a node joins or leaves, the network topology must be updated by the routers. Routing protocols normally use timer-driven "hello" messages or neighbor timeouts to track topology changes, but for ad hoc network environments, reliance on these mechanisms can result in unacceptably slow convergence. RFC 4938-based solutions provide faster network convergence by using link status signals generated by the radio. The router infers a change in neighbor status based on the creation or termination of a PPPoE session by the radio.

In the router, the routing protocols (OSPFv3 and EIGRP) respond immediately to these signals by expediting formation of a new adjacency for a new neighbor, or tearing down an existing adjacency if a neighbor is lost (refer to Figure 4).

For example, if a vehicle drives behind a building and loses its connection, the router immediately senses the loss and establishes a new route to the vehicle through neighbors that are not blocked. This high-speed network convergence is essential for minimizing dropped voice calls and disruptions to video sessions.

Figure 4 Neighbor Up/Down Signaling
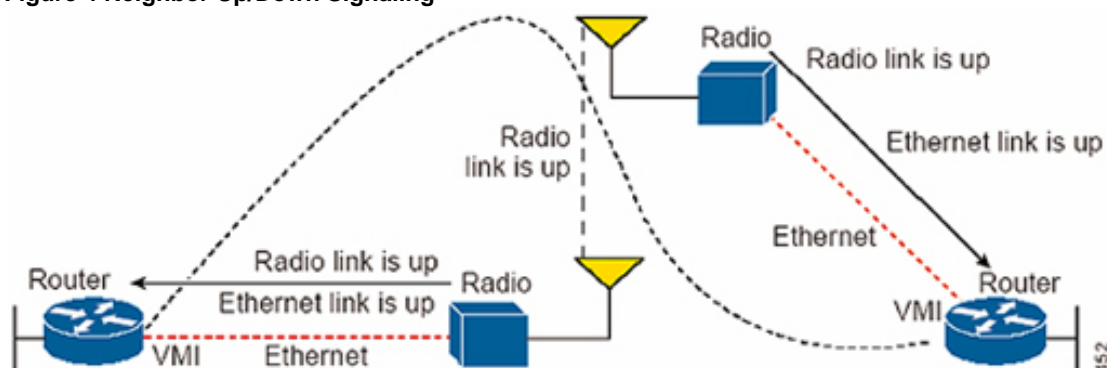
Link Quality Metrics

The quality of a radio link directly affects the throughput that router-to-router traffic can achieve. The PPPoE protocol has been extended to provide a process by which a router can request—or a radio can report—link quality metric information. Cisco OSFPv3 and EIGRP implementations have been enhanced so that the route cost to a neighbor is dynamically updated based on metrics reported by the radio. This capability helps optimize route selection within a given set of radio links.

The routing protocols receive raw radio link data and compute a composite quality metric for each link. In computing these metrics, the following factors may be considered (depending on the routing protocol being used and the radio vendor's implementation of link metrics):

- Maximum data rate: The theoretical maximum data rate of the radio link.
- Current data rate: The current data rate achieved on the link.
- Latency: The transmission delay packets encounter, in milliseconds.
- Resources: A percentage (0 to 100) that can represent the remaining amount of a resource (such as battery power).
- Relative link quality: A numeric value (0 to 100) representing relative quality, with 100 being the highest quality.

Metrics can be weighted during the configuration process to emphasize or deemphasize particular characteristics when computing link cost. For example, if throughput is a particular concern, the current data rate metric could be weighted so that it is factored more heavily into the composite metric. Similarly, a metric that is of no concern can be omitted from the composite calculation.

Link metrics can change rapidly, often by very small degrees, possibly resulting in a flood of meaningless routing updates. In a worst-case scenario, the network would churn almost continuously as it struggled to react to minor variations in link quality. To alleviate this problem, Cisco provides a tunable dampening mechanism that allows you to configure threshold values based on the magnitude or timing of changes. Any metric change that falls below the threshold is ignored.

Interfacing Layer 2 to Layer 3: The Virtual Multipoint Interface

Whereas RFC 4938 defines an effective method for delivering Layer 1 and Layer 2 information to the router, it does not specifically address how this information is presented to the IP layer within the router, where it can be used to influence or adjust networking processes.

The Cisco RFC 4938 implementation incorporates a Virtual Multipoint Interface (VMI) within Cisco

IOS® Software that aggregates all the per-neighbor PPPoE sessions from the radio Ethernet connection. The VMI maps these sessions to appear to Layer 3 routing protocols as a single point-to-multipoint, multiaccess, broadcast-capable network (refer to Figure 5). The VMI aggregation function also reduces the size of the internal database of the router and thus improves scalability and network convergence. The VMI preserves the integrity of the PPPoE sessions on the radio side, helping ensure each point-to-point connection can have its own quality-of-service (QoS) queue.

The VMI relays the link quality metric and neighbor up/down signaling from the radio to the routing protocols. Currently, VMI signals are used by EIGRP (for IPv4 and IPv6 neighbors) and OSPFv3 (for IPv6 neighbors).

Note: Cisco offers a bypass mode so that the VMI aggregation function can be enabled or disabled for multicast operations. Disabling the aggregation function provides full visibility to the router of each PPPoE session and each virtual interface. Using bypass mode may, of course, increase the size of the router database, and may affect scalability and increase network convergence times. It is important to note, however, that network metric information and neighbor up/down signaling should not be affected.

Figure 5 Cisco IOS Software Virtual Multipoint Interface
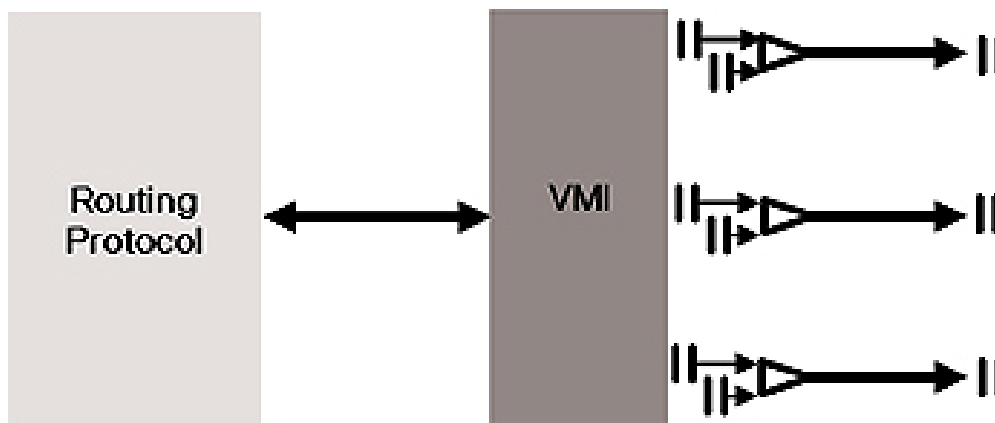
When to Use Radio-Aware Routing

The RFC 4938-based implementation of Cisco Radio Aware Routing is specifically targeted at routing over directional radio networks—radio networks that use directional antennae with multiple beams and electronic switching between beams. Directional radio networks often use higher frequencies where contiguous spectrum availability enables higher data rates. These networks also provide a lower probability of detection or interception and are resistant to jamming. Directional, connection-oriented radios separate traffic and allocate bandwidth based on time, frequency, or spatial multiplexing. These radios, in effect, establish virtual connections between nodes. Directional radio networks appear to the router as a series of point-to-point connections (refer to Figure 6).

Figure 6 Directional, Point-to-Point Radio Network
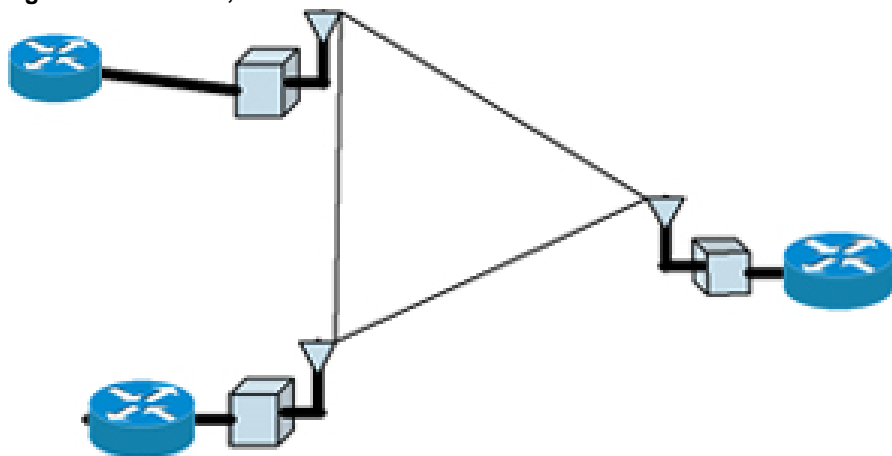
Conclusion

Ad hoc networks are emerging as a means to deliver IP-based voice, video, and data to users who may be operating beyond the reach of traditional fixed-network infrastructure. Ad hoc networking offers a compelling advantage for many environments, but also poses significant challenges. Foremost among these challenges is the need to merge IP routing and mobile radio technologies efficiently. RFC 4938 provides an effective, cross-layer mechanism for communicating radio network status to IP routers.

In 2007, Cisco delivered the industry's first Radio Aware Routing implementation for the Cisco 3200 Series Rugged Integrated Services Routers and Cisco 2800 Series and 3800 Series Integrated Services Routers. Cisco IOS Software has been enhanced to take full advantage of the metric and status information offered by RFC 4938-compliant radios. The company also has partnered with major radio vendors to facilitate their radio-side implementations of this industry standard. The Cisco Radio Aware Routing solution allows network-based applications and information to be quickly and reliably transported over directional radio links. Fast convergence and optimal route selection help ensure satisfactory delivery of mission-critical, delay-sensitive traffic (refer to Figure 7).

Figure 7 RFC 4938-Based Ad Hoc Networking Solutions
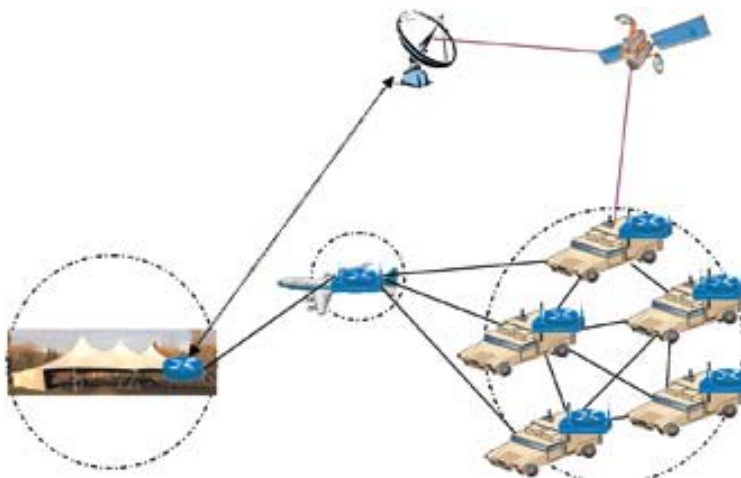
For More Information

Learn more about mobile ad hoc networks, RFC 4938 and Radio Aware Routing at http://www.cisco.com/go/adhocmobility.