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Mobile Ad Hoc Networks (MANETs) for Multimedia Transmission

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INTRODUCTION

Mobile Ad hoc Networks (MANETs) are becoming more essential to wireless communications due to growing popularity of mobile devices. A node in MANETs could act as a router while having also the possibility of being the sender or receiver of information. MANETs offer the freedom to use mobile devices and move independently of the location of base stations (and outside their coverage) with the help of other network devices. The ability of MANETs to be self-configured and form a mobile mesh network, by using wireless links, make them very suitable for a number of cases that other type of networks cannot operate. In addition, MANETs do not require vast technological investments.

An ideal application area for the utilization of MANET technology is for instance any disaster scenario in which the fixed infrastructure is incapacitated or non-existent. In this case it is important to ensure that a suitable communication solution is established within the very first critical hours of an incident, considering national or cross-border emergency incidents.

What is missing, however, from this type of networks is the so called a “killer application” that could boost its utilizations in the real world. Real time multimedia applications have the potential to turn MANETs into a very attractive solution in wireless networks taking into account its unique characteristics.

Our motivation for this article is to present the shortcomings and the current state of the art in MANETs in regards to the transmission of multimedia data, which is a promising application area.

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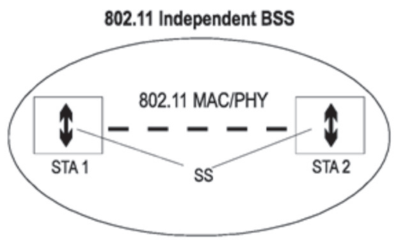
BACKGROUND

Wireless Local Area Networks (WLANs) are one of the most popular and ubiquitous forms of wireless connectivity between different types of equipment. WLAN interfaces are embedded in many common electronic devices: laptops, PDAs, smart phones etc. IEEE 802.11 (IEEE, 2007) is the dominant standard for WLANs. Networks can be deployed using available COTS (Commercial Off-The-Shelf) equipment supporting 802.11 for both home and enterprise scenarios. There is also a multitude of available hardware and software tools for many OS platforms, making them easy to administer. Furthermore, WLANs provide mobility, high-speed transmission, and distributed topologies.

The most common topology of IEEE 802.11 WLAN is infrastructure mode. Stations (STA) connect to an Access Point (AP) using a radio link. The AP is connected to the external network through a wired link (Ethernet being most common). This is a centralized approach, however, more robust topologies can be found in the 802.11 standard.

In ad-hoc mode presented in Figure 1, there is no central station (STA). All STA within range can communicate directly; otherwise a multi-hop packet-forwarding connection is used. This approach provides reliability and robustness to the connection. There is no single point of failure (provided there are multiple paths in the network) which makes them a feasible choice for ad-hoc networks deployments. For ad-hoc mode networks the IEEE 802.11 standard defines physical layer (PHY) and medium access layer (MAC) while network layer with routing protocols are defined mainly by the International Engineering Task Force (IETF).

Figure 1. IEEE 802.11 ad-hoc network



MANETs are based on ad-hoc technology. However, current MANETs built with IEEE 802.11 technology lack scalability and Quality of Service (QoS). Mobility is a unique feature but it results in a very dynamic topology in which routing can become a very complicated task. There is also a need for fast scanning and fast roaming to support real-time applications. The scanning process must consume as little energy as possible. Fast mobility must be supported to serve traffic in MANETs. During handoffs, except for QoS, security is of crucial importance. The routing protocols that have been designed for wireless ad-hoc networks directly affect the performance of the serving applications. Each protocol has its own routing strategy that is used in order to discover a routing path between two ends. The performance varies, depending on network conditions like the density of nodes in a specific area, their speed and direction. It is obvious that the selection of the proper routing protocol for a specific network topology plays a critical role.

On the other hand, multimedia applications and especially video streaming is characterized by three main attributes: a) high bandwidth requirements, b) delay-constraint applications with c) tolerance to small packet losses (usually less than 1%). A major key issue is therefore how to guarantee an acceptable level of QoS to the end users. Therefore, under these conditions there should be implemented additional mechanisms in order to support the utilization of multimedia applications in MANETs.

To this end, over the last few years, new protocols were designed and standardized in an effort to increase the transmission rates of the wireless medium. The IEEE 802.11e (IEEE, 2005) protocol with QoS enhancements is an international standard that is already implemented in MAC chipsets by a number of vendors. The efforts for the enhancements of the IEEE 802.11 protocol aim at creating a wireless environment in which, data transmission can be achieved at higher bit rates and longer distances while meeting the QoS criteria posed by applications with delay constrains, like multimedia transmission.

MAIN FOCUS OF THE ARTICLE

Routing in MANETs

Routing protocols for ad hoc networks can be classified into three main categories. In Proactive schemes, every node in the network has one or more routes to any possible destination in its routing table at any given time. Reactive routing protocols obtain a route to a destination on a demand fashion. When the upper transport layer has data to send, the protocol initiates a route discovery process, if such a route does not already exist, in order to find a path to the destination. In Hybrid routing protocols, every node acts reactively in the region close to its proximity and proactively outside of that region, or zone. Hybrid protocols take advantage of both reactive and proactive protocols, but may require additional hardware, such as GPS devices, separated or integrated into the communication device. Table 1 provides more details on existed routing schemes with associated protocols that are under research and development.

Various solutions have been presented for MANETs routing that rely on the three more dominant routing protocols, namely: Optimized Link State Routing Protocol (OLSR) (Clausen & Jacquet., 2003), Ad hoc On-Demand Distance Vector (AODV) (Perkins & Belding-Royer, 2003) and Dynamic Source Routing Protocol (DSR) (Johnson et al., 2003).

OLSR is a proactive protocol that is based on the link state algorithm. OLSR has been modified and optimized to efficiently operate MANET routing. The main concept of the protocol is to adapt the changes of the network without creating control messages overhead due to the protocol flooding nature. Thus, the designers of OSLR decided to have only a subset of nodes, named Multipoint Relays (MPRs), in the network responsible for broadcasting control messages and generating link state information. A second optimization is that every MPR may choose to broadcast link state information only between itself and the nodes that have selected it as an MPR.

Table 1. Ad-hoc routing protocols

Type	Examples
Pro-active (table-driven)	**OLSR** (Optimized Link State Routing Protocol) (Clausen & Jacquet., 2003) **DSDV** (Highly Dynamic Destination-Sequenced Distance Vector routing protocol) (Perkins et al., 2004) **OSPF-MANET** (Open Shortest Path First for Mobile Ad-hoc Networks) (Bacelli et al., 2008) **MPR-OSPF** (Multi Point-Relay OSPF) (Bacelli et al., 2007)
Reactive (on-demand)	**AODV** (Ad hoc On-Demand Distance Vector) (Perkins & Belding-Royer, 2003) **DSR** (Dynamic Source Routing) (Johnson et al., 2003)
Flow-oriented	**VRR** (Vehicular Reactive Routing protocol) (Koubek et al., 2008)
Hybrid	**TORA** (Temporally-ordered routing algorithm routing protocol) (Park & Corson, 2001) **HWMP** (Hybrid Wireless Mesh Protocol) (IEEE80211s)
Hierarchical	**CEDAR** (Core Extraction Distributed Ad hoc Routing) (Sinha et al., 2009)
Geographic	**DREAM** (Distance Routing Effect Algorithm for Mobility) (Bacelli et al., 2008) **LAR** (Location-Aided Routing) (Ko & Vaidya et al., 2000)
Power-aware	**DSRPA** (Dynamic Source Routing Power-Aware) (IEEE, 2012) **PAMAS** (Power Aware Multi-Access Protocol with Signalling) (Igartua & Frias, 2010)
Multicast	**AMRoute** (Ad hoc Multicast Routing protocol) (Xie et al., 2002) **ODMRP** (On-Demand Multicast Routing Protocol) (Yi et al., 2002) **AMRIS** (Ad hoc Multicast Routing protocol utilizing Increasing id-numberS) (Wu & Tay, 1999) **CAMP** (Core-Assisted Mesh Protocol) (Garcia-Luna-Aceves & Madruga, 1999)

AODV is a reactive routing protocol that is based on the Bellman-Form algorithm. AODV uses originator and destination sequence numbers to avoid both "loops" and the "count to infinity" problems that may occur during the routing calculation process. AODV, as a reactive routing protocol, does not explicitly maintain a route for any possible destination in the network. However, its routing table maintains routing information for any route that has been recently used, so that a node is able to send data packets to any destination that exists in its routing table without flooding the network with new Route Request messages.

DSR is a reactive protocol that is based on two main mechanisms: route discovery and route maintenance. Both mechanisms are implemented in an ad hoc fashion and in the absence of any kind of periodic control messages. The main concept of the protocol is "source routing," in which nodes place in the header of a packet the route that the packet must follow from a source to a destination. Each node "caches" the routes to any destination that has recently used, or discovered by overhearing its neighbors' transmission. When there is no such route, a route discovery process is initiated. The protocol is designed for a MANET of up to two hundreds nodes with high mobility rates and is loop-free.

The experimental results illustrate that the performance of a routing protocol varies across different mobility models, node densities and the length of data paths. A performance evaluation of DSDV, AODV and DSR with respect to group and entity mobility models is presented in Divecha, 2006. Simulation results indicate also that the relative ranking of routing protocols may vary, depending on the mobility model.

In Igartua and Frias (2010), a QoS-aware self-configured adaptive framework is presented to provide video-streaming services over MANETs. The routing algorithm periodically updates a set of paths, classifies them according to a set of metrics, and arranges a multipath-forwarding scheme. This proposal operates in a different way under highly dynamic states than under more static situations, seeking to decrease the probability of having broken links and improving the service performance, while using lower signaling overhead.

Matin addresses the use of multi-hop as an alternative to conventional single hop transmission in order to increase the quality of real time video streaming over MANETs (Matin & Naaji, 2010). The use of the IEEE 802.11e Enhanced Distributed Channel Access (EDCA) function improves the overall performance of the high priority traffic in MANETs, by using the access control mechanisms of the MAC layer.

In Pallot and Miller (2001), priority assignment mechanisms are considered for implementing priority treatment of packets in a MANET using the DSR routing protocol based on a modified IEEE 802.11 MAC layer operating in the distributed mode. The mechanism includes priority queuing and several methods for providing important messages an advantage in contenting for channel access. In Andreopoulos, 2006 an integrated cross-layer optimization algorithm is proposed in order to maximize the decoded video quality in a multi-hop wireless mesh network with QoS guarantees. It is investigated in Qadri et al., 2009 whether or not the operating conditions in a city are likely to permit video streaming. It is found that AODV outperforms DSR over the Manhattan grid model.

Finally, a large variety of research has been conducted regarding the usefulness of the wireless medium-related metrics. Zhang et al. (2008) present a systematically measurement-based study on the capability of to characterize the channel quality. Although it is confirmed that SNR is a good indicator for channel quality, there are also several practical challenges.

Multimedia Transmission in MANETs

With the increase in the bandwidth of wireless channels and the computational power of mobile device, multimedia transmission over MANETs is very appealing. The multimedia transmission over MANETs facing many challenges mainly due to the following characteristics of the MANETs: Dynamic topology, transmission errors, node failures, link quality variations and link failures etc. Multimedia applications on the other hand are characterized by three main properties: the demand for high data transmission rate (bandwidth-consuming applications), the sensitiveness to packet delays (latency and jitter) and the tolerance to packet losses (packet-loss tolerant applications). The above characteristics introduce a number of technical challenges that have to be addressed. Therefore, under these conditions there should be in place additional mechanisms to improve multimedia transmission in MANETs. Such mechanisms may incorporate:

- Priority of multimedia packets against other data packets.
- Implementation of congestion and flow control mechanism for the multimedia transmission application.
- Enhances routing operation with additional wireless medium-related metrics in order to improve the multimedia transmission performance.

The Real Time Protocol (RTP) (Shculzrinne et al., 2003) and the associated RTP Control Protocol (RTCP) protocols constitute the de facto standard for multimedia data transmission. RTP is a real time transport protocol that is used usually on top of the UDP protocol (also other transport protocols are supported). The combination of the RTP/RTCP seems to be an appealing solution also for multimedia transmission over MANETs. The use of UDP in video streaming real-time applications is an obvious solution to avoid latency caused by the retransmission and congestion control mechanisms of TCP. However, UDP may cause two major problems. The first one has to do with possible bandwidth limitations in which uncontrolled transmission of video packets without any congestion or flow control will cause high rates of packet losses. The second issue relates to TCP-friendliness. Under some conditions, uncontrolled video transmission may lead to possible starvation of TCP-based applications running in the same network.

The research community in order to address congestion control came with new proposals that are already successfully implemented in TCP. However, the proposed congestion control schemes are mainly designed for use in wired networks, in which packet losses primarily occur due to congested links. In wireless networks the cause of packet losses is mainly due to interference in the wireless medium. Therefore, one needs to differentiate congestion packets losses against random packet losses (Vazao et al., 2008). To this direction a number of various versions of TCP have been proposed including TCP Veno (Cheng, 2003), TCP New Jersey (Xu et al., 2005) and TCP NCE (Sreekumari & Chung, 2011). In another work (Shagufta, 2009), the impact of TCP variants on the performance in MANETs routing protocols is investigated.

The most well-known congestion control mechanism that can be used on top of other transport protocols, such as UDP, is TFRC (Floyd et al., 2003), which is already an international standard. However, even TFRC is facing some limitations in wireless environments and especially in MANETs. In Chen & Nahrstedt, 2004 these limitations are studied and it is shown that TFRC can be used in MANETs only when strict throughput fairness is not a major concern. Moreover, they analyze several factors contributing to TFRC's conservative behavior, many of which are inherent to the MANET network. While their study reveals the limitations of applying TFRC to MANETs, they address the open problem of multimedia streaming in these networks and propose an alternative scheme based on router's explicit rate signaling and application's adaptation policies. In order to overcome the above limitations an algorithm is proposed in Li et al. (2004), which is termed as Rate Estimation (RE) TFRC, and it is designed to enhance TFRC performance in wireless Ad hoc networks.

In the area of video coding several solutions have been proposed. These solutions include:

- Use of Scalable Video Coding (SVC) (Schier et al., 2007): Scalability has always been a desirable feature of a media bit stream for a wide range of services. This is especially the case for transport over best-effort networks that are not provisioned to provide suitable QoS and especially suffer from significantly varying throughput. A strong advantage of a video bit rate adaptation method relying on a scalable representation is the drastically reduced computational requirements in network elements compared to approaches that require video re-encoding or transcoding.
- Use of multi-stream coding and multi path transport (Mao et al., 2010): As we have already mentioned multimedia transmission over MANETs is a challenge, even more challenging than multimedia transmission over other wireless networks. However, the mesh topology of MANETs makes possible to establish multiple paths between a source and a destination. Indeed, multipath transport provides an extra degree of freedom in designing error resilient video coding and transport schemes.

Quality of Service (QoS)

Routing protocols described above do not support QoS. To guarantee quality of transmission in IEEE 802.11 networks additional mechanisms should be applied. WLANs are susceptible to fluctuations in the radio channel. As a result such factors as fading or interferences may lead to high "bit error rates" (BER). PHY should quickly respond in such situations to prevent high "frame error rate" (FER) at the Data Link Layer.

A wireless device can utilize high transmission rates if the received signal is greater than a predefined threshold dependent on receiver sensitivity. The decision on the rate used is left to the transmission rate selection algorithm. This decision is based on the current radio channel conditions. Modern wireless standards do not specify the method of automatic rate selection in the presence of multi-rate capable devices. Therefore, a number of different solutions were proposed in the literature (Natkaniec et al., 2010). As a result, devices of different vendors do not interoperate properly (Kosek et al., 2008).

EDCA is the basic function implemented in WLAN devices. It defines the concept of Access Category (AC). Each node may use up to four ACs, which represent four priority levels for data transmission: background (BK), best effort (BE), video (Vi) and voice (Vo). Since voice and video traffic are more sensitive to jitter, delay and packet loss ratio, their priorities are higher than those related to BE and BK. In EDCA traffic scheduling is done with the use of four hardware priority queues, each associated with an appropriate AC (Table 2) and several different channel access parameters (Table 3).

EDCA can be used in ad-hoc, infrastructure and mesh networks. However, because of the problem of hidden nodes, the Mesh Deterministic Access (MDA) coordination function is proposed for use in the case of multi-hop mesh networks. MDA permits contention-free access, which, however, is prone to malicious attacks in which rogue stations can prevent legitimate stations from communicating (Glass et al., 2008).

In MANETs the network topology changes unpredictably. Therefore, appropriate routing protocols need to quickly adjust to these changes. Additionally, a proper signaling protocol must be provided. It has to be responsible for admission control, resource reservation, reaction to congestion and negotiation of QoS parameters (Natkaniec et al., 2010b).

Table 2. Mapping of the traffic types to the access categories and user priorities (IEEE, 2005)

Priority	User Priority	Access Category	Informative Designation
Lowest	1	AC_BK	Background
	2	AC_BK	Background
	0	AC_BE	Best Effort
↓	3	AC_BE	Best Effort
	4	AC_Vi	Video
	5	AC_Vi	Video
	6	AC_Vo	Voice
Highest	7	AC_Vo	Voice

Table 3. Parameters of 802.11e access categories (IEEE, 2005)

AC	CWmin	CWmax	AIFSN	TXOPLimit
AC_BK	$aCW_{\min}$	$aCW_{\max}$	7	0
AC_BE	$aCW_{\min}$	$aCW_{\max}$	3	0
AC_Vi	$\frac{(aCW_{\min}+1)}{2}-1$	$aCW_{\max}$	2	6.016 ms/3.008 ms/0
AC_Vo	$\frac{(aCW_{\min}+1)}{4}-1$	$\frac{(aCW_{\min}+1)}{2}-1$	2	3.264 ms/1.504 ms/0

Therefore, the main goals of QoS routing protocols should be the following:

- Network capacity estimation,
- Satisfaction of QoS constraints (e.g., jitter, delay, bandwidth, power consumption) of flows,
- Resource reservation,
- Route maintenance,
- Reliable route selection.

SOLUTIONS AND RECOMMENDATIONS

The possible solutions for MANETs include the following three aspects: Hardware, Software and Networking technologies.

The hardware technologies that support implementation of MANETs include in general low power/power aware hardware and implementation of memory, processor, and other peripherals in small scale. The evolution of hardware design and implementation offers today many solutions for the implementation of MANETs including smart sensors (Smart Dust, 2012) and systems on chip in very low cost (Raspberry, 2012). In addition, the evolution on battery technologies allows the implementation of MANETs nodes with very long operation time.

The software technologies that support implementation of MANETs include Java (Java, 2012), Universal Plug and Play (UPnP) (UPnP, 2012) and Peer-to-Peer (P2P) Computing (Open P2P Project, 2012). Java is a programming framework which offers many technologies and API for the support of MANETs software implementation including Platform/protocol independence, Remote method invocation and others. Universal Plug and Play is architecture for smart home networking and pervasive peer-to-peer connectivity of intelligent appliances like wireless devices, smartphones, etc. Peer-to-peer is a paradigm used for sharing of computing resources and services by direct exchange between peer systems.

The network technologies that support implementation of MANETs technologies varying from Bluetooth (in small distances) to WiMAX (802.16) (WiMax, 2012) (for long distances) with WI-FI (802.11) (Wi-Fi, 2012) to be the most common technology.

FUTURE RESEARCH DIRECTIONS

To make concrete progress in multimedia transmission over MANETs in the future, researchers need to look beyond existing design paradigms and evaluation methodologies. In the following text we provide some research directions:

- **Routing:** Since the topology of the network is constantly changing, the issue of routing packets is a constant challenge.
- **Security and Reliability:** In addition to the common vulnerabilities of wireless connection MANETs have particular security problems due to its nature.
- **Quality of Service (QoS):** Providing different quality of service levels in a constantly changing environment will be a challenge.
- **Power Consumption:** Most of MANETs nodes depend on batteries for their power.
- **Multicast:** Multicast is desirable to support multimedia transmission. Since the multicast tree is no longer static, the multicast routing protocol must be able to cope with mobility.
- **Location-Aided Routing:** Location-aided routing uses positioning information to assist routing.

CONCLUSION

Multimedia applications have enjoyed the global interest over the last few years. The multimedia transmission over MANETs facing many challenges mainly due to the following characteristics of the MANETs: Dynamic topology, transmission errors, node failures, link quality variations and link failures etc. This article presents in detail and analyzes the current state of the art in the area of multimedia data transmission over MANETs which is a promising application area.

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KEY TERMS AND DEFINITIONS

Congestion Control: Actions concerning traffic control into a telecommunications network in order to avoid congestive during the transmission of data.

Mobile Ad Hoc Networks (MANETs): A self-configuring and self-organized wireless network of mobile devices.

Multicast: Transmitting data simultaneously to many receivers without the need to replicate the data.

Multimedia Data: Data that consist of various media types like text, audio, video, and animation.

Quality of Service: The ability to provide specific guarantees to traffic flows regarding the network characteristics, such as packet loss, delay, and jitter experienced by the flows.

Real Time Multimedia Applications: Applications in which multimedia data has to be delivered and rendered in real time.

Routing Protocols: A routing protocol uses routing algorithms to determine optimal network data transfer and communication paths between network nodes.