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Wireless Ad Hoc Networks: Basic Concepts

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This fundamental tutorial introduces the concept of ad hoc, or mesh, networking, which uses whatever resources are available to create communication paths from a user to his or her desired destination.

Ad hoc networks, which are also called *mesh networks*, are defined by the manner in which the network nodes are organized to provide pathways for data to be routed from the user to and from the desired destination.

Actually, the two names ascribed to these networks provide considerable insight. *Ad hoc* has two definitions—the first can be either "impromptu" or "using what is on hand," while the other is "for one specific purpose." For example, members of an ad hoc committee (studying a specific issue) might discover that they are attending the same event and decide to have an ad hoc (impromptu) meeting.

Ad hoc networks follow both definitions, as well. They are formed as they are needed (impromptu), using resources on hand, and are configured to handle exactly what is needed by each user—a series of "one specific purpose" tasks.

The term mesh network accurately describes the structure of the network: All available nodes are aware of all other nodes within range. The entire collection of nodes is interconnected in many different ways, just as a physical mesh is made of many small connections to create a larger fabric.

Figure 1 provides a simple diagram illustrating these concepts. This diagram is modeled after a wireless "hot spot," where an ad hoc network links users to a router with access to the Internet. In this example, two users are highlighted, showing two paths through several nodes to the router.

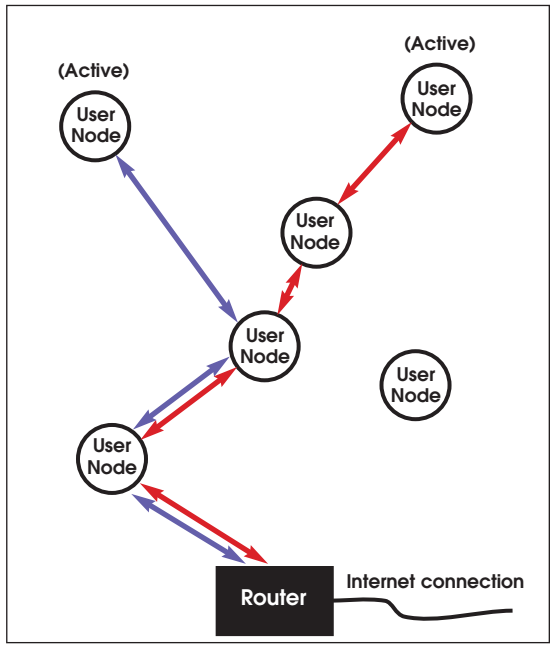

Figure 1 · Basic structure of an ad hoc, or mesh, network. The path from the user's node to the destination node is provided by other users' devices acting as routers.

If one of the intermediate nodes were to fail (e.g. that user leaves the area), the network will automatically reconfigure itself, locating an alternate path from the user to the router. Typically, all available nodes are also network users, each sharing the total data transfer capacity of the particular hardware and operating protocol being used.

The network could also connect users to other users directly, as would be done in an industrial control and monitoring network. Since there is no need for central administration of the network configuration, it is most

efficient to design the system for autonomous operation of each node. In an industrial environment, a situation such as an alarm would be propagated through the network and received directly by each node. Each node would be programmed to respond according to its particular function—machine control, process monitoring, supervisory personnel or central office.

Self-Configuring and Self-Healing Processes

Figure 2 shows how ad hoc networks determine their configuration. In Fig. 2a each node identifies the nodes that are available for communications, based on signal strength, which is mainly related to distance, but is also affected by obstructions or interference. Some nodes may be beyond range, others may be detectable but have insufficient signal strength for reliable communications.

Once the available nodes are identified, this information is communicated to other nodes, along with information about the desired destination (Fig. 2b). Using the lists of available connections, the network configuration algorithm selects a particular routing for each user to its destination. This process requires system operating software to have good decision-making algorithms, based on practical criteria for signal strength, path reliability over time, and network configuration patterns.

Over time, or even near-continuously, the network will change. Users may come and go, nodes may be in motion, or changes in the electromagnetic environment may alter the propagation between nodes. As these changes take place, the network will update its configuration and identify new paths from users to destinations, as illustrated in Fig. 2c. This type of reconfiguration will be repeated over and over as the network changes. Note that this is the same process used in the Internet, where system loading and hardware issues require redirection of a user's data through different routers.

Advantages of Ad Hoc Networks

The principal advantages of an ad hoc network include the following:

- Independence from central network administration
- Self-configuring, nodes are also routers
- Self-healing through continuous re-configuration
- Scalable—accommodates the addition of more nodes
- Flexible—similar to being able to access the Internet from many different locations

Limitations of Ad Hoc Networks

While ad hoc networks are typically used where they have the greatest emphasis on its advantages, there are some limitations:

- Each node must have full performance
- Throughput is affected by system loading
- Reliability requires a sufficient number of available nodes. Sparse networks can have problems
- Large networks can have excessive latency (time delay), which affects some applications

Some of these limitations also apply to conventional hub-and-spoke based networks, or cannot be addressed by alternate configurations. For example, all networks are affected by system loading, and networks with few nodes are difficult to justify in hard-wired solutions.

Key Applications

WLAN is the initial application that received a concerted development effort. Peer-to-peer networks of computer/PDA users have become common. Commercial wireless Internet service providers (WISP) use repeater nodes to extend coverage to a large area, while user nodes can extend service in their locality.

Control systems (e.g. environmental controls) and industrial process monitoring and control are becoming major applications for mesh networking. These environments are difficult to serve with dedicated wiring, being spread over a large area, often with difficult access. Sensor networks from small-scale (e.g. household security monitoring) to large scale (e.g. wildlife tracking) are

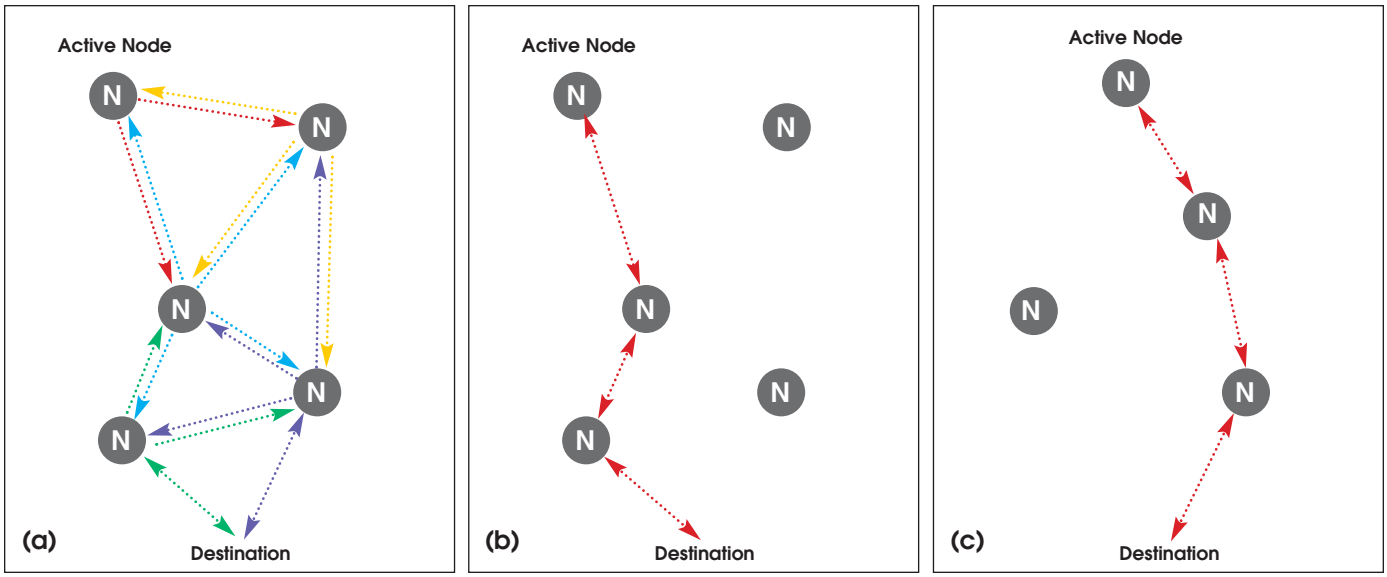

Figure 2 · Creation and adaptation of an ad hoc network: (a) Determination of available nodes, (b) Selection of the optimal routing, and (c) Reconfiguration when the network makeup changes.

also being developed with ad hoc networking as the operational structure.

Developers of these and other applications have determined that ad hoc networks are the most efficient way to maintain system-wide communications. Hopefully, this brief tutorial will help you appreciate the value of this important networking technique for establishing and maintaining wireless communications.