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Quality of Service (QoS) Provisioning in Mobile Ad-Hoc Networks (MANETs)

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1. Introduction

Next generation of wireless communication systems are engineered to service independent mobile users. These autonomous mobile users (nodes) are connected through wireless links to build a live and on-the-fly network called a Mobile Ad-hoc Network (MANET). The nodes involved in this system should collaborate among themselves and can function as both hosts and routers. They work together only based on the mutual agreement, without knowing about the network topology around them. Hence, maintaining appropriate Quality of Service (QoS) for MANETs is a complex task due to the dynamic behavior of the network topology.

Commonly, QoS for a network is measured in terms of the guaranteed amount of data which a network transfers from one place to another during a certain time. The QoS is identified as a set of measurable pre-specified service requirements; such as delay, bandwidth, probability of packet loss, and delay variance (gitter). Therefore, a network needs to meet such requirements for the end users to satisfy a particular application while transporting a packet stream from a source to its destination. The traffic types in ad-hoc networks are quite different from other infrastructures and the widespread use of wireless technologies in MANETs make the QoS approaches more complicated.

The application of MANETs was first proposed for military battlefield and disaster recovery. MANETs are mainly used when we require a quick deployment of a cooperative and distributed computing network, such as wireless sensor networks and integrated cellular networks. Accordingly, such networks are demanding to have special features; i.e., autonomous architecture, distributed operation, multi-hop routing, reconfigurable topology, fluctuating link capacity, and light weight terminals. Thus, several interesting issues can be technically involved when designing MANETs; such as security, routing, reliability, inter-networking, and power consumption due to the shared nature of the wireless medium, node mobility, and battery limitations. Therefore, providing suitable QoS for delivery of real-time communications in MANETs is more challenging than the ones in the fixed networks.

This chapter attempts to provide the reader with a basic understanding of the needs and techniques utilized for the MANETs in today's telecommunication networks by emphasizing on the scalability issues, routing protocols, security administrations, and energy management strategies. Also, a special attention is paid on the fundamental problems that will occur when trying to provide the QoS. The structure of this chapter is organized as follows. First, we discuss and analyze the dynamic nature of the mobile ad-hoc networks. Then, we identify different constrains and technical challenges which may happen while providing the required QoS. After that, we address the related works and also review several QoS frameworks for the MANETs that have been proposed in this area so far. Finally, we investigate some open research issues and give some directions for the future research works.

2. Mobile Ad-hoc networks

A mobile ad-hoc network is an independent system of mobile nodes connected by wireless links forming a short, live, on-the-fly network (as shown in Figure 1) even when access to the Internet is unavailable. Nodes in MANETs generally operate on low power battery devices (Roche et al., 2002). These nodes can function both as hosts and as routers. As a host, nodes function as a source and destination in the network and as a router, nodes act as intermediate bridges between the source and the destination giving store-and-forward services to all the neighbouring nodes in the network. Easy deployment, speed of development, and decreased dependency on the infrastructure are the main reasons to use ad-hoc network.

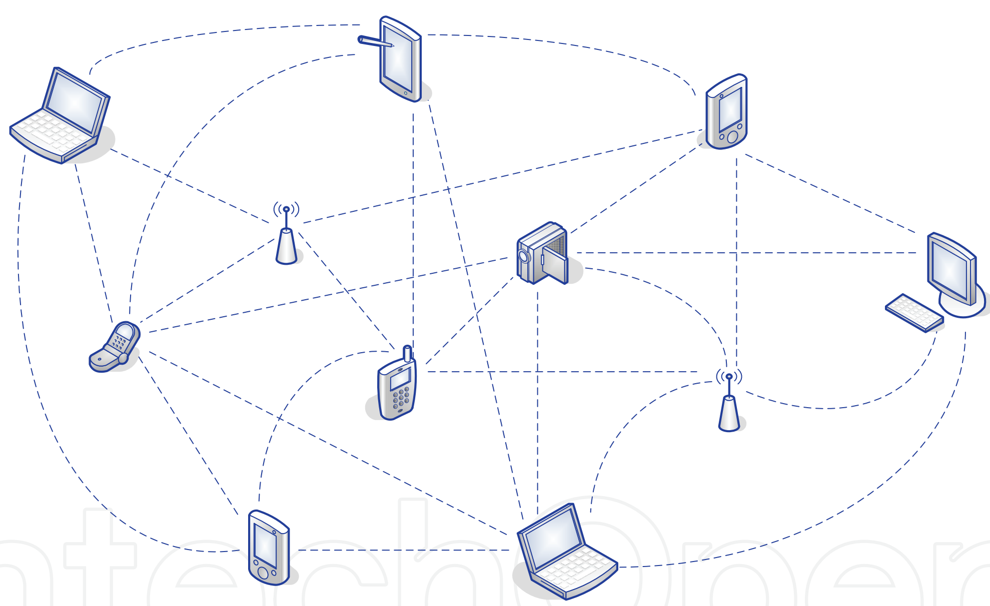

Fig. 1. A Mobile Ad-hoc Network (MANET)

In the past researches, mobile ad-hoc networks are seen as a part of the Internet, with IP-centric layered architecture. This architecture has two main advantages: it simplifies the interconnection to the Internet, and guarantees the independence from heterogeneous wireless technologies. The layered paradigm, which has significantly simplified the Internet design and led to the robust scalable protocols, can result in poor performances when applied to mobile ad-hoc networks.
Wireless networks characterize the new computer prototype. They are presenting to their user a permanent access to the network without depending on their physical location. In recent years with the decrease in the costs of mobile devices and the increase in their capacity, a new idea which is called ad-hoc network has been emerged. Through this

technology, communication is made immediately and directly between person to person, person to machine or machine to person and they use wireless interface to send packet data without having fixed infrastructure like access point in a wireless local area network or base station in a cellular wireless network. Thus, due to the lack of infrastructure, they can be used quickly anywhere and anytime. MANETs have different features such as autonomous terminal, distributed operation, multi-hop routing, dynamic network topology, fluctuating link capacity, and light weight terminals. In MANETs, each mobile terminal is an autonomous node as shown in Figure 2, since the nodes can serve as routers and hosts; they can forward packets on behalf of the other nodes and run user applications.

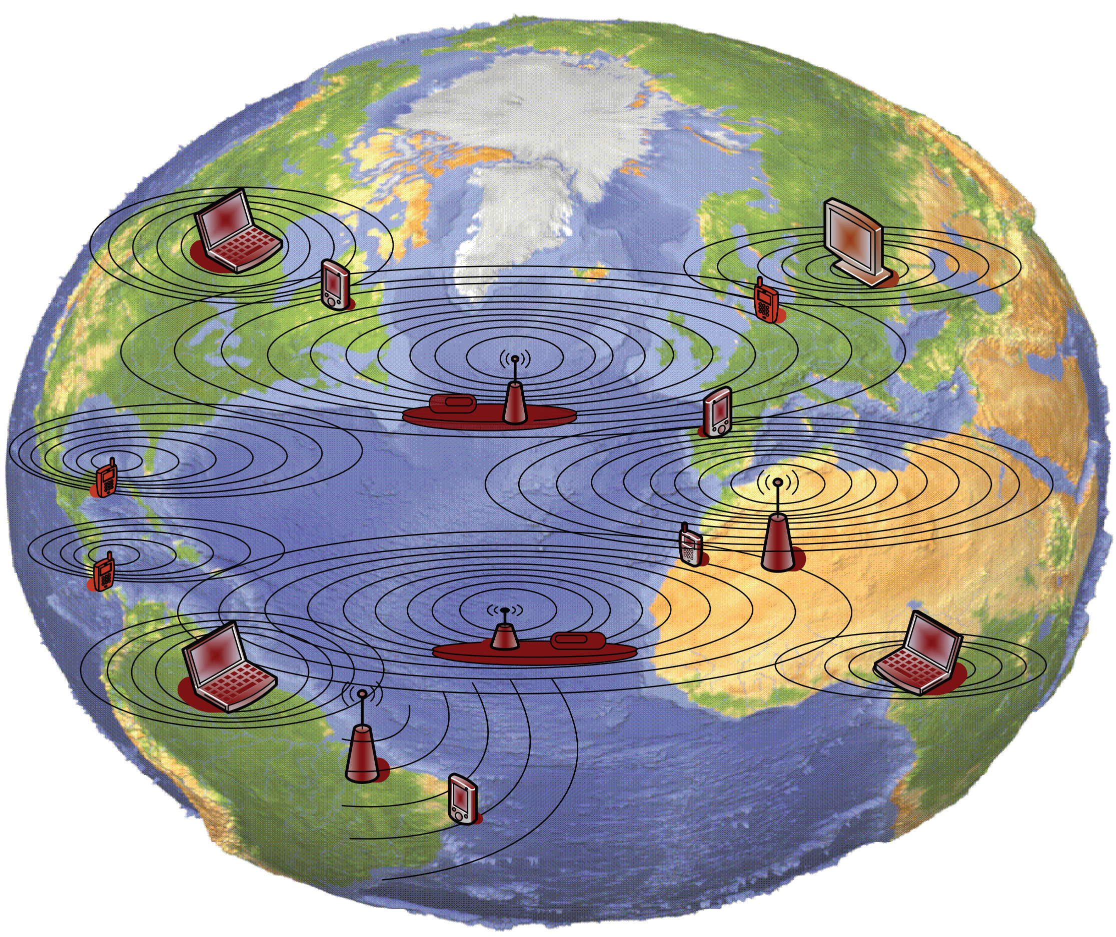

Fig. 2. Autonomous nodes in MANETs

As in distributed operations, there is no background network for the central control of the network operations, the control and management of the network is distributed among the terminals. The nodes involved in a MANET should collaborate amongst themselves and each node acts as a relay when needed to implement functions. In multi-hop routing, basic types of ad-hoc routing algorithms can be single-hop and multi-hop. In multi-hopping, nodes cooperate to relay traffic on behalf of one another to reach remote stations. This technique has increased network capacity, since the spatial domain could be reused for concurrent but physically separated multi-hop sessions (Kumar Sarkar et al., 2008).

In fluctuating link capacity, the nature of high bit-error rates of wireless connection might be more profound in a MANET. The channel over each terminal is subject to noise, fading, and interference and has less bandwidth than a wired network. In light weight terminals, the MANET nodes are mobile devices with less Central Processing Unit (CPU), small memory size, and low power storage (Murthy & Manoj, 2004).

The traffic types in ad-hoc networks are quite different from an infrastructure wireless network, including peer to peer, remote to remote, and dynamic traffic (Tan et al. 2005). In peer to peer communication between two nodes that are within one hop, the flow of the traffic is usually constant. In remote to remote communication between two nodes that are beyond a single hop, and a stable route exist between the two nodes; the traffic is similar to the standard network traffic and several nodes staying within communication range of each other in a single area or possibly moving as a group. In dynamic traffic, the problem occurs when nodes are mobile and moving around, thus, routes must be reconstructed. This causes poor network activity and connectivity in short bursts (Mirhahhak et al., 2000).

MANETs are used when we require quick deployment of a network, collaborative and distributed computing, wireless mesh networks, wireless sensor networks, and integrated cellular and ad-hoc wireless networks. When designing mobile ad-ho c networks, several interesting and difficult problems can arise (such as routing, security and reliability, quality of service, internetworking and power consumption) due to the shared nature of the wireless medium, limited transmission power of wireless devices, node mobility, and battery limitations. Figure 3 illustrates the major issues that affect performance and design of mobile ad-hoc networks.

Generally, QoS for a network is measured in terms of guaranteed amount of data which a network transfers from one place to another during a certain time (Vidhyasanker et al., 2006). There are several service models in wired networks. The two QoS models are the Integrated Services (IntServ) (Braden et al., 1994) and the Differentiated Service (DiffServ) models (Blake et al., 1998). Both of these models require accurate link state such as available bandwidth, packet loss rate, delay, and topology information.

The time-varying low-capacity resources of the network make maintaining the accurate routing information very difficult. The IntServ model provides QoS on a flow basis. It means IntServ architecture allows sources to communicate their QoS requirements to routers and destinations on the data path by means of a signaling protocol. The DiffServ model overcomes the difficulty in implementing and deploying IntServ model and Resource Reservation Protocol (RSVP) (Zhang et al., 1993) in the Internet. The RSVP is used for reserving the resources along the route. In DiffServ model, flows are aggregated into a limited number of service classes. This solves the scalability problem in the IntServ model, but it does not guarantee services on per-hop basis. This problem makes DiffServ model difficult to use in the Internet, and will be a weakness for MANETs.

Quality of Service providing a set of service requirements to the flows while routing them through the network (Crawley et al., 1998). The widespread use of wireless technologies has increased QoS for multimedia applications in wireless networks and traditional internet QoS protocols like RSVP (Braden et al., 1994) can not be used for wireless environment due to the error-prone nature of wireless links and the high mobility of mobile devices in MANETs. Therefore, providing QoS in MANETs is more challenging than in fixed and wireless networks.

Fig. 3. The major issues that affect the performance and design of mobile ad-hoc networks.

3. Related works

A number of research have been conducted on required QoS in internet and traditional wireless networks, but current results are not appropriate for MANETs and still quality of service for MANETs is an open problem. Suitable QoS for delivery of real-time communications such as audio/ video creates a number of different technical challenges. In this section, we review several QoS frameworks for MANETs that have been proposed in this area. A framework for QoS is described as a complete system that offers essential services to each user or application. In (Xiao et al., 2000), a flexible QoS model for mobile ad-hoc networks (FQMM) is presented, which is a hybrid service model and based on IntServ and Diffserv model.

FQMM combines the reservation procedure for high priority traffic with service differentiation for low-priority traffic. Thus, FQMM provides the ideal QoS for per flow and overcomes the scalability problem by classifying the low-priority traffic into service classes. This protocol addresses the basic problem appeared by QoS frameworks (Murthy & Manoj, 2004). But it can not solve other problems such as, decision upon traffic classification, allotment of per flow or aggregated service for the given flow, amount of traffic belonging to per flow service, and scheduling or forwarding of the traffic by the intermediate nodes.

Reference (Luo et al., 2004) describes a packet scheduling approach for QoS provisioning in multihop wireless networks. Besides the minimum throughput and delay bounds for each flow, the scheduling disciplines seek to achieve fair and maximum allocation of the shared wireless channel bandwidth. The coordination of the adaptation between the different layers of the network in order to solve the problems introduced by scarce and dynamic network resources is described in (Bharghavan et al., 1998).

Mobiware effort has investigated the concept of QoS ranges, adaptively, and other mechanisms for providing QoS in wireless environment (Angin et al., 1998). More recently, the INSIGNIA protocol combines the idea of QoS ranges with lightweight signaling carried in the data packet headers as an approach to providing QoS in a mobile ad hoc network (Mirhahhak et al., 2000). This IP-based quality of service framework is designed to be lightweight and highly responsive to changes in the network. Adaptive services support applications that require only a minimum quantitative QoS guarantee (minimum bandwidth) called base quality of service (Lee et al., 2000). INSIGNIA is an in-band signaling protocol, integrated with an ad-hoc routing protocol. An in-band signaling system supports fast flow reservation, restoration, and end-to-end adaptation based on the inherent flexibility, robustness and scalability found in IP networks. This soft state reservation scheme used in this framework guarantees that resources are quickly released at the time of path reconfiguration.

Network feedback based on link and acceptable throughput measurements were made to support higher layer and soft quality of service. However, these schemes do not consider the inherent characteristics (changing network topology, limited resource availability, and error-prone shared radio channel) of MANETs and drawbacks of integrated services and differentiated services (Guimar et al., 2004). Therefore, for supporting a combination of real-time (voice or video) and non-real-time services (data or FTP), an accurate model has to be designed to investigate its applicability within the MANETs.

4. Identifying problems and solutions

In general, the application of MANETs was first proposed for military battlefield and disaster recovery. However, as a result of evolution in multimedia technology and the commercial interest of companies, quality of service in mobile ad-hoc networks has become an area of interest. Because of various requirements of different applications, the services required and the QoS parameters will change for each application. Therefore, quality of service is identified as a set of measurable pre-specified service requirements such as delay, bandwidth, probability of packet loss, and delay variance (jitter) which a network needs to make them available for the end users while transporting a packet stream from a source to its destination.

Real time applications need mechanisms that guarantee restricted delay and delay jitter. For instance, the most important delays that affect the end to end delay in packet delivery from one node to another node are: the queuing delay at the source and intermediate nodes, the processing time at the intermediate nodes, the transmission delay, and the propagation duration over multiple hops from the source node to the destination node (Kurose & Ross, 2007).

Generally in wired networks, QoS parameters are characterized by the requirements of multimedia traffic. But in ad-hoc networks QoS requires new constraints due to highly dynamic network topology and traffic load conditions, time-variant QoS parameters like throughput, latency, low communication bandwidth, limited processing and power capacity than wire-based network.

Moreover, QoS in ad-hoc networks relates not only to the available resources in the network but also to the mobility speed of these resources. This is because mobility of nodes in ad-hoc networks may cause link failures and broken paths. In order to continue a communication therefore, it requires finding a new path. However, delay will occur for establishing a new path, also some of the packets may get lost (Grossglauser & Tse, 2002). Figure 4 depicts some challenges when proving the QoS in MANTEs.

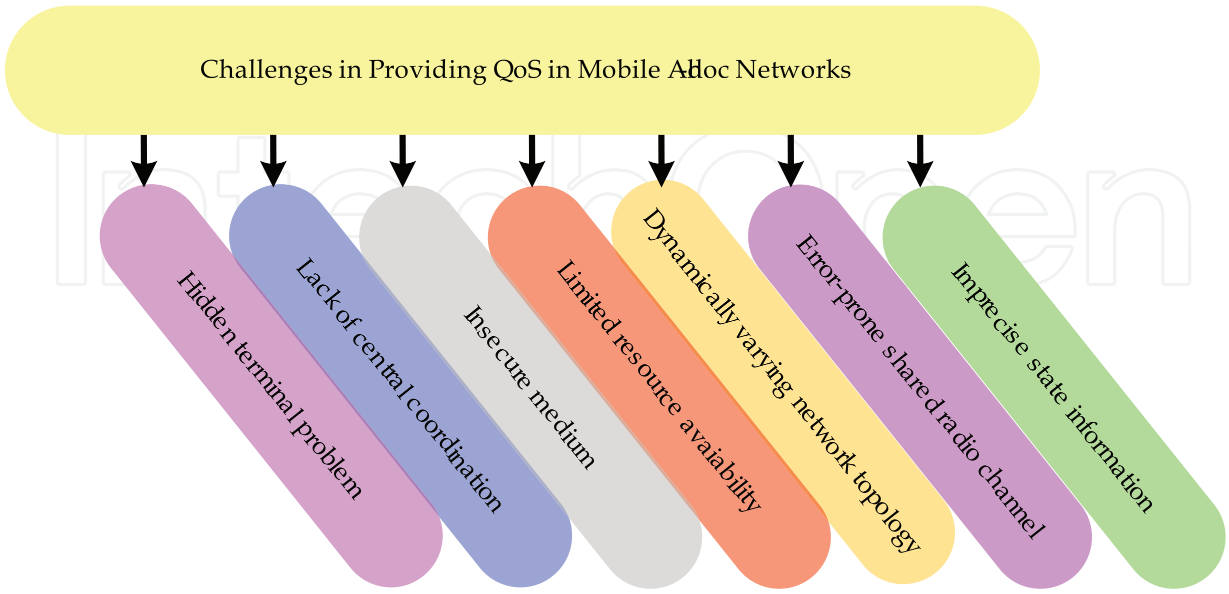

Fig. 4. Some challenges when proving the QoS in MANTEs (Murthy & Manoj, 2004).

Error-prone shared radio channel is another issue for providing QoS as the radio channel in a broadcast medium, thus, during propagation through the wireless environment the radio waves go through several impairments (e.g. attenuation, multipath propagation, and interference) from other wireless devices working in the surrounding area (Rappaport, 2002).

In mobile ad-hoc networks, mobile computation devices are usually battery powered. A limited energy budget constraints the computation and communication capacity of each device. Energy resources and computation workloads have different distributions within the network. The main reasons for energy management in ad-hoc networks are limited energy reserve, difficulties in replacing the batteries, lack of central coordination, constrains on the battery source, and selection of optimal transmission power (Murthy & Manoj, 2004), (Kumar Sarkar et al., 2008).

The battery Life, bandwidth, and buffer space are the important resources in each network. Usually, the transmitter power consumes the most energy in the node and it is essential to conserve the available energy in MANETs either by low-power design of hardware (Lahiri et al., 2002) or special power control mechanisms (Agarwalet al, 2001), (Wattenhofer et al, 2001), (Cartigny et al., 2003).

The hidden terminal problem is inherent mobile ad-hoc networks (Sekido et al. 2005). This may happen when packets originating from two or more sender nodes which are not within the direct transmission range of each other (Figure 5), crash at a general receiver node. Thus, it requires the retransmission of the packets that may not be adequate for flows.

Security issue is an important factor in providing QoS in mobile ad-hoc networks. Communications in wireless environment are not secure due to the broadcasting behaviour of this type of network (Carvalho, 2008). Generally, MANETs have fewer resources than fixed networks and they are more influenced by the resource constraints of the nodes. Therefore, it is hard for these networks to support different applications with appropriate QoS requirements (Wu & Harms, 2001).

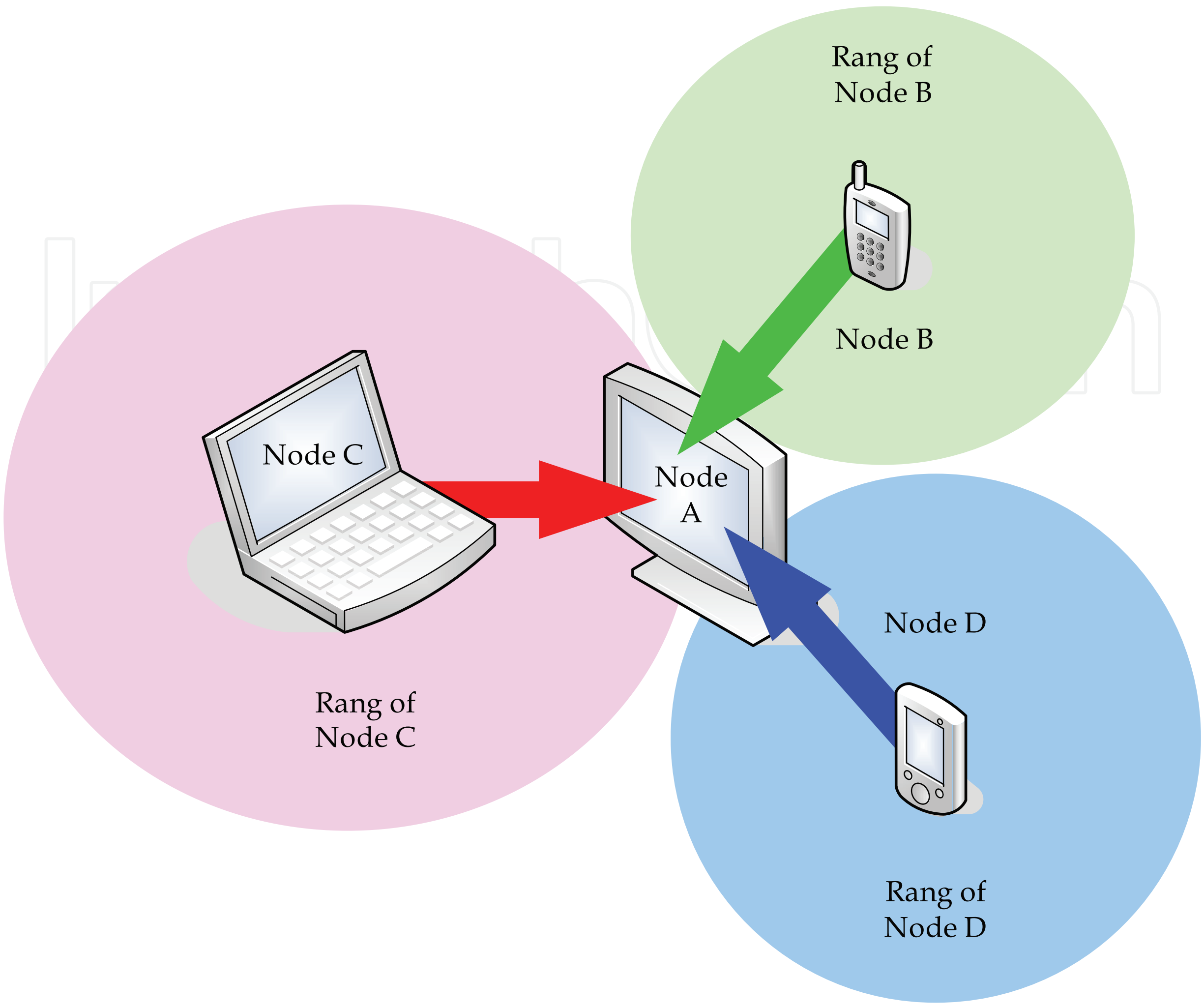

Fig. 5. Hidden terminal problem: when Node C is transmitting to Node A, one or more nodes (here Node B & D) are concurrently transmitting to Node A.

The four main goals of cryptography for any networks are Confidentiality, Integrity, Availability, and Non-repudiation, as demonstrated in Figure 6. The major issues to provide security are as follows: shared radio broadcast channel, unsecured operational environment,

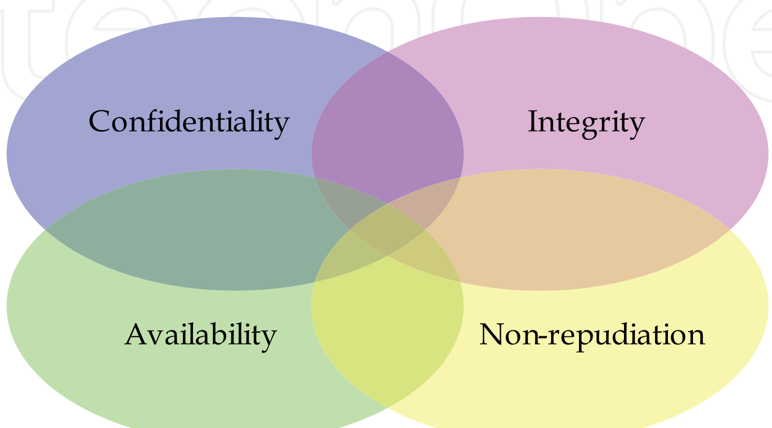

Fig. 6. The four fundamental requirements for a secure network.

lack of central authority, lack of association, limited resource availability, and physical vulnerability. Accordingly, the requirements of a secure routing protocol for MANETs are: detection of malicious nodes, guarantee of correct route discovery, confidentiality of network topology, and stability against attacks (Murthy & Manoj, 2004). Figure 7 displays the security issues in each TCP/IP layer (Yang et al., 2004), (Comer, 2005).

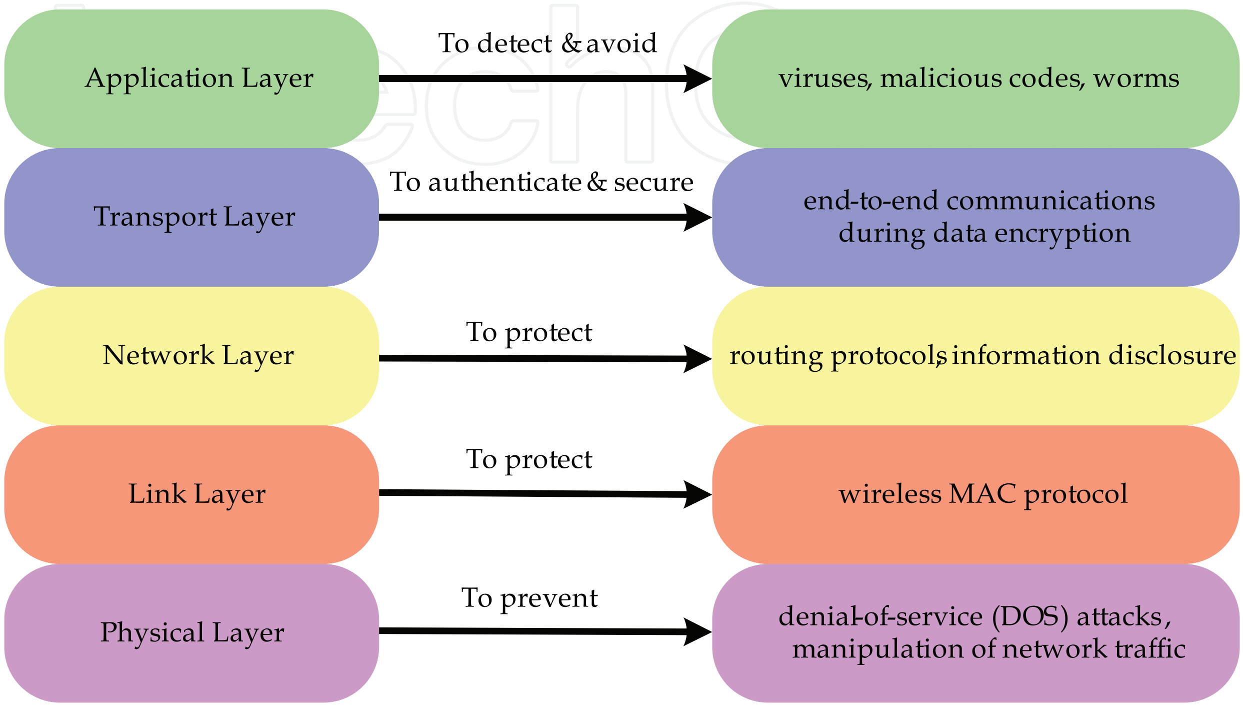

Fig. 7. The security issues: challenges and corresponding layers (Yang et al., 2004).

The other important problems in MANETs when providing QoS are routing, maintenance and variable resource problems (Lin & Liu, 1999).

1. Routing problem: It explains how to find a loop-free from the source to the destination in the network that can be able to support a requested level of QoS. Route selection strategies can be based on the power aware, level of the signal strength, link stability, and the shortest path.
2. Maintenance problem: It describes how to make sure that, when network topology changes, new routes that can support existing QoS obligations are available, or can be quickly found.
3. Variable resource problem: It addresses how to react to changes in available resources, either as the result of a route change, or as the result of changes in link characteristics within a given route.

As we mentioned earlier a mobile ad-hoc network (MANET) may include a group of mobile nodes with a wireless communications device and a controller, in which they operate in accordance with a multi-layer protocol hierarchy (Tanenbaum, 2003). The QoS solutions can be classified based on the QoS approaches or based on the layer at which they operate in the network protocol stack. Generally, the QoS approaches can be classified based on the interaction between the routing protocol and the QoS provisioning mechanism, and the interaction between the network and the Medium Access Control (MAC) layers, or based on the routing information update mechanism (Murthy & Manoj, 2004).

Based on the interaction between the routing protocol and the QoS provisioning mechanism, QoS approaches can be divided into Coupled and Decoupled (Shah & Nahrstedt, 2002).

1. In Coupled QoS the routing protocol and the QoS provisioning mechanism directly interact with each other for delivering the required QoS.
2. In Decoupled QoS the QoS provisioning mechanism does not depend on any specific routing protocol with the intention of having required QoS.

In addition, QoS approaches can be categorized as independent and dependent based on the interaction between the routing protocol and the MAC protocol (Murthy & Manoj, 2004). In independent QoS, the network layer is not dependent on the MAC layer QoS provisioning. While for dependent QoS, it requires the MAC layer to support the routing protocol for QoS provisioning.

Figure 8 illustrates some ad-hoc network routing protocols, each one established for a particular purpose (http://wiki.uni.lu/secan-lab/).

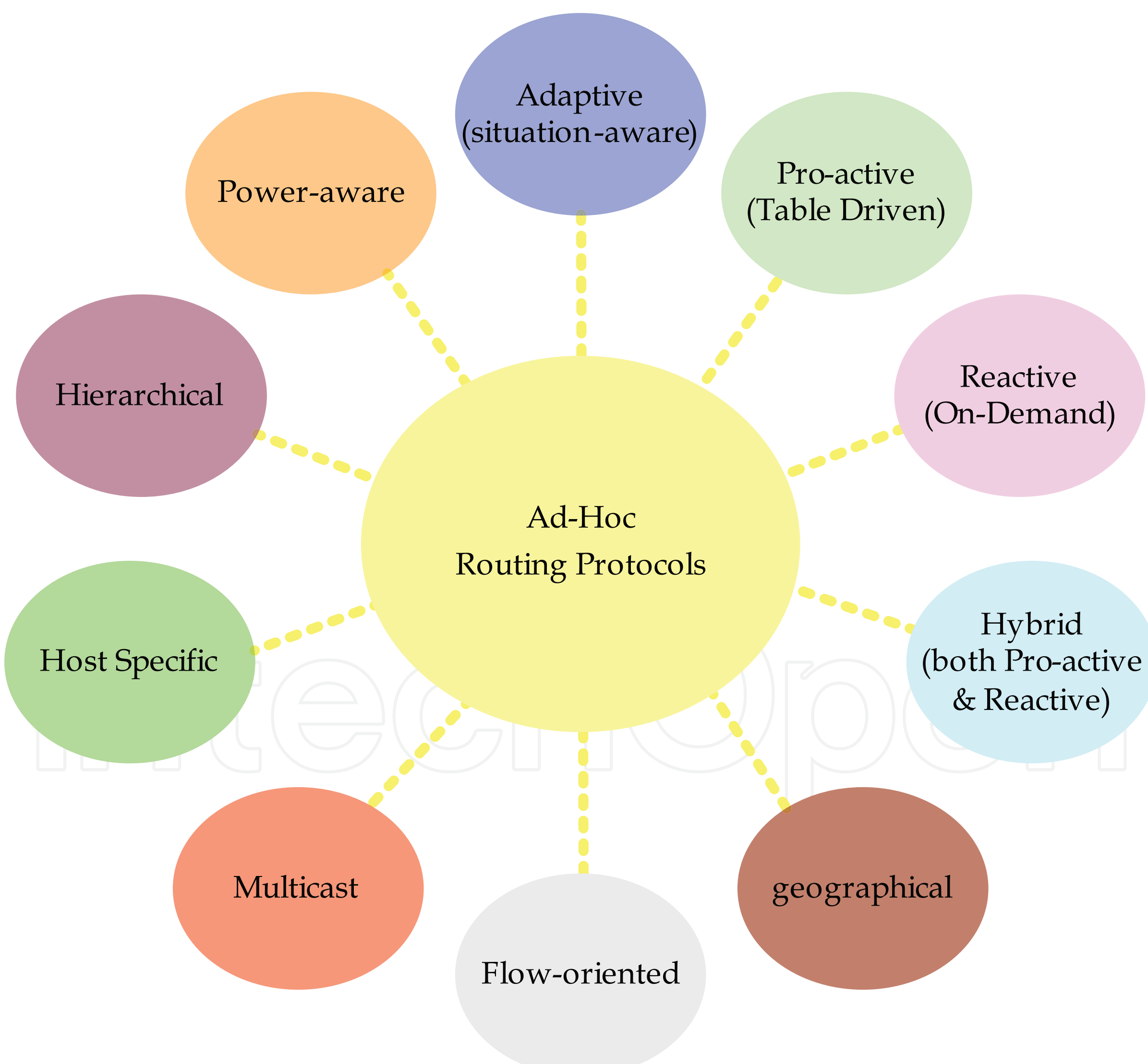

Fig. 8. Some ad-hoc routing protocols (algorithms)

As can be seen, routing strategies can be also categorized as adaptive routing and not-Adaptive routing. For Ad-Hoc-Networks, only adaptive strategies are useful (http://www.cs.uiuc.edu). Accordingly, the route selection strategies are characterized as follows: power-aware routing, signal strength, link stability, shortest path, link-state routing, and distance-vector routing.

Furthermore, QoS approaches based on the routing information update mechanism can be classified as table-driven, on-demand, and hybrid (Mbarushimana & Shahrabi, 2007).

1. Table-driven (Pro-Active), each node in the network holds a routing table which can support the forwarding packets. The routing tables are called periodically or event-driven and it will be only updated if any change happens in the network. The main disadvantages of table-driven QoS are bandwidth consumption in transmitting routing tables and also saving the table of the routes that are not used in future (Reddy ET AL., 2006).
2. On-demand (Reactive), there is no any routing table at nodes; thus, the source node has to discover the route by flooding the network with route request packet. In this technique, routes are calculated when they are needed. The main disadvantages of the on-demand approach are delay when the source node trying to find a route and also excessive flooding can be led to the network clogging (Chen et al., 2002).
3. Hybrid (Pro-Active/ Reactive), which integrates attributes of the two above approaches. The disadvantage of the hybrid technique depends on the number of active nodes in the network (Pandey et al., 2006).

A list of some ad-hoc routing protocols is given in Figure 9 (http://wiki.uni.lu/secan-lab), such as Destination Sequenced Distance Vector (DSDV) Routing (Perkins, 2001), Wireless Routing Protocol (WRP) (Murthy & Aceves, 1995), Hieracical State Routing (HSR) (Iwata et al., 1999), Ad-hoc On demand Distance Vector (AODV) Routing (Royer et al. 2000), Dynamic Source Routing (DSR) (Johnson & Maltz, 1996), Temporally Ordered Routing Algorithm (TORA) (Park & Corson, 1997), Zone Routing Protocol (ZRP) (Haas, 1997), Hazy Sighted Link State (HSLS) Routing Protocol (Santivanez & Ramanathan, 2001), Scalable Source Routing (SSR) (Fuhrmann et al., 2006).

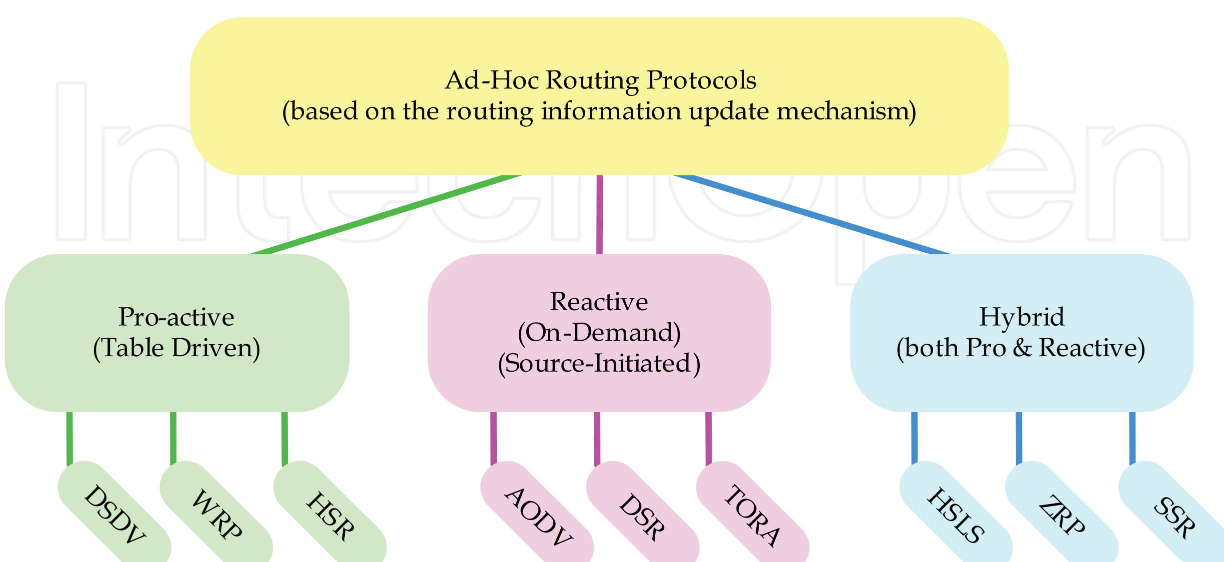

Fig. 9. Some ad-hoc routing protocols (based on the routing information update mechanism)

Finally, some major open issues and challenges in MANETs (Taneja & Patel, 2007) are depicted in Figure 10.

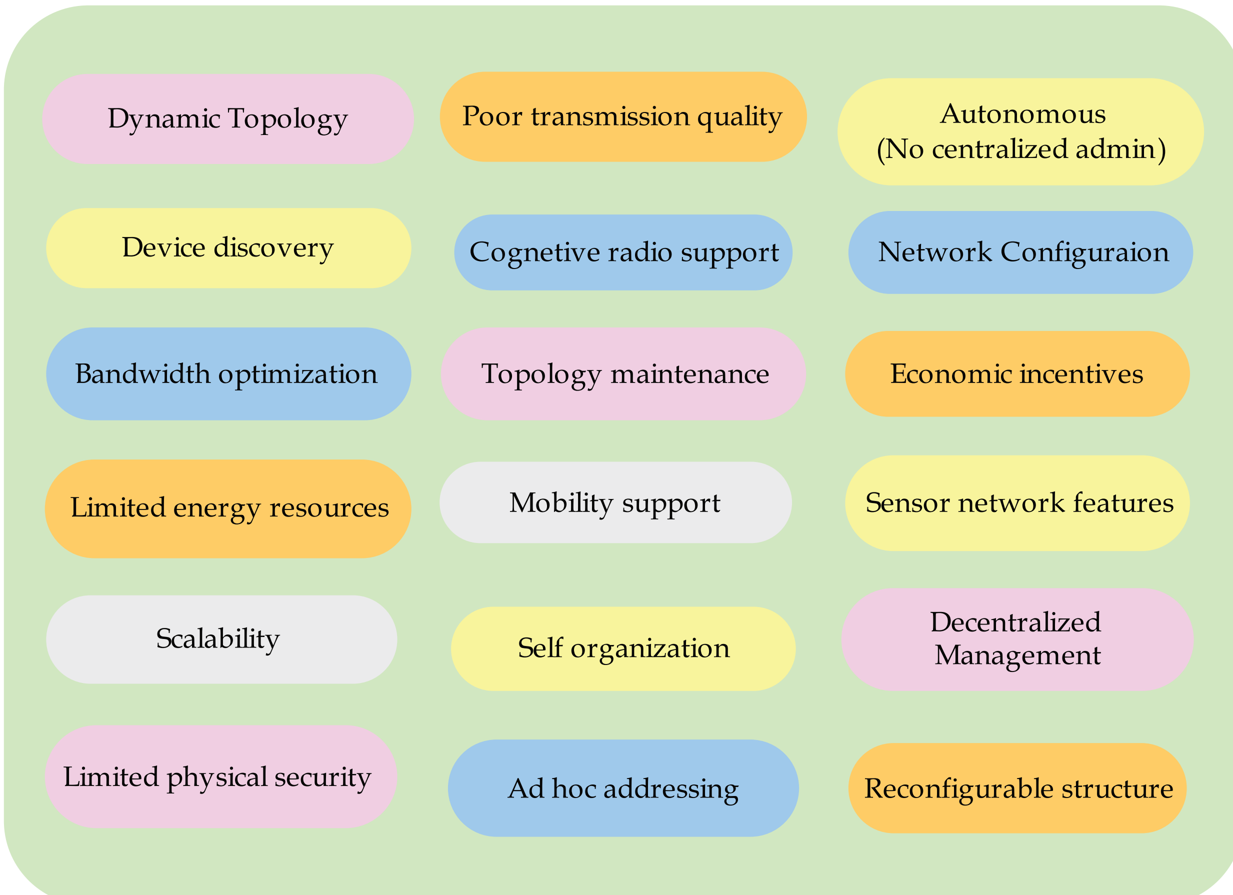

Fig. 10. Some major open issues in MANETs.

5. Conclusions

Multi-hop mobile radio network, also called mobile ad-hoc network is created by a set of mobile nodes on a shared wireless channel. This network is adaptable to the highly dynamic topology resulted from the mobility of network nodes and changing propagation conditions. MANETs are expected to have a significant place in the development of wireless communication systems. Such networks are attractive because they can be rapidly deployed anywhere and anytime without the existence of fixed base stations and system administrators. Hence, mobile ad-hoc networks must be able to provide the required quality of service for the delivery of real-time communications such as audio and video that poses a number of different technical challenges and new definitions.

Many ideas regarding QoS inherited from the wire-based networks can be used for MANETs if we consider various constraints due to the dynamic nature, bandwidth restriction, the limited processing, and capabilities of mobile nodes. Thus, for providing efficient quality of service in mobile ad-hoc networks, there is a solid need to create new architectures and services for routine network controls.

6. Future works

The development of mobile ad-hoc networks provides great chances in various areas including academic, defence, disaster recovery, industrial environments, and healthcare. Nevertheless, there are many challenges that require to be addressed as well. These challenges needs to develop efficient routing procedures, mechanisms for reducing power consumption and extending the battery life, mechanisms for efficient use of limited bandwidth and communication capacity, new algorithms for information security, and making smaller but more powerful mobile devices.

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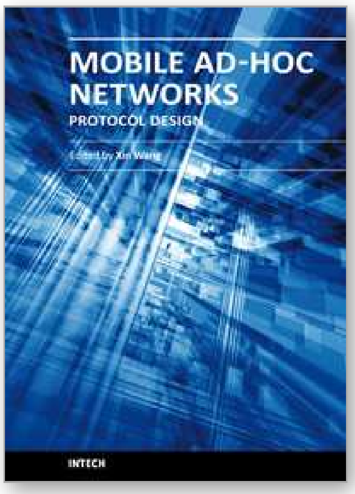

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Being infrastructure-less and without central administration control, wireless ad-hoc networking is playing a more and more important role in extending the coverage of traditional wireless infrastructure (cellular networks, wireless LAN, etc). This book includes state-of-the-art techniques and solutions for wireless ad-hoc networks. It focuses on the following topics in ad-hoc networks: quality-of-service and video communication, routing protocol and cross-layer design. A few interesting problems about security and delay-tolerant networks are also discussed. This book is targeted to provide network engineers and researchers with design guidelines for large scale wireless ad hoc networks.