A Fair Scheduling using Spectrum Load Smoothing Algorithm for Mesh Networks

Zheng Xie, Guido R. Hiertz, Sebastian Max

Abstract—**Fair distributed scheduling is always a big challenge issue in wireless mesh networks. In this work we focus on the IEEE 802.11s proposal by the Mesh Network Alliance (MNA) which aims to enhance the legacy 802.11 medium access protocol to enable efficient mesh operation. We propose an Enhanced Distributed Reservation Protocol (EDRP) to achieve fair scheduling in wireless mesh networks. Our protocol calculates fair shares for all links in the local network in a distributed manner. Each Mesh Point (MP) in the network learns the traffic requirements of all MPs in the local network by analyzing received beacons from its neighbors. With the usage of the acquired knowledge of all neighboring links, MPs are able to calculate the shares of the resources that they should occupy by performing Spectrum Load Smoothing (SLS) Algorithm. We implement this fair scheduling schemes in the WARP2 simulator and compare its performance with which using the Distributed Reservation Protocol (DRP), that executes medium occupation with First-Come-First-Served (FCFS) scheduling discipline. The simulation results show that our solution is fair and collision-free.**

Index Terms—**Fair scheduling, Mesh WLAN, dynamic resource allocation, IEEE 802.11s, Spectrum Load Smoothing.**

I. Introduction

802.11, developed by a Working group of the Institute of Electronics and Electrical Engineering (IEEE) starting from 1997, is the base standard for the Wireless Local Area Network (WLAN) Medium Access Control (MAC) layer and Physical Layer (PHY) specifications. Currently, a new topology of WLANs, the *Mesh Networks*, gains attention of the international scientific community and has led the IEEE to the creation of a special task group – IEEE 802.11 Task Group (TG) “s” [1]. This task group aims to extend WLAN range by allowing data to pass through wireless nodes bringing coverage beyond the typical WLAN connectivity limit of 100 m from an Access Point (AP). In such networks, Mesh Access Points (MAPs) and forwarding-only Mesh Points (MPs) are interconnected with wireless links, which constructs a Wireless Distribution System (WDS) and enables automatic topology learning and dynamic path configuration. MAPs and MPs relay information from one to another, hop-by-hop (multi-hop), in a router-like fashion.

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A proposal for 802.11s [2], which has been developed at the Chair of Communication Networks RWTH Aachen University (Comnets), is able to fulfill the demands using an extensible single transceiver solution. To separate intra Basic Service Set (BSS) and forwarded traffic, time is divided into two periods: the BSS Period and the Mesh Period. In the former, BSS traffic is dealt with, in the latter the associated Stations (STAs) are silenced via the announcement of a Contention Free Period (CFP). In this way, a protocol that is especially designed for multi-hop ability can be used during the Mesh Period without interferences. Medium access in CFP is handled by the Distributed Reservation Protocol (DRP) which allows a decentralized reservation of time periods for transmissions. The DRP is presented together with the Beacon Period Access Protocol (BPAP) which enables a collision-free transmission of the Information Elements (IEs) used for the reservation.

However, the DRP does not provide fair scheduling. Existing reservations cannot be reallocated unless the reservation owner withdraws its reservation. To solve these problems an Enhanced Distributed Reservation Protocol (EDRP) proposal is provided in this paper. EDRP introduces the Spectrum Load Smoothing (SLS) algorithm to enable a fair sharing of the Wireless Medium (WM) among neighboring MPs in decentralized Mesh WLAN.

As a fundamental principle, EDRP enables links to share the capacity of the WM pro rata. Hence, a link which carries more data, dominates in the Mesh Transmission Opportunities (MTxOPs) reservation. It occupies more MTxOPs than a link, which is used to send less data. In order to actualize a fair pro rata apportionment of the medium to every link, each MP needs knowledge about requests from all active links in its neighborhood. Therefore, a Link Information Database (LIDB) is built and updated continuously at each MP. The latest information about all active neighboring links is stored. With the help of the SLS algorithm, EDRP exhibits a *smoothing* effect with a fixed number of links in Mesh WLAN. New links joining a Mesh use EDRP to *fairly* obtain MTxOPs from other links.

This paper is organized as follows. In section II the MNA’s 802.11s MAC proposal is outlined, comprising the BPAP and the DRP. Section III describes the EDRP in detail, which improves the DRP and combines the SLS algorithm to provide a possibility to design a fair scheduling in Mesh WLAN. Simulation results for two simple scenarios are presented in section IV. Finally, the paper ends with some concluding remarks.

II. MNA's 802.11s Medium Access Control Proposal

The purpose of foundation of the Mesh Network Alliance (MNA) is to participate successfully at the standardization process carried out by the TG 802.11s. A proposal of the MNA 802.11s, which have been developed at Comnets, designs an 802.11s MAC protocol to address many representative issues that appear mainly in distributed networks, such as hidden node problem, exposed node problem, congestion control along a multi-hop mesh path etc.. A deeper insight to the proposal can be found in [1]. In the following the term MP is also used for MAP for simplification.

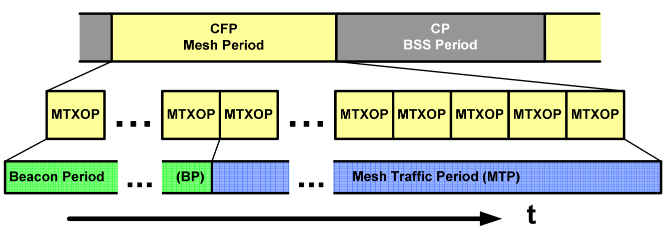


Fig. 1. Frame structure of the MNA 802.11s proposal: The CFP and the CP alternate in time, during the CFP mesh traffic among MPs is handled, whereas in CP the legacy BSS traffic between AP and the associated STAs appears.

In the current MNA 802.11s proposal, time is divided into two alternate phases, namely the BSS Period and the Mesh Period. A BSS Period and a Mesh Period together constitute a superframe which can be seen in Figure 1. In BSS Period the stations in BSS communicate with each other pursuant to the legacy WLAN 802.11 standard. By declaration of a CFP, only mesh traffic between MPs is allowable. Each Mesh Period is subdivided into MTxOPs that construct a Beacon Period (BP) and a Mesh Traffic Period (MTP).

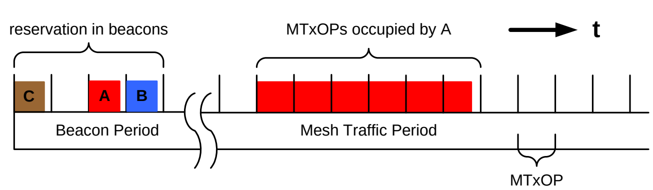


Fig. 2. Time flow of a Mesh period including a BP and a MTP: In BP reservations of MTxOPs in the upcoming MTP for each active MP .is carried out by using DRP.

MNA 802.11s proposal provides a reservation-based collision-free mesh protocol in the Mesh Period. The medium sharing among MPs during the BP is accomplished by the BPAP. Figure 2 gives a time flow of a typical Mesh Period including a BP. In the course of a BP, all MPs send beacons one after another, whereby the organization of the traffic in the upcoming MTP is performed. The decentralized medium assignment during the MTP is conducted by means of the DRP. With the help of the DRP, the occupation of MTxOPs in the upcoming MTP is negotiated between transmitter and receiver. After BP every MP knows which MP transmits and which receives at which point in time. When a MP gets several MTxOPs in the upcoming MTP, it is able to transmit data in these slots without causing collisions. A detailed description of the BPAP and the DRP is presented in [1].

III. Enhanced Distributed Reservation Protocol

The MNA's 802.11s proposal provides an adequate MAC proposal to support the WDS. It describes how the MPs interact with each other by giving strict rules, how to react to received messages, how to structure reservation requests and how to transmit data.

However, the current MNA's 802.11s proposal does not support functionalities for

- *fair scheduling* among routes and
- *medium access* for new links, when the WM is completely occupied by existing links and no free resources are available.

The reason is that using DRP of the MNA's 802.11s proposal in overload situations the MTxOPs occupation is carried out in First Come, First Served (FCFS) way, the first coming links are able to occupy resources preferentially as many as possible and keeps them. The links with later initiated traffic can only access the remaining MTxOPs, and are thereby put at a disadvantage.

To solve these problems an Enhanced Distributed Reservation Protocol (EDRP) is provided in this paper, which lies on the DRP of the current MNA's 802.11s proposal. EDRP introduces the Spectrum-Load-Smoothing (SLS) algorithm to enable a fair sharing of the WM among neighboring MPs in decentralized Mesh WLAN.

A. Basic Principles of the Enhanced Distributed Reservation Protocol

Fair scheduling among routes is link-oriented. A link is identified by the priority of transmitted data, device ID of the sending MP and device ID of the intended receiver. According to the amount of data to transmit, the capacity of the WM is shared among all participating links. Using EDRP the link, which carries more data in the upcoming MTP, dominates in the MTxOPs reservation. It shall occupy more MTxOPs than the link, which is just used to send less data. Therefore, a fundamental principle of the EDRP is that each link occupies corresponding amount of MTxOPs pro rata.

1) Link Information Database: In order to accomplish a fair pro rata apportionment of the medium to every link, each MP needs knowledge about requests of all active links in its neighborhood. Thereby it can evaluate the share that every link shall have, and judge which links should get more MTxOPs, which links have already owned enough MTxOPs, and probably they can contribute MTxOPs to the other MTxOPs-requesting links. Therefore, each MP maintains a Link Information Database (LIDB), in which information about each active link in the neighborhood is stored, such as

- Block Length (BL): the requested data block length of a link for the upcoming MTP,
- Lacking Slots (LS): the amount of MTxOPs, which a link still needs to reserve to fulfill its traffic requirements,
- Threshold: a limit value of the number of MTxOPs, which a link ought to own at least in the upcoming MTP,

and so on. The LIDB at each MP is continually updated by receiving Ownership Information Elements (OIEs) within beacons from other active MPs in the neighborhood. Threshold of a link can be calculated through the Total Block Length (TBL_{prior}) requested by all links with a certain priority and the Block Length of this link ($BL_{Tx\rightarrow RX,\,prior}$):

$$Threshold_{Tx\rightarrow Rx,\,prior} = \left\lceil \frac{allOccupiedSlots_{prior}}{TBL_{prior}} * BL_{Tx\rightarrow Rx,\,prior} \right\rceil. \quad (1)$$

$allOccupiedSlot_{prior}$ is used to denote the number of MTxOPs that are occupied by all active links in a neighborhood to transmit mesh data traffic with the priority *prior*. A link which is used for more traffic wishes shall occupy more MTxOPs in the upcoming MTP, while another one has less transmission intention shall be apportioned less resources.

In the following paragraphs an enhanced handshake of medium occupation negotiation between a sender and the intended receiver is depicted. Using DRP the problems always occur in situations, where routes are overloaded. Therefore, overload traffic circumstances are discussed with emphasis in what follows.

2) EDRP Flow Chart on Transmitter's Side: When a new traffic flow needs some MTxOPs at a transmitter, but yet the overall medium is nearly completely allotted to some other MPs in its neighborhood, the sender will firstly calculate the necessary resources $Threshold_{Tx\rightarrow RX,\,prior}$ for the link, which include specification of the intended receiver and traffic priority. Then it tries to occupy the rest useable MTxOPs according to its internal bitmap, and ascertains the number of lacking MTxOPs. Finally a beacon including a OIE, which contains BL and LS of this link, is sent by the transmitter.

3) EDRP Flow Chart on Intended Receiver's Side: After receiving the beacon the intended receiver of this link evaluates weather the link shall be apportioned more resources. In case the link represented by the received OIE needs more MTxOPs, because the amount of its occupied MTxOPs is less than requested ($successMTxOPs_{Tx\rightarrow Rx} < Threshold_{Tx\rightarrow Rx}$), the reassignment of a certain amount of MTxOPs w from other links to this link is done via execution of a SLS algorithm by using (2). Each of those links is characterized that it has occupied more MTxOPs than it should have owned (more than its $Threshold_{Txi\rightarrow Rxi}$). The amount of MTxOPs $w_{Txi\rightarrow Rxi}$, which are redistributed by SLS using (3), depends on a percentage of the MTxOPs held by the link *i*. That means, a link which occupies more MTxOPs shall contribute more its MTxOPs to eager links.

w can be computed as

$$w = \left\lceil \frac{Threshold_{Tx\rightarrow Rx} - successMTxOPs_{Tx\rightarrow Rx}}{activeLinks_{prior}} \right\rceil. \quad (2)$$

$activeLinks_{prior}$ denotes the number of active links in neighborhood, that are used to transmit traffic with a priority *prior*. By use of division with the $activeLinks_{prior}$, a gradual release of occupied recourses is realizable, whereby the expected MTxOPs will be step by step assigned to the MTxOPs-wanted link.

Each link i that has enough MTxOPs can free the ownership of $w_{Txi\rightarrow Rxi}$ MTxOPs. $w_{Txi\rightarrow Rxi}$ can be computed as

$$w_{Tx_i\rightarrow Rx_i} = \left\lceil \frac{w}{allOccupiedSlots_{prior}} * successMTxOPs_{Tx_i\rightarrow Rx_i} \right\rceil. \quad (3)$$

$successMTxOPs_{Txi\rightarrow Rxi}$ is used to denote the amount of MTxOPs reserved by link i currently.

After that the receiver must decide which MTxOPs in MTP occupied currently by those neighboring links shall take precedence to be released and assigned to its link. Finally, after accomplishment of resources redistributions the intended receiver sends a beacon to inform all its neighboring MPs about the new allocation of MTxOPs in upcoming MTP. A deeper insight to SLS algorithm can be found in following section.

B. Iterative Spectrum-Load-Smoothing Algorithmus

The general idea of the iterative SLS algorithm is weighted equipartition of available MTxOPs for all links in a neighborhood, which was inspired by the work *Spectrum Load Smoothing as Decentralized Coordination of Coexisting Wireless Nerworks* [3]. The principle of SLS is derived from the idea of *water-filling*, which is well known in the field of multi-user information theory and communications engineering. A detailed usage and application of water-filling can be found in [4]–[6].

SLS algorithm is suitable for decentralized coordination. Using this approach in EDRP, the achievement of following two purposes is possible:

- SLS enables fair bandwidth sharing among all links in a neighborhood.
- The equilibrium of the MTxOPs occupation with all active links in a neighborhood is gradually reachable.

The basic SLS scheduling algorithm used in this paper is outlined in Figure 3. SLS algorithm handles received OIEs separately at each MP. In the first step of the scheduling, the LIDB is updated according to a received OIE. The SLS is further executed by a MP, if this MP is the intended receiver of the link represented by the received OIE, and the link is starveling (i.e., it does not occupy enough MTxOPs and needs more MTxOPs). Furthermore, one of the following conditions must be satisfied:

1. There are MTxOPs indicated as free in the internal map of this MP.
2. The MP can not find free MTxOPs in its internal map, but it detects other neighboring saturated links by using its LIDB. A link is regarded as saturated, if it occupies sufficient MTxOPs and can contribute some of them for other MTxOPs-expecting links.

If neither of the conditions is held, SLS terminates. In the next step, a certain amount of MTxOPs *w* is calculated using (2). Free MTxOPs are assigned to the starveling link in the first instance, when there are some revealed in the internal map. After that, the SLS scheduler at this MP repeats a cycle until all saturated links in its LIDB are visited or the demand of the starveling link is met. In the cycle, a saturated link is chosen from the LIDB and the number of MTxOPs $w_{Txi \rightarrow Rxi}$ occupied by it that should be handed over to the starveling link is computed using (3). Then the MP selects these MTxOPs with the lowest priorities in the internal map allotting to the starveling link. Finally, the LIDB is updated for adapting the medium reassignment.

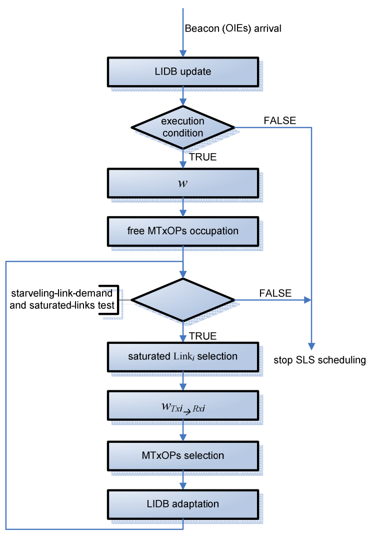


Fig. 3. Iterative Spectrum-Load-Smoothing Algorithm.

With the help of the SLS algorithm, EDRP presents a *smoothig* effect with a fixed number of in Mesh WLAN in overload situations. With varying number of links, new links joining a Mesh are able to *fairly* gain MTxOPs from other links.

C. Bandwidth Dispensation According to the Traffic Priorities

The parameter $allOccupiedSlot_{prior}$ (see (1), (3)) is used to compute

- Threshold value for each link in LIDB and
- the value of $w_{Txi \rightarrow Rxi}$ for each contributing link.

In many cases several data traffic priorities appear in Mesh WLAN, so a general expression of $allOccupiedSlot_{prior}$ is needed. According to the traffic priority *prior*, $allOccupiedSlot_{prior}$ means the maximum number of MTxOPs that can be occupied by all links with *prior*, and is defined as

$$allOccupiedSlots_{prior} = \left\lceil \frac{t_{MTP} - t_{BP} - t_{ACK}}{2^{\,l-2-m_{prior}}} \right\rceil, \qquad (4)$$

where l denotes the total number of priorities in a neighborhood [1] and m_{prior} varies with *prior* as given in Table I. $prior_1$ is the highest priority except for the priority of acknowledgments in all existing priorities. The effect of this formula can be illustrated for example like in Figure 4. If a link is used to transmit acknowledgments, the Threshold value of the corresponding link information in LIDB is equal to its Block Length. Therefore, $allOccupiedSlot_{prior}$ is useful for data traffic. It is unwanted for acknowledgment traffic with $prior = 9$.

TABLE I

$l - 2$	m_{prior1}	m_{prior2}	m_{prior3}	m_{prior4}	m_{prior5}	m_{prior6}	m_{prior7}	m_{prior8}
0	0							
1	0	0						
2	1	0	0					
3	2	1	0	0				
4	3	2	1	0	0			
5	4	3	2	1	0	0		
6	5	4	3	2	1	0	0	
7	6	5	4	3	2	1	0	0

The value of m_{prior}: l indicates the total number of priorities in a neighborhood, and m_{prior} varies with the *prior*. $prior_1$ is the highest priority except for the priority of acknowledgments in all existing priorities. In general $prior_1 > prior_2 > \ldots > prior_8$ applies.

(a) The *allOccupiedSlots* with only one data-traffic-priority: 0.

(b) The *allOccupiedSlots*s for two data-traffic-priorities: 0 and 1.

(c) The *allOccupiedSlots*s for three data-traffic-priorities: 0, 1, and 4.

(d) The allOc*cupiedSlots*s for four data-traffic-priorities: 0, 1, 2, and 4.

(e) The allOc*cupiedSlots*s for five data-traffic-priorities: 0, 1, …, 4.

Fig. 4. $allOccupied\ Slots_{prior}$ with multi-priority

IV. Evaluation

EDRP and SLS are integrated into the Wireless Access Radio Protocol 2 (WARP2) simulation environment, developed at the Chair of Communication Networks, RWTH Aachen University. WARP2 is implemented in Specification and Description Language (SDL) using Telelogic's TAU

SDT, which is widely used in the telecommunication area, especially for analyzing protocols. It allows to run event-driven stochastic simulations to evaluate the performance of the EDRP by the MNA for IEEE 802.11s.

In the following, we take advantage of two scenarios to compare the performance of mesh networks using EDRP with those using DRP in *overload* situations. For all simulations, the durations of the Mesh Period and the BSS Period are both fixed to 32 MTxOPs as given in Figure 5, in which the duration of an MTxOP is equal to 256 µs. Consequently, the presented protocol is only used half the time. Furthermore, each offered traffic is increased stepwise during the first second from 25% to 100% of the final setting which simulates the traffic source using the slow-start mechanism of the Transfer Control Protocol (TCP). And only one data traffic priority is considered in the simulations.

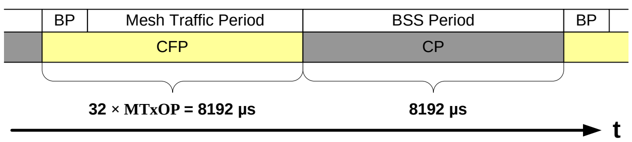


Fig. 5. Simulation parameters

A. *Fair Scheduling for a New Link with an Existing Link*

With the help of EDRP new links can fairly obtain MTxOPs from other links, when the wireless medium is completely occupied and no free MTxOPs are available any more. To demonstrate the performance of EDRP for this effect, the first investigated scenario is presented in Figure 6: MP A transmits data to MP B. Data transmission on Route 2 begins 10 s later. The size of packets, which are created by the traffic sources at both MPs, is 80 B with a constant bit rate. BPSK ½ (6 Mb/s) modulation is used for the both transmissions.

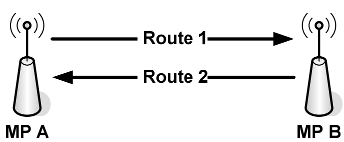
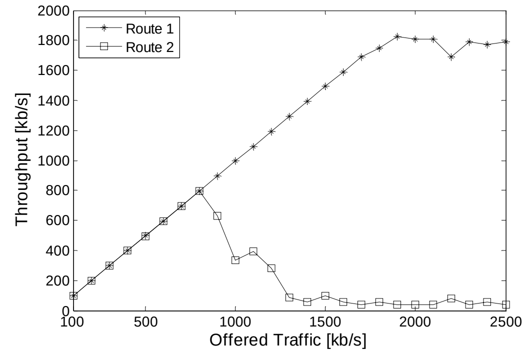
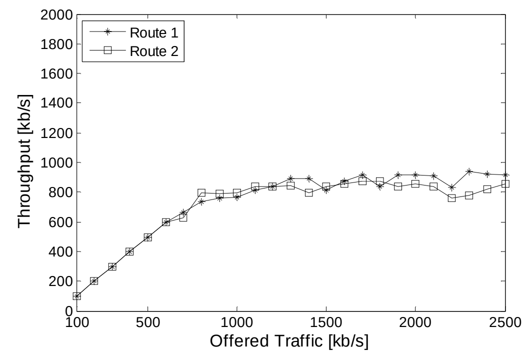


Fig. 6. Simulation scenario for evaluation of EDRP with two routes: MP A transmits traffic to MP B on route 1; the data flow on the second route starts 10 s later.

The simulation results are shown in Figures 7 – 8. A clear advantage of the EDRP proposal can be seen in the comparison of throughput analysis indicated in Figure 7: Using DRP the saturation point of the routes is reached at about 800 kb/s per route, which cumulates to a system throughput of 1600 kb/s. Above this point a throughput increase is still possible, but only with the suppression of the Route2. Route 1 suppresses Route 2 until it uses more than 98% of the available bandwidth. When using EDRP (Figure 6b), each route is saturated at about 700kb/s. Unfair medium sharing by dominating routes is avoided. By executing SLS algorithm, Route 2 tries to obtain MTxOPs from Route1. As a consequence, the throughputs of both routes are nearly equal to each other with any offered traffic including overloaded cases. The available bandwidth can be fairly shared among the two routes.



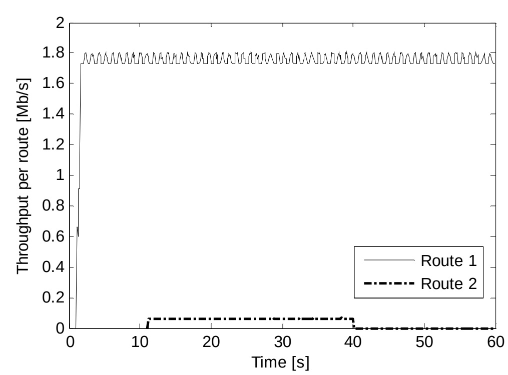
(a) Cumulative throughput using DRP.



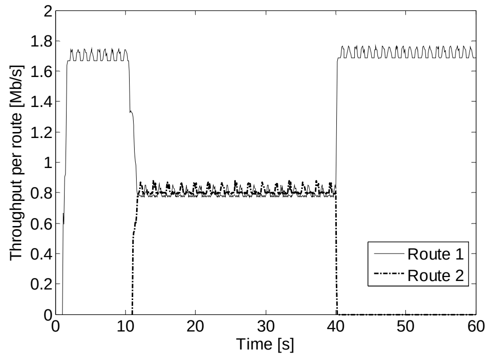
(b) Cumulative throughput using EDRP.

Fig. 7. Simulation results of the Figure 3: cumulative throughput for the traffic between MPs, offered traffic is given per route.

Figure 8 shows the throughput of each route at an offered traffic of 1800 kb/s per route, which is above the saturation point. The data flow on Route 2 starts 10 s later than the data on Route 1, and stops at 40 s. With the usage of DRP, Route 2 achieves very little throughput during the whole simulation time, because it can hardly occupy any MTxOPs of the medium in overload situations. With the usage of EDRP, both routes share nearly the same throughput between 12 s and 40 s. Thereafter the medium can be occupied completely by Route 1 again as there are no packets transmitted on Route 2 any more.



(a) Throughput of each route using DRP.



(b) Throughput of each route using EDRP.

Fig. 8. Simulation results of the Figure 3: throughput of each route, offered traffic is 1800 kb/s per route.

B. *Fair Reallocation of Established Medium Reservations to two Additional Links*

The second scenario setup, displayed in Figure 9, is used to verify the ability of EDRP to gradually and fairly redistribute MTxOPs from existing links, which have completely shared the medium, to several nearly coinstantaneous new links. The mesh network consists of four MPs and four routes. MPs A, C, and D are in the neighborhood of MP B. MP A and B transmit data to MP B and C separately. To simulate asynchronous independent traffic streams, the data flows on both routes are initialized at different times, here the traffic on $Route_{B \to C}$ starts 0.1 s later than $Route_{A \to B}$. The data flow on $Route_{D \to B}$ starts 5 s later and $Route_{C \to D}$ starts another 1 s later than the traffic on $Route_{D \to B}$. The traffic source at each MP creates 80 B packets, they are sent at BPSK ½ PHY mod (6Mb/s).

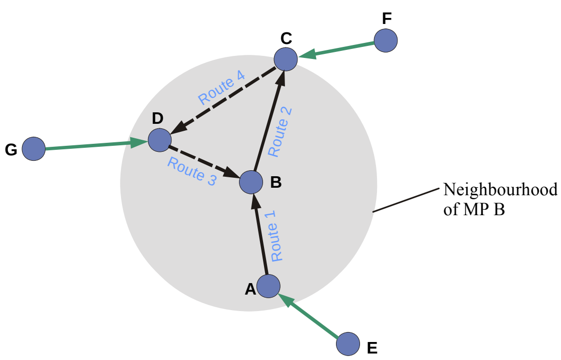
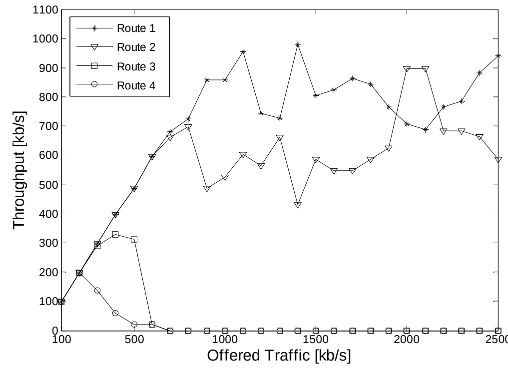
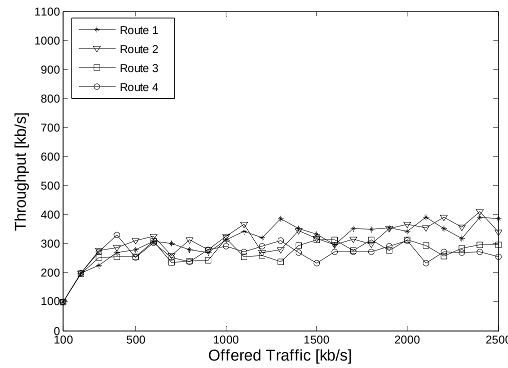


Fig. 9. The $Link_{A \to B}$ and $Link_{B \to C}$ have been set up at the beginning of the simulation, data flow on $Route_{D \to B}$ and $Route_{C \to D}$ start 5 s later and 6 later separately.

Figure 10 shows the accomplished throughput in kb/s depending on the offered traffic using DRP and EDRP. The saturation points of the both proposal are equal. The system is able to carry 200 kb/s per route resulting in 800 kb/s system throughput. With EDRP the available bandwidth can be fairly shared among the four routes with any offered traffic including overloaded cases, whereas using DRP the two new routes can get few MTxOPs, only until the offered traffic is at about 700 kb/s.



(c) Cumulative throughput using DRP.

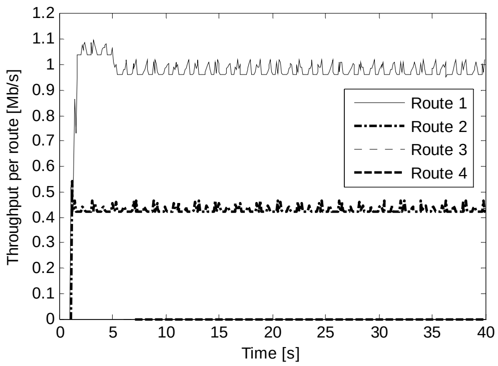


(d) Cumulative throughput using EDRP.

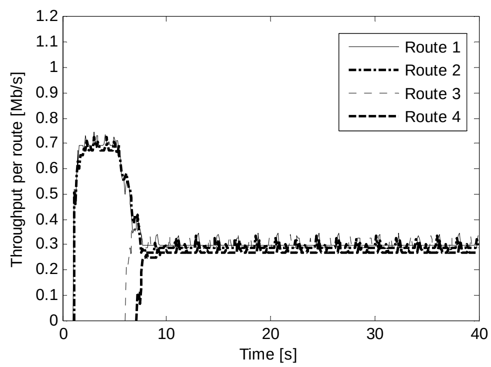
Fig. 10. Simulation results of the Figure 6: cumulative throughput for traffic between MPs, offered traffic is given per route.

Figure 11 compares the resulting throughput of each route depending on simulation duration with the usage of DRP and EDRP. Both evaluations are done at offered traffic of 1400 kb/s per route, which is above the saturation point. With DRP the difference between the simulation results of Route 1 and 2 is sizeable. The throughput of Route 1 holds the value of about 970 kb/s, whereas the throughput of Route 2 can only be reached at about 430 kb/s. Furthermore, the two new routes cannot obtain any MTxOPs from the medium, which is due to the fact that the medium has been completely occupied by the other two routes before they are initiated. This causes no throughput with these two routes. With EDRP Route 1 and Route 2 can share the medium equally in the first 5s, and all routes have nearly the same throughput at about 300 kb/s, which is closed to the theoretical throughput: $(2 \cdot 700\,[kb/s])/4 = 350\,[kb/s]$. The difference between the simulation result and the theoretical result is due to the fact that the amount of MTxOPs for data traffic is decreased as the increase of the amount of MTxOPs for BP and for Acknowledgments (ACKs).

A detailed view of the throughput of each route during the initial 15 s of the simulation is given in Figure 12. In the fist 5s, the throughput of Route 2 in comparison to which in Figure 8a is increased by 60% from about 430 kb/s to 700kb/s, whereas the throughput of Route decreased from about 970 kb/s to 700 kb/s. Later the new Route 3 can begin



(c) Throughput of each route using DRP.



(d) Throughput of each route using EDRP.

Fig. 11. Simulation results of the Figure 6: throughput of each route, offered traffic is 1400 kb/s per route.

to obtain MTxOPs from the other two existing routes separately. It can be noted that Route 1 and 2 free their occupied MTxOPs *simultaneously* and *gradually*, when they are informed that there are new links appearing. Finally all routes can reach an equilibrium of the throughput at about 300 kb/s per route within 1.5 s.

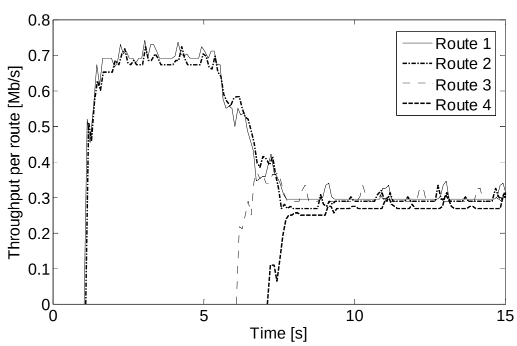


Fig. 12. Detailed view of the throughput of each route during the initial 15 s with the usage of EDRP.

V. Conclusion

In this paper an enhanced protocol proposal, EDRP, for TG "s" of the IEEE 802.11 Working Group is developed and evaluated. It provides mechanisms to design a dynamic resource allocation and prove a fair scheduling with the help of the SLS algorithm.

A detailed performance analysis by means of event driven stochastic simulation is presented, whereby the EDRP in combination with the SLS scheduling scheme is compared with the DRP in current MNA's 802.11s proposal. The results reveal that with EDRP *smoothing* effect is able to be achieved among routes with any traffic load including overloaded cases. New links can gradually obtain MTxOPs from existing links by using LIDB and in a short time equal MTxOPs distribution to neighboring links can be accomplished, when they have the same offered traffic. After release of a link the previously occupied MTxOPs can be reallocated to the other neighboring links. In conclusion, with the usage of the EDRP the medium is able to be *fairly* scheduled and *dynamic* bandwidth reassignment is actualized.

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