A Review on Asynchronous based QoS enabled MAC Schemes for Mobile Ad Hoc Networks

Lokesh Sharma, and Dr. D. P. Sharma

Abstract— Mobile ad hoc network is a wireless or temporary plug-in connection, in which mobile nodes create an infrastructureless network and only communicate while they are in close proximity. In this paper QoS based asynchronous MAC protocols for mobile ad hoc networks (MANET) has been reviewed. Various protocols has proposed by the researchers for QoS aware Medium Access Control in past few years. These protocols are classified broadly into two categories: Synchronous and Asynchronous protocols. These protocols further classified according the principles used to provide QoS such as Service Differentiation, Resource Reservation and Fair Bandwidth Sharing. Asynchronous MAC protocols like RT-MAC, DCF-PC, EDCF, VMAC, BB, ES-DCF, DB-DCF, MACA/PR DBASE and DFS are discussed here with their pros and cons.

Keywords- IEEE 802.11, EDCA, QoS, MAC, DCF.

I. INTRODUCTION

WITH recent advances in wireless mobile ad hoc network (MANET) it is now possible to provide end-to-end Quality-of-Service (QoS) guarantees for real-time service. The MAC protocol is the key concern for QoS provisioning in MANET. In the recent year lot of different MAC protocols for QoS provisioning has been introduced. The parameters that are considered for the QoS are end-to-end delay, bandwidth availability, packet loss probability, jitter, etc. however, it is very hard to provide active QoS in such networks because of, lack of centralized control, error-prone wireless channels, limited bandwidth, node mobility, and power or computational constraints [1, 9-11].

In ad hoc wireless network the nodes join or leave network an at random, so periodic topology updates are required for latest network configuration. If the network change it topology at very rapid rate then it very difficult to guarantee certain levels of QoS. If the network maintain QoS guarantees even after the dynamic topology then network called as 'QoS-robust network'. Or, if the pledges are preserved between any two back to back updates to the topology, the network is said to be 'QoS-preserving network' [1]. The network that provides QoS provisioning on the basis of priority then is known as 'prioritized QoS network'. In Prioritized QoS network the traffic are assigned higher priority to use network other traffic. A 'parameterized QoS' resources than

reserve the resources for the end-to-end path of the application data connection. A new connection is only admitted if minimum essential bandwidth is available to support it and also ensures that the already admitted network flows remain unaffected. Another classification of QoS applications are soft-QoS applications and dynamic-QoS applications. In soft-QoS [12], after the preliminary connection is establishment, there is possibility that, for a short periods of time when there is an interruption in providing the pre-decided QoS guarantees. In dynamic-QoS [13], a resource arrangement demand stipulates a range of values from minimum level of QoS provision that the applications are ready to admit to the maximum level of QoS provision they are able to exploit, and the network makes a promise to deliver service at a definite point within this range. In such a case, allocation of resources needs to be dynamically adjusted through all layers of the network. The ranges in the reservations offers the elasticity required for operation in a dynamic nature of ad hoc networks. Applications that generate real time traffic e.g. audio/video streaming, need a separate portion for relatively long durations of the available bandwidth for QoS requirements. However, stringent delivery guarantees, mainly for short time periods, not always essential for such applications.

Consequently, these applications can be processed by soft or dynamic QoS schemes. Actually, preserving QoS guarantees for traffics that are delay sensitive is relatively more difficult in MANETs, because for a given time of instant it is an intractable problem to take snapshot of topology, queues state and channel at individual nodes.

The factors affecting support for QoS in MANETs are briefly discussed in section II, followed by ephemeral explanation of selected MAC protocols in section III.

II. FACTORS THAT AFFECTS QOS

There are various factors, like admission control techniques, routing protocols, resource reservation, QoS service model, MAC protocols, and signaling techniques are considered in QoS provisioning in MANET. In fact, every layer of the protocol stack is accountable for QoS delivery in MANET because when all the layers are considered altogether in the overall context then we can provided effective QoS to enduser application. We fleetingly discuss below the important factors that affects QoS delivery across different layers:

A. QoS Service Model

The QoS service model defines the architecture that prescribe the list of services could be provided in the network.

Lokesh Sharma is a research scholar at Manipal University Jaipur, India (phone: +917891166900; e-mail:lokesh.sharma@jaipur.manipal.edu).

Dr. D. P. Sharma is Associate Professor at Manipal University Jaipur, India. (e-mail: deviprasad.sharma@jaipur.manipal.edu).

A QoS service model deals with the dynamic topology and time-varying link capacity challenges of the MANETs. Furthermore, the prospective applications of MANETs require a connection to the Internet seamlessly. Therefore, the QoS Service model should consider the existing QoS architectures in the Internet. Some of the protuberant service models suggested for MANET are: cross layer service model [15], flexible quality of service model for MANETs (FQMM) [14], and stateless model for wireless ad-hoc networks (SWAN) [16].

B. Signaling

The signaling system plays a significant role in establishing, adapting, restoring, and terminating end-to-end resource reservations. The signaling system need be designed in such way it consume less amount of available bandwidth and also capable of responding to fast network dynamics such as wireless link degradation, rapid host mobility, and sporadic session connectivity. There are two different signaling approaches; Out-of-band and in-band signaling. INSIGNIA [17] and Integrated Mobile Ad-Hoc QoS (iMAQ) framework [18] are well-known signaling schemes.

C. QoS Routing and Admission Control

To provide certain end-to-end delay or minimum bandwidth, the routing algorithm must to be QoS cognizant. The route must have adequate resources to support the QoS requirement and also valid at the time the data is to be transported [1, 2, 9, and 19].

D. QoS Aware MAC Laye:

The layers above (specially network layer) the MAC layer depends on QoS-aware MAC protocol, that supports errorfree unicast communication, medium contention, and provides resource reservation for real-time traffic in a distributed wireless environment.

III. QOS AWARE MAC PROTOCOLS

Various MAC protocols have been suggested for wireless networks. Most of them, the objectives of these protocols to solve medium contention, hidden and exposed terminal problems and to improve overall throughput of the network. They did not considered the requirements of resource reservation and QoS guarantees for real-time traffic. There are two main objectives of an efficient and QoS aware MAC protocol. First is to solve the hidden or exposed terminal problem and second is to provide provision for resource reservation needed for QoS guarantees to real-time traffic.

MAC layer needs to be firmly tied with network layer for routing. Since in ad hoc network not support any master-slave strategy, all the nodes behave as end nodes as well as routing nodes, therefore centralized control is not available and it is difficult to maintain information about connections and reservations.



Fig.1. Classification of QoS Aware MAC Protocols

As shown in fig.1, the QoS aware MAC are classified into two categories. The first approach includes synchronous schemes like Cluster TDMA [20, 21], Cluster Token [22], and Soft Reservation Multiple Access with Priority Assignment (SRMA/PA) [23]. In Cluster TDMA, the nodes are grouped into clusters, and all the member nodes of the cluster pick a node as cluster-head. The cluster-head is accountable for managing the activities of the nodes under its own control. Each cluster uses a different DS-Spread Spectrum code. A common, globally synchronous slotted TDM frame is defined among clusters. Slots can be reserved for real-time traffic and the other remaining free slots will be used by nonreal-time traffic. The performance of the scheme is very good for real-time traffic handling. However, time synchronization process occupy the resources intensively and it must be avoided in ad hoc networks. The advantages of such TDMA schemes have been reviewed in [3]. In Cluster Token scheme, within each cluster, the TDM access scheme is swapped by an implicit token scheme and also, no synchronization is compulsory across different clusters.

The other approach is asynchronous protocols that do not use any global clock for synchronization and are appropriate for Ad hoc networks. IEEE 802.11 DCF is a widely used asynchronous protocol that uses a best effort delivery model [5-8]. It does not support real-time traffic and the upper bound of channel access delay not deterministic as its random backoff mechanism cannot support it. On the principle of IEEE 802.11 DCF numerous QoS-aware MAC schemes have been suggested in the recent time. No strict taxonomy available in the literature to cluster these schemes. On the basis of major features, below are the classifications of the various schemes:

A. On The Basis Of Shorter Inter-Framing Spacing And Backoff Contention Values

the examples of these category are real-time MAC [24], DCF with priority classes [25] and enhanced DCF (EDCF) [26-28]. These schemes are the extensions of IEEE 802.11 DCF and use shorter inter-framing spacing and back-off contention vales to provide the delay and bandwidth requirement of real-time traffic.

B. On The Basis Of Shorter Inter-Framing Spacing

The black burst (BB) contention[29, 20], elimination by sieving (ES-DCF) and deadline bursting (DB-DCF) [31, 32] protocols use a shorter inter-frame spacing and a different approach than the backoff window for channel contention to support bounded time delay of real-time traffic.

C. Reserves Time Slot Based Schemes

The TMACA/PR[33], asynchronous QoS enabled multihop MAC [34] and dynamic bandwidth allocation/sharing/extension (DBASE) protocol [35] are the examples of this category. These schemes uses reserved time slots at nodes to provide bounded delay and required bandwidth for the real-time traffic instead of directly manipulating inter-frame spacing and contention window. The non-real-time data traffic is treated exactly as in IEEE 802.11.

D. Distributed Fair Scheduling Based Scheme

The schemes those are not part of above mentioned categories are based on a fair proportion of channel access to different network flows. Therefore, some scholars have proposed MAC schemes to provide a rationally fair channel allocation to different flows according to their priority. The example of this category is distributed fair scheduling [36].

It is found that the schemes of different categories usually have some conjoint features. The salient features of major schemes in each categories are discussed below.

1) Asynchronous MAC Protocols Based On Service Differentiation:

The following MAC protocols are the examples of this category:

1.1) Real-Time MAC (RT-MAC):

The packets those missed their deadlines are retransmitted in the IEEE 802.11protocol scheme. But these are not useful anymore and causes wastage network resources and bandwidth. Considering this drawback Baldwin et al. [24] proposed a modified version of the IEEE 802.11 protocol called RT-MAC. This scheme supports real time traffic by evading packet collisions and the transmission of the packets that are already expired. To find out the next backoff value of transmission station, the RT-MAC scheme uses an 'improved collision avoidance' scheme and a packet transmission deadline. When an real time traffic packet is inserted into a queue for transmission, a timestamp is recorded in a local buffer of the node that indicates the time by which the packet should be transmitted. Whether a packet has expired; the sending node checks it at three points: before sending the packet, when its backoff timer expires and when a transmission goes unacknowledged. After this an expired packet is immediately removed from the queue buffered for transmission. Just before a packet is to be sent out, the sending node selects the next backoff value and put this value it in the packet header. Any node that listen to this transmitted packet, choose a different backoff value to eradicate the chance of collision. The contention window (CW) range is a function of the number of nodes in the system and the backoff value is chosen from this range. Thus, the number of nodes should be known or at least estimated in this scheme.

It is shown that, RT-MAC scheme has achieved radical falls in mean packet delay, missed deadlines, and packet collisions in the comparison of IEEE802.11 scheme. However, the range of the contention window become quite large as the number of nodes increases in the network and it causes the wastage of bandwidth even after a little network load.

1.2) DCF with Priority Classes:

DCF-PC is an enhanced version of the IEEE 802.11 protocol proposed by Deng et al. [25]. In this protocol data is being accessed in different classes as per their priority. The principle behind this protocol is to use a combination of shorter Inter-frame spacing (IFS) or waiting times and shorter backoff time values for higher priority data (realtime traffic). As already mentioned, IEEE 802.11 specifies different IFS intervals in the protocol and these are SIFS, PIFS and DIFS [6-8]. The nodes that are not generating real-time traffic waits for the channel to remain idle after DIFS interval before they transmit data, while a higher priority node waits for only PIFS. However, if the longer backoff value taken, the higher priority node can still lose out to another node that has a larger IFS but a shorter random backoff value. In solve the problem mentioned above, the researcher have proposed two different formulae for calculating the random backoff values. This calculated shorter random backoff time is assigned to higher priority nodes.

The researchers have displayed through simulation that, RT-MAC scheme has shown superior performance than 802.11 DCF, in terms of overall throughput, delay and probability of frame loss for higher priority real-time traffic. However, the main drawback of this scheme is that, it do not provide deterministic delay bounds for real-time traffic and non-real-time traffic suffers with higher delay because of longer backoff time even there is no higher priority node is transmitting packets. This causes wastage of channel bandwidth.

1.3) Enhanced DCF:

The objectives of IEEE802.11 Distributed Coordination Function (DCF) scheme is to provide equal probabilities to all the competing nodes for channel access in a distributed manner. Enhanced DCF (EDCF) improves the DCF protocol to provide separate channel access according to the priorities assigned to the frame. EDCF scheme has been developed as a part of the hybrid coordination function (HCF) of IEEE 802.11e [26-28]. The working principle of it is discussed below, without the details of IEEE 802.11e HCF.

In the MAC header of each data frame a different traffic class (TC) is assigned based on its priority as defined by the higher layers. Through the contention procedure, EDCF uses AIFS[TC], CW_{min} [TC] and CW_{max} [TC] in place of DIFS, CW_{min} and CW_{max} of the DCF, respectively, for a frame belonging to a specific traffic class. Here Arbitration Inter Frame Space (AIFS) duration is at least DIFS, and can be enlarged individually for each TC. The CW_{min} of the backoff mechanism is set differently for different priority classes. Thus two measures are combined in EDCF to provide service differentiation. Fig. 2 shows the EDCF channel access.



Fig. 2: IEEE 802.11 EDCF channel access

On the basis of analysis of delay incurred by IEEE 802.11 DCF, Veres et al. [12] suggested a fully distributed Virtual MAC (VMAC) scheme. This scheme supports radio monitoring, admission control and service differentiation for delay-bounded and best-effort traffic. VMAC monitors the radio channel and calculate locally achievable service levels passively. It also calculate important QoS statistics at MAClevel, like delay, jitter, packet collision, and packet loss.

1.4) Black Burst (BB) Contention:

BB contention scheme was introduced by Sobrinho and Krishna kumar[29, 30]. This scheme is distributed and relies on carrier sensing. This scheme enhance the IEEE 802.11 standard. The scheme operates on the principle that the interframe spacing for normal data nodes will be longer than real-time nodes. The system then automatically favors the real-time nodes. The real-time traffic generating nodes jam the channel with pulses of energy called as Black Burst and the other nodes waits till the real-time traffic generation nodes finishes its transmission. The length of black bursts is proportional to the delay due to contention experienced by the node. This delay is the difference between the time instants when an attempt is made to access the channel to the BB transmission started.

To distinctively identify all the BB pulses sent by different real-time nodes, they all differs in length by at least one black slot. After each Succeeding BB transmission, a node senses the channel for a period to decide whether its own BB was the longest or not. If so, the node attempts its data transmission else it has to wait for the idle channel before it again send another BB. In principle, this scheme appears to achieve a dynamic TDM transmission structure without anv synchronization or explicit slot assignments. This scheme provide collision-free guaranteed real-time packets transmission with a higher priority. The contention in BB scheme enforces a round robin scheduling among many realtime nodes and achieve bounded real-time delays.

The BB contention scheme as compared to simple carrier sense networks provides some better QoS guarantees to real-time multimedia traffic. But, this scheme does not consider hidden and exposed terminal problem.

1.5) Elimination by Sieving (ES-DCF) and Deadline Bursting (DB-DCF):

Pal et al. [31, 32] proposed two alternates of the IEEE 802.11 DCF that offer guaranteed time bound delivery for real-time traffic, by using deterministic collision resolution algorithms. The scholars also used black burst features in this scheme.

There are three phased of operation in ES-DCF: elimination, channel acquisition and collision resolution. In elimination phase, every node is assigned a grade based on the deadlines and priority of its packets as in [25]. Shorter the deadline results in a lesser numerical grade, which converts to lower than DIFS channel-free wait times. Consequently, the grade of the packet increases if it is buffered in the queue for a longer time. In the channel acquisition phase, the node transmits a RTS packet for channel acquisition. When the channel has been ideal for the required amount of time, as decided by the grade of its data packet. If it receives a CTS packet in return, and the channel acquisition finishes successfully else, the third phase of collision resolution is initiated by sending out a BB [29, 30]. The duration of the BB for a node is in order of identification (Id) number. The nodes that generates a lot of real-time data are given higher Id numbers. The node that sends out the longest burst accesses the channel at the subsequent attempt.

In the DB-DCF, the first phase is for BB contention where in the lengths of the BB packets are proportional to the relative deadlines of the real-time packet. This is followed by phases for channel acquisition and collision resolution, which are similar to the corresponding phases in ES-DCF.

Both schemes assign channel-free wait time longer than DIFS to the non- real-time nodes and these nodes are allowed to transmit only when no data in wait state that to be sent by the other real-time nodes. The simulations results carried shows that ES-DCF is more suitable when hard real-time traffic is to send, and nodes with soft real-time packets are handled in better way by DB-DCF scheme. Due to the use of BB and longer (than DIFS) channel-free wait time for non- real-time traffic, these schemes cannot be directly override any existing IEEE 802.11 DCF implementation.

2) Asynchronous MAC Protocols Based On Use of Reservation:

The following MAC protocols are the examples of this category:

2.1) Multiple Access Collision Avoidance with Piggyback Reservations (MACA/PR):

The MACA/PR architecture was proposed by Lin and Gerla to provide effective real-time multimedia support over ad hoc networks [33]. MACA/PR is an extended version of IEEE 802.11 [6-8] and FAMA [4]. The architecture of it the combination of a MAC protocol, a resource reservation protocol and a QoS aware routing protocol. Here only MAC protocol being discussed.

A special reservation table is maintained in MACA/PR by every nodes that tells them when a packet is due to be transmitted. The reservations sets up along the entire path is done by the first data packet of real-time data stream by using the standard RTS-CTS approach. The header of these control packets contain the information regarding the expected length of the data packet. After the resource reservation on a the link, a transmission slot is allocated to the sender and the next receiver node at suitable time intervals (typically in the next time cycle) for the successive packet of that stream. The sender also piggybacks the information related to reservation for the consequent data packet in the current data packet. The receiver store this reservation information in its reservation table, and acknowledge it by ACK packet.

The other neighbouring nodes listening the data and ACK packets, sets its back-off value according to the subsequent packet transmission schedule. The ACK only helps to renew the reservation, as the data packet is not retransmitted even if the ACK is lost due to collision. If the sender successively fails to receive ACK N times, it assumes that the link cannot satisfy the bandwidth requirement and informs the upper layer. Since there is no RTS-CTS exchange after the first data packet, collision prevention of real-time packets is through the use of the reservation tables and non-real-time data packet uses IEEE 802.11 DCF.

The authors have demonstrated using simulations that this MACA/PR scheme is realize a lower end-to-end delay than other time synchronization scheme. Though, the cluster based schemes can achieve higher aggregate throughput efficiency by using code separation. The main reason for lower throughput achieved by MACA/PR is the overhead of frequent transmission of control packet that are used to kept reservation tables updated.

2.2) Asynchronous QoS Enabled Multi-Hop MAC:

This asynchronous scheme is proposed by Ying et al. [34] that based on the IEEE 802.11 DCF. This scheme supports constant bit-rate (CBR) and variable bit rate (VBR) real-time traffic, and also regular non-real-time datagram traffic. The basic RTS-CTS-DATA-ACK sequence is used between the sender and the receiver for non-real-time data transmission. Here we use two different acknowledgments in response to non-real-time and real-time packets and these known as D-ACK and R-ACK, correspondingly. In the same way, the nonreal-time and real-time data packets are named as D-PKT and R-PKT, correspondingly. In the case of real-time traffic, RTS-CTS exchange is not used and the data packets are delivered subsequently the first R-PKT as we used in MACA/PR scheme [33]. This R-ACK packet reserves the transmission slot for the subsequent real-time data packet. In this scheme every node maintain two reservation tables, R_xRT and T_xRT. The former informs the node when neighbours expect incoming (to transmit) real-time traffic. Corresponding table records these estimations based on the overhearing of R-PKT and R-ACK packets. The nodes look for a common free slot based on the information in the reservation tables before sending any RTS so that no interference with real-time transmissions already in the queue at the neighbourhood. Correspondingly, if a node receives an RTS, it does the same checks before replying against a CTS packet. Then data is sent out after a successful RTS-CTS exchange, and an ACK is replied. If an ACK is lost, the node starts to backoff and uses the IEEE 802.11 contention windows.

This scheme allows for bounded delays in real-time traffic but depends on the overhearing within each node's transmission range of R-PKT and R-ACK packets to avoid hidden node problem. Both the receiver and transmitter nodes check their own tables, thereby removing the overhead of exchanging table statistics. The authors using simulations, have demonstrated that this scheme achieves lower delays for real-time traffic than Black Burst Contention, MACA/PR and DFS [36] schemes. The packet loss rates are also relatively small.

Dynamic Bandwidth Allocation/Sharing/Extension (DBASE) protocol that also use reservation tables to support real-time traffic proposed by Sheu et al. [35]. This scheme a inimitable feature of dynamical change in depicts bandwidth allocation over time, which permits effective support of CBR as well as VBR traffic. The scheme gain very high throughput and low packet loss probability for realtime packets even at heavy traffic load, and beats the IEEE 802.11 DCF [23-25] and DFS [36] schemes. But this scheme assumes one hop ad hoc networks and not suitable for multihop ad hoc networks with hidden terminals. Generally, DBASE is a fairly dissimilar scheme than the other two reservation based schemes.

3) Asynchronous MAC Protocols Based on use of Fair Sharing:

Distributed Fair Scheduling is the examples of this category:

3.1) Distributed Fair Scheduling (DFS):

Distributed Fair Scheduling is proposed by Vaidya et al. [36]. This scheme is provide guarantee that the different flows that share a common wireless channel are allocated suitable bandwidth according to their priorities or weights. DFS is inherited from the IEEE 802.11 DCF scheme and not required any central coordinator to control the access to the medium. The basic principle of DFS is to attach start and finish timestamps with each packet. A packet with higher priority is assigned a shorter backoff periods and small finish timestamp. This approach confirms that packets assigned higher priority will regularly have shorter backoff times, thus it achieve a higher throughput.

This scheme use Self-Clocked Fair Queuing (SCFQ) algorithm proposed by Golestani [37] to calculate the start and finish timestamps for the packets. As per the SCFQ algorithm, a local virtual clock is maintained at every node of the ad hoc DFS does not, however, REMOVE short-term network. unfairness in certain cases. The authors observe that the use of collision resolution schemes such as those proposed in [38] can resolve this anomaly. In order to calculate backoff intervals, the authors have proposed two alternate approaches: linear mapping and exponential mapping. A disadvantage of the linear mapping scheme is that if many packet flows have low priorities, all of them are assigned large backoff intervals. As a result, the system remains idle for long periods of time. The exponential mapping approach is proposed as one solution to this problem.

Using simulations, the authors have shown that DFS obtains a higher throughput than IEEE 802.11. Also, they have verified that use of exponential mapping technique for calculating backoff intervals leads to higher throughput than linear mapping. However, the DFS does not consider the hidden terminal problem and delay bound of real-time packets [35]. Nandagopal et al. [39] have also proposed a general analytical framework for modeling the fairness.

IV. CONCLUSION

In this review paper we briefly discussed major QoS aware MAC protocol especially asynchronous protocols. These asynchronous MAC protocols are more suitable for mobile ad hoc networks as these networks do not have centralized controlling node. As multimedia applications are growing over such ad hoc networks, QoS parameters and issues become more important. The MAC layer plays an important role in the performance of the overall system, affecting other layers in particular the network layer. Here discussed various MAC protocols that provides provision for Quality of Service means support multimedia traffic. The advantages and disadvantages are discussed for each protocol.

REFERENCES

- S. Chakrabarti and A Mishra, "QoS Issues in Ad Hoc Wireless Networks," IEEE Commun.Mag., Vol. 39(2), Feb. 2001, pp. 142-48. http://dx.doi.org/10.1109/35.900643
- [2] E. M. Royer and C. K. Toh, "A Review of Current Routing Protocols for Ad Hoc Mobile Wireless Networks," IEEE Personal Commun., Vol. 6(2), April 1999, pp. 46-55. http://dx.doi.org/10.1109/98.760423
- [3] I. F. Akyildiz, J. McNair, L.C. Martorell, R. Puigjaner and Y. Yesha, "Medium access control protocols for multimedia traffic in wireless networks," IEEE Network, Vol. 13, July/August 1999, pp. 39-47. http://dx.doi.org/10.1109/65.777440
- [4] C. L. Fullmer and J. J. Garcia-Luna-Aceves, "Floor Acquisition Multiple Access (FAMA) for Packet-Radio Networks," Proc. ACM SIGCOMM, Cambridge, MA, Aug. 28 - Sep. 1, 1995.
- [5] K. C. Chen, "Medium Access Protocols of Wireless LANs for Mobile Computing," IEEE Network, Vol. 8(5), 1994, pp. 50-63. http://dx.doi.org/10.1109/65.313014
- [6] IEEE 802.11 Working Group, "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, 1997.
- [7] Bob O'Hara and Al Petrick, IEEE 802.11 Handbook: A Designer's Companion, IEEE Press 1999.
- [8] B. P. Crow, I. Widjaja, J. G. Kim and P. T. Sakai, "IEEE 802.11 wireless local area networks," IEEE Commun. Mag., Sept. 1997. http://dx.doi.org/10.1109/35.620533
- [9] P. Mahapatra, J. Li, C. Gui, "QoS in Mobile Ad Hoc Networks," IEEE Wireless Commun., Vol. 10(3), 2003, pp. 44-52. http://dx.doi.org/10.1109/MWC.2003.1209595
- [10] D. Chalmers and M. Slomon, "A survey of quality of service in mobile computing environments," IEEE Commun. Surveys, Vol. 2(2), 1999.
- [11] D. D. Perkins and H.D. Hughes, "A survey on quality-of-service support for mobile ad hoc networks," Wirel. Commun. Mob. Comput., Vol. 2, 2002, pp. 503-513. http://dx.doi.org/10.1002/numr.72
 - http://dx.doi.org/10.1002/wcm.73
- [12] A. Veres, A. T. Campbell, M. Barry and L. H. Sun, "Supporting Service Differentiation in Wireless Packet Networks Using Distributed Control," IEEE J. of Sel. A. in Commun., Vol. 19(10), 2001, pp. 2081-93.
- [13] D. Thomson, N. Schult and M. Mirhakkak, "Dynamic Quality-of-Service for Mobile Ad Hoc Networks," MobiHoc 2000, Boston, Massachusetts, USA.
- [14] H. Xiao, W. K. G. Seah, A. Lo and K. C. Chua, "A Flexible Quality of Service Model for Mobile Ad-hoc Networks," IEEE VTC-Spring, Japon/Tokyo, 2000.
- [15] N. Nikaein and C. Bonnet, "A Glance at Quality of Service Models for Mobile Ad Hoc Networks," 16eme Congrès DNAC (De Nouvelles Architectures pour les Communications), Paris, Dec. 2-4, 2002.
- [16] G. S. Ahn, A. T. Campbell, A. Veres and L. H. Sun, "SWAN: Service Differentiation in Stateless Wireless Ad Hoc Networks," IEEE INFOCOM, 2002.
- [17] S. B. Lee and A. T. Campbell, "INSIGNIA: In-band Signaling Support for QoS in Mobile Ad Hoc Networks," Proc. 5th International Workshop on Mobile Multimedia Communication MoMuc, October 12-14, 1998, Berlin, Germany..

- [18] Multimedia Operating Systems and Networking (MONET) Group, "iMAQ: An Integrated Mobile Ad-hoc QoS Framework," http://cairo.cs.uiuc.edu/adhoc/
- [19] C. R. Lin and J. S. Liu, "QoS Routing in Ad Hoc Wireless Networks," IEEE J. Sel. A. Commun., Vol. 17, No. 8, Aug. 1999.
- [20] M. Gerla and J. Tzu-Chieh Tsai, "Multicluster, Mobile, Multimedia Radio Network," Wireless Networks, Vol. 1, 1995.
- [21] C.R. Lin and M. Gerla, "Adaptive clustering for mobile wireless networks," IEEE J. Sel. A. in Commun., Vol. 15(7), 1997, pp. 1265-75.
- [22] C.-H. Lin, A Multihop Adaptive Mobile Multimedia Network: Architecture and Protocols, Ph.D. disseration, CS Department, Univ. of California, Los Angeles, 1996.
- [23] C. W. Ahn, C.G. Kang and Y. Z. Cho, "Soft reservation multiple access with priority assignment (SRMA/PA): A novel MAC protocol for QoS-guaranteed integrated services in mobile ad-hoc networks," Proc. IEEE VTC, Vol. 2, pp. 942-47, 2000.
- [24] R. O. Baldwin, N. J. Davis IV and S. F. Midkiff, "A Real-time Medium Access Control Protocol for Ad Hoc Wireless Local Area Networks," Mobile Computing and Commun. Rev., Vol. 3(2), 1999, pp. 20-27.

http://dx.doi.org/10.1145/584027.584028

- [25] D. J. Deng and R. S. Chang, "A Priority Scheme for IEEE 802.11 DCF Access Method," IEICE Trans. Commun., E82-B(1), Jan. 1999, pp. 96-102.
- [26] M. Benveniste, G. Chesson, M. Hoeben, A. Singla, H. Teunissen and M. Wentink, "EDCF Proposed Draft Text," IEEE Working Document 802.11-01/12 1r1, March 2001.
- [27] S. Choi, J. del Pedro, N. S. Shankar and S. Mangold, "IEEE 802.11e contention-based channel access (EDCF) performance evaluation," Proc. IEEE ICC, May 2003.
- [28] S. Mangold, S. Choi, P. May, O. Klein, G. Hiertz and L. Stibor, "IEEE 802.11e wireless LAN for quality of service," Proc. European Wireless, Florence, Italy, 2002.
- [29] J. L. Sobrinho and A. S. Krishnakumar, "Real-time Traffic Over the IEEE 802.11 Medium Access Control Layer," Bell Labs Technical Journal, Vol. 1, Autumn 1996, pp. 172-187.
- [30] J. L. Sobrinho and A. S. Krishnakumar, "Quality-of-Service in Ad Hoc Carrier Sense Multiple Access Wireless Networks," IEEE J. Sel. Areas in Commun., Vol. 17(8), Aug. 1999, pp. 1353-1368. http://dx.doi.org/10.1109/49.779919
- [31] A. Pal, A. Dogan and F. Ozguner, "MAC layer protocols for real-traffic in ad-hoc networks,"Proc. IEEE Intl. Conf. Parallel Processing, 2002. http://dx.doi.org/10.1109/ICPP.2002.1040911
- [32] A. Pal, Distributed MAC Layer Protocols for Real-Time Communication in Ad-Hoc WirelessNetworks, M.S. Thesis, Ohio State University, 2001.
- [33] C. R. Lin and M. Gerla, "MACA/PR: An Asynchronous Multimedia Multihop Wireless Network," Proc. IEEE INFOCOM, March 1997. http://dx.doi.org/10.1109/INFCOM.1997.635121
- [34] Z. Ying, A.L. Anand and L. Jacob, "A QoS enabled MAC protocol for multi-hop adhoc wireless networks," Proc. 22nd IEEE Intl. Performance, Computing, and Commun. Conf. (IPCCC), Phoenix, AZ, April 2003, pp. 149-156.
- [35] S.-T. Sheu and T.-F. Sheu, "A bandwidth allocation/sharing/extension protocol for multimedia over IEEE 802.11 ad hoc wireless LANs," IEEE J. Sel. Areas in Commun., Vol. 19(10), Oct.. 2001, pp. 2065-80. http://dx.doi.org/10.1109/49.957320
- [36] N. H. Vaidya, S. Bahl and S. Gupta, "Distributed fair scheduling in a wireless LAN," 6th Annual Intl. Conf. Mobile Computing and Networking, Boston, August 2000.
- [37] S. J. Golestani, "A Self-Clocked Fair Queuing Scheme for Broadband Applications," IEEE INFOCOM, 1994.
- [38] R. Garces and J. J. Garcia-Luna-Aceves, "Near-Optimum Channel Access Protocol Based on Incremental Collision Resolution and Distributed Transmission Queues," IEEE INFOCOM, March-April, 1998.
- [39] T. Nandagopal, T.-E. Kim, X. Gao and V. Bharghavan, "Achieving MAC layer fairness in wireless packet networks," Proc. MOBICOM, Boston, MA, Aug. 2000. http://dx.doi.org/10.1145/345910.345925