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## Chapter 0

# Mobile Ad-Hoc Networks

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### Abstract

*Ad-hoc networks are a key in the evolution of wireless networks. Ad-hoc networks are typically composed of equal nodes, which communicate over wireless links without any central control. Ad-hoc wireless networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimisation, power control and transmission quality enhancement. In addition, the multi-hop nature and the lack of fixed infrastructure brings new research problems such as configuration advertising, discovery and maintenance, as well as ad-hoc addressing and self-routing. Many different approaches and protocols have been proposed and there are even multiple standardization efforts within the Internet Engineering Task Force, as well as academic and industrial projects. This chapter focuses on the state of the art in mobile ad-hoc networks. It highlights some of the emerging technologies, protocols, and approaches (at different layers) for realizing network services for users on the move in areas with possibly no pre-existing communications infrastructure.*

## INTRODUCTION

Future information technology will be mainly based on wireless technology ([51], [57], [50]). Traditional cellular and mobile networks are still, in some sense, limited by their need for infrastructure (i.e., base stations, routers). For mobile ad-hoc networks, this final limitation is eliminated.

Ad-hoc networks are a key in the evolution of wireless networks [49]. Ad-hoc networks are typically composed of equal nodes, which communicate over wireless links without any central control. Although military tactical communication is still considered as the primary application for ad-hoc networks, commercial interest in this type of networks continues to grow. Applications such as rescue missions in times of natural disasters, law enforcement operation, commercial and educational use, and sensor networks are just few possible commercial examples.

Ad-hoc wireless networks inherit the traditional problems of wireless and mobile communications, such as bandwidth optimisation, power control and transmission quality enhancement. In addition, the multi-hop nature and the lack of fixed infrastructure generates new research problems such as configuration advertising, discovery and maintenance, as well as ad-hoc addressing and self-routing.

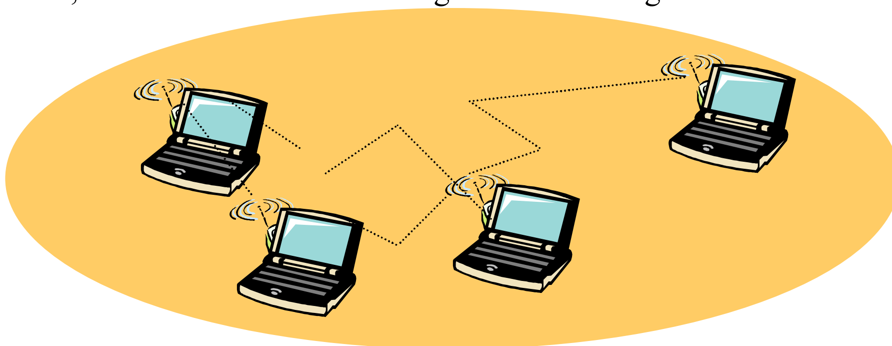

**Figure 1 A mobile ad-hoc network**

In mobile ad-hoc networks, topology is highly dynamic and random. In addition, the distribution of nodes, and, eventually, their capability of self-organising play an important role. The main characteristics can be summarized as follows:

- The topology is highly dynamic and frequent changes in the topology may be hard to predict.
- Mobile ad-hoc networks are based on wireless links, which will continue to have a significantly lower capacity than their wired counterparts.
- Physical security is limited due to the wireless transmission.
- Mobile ad-hoc networks are affected by higher loss rates, and can present higher delays and jitter than fixed networks due to the wireless transmission.
- Mobile ad-hoc network nodes rely on batteries or other exhaustible means for their energy. As a consequence, energy savings are an important system design criterion. Furthermore, nodes have to be power-aware: the set of functions offered by a node depends on its available power (CPU, memory, etc..).

A well-designed architecture for mobile ad-hoc networks involves all networking layers, ranging from the physical to the application layer.

Despite the fact that the management of the physical layer is of fundamental importance, there is very little research in this area: nodes in mobile ad-hoc networks are confronted with a number of problems, which, in existing mobile networks, are solved by the base stations. The solution space ranges from hierarchical cell structures (a self-organized pendant of cellular networks) to completely ad-hoc, stochastic allocations. Power management is of paramount importance. General strategies for saving power need to be addressed, as well as adaptation to the specifics of nodes of general channel and source coding methods, of radio resource management and multiple access.

Mobile ad-hoc networks do not rely on one single technology; instead, they should be able to capitalize on technology advances. One challenge is to define a set of abstractions, which can be used by the upper layers, and still not preclude the use of new physical layer methods as they emerge. Primitives of such an abstraction are for example the capabilities and covering ranges of multicast and unicast channels.

Information as node distribution, network density, link failures, etc.., must be shared among layers, and the MAC layer and the network layer need to collaborate in order to have a better view of the network topology and to optimise the number of messages in the network.

In mobile ad-hoc networks, with the unique characteristic of being totally independent from any authority and infrastructure, there is a great potential for the users. In fact, roughly speaking, two or more users can become a mobile ad-hoc network simply by being close enough to meet the radio constraints, without any external intervention.

Moreover, telecommunication networks are expected to grow with the advent of new (and totally unexpected) applications. While in the past telecommunication networks were studied and developed in separate building blocks, for mobile ad-hoc networks the interaction between higher layers and lower layers is essential for the users.

Resilient and adaptive applications that can continue to perform effectively under degraded conditions can significantly enhance network operations from a user's perspective. Such applications can also ease the design pressure significantly in complex engineering areas such as quality of service (QoS) and mobile routing at the network layer [47].

As illustrated in Figure 2, the communication among layers is the only approach for a demanding environment raising issues that rarely occur in other networks [35].

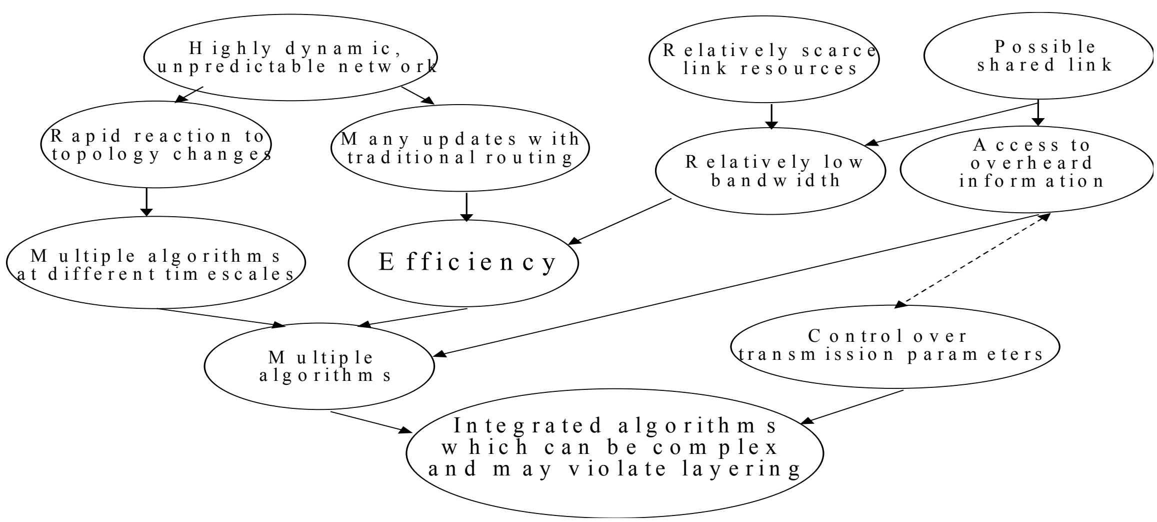


**Figure 2 Complexity of Mobile Ad-hoc Networks: the network can be highly dynamic, implying that (1) traditional routing algorithms will either not stabilize or will generate many routing updates, and (2) rapid response to topology change is needed [35].**

This chapter focuses on the state of the art in mobile ad-hoc networks and highlights some of the emerging technologies, protocols, and approaches at different layers for realizing network services for users on the move in areas with possibly no pre-existing communication infrastructures.

The remaining of this chapter is organized as follows. In Section 2 we present the layered architecture of mobile ad-hoc networks, and we introduce some relevant concepts and technologies that will be discussed further. In Section 3 we cover some emerging MAC technologies that can be used for constructing a mobile ad-hoc network: IEEE 802.11, and Bluetooth. In Section 4 we provide an overview of the standardization efforts within the Internet Engineering Task Force. Section 5 introduces a human based approach to a particular class of mobile ad-hoc networks, referred to as self-organising networks. Finally, in Section 6, we present mobile ad-hoc networking from the users/applications point of view.

The Conclusion provides a discussion on the future evolution and applications of mobile ad-hoc networks.

# LAYERED ARCHITECTURE OF MOBILE AD-HOC NETWORKS

Precursor of the ad-hoc networking technology was the Packet Radio Network [34], [33]. Packet radio applies packet communications to a radio channel rather than to a wire-based media. This technology can be used to create LANs that link devices, as well as provide gateways to other network systems and databases [11]. The current version, referred to as "Distributed Packet Radio", is completely distributed, permitting flexible and rapid adaptation to changes and mobility.

Later on, research mainly focused on cellular systems that are, in principle, single-hop wireless systems. Within the framework of the multi-hop wireless systems, research communities worked on projects that address mainly medium access control and routing issues.

Appropriate physical and data link protocols need to be developed for wireless mobile networks in conjunction with the embedded MAC sub-layer and the higher-level networking and/or transport layers.

A key aspect of wireless communications is the radio propagation channel, which introduces co-channel and adjacent channel interference among users. Exploiting the physical environment and controlling the location of radio users as much as possible is one way to mitigate interference, but this is not realistic for uncoordinated wireless systems that share the same radio spectrum. For ad-hoc networks that share the same spectrum, new methods of cooperation are required to permit coexistence. Such methods are difficult to research without real-world channel models and simulation methodologies; there is still fundamental work to be done in this area [50].

There have been many successful attempts to reduce the power consumption of digital circuits. Today, there are many different techniques known, starting from the circuit level [19] and reaching into architecture and software. Clearly, the energy necessary to execute a given algorithm very much depends on the implementation technology. For current software-radio projects, large emphasis has been placed on low power consumption, see [67] and [56].

Current research covers lower-layer issues, such as modulation and coding, multiple access, wireless/mobile protocols, and location protocols. In the USA, most of the research in this and in the sensors networks fields is sponsored by NSF (Advanced Networking Infrastructure and Research Division and Computer-Communications Research Division) and DARPA (Microelectromechanical Systems and Global Mobile Information Systems), see [52], [3], [14], [23], [42].

Similar projects are conducted in Europe (in the Mobility and Personal Communications Networks Domain [2], in ETSI [25], or in some Universities e.g., [20]), by industrial consortia (e.g., [8]), [61], and by operator (e.g., [60]).

The MAC layer specified in the IEEE 802.11 standard [29], or its variations, is typically applied in the existing ad-hoc network projects. The standard is built on Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) scheme that is extended with a capability for short channel allocation and acknowledgement control messages. With 802.11, all the nodes must use the same channel. All nodes can communicate with every other node that is within range. The 802.11 standard can be a good platform to implement a one level multi-hop architecture because of its extreme simplicity. IEEE 802.11 is a digital wireless data transmission standard aimed at providing a wireless LAN *(WLAN*) between portable computers and between portable computers and a fixed network infrastructure. While it is easy to foresee that the *WLAN*s will be the solution for the home and office automation [5], the existing standard does not support multi-hop systems and since only one frequency can be used, the achievable capacity is limited. HomeRF [27] is seen as the main contender of 802.11 to be used in home network. This is based on the Shared Wireless Access Protocol (SWAP) that defines a new common interface that supports wireless voice and data networking in home. Wireless LAN technology is already widely commercially available. The main aim of Bluetooth technology [8] [10] is to guarantee the interoperability between different applications on devices in the same area that may run over different protocol stacks, and therefore to provide a solution for wireless Personal Area Networks. Section 2 covers in more detail the MAC layer.

The Internet Engineering Task Force (IETF) working group on Mobile Ad-hoc NETworks (MANET) is standardizing routing in ad-hoc networks. The group studies routing specifications, with the goal of supporting networks scaling up to hundreds of routers [40]. The work inside MANET relies on other existing IETF standards such as mobile-IP and IP addressing. Most of the currently available solutions are not designed to scale to more than a few hundred nodes. Section 3 presents some aspects of the protocols designed to extend Internet services to mobile ad-hoc networks' users.

Designing protocols that scale to very large wireless networks remains among the main challenges of research in this field, and there are several factors that distinguish protocols for realizing a wide-area mobile ad-hoc network with different peculiarities, as explained in Section 4.

Location-management functions make it possible to access the network regardless of the user's location. Not limited only to users, it is easily imagined that entire networks might one day be mobile as well, e.g., networks on aircraft or other vehicles. Location management works at several layers and is, therefore, a complex process [49].

The well-established techniques to locate mobile devices in infrastructure-based networks, even if they contain concepts to deal with nomadic nodes, are not useful as soon as infrastructure is no longer available.

As stated within the Zeroconf Working Group of the IETF [78], the common TCP/IP protocols commonly used for the network configuration, e.g. DHCP, DNS, MADCAP, and LDAP, are not appropriate for mobile ad-hoc networks because they must be configured and maintained by an administrative staff.

For all these networks, an administrative staff will not exist and the users of these networks neither have the time nor inclination to learn network administration skills. Instead, these networks need protocols that require zero user configuration and administration. New approaches are being investigated, as described in chapter [64].

Bootstrapping protocols and a basic infrastructure must be available, however. Current schemes on the network layer are incorporated in Bluetooth and related technologies [8], whereas on the services layer Jini [31] is the most prominent example of a system enabling federations of services and clients.

At the service level, for IP networks, the Service Location Protocol (SLP) proposed by the Internet Engineering Task Force [73] is used; other examples are SSDP (Simple Service Discovery Protocol) in Universal Plug and Play networks [72] that are XML based, or SDP (Service Discovery Protocol) in Bluetooth [8].

Finally, also at the application level, the location requires the choice of a topology, addressing within the topological space, and location and distance-dependent operations, as in [30], [48].

Information transport and its associated infrastructure must demonstrate high assurance capabilities in times of crisis and attack, as well as in normal conditions. Scarce attention has been given to security in mobile ad-hoc networks so far. This computing environment is very different from the ordinary computing environment. In many cases, mobile computers will be connected to the network via wireless links. Such links are particularly vulnerable to passive eavesdropping, active replay attacks, and other active attacks [18].

To our knowledge, few works have been published on this topic, see [65], [79] and [18], and much effort is required in order to overcome the vulnerability (in particular, the privacy vulnerability) of this type of network with an integrated approach that is not limited at the routing layer.

Security in networks (including ad-hoc networks) is mainly confidentiality and integrity of information, as well as legitimate use and availability of services [21]. In military applications, confidentiality is considered to be the most important security objective. In civilian scenarios, the major users requirement is availability [66].

Denial-of-service attacks are typically impossible to prevent. However, they can be made very expensive by exploiting the inherent redundancy of the ad-hoc networks [79]. For instance, a packet can be sent to its destination via several disjoint routes, which makes its interception considerably more expensive for the attacker.

A fundamental tool to achieve the network security objectives is cryptography. The challenge of using cryptography in the mobile ad-hoc networks is the management of cryptographic keys. Since nodes are mobile, their interactions are spontaneous and unpredictable, which makes public key cryptography more appropriate in this setting than conventional cryptography. The most widely accepted solution for the public key management problem is based on public key certificates that are issued by (online) certification authorities and distributed via (online) key distribution servers.

The design issues associated with the real time services become particularly important for multimedia delivery; e.g., voice, images and video. The multimedia data will typically be provided with some form of coding, as multiple data streams each with their own QoS requirements.

New networking technologies engender a radical transformation in high-end applications and the manner in which researchers and educators throughout the globe access and manipulate R&E resources [53]. There are limitless possibilities for mobile applications. While potential applications exist in commerce, education, medicine, government, public safety, and numerous other areas, market and social forces will determine which are accepted or rejected [49].

Indeed, the telecommunications industry expects an exponential growth of subscribers for wireless services (PCS, GSM, MobileIP). This growth will occur in an environment characterized by rapid development and migration of end-user applications.

A related characteristic is the evolution of new applications, made possible by mobility and ubiquitous access that would normally not be found in fixed networks. Researchers in the field must understand and explore these problems, finding solutions that will integrate efficiently with existing systems and endure over time [49].

In mobile computing, geographic location is critical for distributed applications. Several projects currently address the problem of location-aware applications [30], [39], [48], [71].

Information management in highly distributed and mobile areas recently became the core of a new area called cooperative information systems (e.g. [17]).

Notable applications of ad-hoc networks are sensor networks, which can be used for several purposes as an instrumented hospital or an instrumented atmosphere to predict weather [68], as well as social networks [58], [41].

Information technologies are an integral part of our lives, businesses, and society. The wide acceptance of Internet standards and technologies is helping us build global computer networks capable of connecting everything and reaching everyone [57].

Almost daily, new wired or wireless e-business models emerge: e-shop, e-procurement, e-auction, e-mall, third party marketplace, virtual community, value chain service provider, value chain integrator, collaborative platform, information brokerage and trust [70]. Mobile ad-hoc networks are envisioned to naturally support these applications. However, in order to realize these new technologies, it is necessary to understand economic, social, and policy issues in much greater depth.

# MAC LAYER

We present here two emerging technologies for wireless media interfaces that can be used for building a mobile ad-hoc network: the IEEE 802.11 standard for wireless LANs (WLANs) [29], [1] and on the Bluetooth technology [8], [10] which is a de-facto standard for wireless Personal Area Networks (WPAN). A WLAN is a wireless network characterized by a small scope, while a WPAN is a network constituted by connected devices placed inside a circle with a radius of 10 meters. The Bluetooth Special Interest Group releases the Bluetooth specifications. In addition, the IEEE 802.15 Working Group for Wireless Personal Area Networks has started a project to publish and approve a standard derived from the Bluetooth Specification.

Bluetooth and IEEE 802.11 technologies also exemplify the two categories in which multiple access networks can be roughly categorized, random access (e.g. CSMA, CSMA/CD) and demand assignment (e.g. Token Ring) [5]. Due to the inherent flexibility of random access systems (e.g. random access allows unconstrained movement of mobile hosts) the IEEE K.11 standard committee decided to adopt a random access CSMA-based scheme for WLANs. On the other hand, demand assignment access schemes are more suitable for an environment that needs to provide guarantees on the Quality of Service (QoS) perceived by its users. The Bluetooth technology that is designed to support delay sensitive applications (such as voice traffic) beyond data traffic adopts a (implicit) token-based access method.

# *IEEE 802.11*

IEEE 802.11 is a digital wireless data transmission standard in the 2.4 GHz ISM band aimed at providing a wireless LAN between portable computers and between portable computers and a fixed network infrastructure. This standard defines a physical layer and a MAC layer. Three different technologies are defined as an air interface physical layer for contention-based and contention-free access control: infrared, frequency hopping and direct sequence spread spectrum. The most popular technology is the direct sequence spread spectrum and can offer a bit rate of up to 11 Mbps in the 2.4 GHz band, and, in the future, up to 54 Mbps in the 5 GHz band. The basic access method in the IEEE 802.11 MAC protocol is the *Distributed Coordination Function* (DCF) which is a *Carrier Sense Multiple Access with Collision Avoidance* (CSMA/CA) MAC protocol.

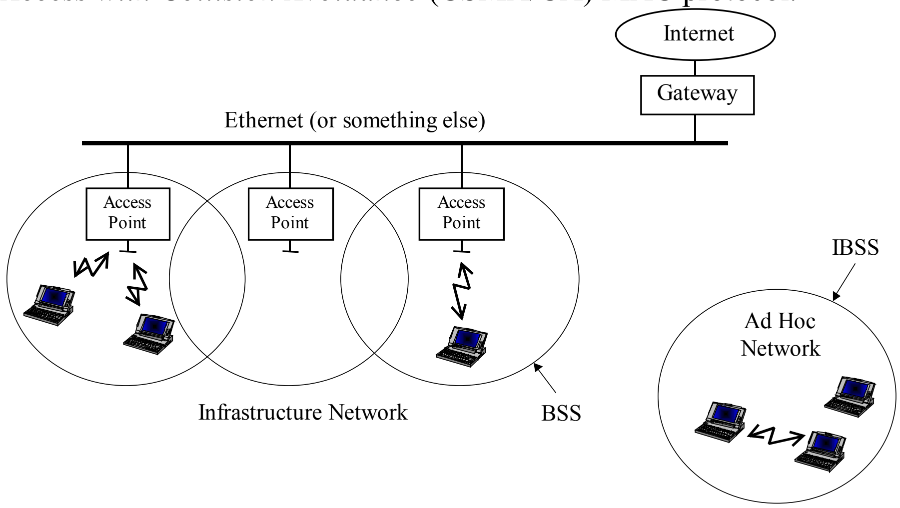


**Figure 3 802.11 Infrastructure or ad-hoc network**

802.11 can be used to implement either an infrastructure-based W-LAN architecture or an ad-hoc W-LAN architecture (see Figure 3). In an infrastructure-based network, there is a centralized controller for each cell, often referred to as *Access Poin*t. The access point is normally connected to the wired network thus providing the Internet access to mobile devices. All traffic goes through the access point, even when it is sent to a destination that belongs to the same cell. Neighbour cells can use different frequencies to avoid interference and increase the cell's capacity. All the cells are linked together to form a single broadcast medium at the LLC layer. A so-called distribution system handles the packet forwarding towards destination devices outside the cell across the wired network infrastructure. The distribution medium that forwards packets between the access points is not defined by the standard. It is possible to use a wireless link to connect the different access points, for example an 802.11 ad-hoc link in another frequency. Such a feature permits the implementation of a two-level multi-hop architecture.

In ad-hoc mode, every 802.11device in the same cell, named *Independent Basic Service Set* (IBSS), can directly communicate with every other 802.11 device within the cell, without the intervention of a centralized entity or an infrastructure. In an ad-hoc cell, identified by an identification number (IBSSID) that is locally managed, all devices must use a predefined frequency. Due to the flexibility of the CSMA/CA algorithm, devices' synchronization (to a common clock) is sufficient to receive or transmit data correctly. *Synchronization acquirement* is a scanning procedure used by an 802.11 device for joining an existing IBSS. If the scanning procedure does not result in finding any IBSSs, the station may initialise a new IBSS. *Synchronization maintenance* is implemented via a distributed algorithm, based on the transmission of beacon frames at a known nominal rate, which shall be performed by all of the members of the IBSS. Additionally, given the constraints on power consumption in mobile networks, 802.11 offers power saving (PS) policies. The policy adopted within an IBSS should be completely distributed for preserving the self-organizing behaviour.

The 802.11 standard is an interesting platform to experiment multi-hop networking. This standard cannot do multi-hop networking as it is. The development of a number of protocols is required.

It must be noted that, as illustrated via simulation in [5], depending on the network configuration, the standard protocol can operate very far from the theoretical throughput limit. In particular, it is shown that the distance between the IEEE 802.11 and the analytical bound increases with the number of active networks. In the IEEE 802.11 protocol, due to its backoff algorithm, the average number of stations that transmit in a slot increases with the number of active networks and this causes an increase in the collision probability. A significant improvement of the IEEE 802.11 performance can thus be obtained by controlling the number of stations that transmit in the same slot.

# *BLUETOOTH*

Bluetooth is a digital wireless data transmission standard operating in the 2.4 GHz Industrial, Scientific, and Medicine (ISM) band aimed at providing a short range wireless link between laptops, cellular phones and other devices. In this band are defines 79 different Radio Frequency (RF) channels that are spaced of 1 MHz.

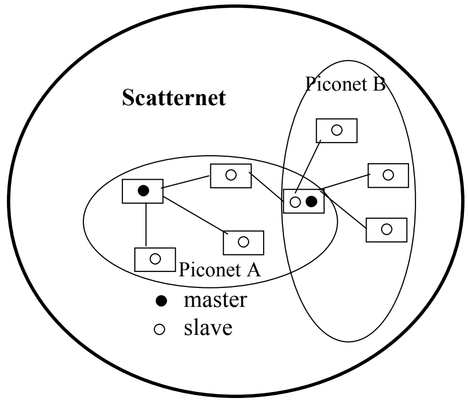


**Figure 4 Bluetooth**

The Baseband and the Bluetooth radio layers compose the Bluetooth core protocols. Bluetooth radio provides the physical links among Bluetooth devices while the Baseband layer provides a transport service of packets on the physical link.

The physical layer utilizes as a technique of transmission a frequency hopping spread spectrum (FHSS) where the hopping sequence is a pseudo-random sequence of 79-hop length, and it is unique for each ad-hoc network that we establish. Therefore the establishment of a physical channel is associated to the definition of a channel frequency hopping sequence that has a very long period length and that does not show repetitive patterns over short time interval. Bluetooth is based upon a low-cost, short-range radio link, integrated into a microchip, enabling protected ad-hoc connections for wireless communication of voice and data in stationary and mobile environments. The air interface symbol rate of Bluetooth is 1 Ms/s. As a binary FSK modulation is used, this gives a raw data rate of 1 Mb/s.

From a logical standpoint, Bluetooth belongs to the contention-free token-based multi-access networks [5]. In a Bluetooth network, one station has the role of master and all other Bluetooth stations are slaves. The master decides which slave is the one to have the access to the channel. More precisely, a slave is authorized to deliver a single packet to the master only if it has received a polling message from the master.

The Bluetooth protocol uses a combination of circuit and packet switching. Slots can be reserved for synchronous packets. Two types of physical links are defined: the Synchronous Connection-Oriented (SCO), a point-to-point, symmetric circuit-switched connection between the master and a specific slave used for delivering delay-sensitive traffic, and the Asynchronous Connection-Less (ACL) a packet-switched connection between the master and all its slaves that can support the reliable delivery of data.

Two or more devices (units) sharing the same frequency hopping sequence (channel) form a piconet. A unit can belong to more than one piconet, but can be master to only one. Different piconets are not synchronized, and when they overlap they form a scatternet (see figure 4).

A maximum of one ACL link can be opened between a master and a slave. A master can have up to three SCO links with one or several slaves. A slave can support SCO links with different masters at the same time, but only 1 SCO link with each. A slave may communicate with different piconets only in a time-multiplexing mode. This means that for any time instant it can only transmit on a single piconet In fact, it has to change its synchronization parameters before listening to different channels.

Therefore, the communication among devices within different piconets can happen only in an asynchronous mode, unless the device acting as router between two piconets has two Bluetooth interfaces. We note here that the multihop networking routing protocols is still to be defined.

Before starting a data transmission, a Bluetooth unit inquires, by continuously sending an inquiry message, its operating space in order to discover the presence of other units.

Another unit listening to the channel used for the inquiry message, upon the same frequency, replies to the inquiry by exploiting a random access protocol.

The unit that starts paging it is automatically elected the master of the new connection, and the paged unit is the slave. A unit can periodically listen to the channel to find a page message, by tuning its receiver on to the frequencies of the paging hopping sequence. After the paging procedure the slave now has an exact knowledge of the master clock and of the channel access code, so it and the master can enter the connection state. However, the real transmission will begin only after a polling message from the master to the slave. When a connection is established, the active slaves have to maintain the synchronization. In [5] a sketch of Bluetooth performance is given.

Between two devices Bluetooth can support one asynchronous data link, up to three simultaneous synchronous voice links, or a link that simultaneously supports asynchronous data and synchronous voice. Each voice link supports a synchronous data rate of 64 kb/s in each direction. The asynchronous link can support a maximal asymmetric data rate of 723.2 kb/s (and still up to 57.6 kb/s in the return direction), or a symmetric data rate of 433.9 kb/s.

The main aim of the Bluetooth Specification is to guarantee the interoperability between different applications that may run over different protocol stacks.

A number of service profiles define how Bluetooth enabled devices should use the Bluetooth links and physical layer, and this allows the manufacturers interoperability. All profiles define end-to-end services: cordless telephony, intercom, serial port, headset, dial-up, fax, LAN access (with PPP), generic object exchange, object push, file transfer, synchronisation. However, in order to implement a wireless multi-hop network over Bluetooth, either/both a packet switch layer and a circuit switch layer need to be defined on top of the Bluetooth data link layer protocol (L2CAP).

# MOBILE AD-HOC NETWORKS AND INTERNET

The wide acceptance of Internet standards and technologies was and is one of the key steps for building global computer networks capable of connecting everything and reaching everyone. In the near future, with the advent of inexpensive wireless technologies, a large number of users will be mobile.

Extending IP internetworking for seamless operation over wireless communication technologies challenges present performance requirements of network protocols and applications, especially if wireless technologies evolve to become a significant part of the infrastructure [47].

The Internet Engineering Task Force (IETF) working group on Mobile Ad-hoc NETworks (MANET) is standardizing routing in ad-hoc networks. The group studies routing specifications, with the goal of supporting networks scaling up to hundreds of routers [40]. The work inside MANET relies on other existing IETF standards such as mobile-IP and IP addressing.

A mobile ad-hoc network that supports explicitly the Internet still presents the major salient characteristics we described above, as described in [16]: 1) Dynamic topologies; 2) bandwidth-constrained and variable capacity links; 3) energy-constrained operation; 4) limited physical security. However, the managing of IP addresses of the nodes in a mobile ad-hoc network is not straightforward, as discussed below.

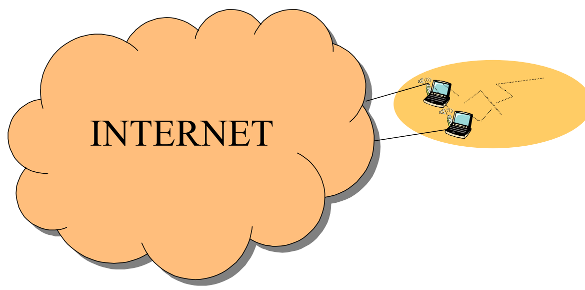


**Figure 5 A mobile ad-hoc IP network**

As presented in [47], the approach followed by the protocols produced in the MANET working group, and by similar protocols worked on outside of MANET, is based on the traditional two level hierarchy routing architecture.

With this view, these routing protocols fall into the class of interior gateway protocols, i.e. protocols used to route within a (mobile wireless) network or a set of interconnected (mobile wireless) networks under the same administration authority. Several of these protocols [59], [7], [32], [24], [9], [54], [55], [12] have been implemented in prototypes [45] and, while they are not yet available commercially, some of them are under commercial consideration [22].

In [16] a list of desirable qualitative properties of mobile ad-hoc networks routing protocols for the Internet is given: 1) Distributed operation; 2) Loop-freedom; 3) Demand-based operation; 4) Proactive operation; 5) Security; 6) "Sleep" period operation; 7) Unidirectional link support.

Also, a list of quantitative metrics is given that can be used to assess the performance of any of those routing protocol: 1) End-to-end data throughput and delay; 2) Route Acquisition Time; 3) Percentage Out-of-Order Delivery; 4) Efficiency.

These protocols are generally categorized according to their method of discovering and maintaining routes between all source-destination pairs:

- Proactive protocols
- Reactive protocols

Proactive protocols (also referred to as table-driven) attempt to maintain routes continuously, so that the route is already available when it is needed for a packet to be forwarded. In such protocols, routing tables are exchanged among neighbouring nodes each time a change occurs in the network topology. In contrast, the basic idea of reactive protocols (also referred to as source-initiated) is to send a control message for discovering a route between a given source-destination pair only when necessary.

Most of the existing protocols for mobile ad-hoc networks are not univocally proactive or reactive, as some of the protocols have a hybrid proactive and reactive design or simply present elements of both approaches.

The proactive approach is similar to the connectionless approach of traditional datagram networks, which is based on a constant update of the routing information [63]. To maintain consistent and up-to-date routes between each pair of source-destination is required the propagation of a large number of routing information, regardless if this is needed or not. As a consequence, with proactive protocols, a route between any source-destination pair is always available, but such protocols could not perform properly when the mobility rate in the network is high or when there is a large number of nodes in the network. In fact, the control overhead, in terms of both traffic and power consumption is a serious limitation in mobile ad-hoc networks, where the bandwidth and power are scarce resources [63]. The proactive approaches are more similar in design to traditional IP routing protocols; thus, they are more likely to retain the behaviour features of present routing protocols used in practice. Existing transport protocols and applications are more likely to operate as designed over proactive routing approaches than over on-demand routing approaches [47].

A reactive protocol creates and maintains routes between a pair of source-destination only when necessary, in general when requested by the source (on-demand approach). Therefore, in contrast to the proactive approach, in reactive protocols the control overhead is drastically reduced. However, similar to connection-oriented communications, a route is not initially available and this generates a latency period due to the route discovery procedure. The on-demand design is based (1) on the observation that in a dynamic topology routes expire frequently and (2) on the assumption that not all the routes are used at the same time. Therefore, the overhead expended to establish and/or maintain a route between a given source-destination pair will be wasted if the source does not require the route prior to its invalidation due to topological changes. Note that this assumption may not hold true in all architectures, but it may be suitable for many wireless networks. The validity of this design decision is dependent, in part, on the traffic distribution and the topology dynamics in the network [47].

As previously stated, some protocols can combine both proactive and reactive characteristics, in order to benefit from the short response time provided by the proactive approach under route request and to limit the control overhead as in reactive protocols. An evident, advantageous approach is to proactively handle all the routes that are known to be more frequently used and to create on demand all the other routes.

Achieving the right balance between reactive and proactive operation in a hybrid approach may require some a priori knowledge of the networking environment or additional mechanisms to adaptively control the mode of operation [47].

A general comparison of the two protocols categories is presented in both [RT99] and [47].

As we anticipated above, one critical aspect of Internet based mobile ad-hoc networks is the addressing. In fact, the addressing approach used in wired networks, as well as its adaptation for mobile IP [46], would drastically increase the control overhead. Therefore, a new addressing approach for such networks is required. Moreover, given that, in the foreseen topology of the addressing approach, the interaction among different routing protocols can easily happen, a common addressing approach is necessary.

This issue is still a matter of ongoing research. The IETF document describing Internet mobile ad-hoc networks states that: The development of such an approach is underway, which permits routing through a multi-technology fabric, permits multiple hosts per router and ensures long-term interoperability through adherence to the IP addressing architecture. Supporting these features appears only to require identifying host and router interfaces with IP addresses, identifying a router with a separate Router ID, and permitting routers to have multiple wired and wireless interfaces [16].

Geographical location of nodes, i.e. node coordinates in two or three-dimensional space has been suggested, among other purposes, for simplifying the addressing issue in combination with the Internet addressing scheme. The existing location-based routing protocols [lar, dream, etc] propose to use the location information for reducing the propagation of control messages, for reducing the intermediate system functions or for making packet-forwarding decisions.

Geographical routing allows nodes in the network to be nearly stateless; the information that nodes in the network have to maintain is about their one-hop neighbours. A detailed review of geographical routing and related issues is given in chapter [64].

There are also solutions that do not rely on the Internet addresses. [26] proposes a solution where each node has a permanent, unique end-system identifier, and a temporary, location-dependent address. The location-dependent addresses management, which is based on the association of each end-system identifier to an area of geographical coordinates that acts as distributed location databases, allows a node to obtain a probable location of any other node with a known end-system identifier [44], [75].

The work proposed in the context of Internet mobile routing considers networks traditionally classified as small networks. However, even in networks of one hundred nodes, scalability is an important performance.

One approach for achieving scalability in mobile ad-hoc networks is clustering. With this approach, the network is partitioned in subsets (clusters). Within a cluster a traditional MANET algorithm is assumed, and the communication between clusters is done by means of clusterheads and border nodes. The clusterheads form a dominant set that works as backbone for the network. In cluster-based algorithms, one of the main issues is the determination of the clusters and, consequently, of the clusterheads in such a way that the reconfigurations of the network topology are minimized. However, choosing clusterheads optimally is an NP-hard problem [4].

Other strategies for dominating sets, which are able to build more performing dominating sets than clustering for ad-hoc networks are described in [64].

Finally, multicast routing is a strategy that could allow optimising the resource usage, and this is seen as an important feature for energy and bandwidth constrained networks as mobile ad-hoc networks. Additionally, the underlying layer has a broadcast nature that can be exploited by an integrated design, as it is done for example in [77]. Several multicast routing algorithms have been proposed and evaluated [37]. While there is the conviction that multicast mobile routing technology is a relatively immature technology area and much of what is developed for unicast mobile routing—if proven effective—can be extended to develop multicast mobile routing variants [47], some works assess the definition of network protocols with an integrated approach, thereby permitting improved energy efficiency [77]. However, shortest path based multicast algorithms requires too much power (quadratic in size of network), because they require that each node maintains a global view of the network. Real power savings can be obtained only with localized algorithms where nodes only know their neighbors information and make decision based only on that [64].

Mobile ad-hoc networks do not provide QoS by design. While the controversial discussion about whether or not QoS mechanisms are needed in the wired Internet, it is indisputable that some applications can be supported by wireless networks only under QoS provisioning.

Architecture for supporting QoS in mobile ad-hoc networks should have two primary attributes [13]

- Flexibility. Necessary for the heterogeneity of the physical and MAC layers, as well as of multiple routing protocols.
- Efficiency. Necessary for the limited processing power and storage capabilities of nodes, as well as the bandwidth that is scarcely available

In the literature, several approaches have been adopted for assessing the issue of QoS in mobile ad-hoc networks: QoS routing protocol [15], [28], [62]; signalling systems for resource reservation [36], etc. Although some work has been done to date, more studies need to be conducted to explore further the problem of QoS provisioning for mobile ad-hoc networks.

# ROUTING IN SELF-ORGANISED NETWORKS

As stated above, ad-hoc networks can be considered small networks (up to hundreds of routers [40]), where the nodes are typically IP routers with a large computing capacity. However, large mobile ad-hoc networks are the natural solution for applications based on models similar to the business model of citizen band, amateur radio, and talkie-walkie systems, where multi-hop wireless communications allow voice and data messaging among all users. These networks are likely to be very large and not Internet based, both because more dedicated to human communications and because this would generate an unacceptable complexity.

The step toward such a network (larger than a thousand nodes, and/or constituting a wide or geographical network) consisting of nodes with limited resources is not simple. It is clear that existing solutions are not designed for such an environment. They (1) do not easily adapt to a large number of mobile nodes, and (2) they do not exploit certain key characteristics of these networks (e.g. cooperation among nodes). Moreover, other relevant issues like the distribution of nodes or the ability of nodes to self-organise are not usually addressed in current ad-hoc networks research, which focuses mainly on pure communication aspects.

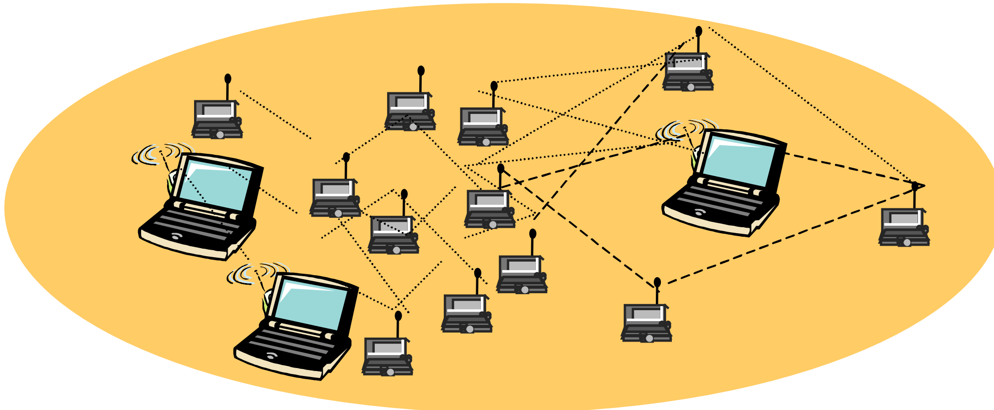

**Figure 6 A self-organised network**

We refer here to these networks as *self-organised networks* in order to distinguish them from traditional mobile ad-hoc networks and to emphasise their self-organisation peculiarities:

- Self-organized networks are non-authority based networks, i.e. they can act in an independent way from any provider or common denominator, such as the Internet. However, similar to Amateur Radio Networks they require regulation (self-organisation) [34].
- Self-organized networks are potentially very large and not regularly distributed. In principle, one single network can cover the entire world. There can be small areas with high density, as well as large areas with very low density.
- Self-organized networks are highly co-operative. The tasks at any layer are distributed over the nodes and any operation is the result of the collaboration of a group of them.

The "small world" design has been proposed for self-organised networks [6]. Small world graphs [small-world] are very large graphs that tend to be sparse, clustered and have a small diameter. Small-world phenomenon was inaugurated as an area of experimental study in social science through the work of Stanley Milgram in the 60's. These experiments have shown that the acquaintanceship graph connecting the entire human population has a diameter of six or less edges; small world phenomenon allows people to speak of the "six-degrees of separation".

Self-organised networks can be structured as a small world graph, emphasising the fact that nodes can collaborate in a "human-way" to find a route between each source-destination pair when needed [6].

In this case, the routing solution is designed with three requirements in mind: (1) to scale well in a very large network; (2) to cope with dynamically changing network connectivity owing to mobility; and (3) to be based on high collaboration among nodes, that are assumed not to use complex algorithms or protocols. For the first requirement, the solution is designed such that a node relies only on itself and a small number of other nodes for packet forwarding. The uncertainty in the network due to the nodes mobility is addressed by considering multipath routing as a rule. The third requirement is assessed by design.

The solution proposed in [6] combines two routing protocols: (1) a mechanism that allows to reach destinations in the vicinity of a node and does not use location information for making packet forwarding decisions; and (2) a mechanism that is used to send data to remote destinations and uses geographic information. The latter is the small-world graphs element that is introduced for achieving scalability and reduced dependence on intermediate systems.

The small world graph approach is mainly used for route discovery: For a potentially large network both traditional proactive and reactive approaches are not feasible, due to the large amount of information to maintain and to the high latency, respectively. With the small world graph approach, a source discovers a (possible) route to the destination with the collaboration of some other nodes within the network. This is done on-demand, thus avoiding large routing tables, but inquiring only a small set of nodes, thus avoiding flooding to a large number of nodes. The returned route is not a list of nodes, but a rough shape of the geographical path from the source to the destination, a set of points (anchors) described by geographical coordinates. This geographical information, rather that a traditional list of nodes' addresses, permits to coping with the network dynamicity (that increases with distance between the source-destination pair). Between anchors, geodesic packet forwarding is performed; this is a greedy method that follows successively closer geographic hops to the next point or the final destination [Finn87].

A comparison between this approach and the Internet based one presented in the previous section does not hold, as the target is completely different. It is straightforward that a wireless subnet connected to the Internet will work better with a solution designed with the characteristics described in the previous section. The solution presented here is more appropriate for "users' networks", where a (potentially large) number of users (with potentially small devices) combine in a network, eventually connected to the Internet.

# PEOPLE-BASED NETWORKS

In People-Based Networking, instead of sharing and routing information via a physical network the information is transmitted using *people*- from a personal device of some type (such as a personal digital assistant (PDA)) to another, which is close, and so on. Such a network is, evidently, a mobile ad-hoc network, with no central administration - each part of it, being based on a person, is free to constantly move about. These networks may be, because their behaviour is so self-organising, be fairly robust: there are no wires to break, and if one 'router' fails, there are many others around; as many as there are people carrying them.

The users have, at the same time, their traditional role together with the "network" role. The way the network is built depends mainly on the way the users interact and the type of application(s) is run.

With this user/application-oriented approach, the architecture is dictated by the configuration requirements posed by the application. In [22] are presented some challenges posed by this approach, as well as some possible techniques that can be used to address them. Together with traditional aspects of mobile ad-hoc networking– network boundaries are poorly defined; the network is not planned; hosts are not pre-configured;

there are no central servers- this work points out that users are not experts, and therefore, it is important to minimize the inexpert user's exposure to the administrative infrastructure and make necessary activities as intuitive as possible.

The area of people-based networking ranges from issues of networking, such as the best way of sending messages to a particular device through a network, to those of the kinds of applications and activities that such a technology may support, ranging over everything from low level technical issues, to those relating to users and collaboration.

Applications of people-based networking are multiple, mainly devoted to study and enhance the social interaction among people, and facilitate their daily life.

For example, augmenting everyday face to face interaction between with various types of technological support, using a variety of devices such as "thinking tags", which could be used in various ways to indicate how alike people were in relation to a number of common topics, or "Meme tags", which could be programmed with 'ideas' that people might then talk about, or also they might want to keep [41].

Another example is PDAs that carry information, which 'attaches' to the devices as pollen does to bees. This information is then transmitted across nodes where the PDAs dock. Every time the PDA docks, it collects packets of 'pollen' as well as the information for which it has docked.

The Pollen network makes it possible for information to be shared and distributed where needed simply by the everyday actions of groups of people. People need not be aware of how the distribution is taking place nor of the details of their participation in the process. As a side effect, information (such as hints, tips and other comments) can be associated with physical objects in the user environment. Through the cumulative actions of many people interacting with devices and other people, messages are transferred node-by-node across the network [58].

# CONCLUSION

Ad-hoc networks are seen as a key in the evolution of wireless networks. They have several potentialities that are not available with traditional wireless networks and can be used in different environment. The research in mobile ad-hoc networking covers all the networking layers, ranging from the physical to the application layer, including social and economical aspects. We presented an overview of some MAC layer technologies that can be used for ad-hoc networks, as well as the Internet-based approach and a human-based approach to routing. Finally we illustrated a user/application approach to, highlighting some application and social aspects of mobile ad-hoc networks.

While there are several applications for mobile ad-hoc networks that will require being part of the Internet, mobile ad-hoc networks are also envisioned for different application models. For example, applications devoted to study and enhance the social interaction among people, and facilitate their daily life; as well as applications based on models similar to the business model of citizen band, amateur radio, and talkie-walkie systems, where multi-hop wireless communications allow voice and data messaging among all users.

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