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TKN EDCA Model for ns-2

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Abstract

IEEE approved the 802.11 standard amendment for QoS support in 2005 after having issued 13 draft versions. Over this period, several technical changes, e.g., regarding the backoff procedure evolved. The original TKN EDCF model, published in 2003 for ns-2.26 is based on 802.11e Draft 2 respective 4 and had to be adjusted accord to the final standard amendment. The resulting novel TKN EDCA model is simply integrable into the newest version of ns-2. As it is based on ns-2's legacy WLAN model developed by the CMU group, it allows wired-cum-wireless simulations. This paper firstly describes the TKN EDCA model and shows verification results. Secondly, since investigations of in-house scenarios with small-scale fading and rate adaptation models are highly topical, an application example finally shows recent simulation results in an 802.11g/EDCA cell with rate adaptation and Ricean fading.

Contents

Chapter 1

Introduction

The standardization process of the IEEE 802.11e Working Group (WG) lasted more than 5 years, thus lots of different modifications have been incorporated from early draft versions to the final one. Basically, 802.11e introduces the Hybrid Coordination Function (HCF) enhancing the legacy 802.11 medium access functions. HCF consists of HCF Enhanced Distributed Coordination Function (EDCF) and HCF polled channel access in early draft versions [6]. EDCF thereby regulates prioritized, contention-based medium access. Later on, EDCF became Enhanced Distributed Channel Access (EDCA), while the polling based medium access function was denoted as HCF Controlled Channel Access (HCCA) [8]. In between, EDCA was changed with regards to the backoff decrement [7].

During the standardization, several researchers developed 11e models based on various draft versions for ns-2. To the knowledge of the authors, the Stanford model from the Mosquito group was the first considering EDCF and HCF [5]. In 2003, we developed an EDCF module for ns-2.26 based on draft version 2 and 4 [6, 8]. Ni et al. [15] implemented HCF and EDCF models as well as various enhancements for adaptive contention parameter tuning and fair resource allocation. A pure HCCA model was published by Cicconetti et al. [3]. Based on their own HCCA implementation, Boggia et al. [2] investigated feedback-based scheduling algorithms.

Lacage et al. have developed a new model including the IEEE 802.11 MAC, 802.11e EDCA and HCCA functionality, as well as multi-rate support [10]. The model is available and integrated into the newest release ns-2.29.

All models described above are either based on old ns-2 versions or do not support EDCA functionality for scenarios consisting of wired as well as wireless parts. Additionally, the approved draft version 13 differs with respect to backoff decrement from early draft versions. Thus, we decided to update our previous EDCF model for ns-2.26 and adapted it to current version of ns-2.*

Since 802.11e was developed to enable QoS support for wireless networks, its influence on delay-sensitive applications is an interesting issue. In [19], EDCF's influence on the perceptual quality of Voice over IP (VoIP) was studied in detail. Additionally, not only the MAC scheme itself but other components have great impact on VoIP. For in-house scenarios,

*The model has been published for ns-2.28 but only very minor changes, specifically to *ns-mobilenode.tcl*, are required for ns-2.29.

the characteristics of the wireless channel with regards to fading highly influence WLAN's performance. A hot research topic thereby is how MACs adapt their transmission rates for multi-rate 802.11a/b/g WLANs to the current state of the wireless channel. In an application example, we combine the TKN EDCA model with the Ricean fading model of Punnoose et al. [14] plus a rate adaption implementation of AARF [12, 11]. Results show the overhead of wireless transmissions in an 802.11g/EDCA WLAN for VoIP in the presence of fading as well as rate adaptation.

The paper is structured as follows. Section 2 describes the EDCA of the finally standardized amendment. Design aspects and details of the TKN EDCF as well as the TKN EDCA model are discussed in Section 3 and 4, respectively. Section 5 presents verification results of the TKN EDCA model. Finally, the application example consisting of TKN EDCA model, Ricean model and rate adaptation scheme and its results are presented in Section 6, while Section 7 summarizes the paper.

Chapter 2

IEEE 802.11e EDCA

EDCA extends the CSMA/CA-based medium access scheme of IEEE 802.11 DCF by introducing priority-based medium access for different traffic categories.

In order to allow prioritized and separate handling of traffic, 802.11e EDCA [7] uses the eight IEEE 802.1D User Priorities (UPs). Arriving traffic of these eight UPs is mapped to four different Access Categories (ACs)—for Voice (AC_VO), Video (AC_VI), Best-Effort (AC_BE), and Background (AC_BK) traffic. Each Access Category is equipped with a single transmit queue.

For each AC, an Enhanced Distributed Channel Access Function (EDCAF) contends separately for the right to initiate one or more transmissions during the contention phase. The basic reference model is shown in Figure 2.1.

Each EDCAF has an own parameter set which is listed in Table 2.1. It consists of the upper and lower bounds of the contention window (abbreviated as CW_{min} respective CW_{max}), inter-frame spaces, and $TXOPLimit$ values.

EDCA extends $DIFS$ of legacy DCF by enlarging the duration that the channel has to be idle prior initiation of a transmission dependent of AC. These Arbitration Inter-frame Spaces ($AIFS$) compute as follows

$$AIFS[AC] = SIFS + AIFSN[AC] * t_{slot} \tag{2.1}$$

whereby t_{slot} is the duration of a slot. Figure 2.2 shows the impact of $AIFS$. The lower the priority of an AC, the larger is its AIFS value. Thus lower priorities have to defer longer prior transmission initiation or backoff decrement. EDCAFs of AC_VO and AC_VI defer for the same amount of time as legacy 802.11 stations when applying the default parameter set (Table 2.1). Therefore, aCW_{min} and aCW_{max} values, which depend on the underlying PHY, have smaller values for AC_VO and AC_VI such that their channel access probability increases.

The right to initiate one or more transmissions per contention is denoted as Transmission Opportunity (TXOP), whereby the $TXOPLimit$ determines the maximum amount of transmittable frames. It is specified as a maximum occupancy duration of the wireless channel and is AC dependent, too.

Each EDCAF starts a backoff when either the medium is busy upon frame arrival from its transmit queue, an ACK timeout occurs while waiting for an ACK, a collision of a lower

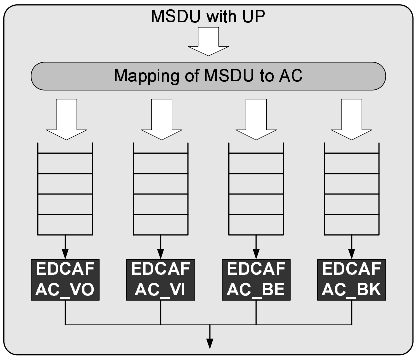


Figure 2.1: EDCA: priority queues and EDCAFs

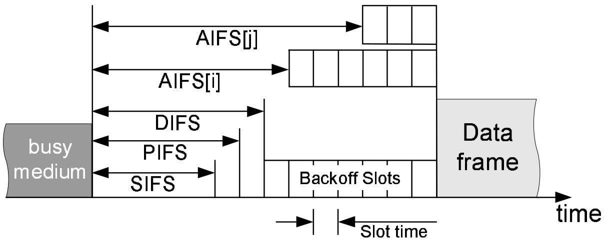


Figure 2.2: Inter-frame spaces with 802.11e EDCA

EDCAF happens with a higher priority within the same station (internal collision), or a frame was transmitted successfully and the corresponding ACK was received properly (post backoff).

Compared to early draft versions, the final, approved EDCA backoff decrement is different. Basically, the decision for a decrement of the backoff counter is now shifted prior to the *beginning* of a slot time. An EDCAF which had an idle medium of $AIFS^*$ decrements now its backoff counter immediately. It does this regardless whether the medium is busy or idle during the following slot time. In the latter case, the backoff counter is further decreased for each ensuing slot time that the medium remains idle.

Note, that an EDCAF is only allowed to perform one of the following steps prior the beginning of a slot time: Either it can decrement the backoff counter, initiate a transmission, start the backoff procedure, or do nothing. An example for the backoff algorithm discussing its consequences is given further below in the Section that describes the TKN EDCA Model.

Similar to DCF, a transmission failure leads to an increased contention window of an EDCAF according to the Binary Exponential Backoff (BEB) algorithm, which doubles CW

*The final amendment specifies a duration of an idle medium of $AIFSN[AC] * aSlotTime - aRxTxTurnaroundtime$ after SIFS. It is stated that the medium does not necessarily need to be idle during SIFS. In the comments to previous drafts, it was discussed not to consider noise that follows a transmission within SIFS. Since one barely models these effects in simulations, we assume an idle channel for $AIFS - aRxTxTurnaroundtime$. Additionally, we neglect the turnaround time for the purpose of readability.

Table 2.1: Default Parameter Set

AC	CW_{min}	CW_{max}	$AIFSN$	$TXOPLimit$ DSSS and HR/DSSS PHYs of 802.11/b	OFDM and ERP PHYs of 802.11a/g	other PHYs
AC_BK	$aCWmin$	$aCWmax$	7	0	0	0
AC_BE	$aCWmin$	$aCWmax$	3	0	0	0
AC_VI	$\frac{aCWMin+1}{2} - 1$	$aCWmax$	2	$6.016\,ms$	$3.008\,ms$	0
AC_VO	$\frac{aCWmin+1}{4} - 1$	$\frac{aCWmin+1}{2} - 1$	2	$3.264\,ms$	$1.504\,ms$	0

as long as it does not exceed CW_{max}. After a successful transmission, CW is reset to to the minimum value for the corresponding AC.

Internal collisions between two EDCAF within one station are resolved such the higher-prioritized EDCAF gains access to the wireless medium, while the lower-prioritized EDCAF performs actions as if an external collision happened.

Chapter 3

TKN EDCF model

The older EDCF model for ns-2.26 was based on 802.11e draft version 2 [6] as well as 4 [8] and on the WLAN model of ns-2 developed by the CMU group. For the latter, several improvements were identified which are described in [19], while the corresponding patch for ns-2.28 is available at [1].

The reasons to base our work on the patched WLAN model were firstly that it already implemented a CSMA/CA MAC whose behavior was studied by others extensively before. Secondly, since this model was completely incorporated into ns-2, it was possible to reuse its interfaces. Thus, only few changes were required to the rest of ns-2. Thirdly, the legacy model allows simulations of wireless plus wireless networks.

The WLAN model was extended by introducing multiple interface queues between Layer 3 and MAC. Dependent on their priority, packets are stored in one of these queues. In the EDCF model, the *prio field* of packet's IP header specifies the priority. The highest priority is indicated by a value of zero. This was chosen in order to assure that management packets of higher layers, which carry for example routing information, are delivered properly even in high-load scenarios by highest priority.

Instead of implementing one EDCF instance per queue respective per priority, which would increase the complexity since it requires a virtual collision resolution entity, we used another design approach: A single packet buffer for each priority at MAC plus variables storing contention parameters allows to have only *a single EDCF instance*. This approach is not only simple but also allows an easy resolution of internal collisions: Only the backoff of the priority that will firstly expire is scheduled. In case that two or more priorities have the same smallest residual duration, the timer is always scheduled for the highest priority. Variables of other priorities such as residual backoff times are adapted accordingly after expiration (or in pause functions, if the wireless medium becomes busy in the meanwhile).

In case of an internal collision, i.e, two or more priorities had the same residual backoff duration, a TXOP is granted to the highest priority, while another backoff is started for the others. In the old EDCF model, CW but not the retry counter has been increased for the lower priority in case after an internal collision.

Since the development of our model started with 802.11e draft version 2, the parameter set still includes the Persistence Factor (PF), which determines the modus of increment for CW. PF equal to two results in BEB, thus the backoff procedure behaves in the same way as DCF.

Additionally, the EDCF model has the Contention Free Bursting (CFB) capability as specified later on in draft version 5. With CFB, a priority that grants access to the medium is allowed to have multiple transmission sequences separate by SIFS as far as they occur error-free and do not exceed the $TXOPLimit$.

The results of the EDCF model for ns-2.26 have been compared with previous work in [19]. Later on, it has been used extensively to study the perceived quality of VoIP in 802.11b/e WLAN scenarios [20]. The EDCF model was used by other researchers in various publications. A short, incomplete list is provided at model's website [1].

Chapter 4

TKN EDCA model

After the IEEE 802.11e WG finished its work and finalized the standard amendment, we started including the backoff changes to the EDCA medium access into our model. The backoff algorithm is explained below shortly.

In the final amendment, an EDCAF decrements the residual backoff counter prior the *beginning* of the corresponding slot. Actions are taken by an EDCAF however only at the end of this slot. Assuming that the medium remains idle, sending or next backoff decrement occurs at the *end* of the slot time.

Modeling the backoff decrement at the beginning of a slot and having the decisions for the actions at the end, implies that one (re)schedules a timer for every slot. Obviously, this will result in computationally poor performance.

Instead, we schedule a timer for the whole backoff duration similar to the TKN EDCF model. This however requires some modifications if the timer is paused, e.g, due to a change of the wireless medium from idle to busy state.

The functionality is shown for two simple cases: the uninterrupted and interrupted backoff example. In the first, shown in Figure 4.1, EDCAF got a packet from its transmit queue while the medium was busy. Thus, a backoff was started, whereby a backoff of three slots were diced. When the medium becomes idle, the backoff timer schedules for $AIFS + r_b$, r_b being the residual backoff. Assuming that the medium remains idle, this is the same as final 11e's behavior.

However, if the backoff is interrupted due to a busy medium, a change is required which is discussed in the following. In the second example shown in Figure 4.2, two EDCAFs located on two different stations contend for the medium access, whereby EDCAF1 has higher priority

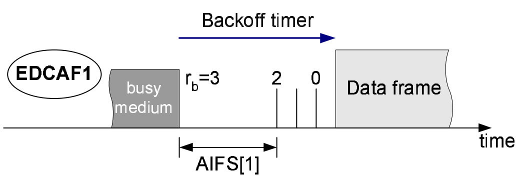


Figure 4.1: Uninterrupted Backoff example

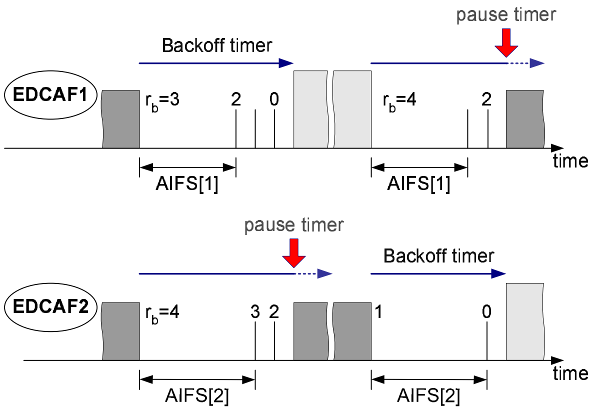


Figure 4.2: Interrupted Backoff example

than EDCAF2. Since EDCAF1 has lower AIFS as well as smaller r_b, it is allowed to initiate a transmission first. When the medium becomes busy, EDCAF2 has to pause its backoff timer. After pausing a backoff timer, it is checked whether the bygone amount of time since its start point until pausing is equal or larger than $AIFS$. This duration is denoted as D in the following.

We can distinct three cases: $D < AIFS$, $D = AIFS$, and $D > AIFS$. In the first case, r_b is not decreased, while r_b decrements by one in the second case. In the latter, r_b decreases by the number of slots that the medium remained idle additionally.

Despite the modification for the standardized EDCA backoff, the TKN model still provides a switch within the code such that the previous EDCF backoff can be simulated, whereby retry counters are now increased also for internal collisions.

Chapter 5

Verification of TKN EDCA model

This section discusses results of TKN EDCA model by showing its functionality with traffic of different ACs and its behavior when system changes from non- to the saturated area. The same scenario and traffic conditions are applied which were used for verification of the older model already.

The older TKN EDCF model was verified by comparing its behavior with the results of Mangold et al. [13]. These results were published together with the model description in [19]. This work used an IEEE 802.11a PHY with a transmission rate of 6 Mbps for frame's PLCP part (we refer to this as PLCP rate in the following) and a data rate of 24 Mbps for MAC headers and payload. Further details to the PHY parameter values are described in [19].

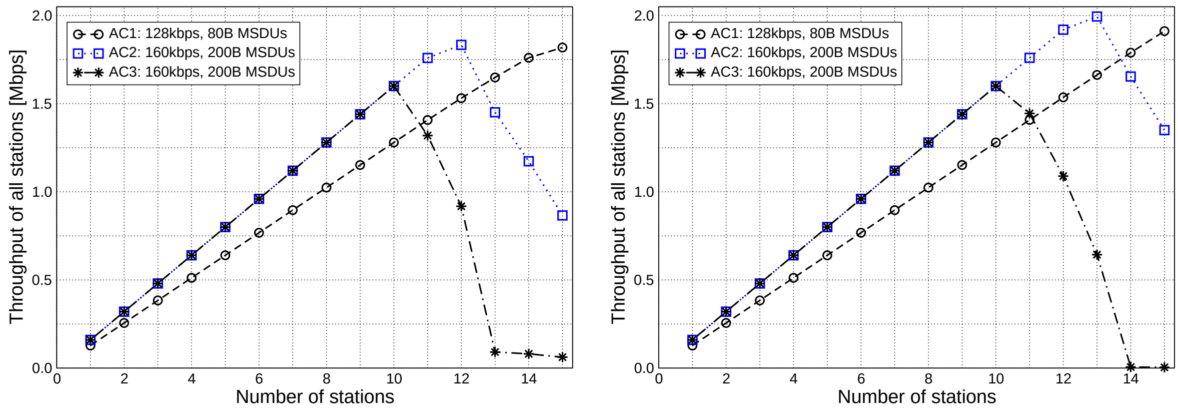
The scenario consists of a single AP with a different number of stations, whereby all nodes are within the transmission range of each other. Each station transmits three traffic flows in the uplink direction: a high-priority flow with 128 kbps and 80 Byte MSDUs, as well as a medium- and low-priority flow with 160 kbps and 200 Byte MSDUs, respectively. Although the authors of [13] use Poisson traffic for medium- and low-priority traffic, we decided to use isochronous flows for all three ACs, since MAC's behavior will be investigated in the saturated area.* Table 5.1 lists the contention parameters for the three ACs, which were used in [13, 19].

The first metric for the verification is the throughput at MAC level of all stations as used in [19]. Additionally, we measure the access delay which consists of the duration of contention

Table 5.1: Parameters for verification

	high	medium priority	low
AIFSN	2	4	7
CW_{min}	7	10	15
CW_{max}	7	31	255

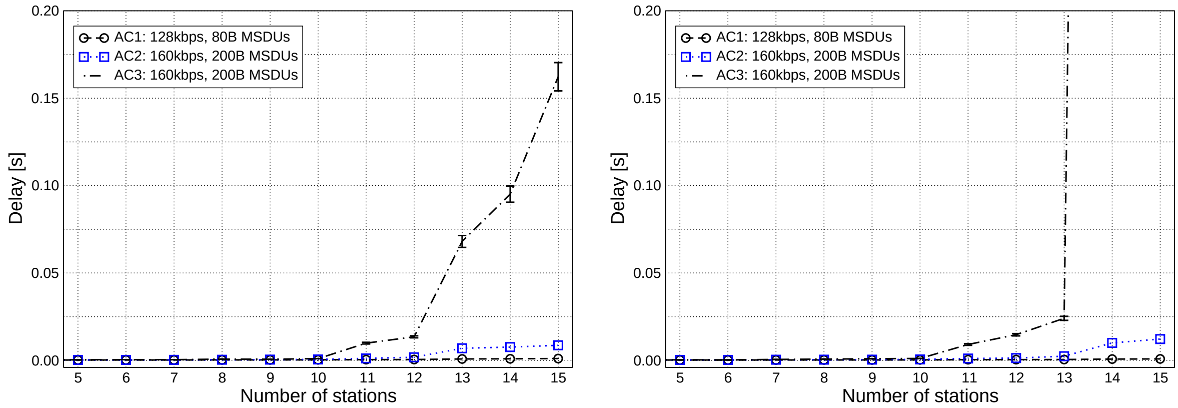
*Due to interface queues with lengths of 50 packets, Poisson arrivals average out in overload cases such that the MAC behavior dominates inter-transmission times.



(a) EDCA

(b) EDCF

Figure 5.1: Accumulated MAC layer throughput of all stations



(a) EDCA

(b) EDCF

Figure 5.2: Access delay for each AC

for medium access, (re)transmissions, as well as ACK reception for each AC. We investigated both metrics for the novel EDCA as well as the EDCF model with ns-2.28.

The Akaroa tool [4] was used for evaluation of results, run-length control, as well as parallelized simulation runs with the MRIP (Multiple Replications in Parallel) capability. The simulation process terminates, if the mean value reaches a confidence level of 95 percent and has a relative error below 5 percent.

For each simulation run, the number of contending stations was increased by one. Figure 5.1(b) shows the total throughput for EDCF. The high-priority flows are not affected, i.e., throughput is not decreased even for the highest number of 15 stations transmitting simultaneously. Contrary, the throughput for low and medium priority flows decreases for more than 10 and 13 stations, respectively. These results show a similar behavior as [13]. Since a radio channel model is not applied in our work, we gain small differences at a high number of stations.

Figure 5.2(b) plots the delay for each AC and the EDCF MAC. The delay remains far below 25 ms for medium and high priority, but rapidly grows for the lowest priority and more than 13 stations. Thus, a low-priority flow suffers from starvation in terms of waiting for an EDCF TXOP.

The throughput with the EDCA MAC shows a slightly different behavior in the saturated case 5.1(a). The 128 $kbps$ high-priority flows are not completely transmitted for more than 14 stations, while the medium-priority throughput of all flows degrades for more than 12 stations. Although the throughput of the lowest AC decreases faster for more than 10 stations, it has a larger throughput for more than 13 stations compared to EDCF.

The reason for the small difference between EDCF and EDCA lies in the modified backoff, i.e., the residual backoff counter decreases by one for each idle period of AIFS. Figure 5.2(a) shows that the EDCA backoff also leads to reduced contention and transmission delay for low-priority traffic.

In general, the capacity of EDCA MAC seems to be slightly lower in saturated conditions, since lower throughput is gained in total for all ACs. This result is not surprising as the collision probability increases for EDCA MAC.

In conclusion, the EDCA model behaves similar to previous work [13, 19, 20] but shows slightly lower throughput under saturated conditions due to the backoff counter decrease for an idle medium equal to AIFS.

Chapter 6

Application Scenario

IEEE 802.11e targets to enable QoS support for delay-sensitive applications like VoIP. Beside the standardized MAC scheme, other parts such as the characteristics of the wireless channel as well as the rate adaptation scheme, which tries to adapt to the channel conditions, have influence on QoS.

In this application example, we combine the TKN EDCA model with a Ricean fading model and apply a rate adaptation scheme to study their behavior in the presence of VoIP calls in an in-house scenario. Thereby, this work focusses on an 11e/g WLAN environment with respect to the resource consumption of each single WLAN user. The rationale behind this is the idea to enable admission control or even handover decisions dependent on the amount of consumed resources per user.

6.0.1 Real-World Case

The scenario under study consists of a WLAN cell covering a large area like a departure lounge in an airport or the concourse in a train station. The single IEEE 802.11g AP is 11e-capable by providing EDCA functionality.

In this scenario, we assume to have VoIP users only, who are equally distributed over the area of interest. Users are stationary and equipped with 11g devices such that 802.11g Extended Rate Physicals (ERPs) with OFDM modulation is applied only—from 6 up to 54 Mbps. The 802.11g parameters were chosen according to [9]. For 11e's AC_VO (Table 2.1), this results in CW_{min} and CW_{max} values of 3 and 7, respectively. The $TXOPLimit$ was set to zero such only one packet is transmitted per TXOP.

6.0.2 Assumptions

In the environment described above, radio signals are not only affected due to path loss but also due to multi-path propagation. The impact of these effects vary in an environment whose parts are non-stationary.

Path loss of radio signals is modeled by ns-2's TwoRayGround model. For multi-path propagation, the Ricean fading model of Punnoose et al. [14] was applied, whereby the slow movements of the environment have been set to $2\,km/h$. The Ricean K-Factor, which specifies

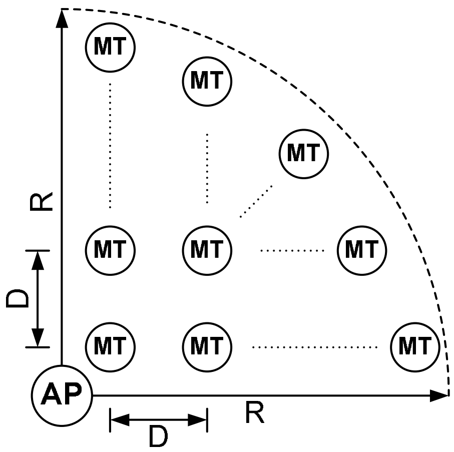


Figure 6.1: Distribution of nodes over region of interest

the ratio between the amount of signal power received on line of sight and the variance of the multipath [16], was set according to the measurements of [17] to $3\,dB$.

Since the original Ricean model uses the same start point in its trace for different stations, its behavior would be similar for all involved nodes. Therefore, the start point in the Ricean-fading trace was chosen randomly for each node as well as dependent on the transmitting node.

6.0.3 Simulation Scenario and Traffic Model

In this scenario, 15 VoIP nodes are distributed equally over the area of interest, whereby the AP is located at the corner of the considered environment, such that no hidden nodes appear. Figure 6.1 shows the investigated scenario whereby the radius R was set to $150\,m$ and D to about $34\,m$.

All wireless stations have a VoIP call with a wired node outside the WLAN. The delay between AP and the wired nodes was set to $100\,ms$. All VoIP calls use the ITU-T codec G711 with a packetization of $20\,ms$, i.e., a single VoIP call consists of a bi-directional flow with $160\,Byte$ audio frames. The QoS constraints for G711-coded VoIP calls and the framing overhead are described in detail in [18].

6.0.4 Rate Adaptation

Since this application example uses a small-scale fading model and targets to identify the occupied amount of resources by each user, we decided to implement Adaptive Automatic Rate Fallback (AARF) of Lacage et al. [12].*

The effect of AARF is shown in Figure 6.2 for a single terminal within the WLAN cell. For each simulation run, the distance between MT and AP is varied. The data rates for all

*An overview of rate-adaptation mechanisms as well as a short explanation of AARF is provided in [18].

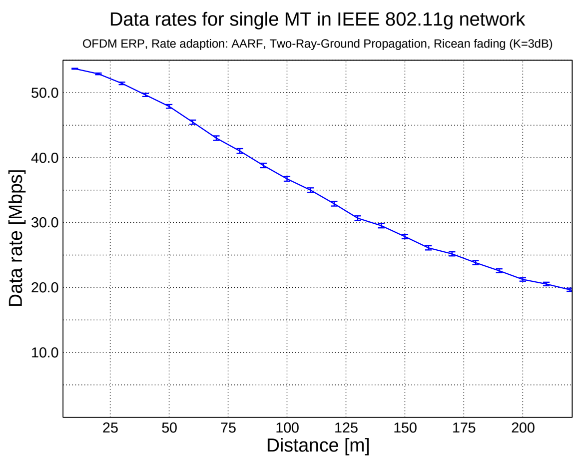


Figure 6.2: Data rates for single MT in 802.11g WLAN

transmissions within downlink direction are averaged and plotted with a 95 percent confidence level.†

6.0.5 Admission Control Metric

In order to determine the amount of resources that each user in WLAN cell consumes for his transmissions in up- as well as downlink direction, the Virtual Utilization (VU) metric was introduced in [18]. Basically, it is the virtual and physical occupancy time for the transmissions of each user averaged over an interval of 100 ms. The physical duration consists of the amount of time required to transmit the data frame as well as the immediate ACK, whereby the virtual part includes the inter-frame spaces—AIFS as well as SIFS.

The AP keeps track of all transmissions to and from each node. Thus, it is able to measure the actual VU ($VU_{measured}$). Additionally, the AP determines the optimal VU (VU_{opt}) assuming that each transmission of an MPDU takes place at the highest data rate as well as without any retransmissions.

The resource consumption overhead r_{oh} for each flow is defined in Equation 6.1.

$$r_{oh} = \frac{\Delta VU}{VU_{opt}} = \frac{VU_{measured} - VU_{opt}}{VU_{opt}} \tag{6.1}$$

6.0.6 Results

For each VoIP node in the scenario described above, we measured the resource consumption overhead at AP. Simulations have been repeated 80 times to gain significant results. The overhead dependent on the distance to the AP is plotted in Figure 6.3.

†Since results do not vary significantly for up-and downlink direction, only one direction was plotted to improve readability.

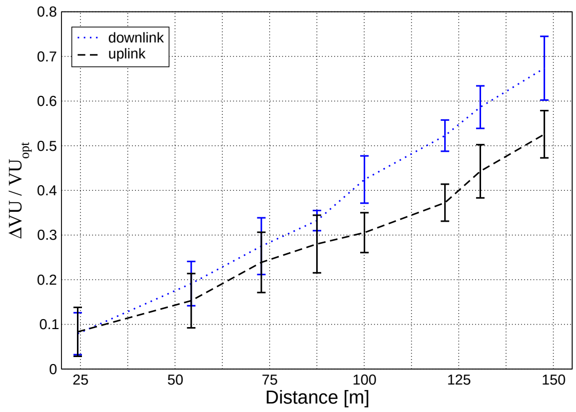


Figure 6.3: Resource consumption overhead over distance

The overhead increases monotonically with the distance for both up- as well as downlink direction. It is around 10 percent near AP, while it increases about up to 70 percent for the farthest terminal.

Interestingly, the overhead for up- and downlink differs significantly at larger distances. The reason for this lies in the fact that the AP can only take into account packets for nodes' $VU_{measure}$, which are assignable to specific nodes. This is not possible in case of erroneous packets in uplink direction.

Chapter 7

Summary

This work describes the final 802.11e amendment with the focus on EDCA. The finally standardized EDCA backoff was adopted to the older TKN EDCF model, whereby the modified backoff algorithm has been described in detail. The TKN EDCA model as well as its predecessor are publicly available together with improvements for ns-2's legacy WLAN model at [1].

The verification of the TKN EDCA model has been done—similar to the previous model version [19]—by comparing its results with previous work [13]. Additionally, the verification section shows the influence of the modified EDCA backoff algorithm compared to the older DCF-compliant backoff.

Not only the standardized MAC scheme but also other aspects like conditions of the wireless channel and the rate adaptation scheme highly influence QoS of delay-sensitive applications. Therefore, this work finally combines the TKN EDCA model with an underlying small-scale fading model and the rate adaptation scheme AARF. Results of this application example show the overhead of VoIP transmissions in an 802.11g/EDCA multi-rate environment in the presence of small-scale fading and rate adaptation.

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