# Mobile ad hoc networks

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## Introduction

This chapter offers a state-of-the-art review in mobile ad hoc networks (MANETs). It first introduces the history of ad hoc networks, explaining the ad hoc network concept and referring to the main characteristics of these networks and their fields of application.

It then focuses on technologies and protocols specific to ad hoc networks. Firstly, it refers to relevant proposals targeting the PHY/MAC layers. Secondly, it discusses the different routing protocol proposals for ad hoc networks according to the category they belong to. Finally, it includes an overview of the different protocols proposed for ad hoc networks at the transport layer. The chapter concludes with some remarks on future trends in these networks.

## Background

The history of wireless networks dates from the 70s. In fact, radio communications and computer networks were first combined by the University of Hawaii in 1971 in an experimental network named ALOHANET. That network offered bidirectional communications following a star topology and its purpose was to allow communicating with US mainland. During the 80s, the technology was improved and towards the end of the 90s interest on wireless networks reached a peak mainly due to the fast growth of the Internet.

Nowadays we can split existing wireless networks into different categories according to their scope and size. Wireless Wide Area Networks (WWANs), such as GSM and UMTS (Ojanpera, T. & Prasad, R., 1998), usually cover hundreds of kilometers and use private frequency bands. Such networks are usually owned and maintained by telecommunications providers and their purpose is to offer services in a country or a region of it. Wireless Metropolitan Area Networks (WMANs), such as WiMax (IEEE 802.16 WG, 2004), typically have a range of a few kilometers, and can operate over both private and public frequency bands, so that both telecommunication companies and private users can take advantage of them. Wireless Local Area Networks (WLANs), such as WiFi (IEEE 802.11 WG, 1999), usually cover areas between a few tens of meters up a kilometer. They typically use public frequency bands so that users can freely install and use them. At the lower end we have Wireless Personal Area Networks (WPANs), such as Bluetooth (IEEE 802.15 WG, 2005), which also use free frequency bands are used to replace cables within a very limited area (few meters).

This article focuses on recent developments in terms of infrastructure-less wireless networks, more commonly known as ad hoc networks, which make extend WLAN technologies to offer more flexible solutions. All nodes within an ad hoc network provide a peer-level multi-hopping routing service to allow out-of-range nodes to be connected. Unlike a wired network, nodes in an ad hoc network can move freely, thus giving rise to frequent topology changes.

Such a network may operate in a stand-alone fashion or be connected to the larger Internet. An ad hoc architecture has many benefits, such as self-reconfiguration and adaptability to highly variable characteristics, namely power and transmission conditions, traffic distribution variations, and load balancing. However, those benefits come with many challenges. New algorithms, protocols, and middleware have to be designed and developed to create a truly flexible and decentralized network.

In terms of applications, ad hoc networks offer the required flexibility to adapt to situations were no sort of infrastructure is available. Examples of such situations are army units moving inside hostile territories or organized teams such as firemen performing rescue tasks. In general, mobile ad hoc networks can be used on all those situations characterized by lack of fixed infrastructure, peer-to-peer communication and mobility support.

# Technologies and protocols for ad hoc networks

## A. PHY/MAC layer technologies

Throughout the past few years novel solutions for MAC/PHY layers have been sought in the wireless ad hoc networking field. In particular, there have been several proposals targeting the MAC layer (Kumar et al., 2006).

Despite the many proposals available, very few have made it to the market. Nowadays almost every ad hoc network relies on IEEE 802.11 technology (IEEE 802.11 WG, 1999), which defines both physical and MAC layers. Since this standard has gained much relevance, we now offer more details about it.

In 1997 IEEE group 802.11 was created. The purpose was to create a technology for wireless local area networks operating on ISM (Industrial, Scientific and Medical) frequency bands. With that purpose, a MAC layer and three different physical layers were defined, operating at 1 and 2 Mbit/s:

- Infrared (IR) – baseband
- Frequency hopping spread spectrum (FHSS) – 2.4 GHz band
- Direct sequence spread spectrum (DSSS) – 2.4 GHz band

On December 1999, the IEEE 802.11a standard was completed, proposing a different technique for the physical layer named Orthogonal Frequency Domain Multiplexing (OFDM). This technology was able to offer up to 54 Mbit/s on the 5 GHz band. A year later, on January 2000, the IEEE 802.11b standard was completed, consisting basically of an extension to the original standard offering up to 11 Mbit/s on the 2.4 GHz band. Only in July 2003 was the IEEE 802.11g standard completed, offering 54 Mbit/s speeds on the 2.4 GHz frequency band. Recently, the 802.11n group is proposing higher speed extensions to the standard, targeting data rates above 300 Mbit/s.

Concerning 802.11's MAC layer, its main functions are reliable data delivery, fair access to the wireless media and data protection. Moreover, it is responsible for a correct operation in noisy, unreliable environments.

The 802.11 standard offers two different medium access mechanisms:

- Distributed coordination function (DCF), a mandatory access mechanism based on CSMA/CA. (*Carrier Sense Multiple Access with Collision Avoidance*).
- Point coordination function (PCF), optional, based on a polling method to support services with time restrictions.

Since the latter only applies to access points, in ad hoc networks the DCF must be used instead. Despite the ad hoc mode proposed by the IEEE 802.11 standard did not target specifically multi-hop ad hoc networks, it is widely used and offers relatively good performance.

## B. Routing protocols

A routing protocol is required when a packet must go through several hops to reach its destination. It is responsible for finding a route for the packet and making sure it is forwarded through the appropriate path.

Routing techniques can be divided into three families: *distance vector* (Bellman, R.E. 1957) (Ford, L.R. & Fulkerson, D.R., 1962), *link state* (Dijkstra, 1959) and *source routing* (Estrin, Li, Rekhter, Varadhan & Zappala, 1996).

Internet routing protocols based on these techniques generate periodic control messages, a procedure that is not adequate for a large mobile network with long routes since it would result in a large number of control messages. Reducing routing overhead is critical for mobile nodes since CPU use, as well as radio transmissions and receptions, would cause batteries to be quickly depleted.

Below, we present different routing protocol proposals for MANETs that are currently available. We have organized them into three groups: proactive, reactive and other strategies, being that the latter embraces all those that do not fall under the former two categories.

<u>Proactive routing protocols</u>

When using proactive routing protocols, all the nodes (routers) periodically exchange routing information with the aim of maintaining a consistent, updated and complete network view. Each node uses the exchanged information to calculate the costs towards all possible destinations. That way, if a destination is found, there will always be a route available towards it.

The main advantage of proactive routing schemes is that there is no initial delay when a route is required. On the other hand, these are usually related to a greater overhead and a larger convergence time than for reactive routing techniques, especially when mobility is high. To increase the performance in ad hoc networks both *link-state* and *distance vector* algorithms were modified. Examples of routing protocols using *distance vector* techniques are the *Destination-Sequenced Distance Vector* (DSDV) (Perkins & Bhagwat, 1994) and the *Wireless Routing Protocol* (WRP) (Murty & Garcia-Luna-Aceves, 1996). Examples of *link-state* based protocols are the *Optimized Link State Routing* (OLSR) (Clausen et al., 2001) and the *Topology Broadcast Reverse Path Forwarding* (TBRPF) (Bellur & Ogier, 1999).

<u>Reactive routing protocols</u>

Reactive routing does not depend, in general, of periodic exchange of routing information or route calculation. Therefore, when a route is required, the node must start a route discovery process. This means that it must disseminate the route request throughout the network and wait for an answer before it can proceed to send packets to the destination. The route is maintained until the destination is unreachable or until the route is no longer necessary. By following this strategy, reactive routing protocols keep to a minimum the resource consumption by avoiding the maintenance of unused routes. On the other hand, the route discovery process causes a significant startup delay and causes a considerable waste of resources. If the network is wide enough, the overhead will be similar or superior to that achieved with proactive routing protocols.

The most common routing algorithms found among reactive routing protocols are *distance vector* and *source routing*. Example of reactive routing protocols are the *Ad hoc On-demand Distance Vector* (AODV) (Perkins & Royer, 1999), the *Dynamic Source Routing* (DSR) (Johnson et al., 2004), and the Dynamic On-demand Routing protocol (DYMO) (Chakeres & Perkins, 2008).

<u>Other strategies</u>

There are other strategies proposed for the design of routing protocols. There are, for instance, hybrid solutions such as the *Zone Routing Protocol* (ZRP) (Hass & Pearlman, 1999) which uses both reactive and proactive concepts. Some protocols are based on *clustering* and hierarchical architectures, such as the

*Distributed Mobility-Adaptive Clustering* (DMAC) (Basagni, 1999) and the *Cluster-based Energy Saving Algorithm* (CERA) (Cano et al., 2003).

The LAR protocol (Ko & Vaidya, 1998) tries to avoid the flooding associated to route discovery by using GPS information so that only those nodes on a certain geographic area between source and destination must retransmit route requests.

Finally, *Power Aware Routing* (PAR) (Singh et al., 1998) is a solution that techniques that intends to improve the power consumption by taking into account the battery lifetime, selecting those routes that minimize the energy consumption of the system.

### C. Transport protocols

The Transmission Control Protocol (TCP) is perhaps the most important and widely used transport protocol in the Internet. Most applications, such as web, mail, SSH and peer-to-peer networking, depend on it for the reliable data delivery on an end-to-end basis.

Since TCP was designed for the Internet environment, it is prone to suffer from poor performance in wireless networks, especially in mobile ad hoc networks. The main reasons have to do with packet losses and node mobility.

In the Internet environment the physical media is very reliable, and the path traversed by packets is typically the same throughout the duration of a connection. So, losses are usually related to congestion. TCP’s congestion control mechanisms act upon packet losses to regulate the data rate, being quite effective for the Internet. Contrarily to wired media, wireless transmission are prone to frequent bit errors due to fluctuations in Signal-to-Noise ratio (SNR), multipath and shadowing effects, etc. Such errors are not related to congestion, and so should not receive a similar treatment at the transport layer.

Mobile ad hoc networks suffer from frequent topology updates, which require highly adaptive routing protocols, as referred above. Route maintenance, though, is not instantaneous and often causes large groups of packets to be delayed and/or lost. This occurrence is not related to congestion either and, therefore, should also receive a differentiated treatment.

Due to the aforementioned problems, specific transport layer proposals for ad hoc network environments are available in the literature. They can be group into three different categories:

- Solutions that propose improvements to the TCP protocol
- TCP-aware cross layer solutions
- Transport protocols specific to ad hoc networks

In terms of solutions proposing improvements to the TCP protocol, the most relevant work in the field is ELFN (Explicit Link Failure Notification) (Holland & Vaidya, 1999). This solution mitigates the route discovery problem through explicit link failure notification from network nodes to the TCP sender. The sender then enters a hold state, periodically probing the network to assess if the path has been re-established. When a new path is available, the TCP agent returns to its previous state (before the path was lost), hence improving resource usage.

Concerning TCP-aware cross layer solutions, the most relevant work in the field is the Atra framework (Anantharaman & Sivakumar, 2002). This proposal basically consists of three mechanisms – two at the routing layer and one at the MAC layer – that cooperate to improve the performance of TCP. At the MAC layer there is a mechanism that predicts route failures to improve routing tasks. At the routing layer it includes a mechanism – Symmetric Route Pinning – to reduce the frequency of route failures. It also includes a proactive mechanism that informs all interested nodes about failing links, improving global performance.

Finally, in terms of protocols specific to ad hoc networks, the most relevant proposal in the field is the Ad hoc Transport Protocol (ATP) (Sundaresan & Anantharaman, 2003). This protocol consists of a complete redesign of the transport layer for optimum performance in ad hoc network environments. Its main characteristics are the use of rate-based transmissions instead of TCP’s sliding windows paradigm, a quick start mechanism, a delay-based congestion indicator and a feedback mechanism from receiver to source that includes SACK (Selective ACKnowledgements) blocks similar to those proposed in TCP-SACK (Mathis et al., 1996).

## Future Trends

The field of mobile ad hoc networks is still under intensive research. New application areas are emerging, such as vehicular ad hoc networks (VANETs), which rely on ad hoc connections between vehicles to improve road safety. The sensor networks area is also strongly related to ad hoc networks, and a merge of some of the ideas and solutions employed is prone to occur. Wireless mesh networking (WMN) is an area also intimately related to mobile ad hoc networks; the former are characterized by minimal or no mobility compared to the latter.

Concerning improvements to the MAC layers, the IEEE 802.11e standard represents an important enhancement to the MAC layer to offer quality of service (QoS) support. In the future we expect to see MAC layer solutions that further improve QoS traffic discrimination at this layer.

In terms of routing, a merge of independent solutions is required to offer a protocol that takes into consideration issues such as power consumption, security and anonymity, QoS, as well as the physical and MAC layers used.

For the transport layer, a cross-layer solution specific to ad hoc networks offering efficient support to both best effort and real-time traffic is still one of the missing points. Also, since these networks are very prone to errors, enhancements to the transport layer are expected to include advanced error correction techniques that completely avoid retransmissions up to a certain loss rate.

## Conclusion

Mobile ad hoc networks are a field under intensive research due to their flexibility and lack of requirements in terms of infrastructure. Currently several solutions are available for the different network layers involved – physical, MAC, routing and transport – both in terms of theoretical and real-world implementations of protocols and technologies. Despite the on-going efforts, there is still much room for improvements since the performance of these networks is typically poor compared to other wireless technologies such as UMTS, WiMax, etc.

In years to come, and with the advent of novel applications requiring these networks (e.g., VANETs), it is expected that this type of networks becomes widely adopted by the industry, resulting in the deployment of new products and solutions that rely on ad hoc networks to offer a set of functionalities and services that no other technology is able to offer. Once the technology becomes mature, it can be adopted also for critical missions such as rescue, disaster and military scenarios.

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## Terms and definitions

**Distance Vector:** Routing technique that maintains a table for the communication taking place and employs diffusion (not flooding) for information exchange between neighbors. All the nodes must calculate the shortest path towards the destination using the routing information of their neighbors.

**Link State:** Routing protocols based on this technique maintain a routing table with the full topology. The topology is built by finding the shortest path in terms of link cost, cost that is periodically exchanged among all the nodes through a flooding technique.

**MAC layer:** The Medium Access Control layer is a protocol layer embedded within the link layer that is responsible for coordinating the access to a shared medium according to a set of rules.

**Source Routing:** Technique where all the data packets have the routing information on their headers. The route decision is made on the source node, which avoids routing loops entirely.

**VANET:** Vehicular ad hoc network, consisting of a network of vehicles moving at a relatively high speed that communicate among themselves with different purposes, being the main purpose that of improving security on the road.

**Node:** In the context of mobile ad hoc networks (MANETs), it usually refers to a mobile terminal such as a PDA, laptop, smartphone or other device with wireless communication capabilities that participates in the networks both as a traffic generator and traffic forwarder.

**SSH:** Secure Shell is a protocol that allows accessing a remote computer in a secure manner by employing cryptographic techniques. Usually, the term refers also to the client/server tools that support this protocol.